REVIEW

Nutritional Sustainability of Pet Foods[1,2]

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ABSTRACT

Sustainable practices meet the needs of the present without compromising the ability of future generations to meet their needs. Applying these concepts to food and feed production, nutritional sustainability is the ability of a food system to provide sufficient energy and essential nutrients required to maintain good health in a population without compromising the ability of future generations to meet their nutritional needs. Ecological, social, and economic aspects must be balanced to support the sustainability of the overall food system. The nutritional sustainability of a food system can be influenced by several factors, including the ingredient selection, nutrient composition, digestibility, and consumption rates of a diet. Carbon and water footprints vary greatly among plant- and animal-based ingredients, production strategy, and geographical location. Because the pet food industry is based largely on by-products and is tightly interlinked with livestock production and the human food system, however, it is quite unique with regard to sustainability. Often based on consumer demand rather than nutritional requirements, many commercial pet foods are formulated to provide nutrients in excess of current minimum recommendations, use ingredients that compete directly with the human food system, or are overconsumed by pets, resulting in food wastage and obesity. Pet food professionals have the opportunity to address these challenges and influence the sustainability of pet ownership through product design, manufacturing processes, public education, and policy change. A coordinated effort across the industry that includes ingredient buyers, formulators, and nutritionists may result in a more sustainable pet food system. *Adv. Nutr. 4: 141–150, 2013.*

Introduction

Companion animals play an important role in our lives, providing a positive impact on both the emotional and physical health of people with whom they have contact, as well as strengthening the communities in which we live. Physical benefits include associations of pet ownership with decreased medical expenses and visits to the doctor, increased physical activity, reduced blood pressure and risk of heart disease, and reduced risk of allergies linked to asthma in children (1–5). Psychological benefits include an association of pet ownership with reduced levels of stress, lower incidence of depression associated with spousal loss, and higher self-esteem in children and adolescents (1,2). Pet ownership has also been associated with increased social engagement and social cohesion (6).

Often based on consumer demand rather than nutritional requirements, many commercial pet foods are formulated to provide nutrients in excess of current minimum recommendations, use ingredients that compete directly with the human food system, or are overconsumed by pets, resulting in food wastage and obesity, which presents challenges in optimizing the sustainability of the pet food system and pet ownership. To ensure that pet ownership can be sustained in the future, it needs to be affordable and culturally acceptable and must effectively satisfy the needs for good health and well-being of animals as pets. One important component of ensuring that these needs are met is appropriate nutrition. It is imperative to evaluate whether and how the pet food system as a whole can sustainably support the health and nutrition of the growing population of companion animals not only now, but in the future. In this review, we describe the concept of nutritional sustainability and propose its application to companion animal nutrition. Unknown components and future challenges are also highlighted to provoke discussion among the companion animal scientific community.

Current status of knowledge

Defining sustainability

Sustainability can be described as ensuring a better quality of life for everyone and the ability of society to be maintained over the long term. Sustainability calls for transformation to meet "the needs of the present without compromising the

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ability of future generations to meet their needs" (7). In addition to the environmental components most often considered, sustainability includes building social equity and increasing long-term profitability as well. If a system is not sustainable in even 1 of these areas, then its overall sustainability will not be possible. Concepts of sustainability can be applied to food systems (**Fig. 1**). A food system consists of all aspects of food production and consumption, including implications on health. The different sectors of the food system include production, transformation (processing, packaging, labeling), distribution (wholesaling, storage, transportation), access (retailing, institutional foodservice, emergency food programs), and consumption (preparation, health outcomes) (8). This includes the machinery and structures used in these processes and the people who participate in the system. A food system can be considered on a local, regional, national, or global level. The American Public Health Association defines a sustainable food system as "one that provides healthy food to meet current food needs while maintaining healthy ecosystems that can also provide food for generations to come with minimal negative impact to the environment. A sustainable food system also encourages local production and distribution infrastructures and makes nutritious food available, accessible, and affordable to all. Further, it is humane and just, protecting farmers and other workers, consumers, and communities" (9).

When considering the development of sustainable practices, the measurements are not as dichotomous as "sustainable" or "unsustainable." Typically, sustainability measurements are on a continuous scale, and practices are viewed as more or less sustainable, given the uncertainty of future challenges that may

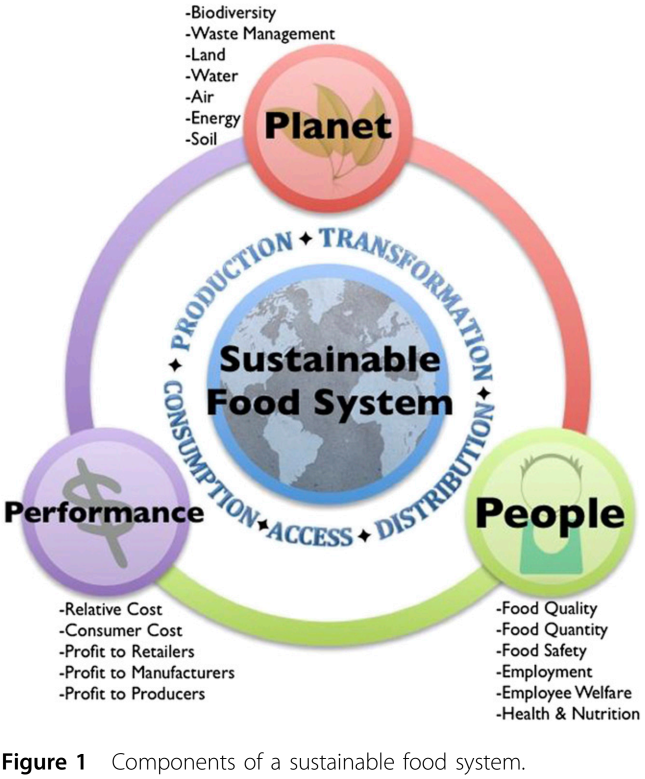

Figure 1 Components of a sustainable food system.

present themselves. The environmental sustainability of a food system is measured by several factors, including land use, waste management, greenhouse gas (GHG)[5] emissions, or biological diversity (10). Life-cycle assessment is a standardized process to evaluate the environmental impact of all stages of a product's life and includes measurements of the product's impact on global warming, eutrophication, acidification, photochemical smog, and land use (11). Social sustainability of a food system considers factors such as food quality, food quantity, food safety, employment, employee welfare, health, and nutrition. Finally, economic sustainability considers factors such as profit to producers, manufacturers, and retailers and the cost to consumers.

Nutritional sustainability

One component of a food system's sustainability is its ability to provide adequate, safe nutrition to its end users. For the purpose of this review, nutritional sustainability is defined as the ability of a food system to provide sufficient energy and the amounts of essential nutrients required to maintain good health in the population without compromising the ability of future generations to meet their nutritional needs. As part of nutritional sustainability, foods can affect health not only by their nutrient content and the amount consumed, but also by non-nutritive components, such as pesticides, fertilizers, preservatives, heavy metals, and microbiological contaminants.

Many food systems may be nutritionally sustainable or provide safe, adequate nutrition to its users. The ecological, social, and economic aspects of sustainability, however, must be balanced to support overall food system sustainability. The current global food system may be considered nutritionally unsustainable for a multitude of reasons. In developed countries, the overconsumption of inexpensive, highly processed foods high in sugar, saturated fat, and sodium has been a key contributor to the epidemic of obesity and obesity-associated diseases in humans (12). Conversely, the unavailability of affordable, nutrient-rich foods in developing countries continues to contribute to hunger and malnutrition. This condition may only worsen in the future, as more crops such as maize, wheat, sugarcane, rapeseed, and oil palm are used for ethanol and/or biodiesel production and are in direct competition with food production. Moreover, most countries with the greatest population growth are those in the developing world that have poor economies, political unrest, or unsuitable farm land (13).

Diet composition and sustainability

Humans and animals have evolved to consume and thrive on a variety of diets. Although many species are quite specific in their dietary selection (e.g., herbivores, carnivores), omnivorous species have evolved to use a variety of foods,

[5] Abbreviations used: AAFCO, Association of American Feed Control Officials; CH_4, methane; CO_2, carbon dioxide; CO_2e, carbon dioxide equivalents; CP, crude protein; DMB, dry matter basis; GHG, greenhouse gas; N_2O, nitrous oxide; NRC, National Research Council; RA, recommended allowance.

often taking advantage of what is most available at any one time. Generally speaking, cats are carnivorous, whereas dogs are more omnivorous in nature. Whether the choices are based on availability, dietary preference, or metabolic necessity, the diet of an animal greatly affects its footprint on the world in terms of sustainability.

Although many factors contribute to the earth's carbon, water, and nitrogen cycles, agriculture is a considerable source of water pollution and GHG emission. Major fossil energy inputs for grain, vegetable, and forage production include fertilizers, agricultural machinery, fuel, irrigation, and pesticides. These inputs, plus the direct costs associated with raising animals, are applied to livestock production. It has been estimated that 6.4% of U.S. GHG emissions are derived from agriculture, with beef cattle, dairy cattle, swine, and poultry accounting for 37%, 11.5%, 4.4%, and 0.6% of these emissions, respectively (14,15). Globally, livestock wastes are the largest source of methane (CH_4) emission and directly responsible for ~9% of global GHG emissions [in the form of CH_4 and nitrous oxide (N_2O)] (16). If all aspects of livestock production are considered, including manure management and use of fertilizers, global livestock systems are estimated to make up 18% of GHG (16,17). Although these calculations have been challenged, the fact remains that livestock are significant contributors to GHG emissions, primarily via deforestation and desertification (35.4% of GHGs from livestock), manure (direct and indirect; 30.5% of GHGs from livestock), and enteric fermentation by ruminants (25.0% of GHGs from livestock) (17).

The carbon footprint is the aspect of sustainability that has received the most headlines and is most commonly the measure by which companies promote themselves as being "green." The carbon footprint not only measures carbon dioxide (CO_2) emissions, but also includes other GHG emissions. In addition to CO_2, the primary GHGs of concern include CH_4, N_2O, and refrigerants. GHGs are usually expressed as CO_2 equivalents (CO_2e), derived by converting non-CO_2 gas emissions to an equivalent global-warming potential quantity of CO_2. The most recent 100-y time horizon global-warming potential equivalents reported by the Intergovernmental Panel on Climate Change are quite different among gases: CO_2 = 1, CH_4 = 25, and N_2O = 298 (18). This indicates that CH_4 has 25 times and N_2O has 298 times more effectiveness to trap heat, or global-warming potential, compared with CO_2 for similar weights of gas produced. The carbon footprint and the primary sources of GHG emissions vary greatly depending on plant and/or livestock species.

Livestock species differ in their diet and ingredient selection, reproductive and metabolic efficiency, production strategy, and other inherent differences, all of which affect carbon footprint estimates (**Table 1**). Although some footprint estimates are measured in terms of kilocalories of fossil input for kilocalories of protein output, others are represented in terms of kilograms of CO_2 emitted per kilogram of product. Carbon footprint estimates of nonruminant animal protein production range from 2.8–4.5 kg of CO_2e/kg of pork (19–22), 1.9–2.9 kg of CO_2e/kg of chicken (20,23,24), 1.2–4.2 kg of CO_2e/kg of fish (25–27); and 1.4–2.8 kg of CO_2e/kg of eggs (20,28). Similar calculations have been done for ruminants: 15–31 kg of CO_2e/kg of beef (20,29–35). Although carbon footprint estimates are often focused on identifying interspecies differences, recent estimates have also demonstrated great variation within species, depending on production strategy, natural resources, and geographical location. Because various methods are used to make these estimates and the units by which they are provided, head-to-head comparisons may not always be valid.

Table 1. Fossil energy estimates to produce 1 kcal of animal protein[1]

Animal product	Fossil energy input (kcal):protein produced (kcal)
Broilers	4:1
Turkeys	10:1
Dairy (milk)	14:1
Swine	14:1
Beef cattle	40:1
Lamb	57:1

[1] Adapted with permission from (82).

The other major footprint that has been considered in terms of agriculture and nutrition is that of water, which pertains to its use and pollution. To estimate efficiency of water use for food production, water efficiency (use vs. evaporation, leaching, etc.), production efficiency (total production vs. water consumption over life span), and consumption efficiency (consumption vs. waste) must all be considered. The concept of the water footprint was first introduced by Hoekstra et al. (36) and has most recently been defined as the total volume of freshwater used to produce a product and is broken down into blue, green, and gray water components (37). The blue water footprint refers to the volume of surface and groundwater consumed (evaporation), whereas the green water footprint refers to the rainwater consumed as a result of the production of a good. The gray water footprint of a good refers to the volume of freshwater required to assimilate the load of pollutants based on existing ambient water-quality standards. Mekonnen and Hoekstra (38,39) recently calculated the water footprints of crop and animal products. Global average water footprint per ton of crop increases from sugar crops (~200 m^3/ton), vegetables (~300 m^3/ton), roots and tubers (~400 m^3/ton), fruits (~1000 m^3/ton), cereals (~1600 m^3/ton), oil crops (~2400 m^3/ton) to pulses (~4000 m^3/ton). Similar to the carbon footprint, the water footprint of a product greatly differs within and among product categories and per region of the world. The water footprints for some of the crop and animal products commonly used in human and pet foods are listed in **Tables 2** and **3**, respectively.

Applying nutritional sustainability to companion animals

Sustainability issues of the world's human food supply is nothing new. Because the global population continues to grow at an alarming rate, estimated to reach ~9 billion by 2050 (40), an increasing pressure has been put on the agricultural industries to produce a sufficient amount of food.

Table 2. Water footprints of common crops and crop-derived oils[1]

Product	Water, m^3/ton
Maize	1222
Barley	1423
Rye	1544
Rice (paddy)	1673
Oats	1788
Wheat	1827
Soybeans	2145
Sorghum	3048
Millet	4478
Maize oil	2575
Soybean oil	4190
Rapeseed (canola oil)	4301
Sunflower oil	6796
Linseed oil	9415
Olive oil	14,726

[1] Adapted with permission from (38).

In the United States, ~50% of the total land area, 80% of the fresh water, and 17% of fossil energy is used for food production (41). Again, from a sustainability point of view, a balance of nutritional, ecological, social, and economic concerns must be considered. These concepts not only apply to human foods, but to pet foods as well.

The pet food industry is a $55 billion business, with almost $18 billion coming from the United States alone (42). Given the size of the industry, adoption of sustainable practices may have a significant impact globally. The pet food system is quite unique. First, it is tightly interlinked with livestock production and the human food system (**Fig. 2**). Despite competing with the human food system and livestock production for many of the same ingredients, the pet food system is also an important user of various by-products. The Association of American Feed Control Officials (AAFCO) defines by-products as "secondary products produced in addition to the principal product" (43). Many ingredients that include "by-product" in their name exist. These ingredients can be generated from any food system, but are most commonly a secondary product of the human food system. The environmental "cost" of using by-products is often difficult to estimate, but must be addressed. Second, given the recent anthropomorphism of pets, the social aspects of the pet food system are increasingly important. Any food system needs to be socially acceptable and supply culturally appropriate foods that satisfy the taste preferences of consumers. In the case of pet foods, the products need to

Table 3. Water footprints of common animal products[1]

Product	Water, m^3/ton
Cow's milk	1000
Chicken egg	3300
Chicken	4300
Goat	5500
Pig	6000
Sheep	10,400
Beef cattle	15,400

[1] Adapted with permission from (39).

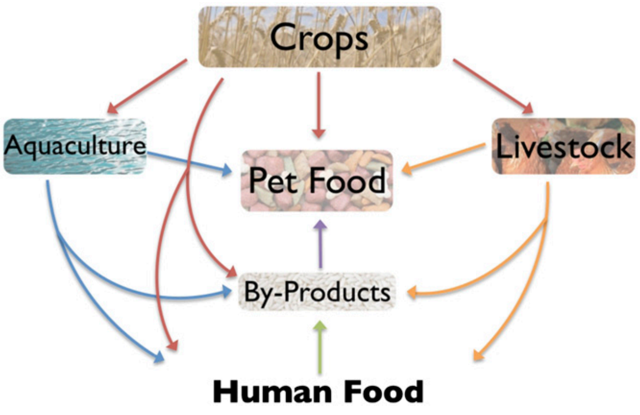

Figure 2 Complexities of the pet food system.

be culturally acceptable to the pet owners, while still being nutritious and palatable to the pets. Finally, the recent economic woes throughout the world highlight the need for human and pet foods that are economical for the consumer. Depending on the region of the world in question, which differs in terms of socioeconomics, cultural beliefs, availability of natural resources, etc., the husbandry of dogs and cats may vary greatly. In some regions, pets are fed and treated as if they were human. In others, however, they are fed as if they were livestock or not fed or cared for at all. Because strong and competing ecological, social, and economic interests exist worldwide, a "one-size-fits-all" strategy for sustainability is not possible. However, identifying and discussing the opportunities and challenges that exist within the pet food industry may highlight areas for improved sustainability in the future.

Similar to the human food system, dietary ingredient selection and nutrient composition are major factors affecting the sustainability of the pet food system. In addition to the nutritional issues considered in this review, pet food sustainability is also affected by the sustainability of the manufacturing facilities, packaging, and transportation of products, among other factors.

A unique aspect of the pet food industry is that the foods are typically formulated to be "complete and balanced," meaning that the diet will meet all nutrient needs of the pet if the proper amount of food and water are consumed. Initial pet foods were not nutritionally complete and often resulted in gastrointestinal distress and nutrient deficiencies. Decades of research in dog and cat nutrition and manufacturing processes in the mid to late 1900s dramatically improved the quality of pet foods and the health and life span of pets that consumed them (44–46).

Thousands of dog and cat food formulas currently exist worldwide, ranging widely in nutrient composition, ingredient selection, and manufacturing methods. Pet food professionals and expert panels, such as AAFCO and the National Research Council (NRC), have evaluated the literature and devised nutrient recommendations for dogs and cats (43,47). The strategy by which companies use this information to formulate and market pet foods differs greatly. In addition to deciding on the nutrient composition, ingredient selection is a key consideration in terms of cost and consumer demand. Although the majority of the commercially available pet foods are based on a variety of animal- and plant-based ingredients, extremes at each end also exist, including vegetarian diets and those based on very high amounts of animal-based proteins. There are also many options within each plant- or animal-based ingredient category. When considering the protein source, for example, one must not only consider whether an animal- or plant-based protein will be used, but the specific organism from which it is derived (e.g., animal: chicken, beef, lamb, pork, etc.; fish: salmon, menhaden, etc.; plant: corn gluten meal, soybean meal, etc.), what part(s) of that organism will be included (e.g., plant: whole wheat vs. wheat germ vs. wheat bran; animal: entire animal vs. skeletal muscle vs. organ meats), and the form in which it will be added (animals: frozen, fresh, meal), all of which affect the diet in terms of cost, nutrient composition and stability, manufacturing requirements, and ingredient handling, transport, and storage.

Nutrient composition. Because protein is the most expensive macronutrient in both economic and ecological terms, it is arguably the nutrient requiring the most attention as it pertains to sustainability. Pet food professionals need not only consider the total amount of protein to target, but also the quality, bioavailability, and ingredient source as well. A unique issue in the pet food industry (vs. livestock feed industry) is the large disconnect between the protein requirements of dogs and cats and the crude protein (CP) concentration present in the average pet food. Because dogs and cats are both members of the Carnivora order, many believe that dogs and cats require very high dietary protein concentrations to thrive. The natural preferences of dogs and cats may support these consumer opinions. A series of recent experiments in cats focused on macronutrient selection demonstrated that when given the choice, cats will select dietary protein (52% of metabolizable energy) and fat (36% of metabolizable energy) at much higher levels than required metabolically (48). Studies in dogs have shown that protein content of the diet is also positively associated with food selection, albeit at a somewhat lower level than in cats (∼25% metabolizable energy) (49). Despite this evidence and the fact that the cat is an obligate carnivore and requires more dietary protein than the dog, which is considered to be an omnivore or semicarnivore, the concentrations required are not nearly as high as that provided by a meat-only diet.

According to the NRC (47), the CP minimal requirement of adult dogs and cats is 8% [dry matter basis (DMB)] and 16%, respectively. The NRC (47) also provides a recommended allowance (RA) of 10% and 20% CP for adult dogs and cats, respectively. The RA is often used because it accounts for differences in nutrient bioavailability among ingredients and genetic variation among animals. The recommendations made by AAFCO (43) for adult dogs (18% CP) and cats (26% CP) were also established to account for these differences. A recent paper by Hill et al. (50) reported the chemical analysis of 1156 commercial canned and 750 commercial dry dog and cat foods. Using the as-is CP and moisture data reported in that paper, diets contained an average of 40.8% CP (DMB) for canned diets and 31.4% CP (DMB) for dry diets. Although this paper did not distinguish diets marketed for dogs or cats, both forms of food were well above the CP requirements for both species.

Although the minimum requirements of protein are significantly lower than those found in typical pet foods, it cannot be excluded that a higher protein level may support a health benefit. This remains an open question based on current research, given that current estimates of the minimum requirements for adult dogs and cats are typically based on relatively short-term studies of <6 mo and use growth or markers of protein status (e.g., nitrogen balance) rather than markers of health or wellness. Thus, the minimal requirement and RA values that are established for the general population of dogs/cats of a given life stage may not provide optimal nutrition for any specific individual.

Protein quality (digestibility and how the amino acid profile of a food corresponds to the physiological needs of the animal) greatly affects animal performance and should be considered during diet formulation. In addition to meeting crude protein requirements, the essential amino acid requirements of the animal must be met. The importance of amino acid balance has been known for >70 y (51). In the 1970s and 1980s, companion animal researchers at the University of California–Davis and University of Illinois determined minimal amino acid requirements of growing puppies and kittens. Similar to what has been done for growing swine (52) and poultry (53), these data were used to estimate ideal amino acid profiles for dogs and cats (54). Formulators often include high concentrations of CP, use a combination of complementary protein sources, or include synthetic amino acids to meet all amino acid needs. Because the majority of today's pet foods contain a surplus of protein, however, specific amino acid ratios are rarely considered during formulation. Metabolically speaking, the inclusion of poor-quality proteins or excess protein for energy is inefficient compared with calories derived from fat or digestible carbohydrates. Even though there is evidence to suggest that cats use protein calories more efficiently than other mammalian species (55), increased protein oxidation of high-protein diets leads to increased urinary nitrogen and energy loss (56).

Certain physiological conditions may benefit from high-protein diets, which should be considered when assessing nutritional sustainability. High-protein, low-carbohydrate foods elicit lower glycemic responses compared with those containing high concentrations of carbohydrate, which can benefit dogs with insulin resistance or diabetes (57,58). Furthermore, studies have shown that foods with a higher protein content (103 g/1000 kcal, or ∼31% for a 3000 kcal/kg diet), in addition to higher fiber content, decrease voluntary intake, increase the amount and rate of weight loss, and increase fat mass loss during weight loss in dogs (59,60). Dog foods containing high protein and low energy maintain muscle mass during weight loss (61,62). Additionally, high-protein diets can be beneficial for endurance exercise in dogs. Sled dogs fed a diet consisting of 35% of energy from protein had higher plasma volume than dogs fed a diet with 18% of energy from protein (63). The 18% protein diet also resulted in decreased V_{O_2} max and greater rate of soft-tissue injuries.

Ingredient selection. As is the case with human foods, the choice between plant- and animal-based proteins is one of contention, but is one that may influence the environmental impact of pet foods. The anthropomorphism of pets continues to increase and has influenced the way in which companies formulate and market pet foods and treats to consumers. The quality of ingredients and having meat-based diets are important factors that pet owners consider when choosing a pet food (64,65). However, most owners do not know or consider that dogs and cats, like all animals, require specific nutrients—not ingredients. Although dogs and cats have unique metabolic and nutrient requirements (e.g., protein, arginine, taurine, arachidonic acid, vitamin A, vitamin D, niacin), these targets may be reached with a wide variety of ingredient sources.

As demonstrated in Table 1, the energy input required to produce animal protein (kilocalories of fossil energy input: kilocalories of protein output) varies greatly depending on animal species. On average, the energy input:protein output of animal-based proteins (25:1) is ~11 times greater than that for grain-based proteins (2.2:1) (66). Because these figures used corn as the grain, assuming 9% protein, and assumed animal-based proteins to have a biological value 1.4 times that of grain protein, these numbers may change slightly based on these assumptions. In general, however, animal proteins have a much larger carbon footprint than plant proteins. Similar comparisons have been applied to water use. Pimentel and Pimentel (66) estimated that 1 kg of animal protein requires 100 times more water than 1 kg of grain protein. Because soy is one of the most common plant-based protein sources used in pet foods, its comparison with animal proteins is of interest. Recent reports estimate that soy-based proteins are 6–20 times more efficient in terms of fossil fuel requirement (67–69), 4.4–26 times more efficient in terms of water requirement (68), and 6–17 times more efficient in terms of land use (70) vs. animal proteins.

Pet foods can contain considerable amounts of fish-based proteins. Unlike conventional livestock production, the primary costs associated with wild-caught fish are those associated with fossil fuel use, with the amount dependent on fishing strategy. Per gram of protein, fishing by trawling and crop rearing is estimated to use ~14 times more fossil fuels compared with vegetable protein (67,68). These costs would be expected to increase even more when processing is considered. Given the shortage of natural fishing grounds, the field of aquaculture continues to grow rapidly worldwide. Because there are more environmental impacts compared with wild-caught fish (e.g., area requirements, release of biocides or nutrients), the "costs" of aquaculture-based fish proteins have been estimated to be similar to conventionally raised livestock (71). Carnivorous fish raised on fishmeal can have an even greater environmental burden than livestock. Certification programs have been organized to assess the sustainability of fisheries, including the Marine Stewardship Council and Friend of the Sea. Certification requires meeting specific criteria, including the requirement that the fish are sourced from sustainable stocks and the catching method minimizes the impact on the ecosystem. When considering production strategy and nutritional sustainability, the nutritional differences between wild-caught fishing and aquaculture-based practices should be considered. For example, higher total fat content has been reported in farmed compared with wild-caught fish for gilthead seabream (72), catfish, and salmon (73). Although total n-3 fatty acid content was shown to be higher in farmed fish, the n-3:n-6 fatty acid ratio was lower due to the increased total fat content.

The pet food chain is a complex network, involving various industries. The current carbon and water footprint estimates for dietary ingredients are useful to some extent as they pertain to pet foods, but only if the ingredients are suitable for human consumption and are directly competing with the human food system. In recent years, the use of human-grade ingredients has been suggested in homemade and commercial diets. For the majority of diets in the pet food industry that are based largely on human food by-products, however, such estimates may have limited use. Hundreds of human food by-products are currently available and used by the pet food industry. For example, broken kernels of rice are used in pet food in the form of brewer's rice, and animal flesh remaining after the cuts of meat for human consumption are removed are used in pet food. Rather than competing with humans for food, pet foods based on by-products actually lighten the environmental burden of the human food system. Although some have discussed the feeding of by-products and have estimated their environmental impact on livestock production (74,75), an in-depth analysis of all human food by-products, with application to livestock production and pet foods, is sorely needed. One method for estimating the environmental impact of by-products is economic allocation in which values, such as CO_2e, are mathematically allocated between human-grade, or primary-use, products vs. by-products, either by mass or economic allocation.

In addition to the ingredients currently used in typical pet foods, development of novel ingredients, particularly alternative protein sources, can have an impact on improving the nutritional sustainability of the pet food system. Alternative protein sources may include the use of by-products currently viewed as waste or the development of new protein sources from plants, lower order animals, or single-cell organisms with a lower environmental impact compared with typical animal-based protein sources. Expired human food products and food wastage are other potential sources of ingredients for pet food. Approximately 26% or 48.1 megatons of edible human food in the United States is wasted at home and at food service establishments, with fresh fruits and vegetables and fluid milk accounting for 19% and 18% of these losses, respectively (76). Currently, food waste recovery is quite low. In 1998, <2.6% (by weight) of food wastes were recovered (77). Although human food waste is used to feed livestock in certain regions, this may be another opportunity for the pet food industry.

Heitschmidt et al. (78) discussed the sustainability of agriculture in terms of the ecosystem concept 15 y ago. In this system, producers are organisms that capture solar energy (e.g., plants, phytoplankton), consumers are organisms (almost always animals) that obtain their energy by consuming other organisms, and decomposers are the final consumers of organic matter (usually bacteria and fungi). Scavengers are considered decomposers because they hasten the process of decay for final decomposers, such as bacteria and fungi. The same concept may be applied to the pet food industry. In its original form, dogs and cats are naturally classified as secondary consumers in the ecosystem. Depending on ingredients included in the formula, however, could one not argue that dogs and cats also represent decomposers in the system? When pet diets are formulated with ingredients directly competing with livestock or humans, the secondary consumer title fits. When diets are formulated with by-products or the waste of the human food system that would otherwise be discarded, pets may assume the decomposer role as a scavenger. Although it may not be worth spending much time on semantics, this concept does highlight the importance of by-products and the need to accurately estimate their role and impact on sustainability.

Responsibility of pet food manufacturers

Unbeknownst to most owners, numerous factors on the local, regional, and international levels affect the sustainability of owning a pet. Pet food professionals, including nutritionists, formulators, process engineers, ingredient buyers, marketers, and regulators, have the opportunity to influence the sustainability of pet ownership through product design, manufacturing processes, educating the public, and policy change to improve the sustainability of pet foods. The primary sustainability issues surrounding the nutrition of pet foods involve ingredient selection and nutrient composition. Additional factors that pet food professionals can influence include minimizing food waste through nutrition by appropriate consumption rates and reducing fecal waste by improving digestibility and bioavailability. Nutrient composition, ingredient selection, consumption rates and digestibility all have an effect on pet health and therefore affect the nutritional sustainability of pet foods.

Integration of sustainability measurements into pet food formulation programs could provide a tool to assess products and choose more sustainable formulations based on ingredient selection and nutrient composition. Sustainability measures, such as CO_2e, water use, ingredient scarcity, material digestibility, and food miles, may be entered for individual ingredients to predict sustainability measures for the total formula. This would allow a comparative evaluation of formulas to minimize carbon and water footprints and ingredients that are scarce. Such a tool could be used to identify high-risk areas with respect to sustainability and allow for mitigation plans to make improvements in ingredient selection and nutrient composition to optimize sustainability within the constraints of the product design.

The sourcing of ingredients can be optimized to choose responsible suppliers that integrate sustainability efforts into their work streams. Choosing certified sustainable ingredients or suppliers that include sustainability practices in their production processes can influence ingredient suppliers to integrate sustainability efforts into their processes. Also, since its beginning, the pet food industry has been based on by-products that do not directly compete with the human food industry. The benefits of using such ingredients, in terms of nutritional quality and sustainability, can be promoted and highlighted in consumer education programs.

Obesity is a serious problem with an estimated 34% of dogs and 35% of cats in the United States being labeled overweight or obese (79,80). Being overweight can lead to health problems including diabetes, orthopedic disease, and respiratory problems, and it can shorten life expectancy by as much as 2 y (81). Maintaining ideal body weight not only has health benefits of avoiding obesity-associated disease, but also minimizes food wastage through overconsumption. If the current population of overweight/overfed pets were suddenly fed the proper amount, it would have an immediate and significant impact on the health of those pets and overall footprint associated with the pet food industry. Thus, pet owner education programs focused on healthy body condition, proper feeding guidelines, and nutrient requirements (e.g., protein) can provide a means of influencing pet owner behavior to influence nutritional sustainability of the pet food system.

Another strategy to improve pet food sustainability is to maximize nutrient density, digestibility, and bioavailability to use fewer resources and minimize fecal waste. However, the influence on nutritional sustainability should be considered. For example, although the inclusion of higher levels of dietary fiber decreases dry matter digestibility, balanced levels of fiber promote digestive health and can provide functional benefits, such as weight control or hairball control. Exclusion of fiber to improve overall dry matter digestibility, and therefore environmental sustainability, could have a negative impact on nutritional sustainability. Additionally, maximizing caloric and nutrient density with the concept of feeding less food could have detrimental effects on pet health by promoting obesity if appropriate feeding management practices are not adopted by owners. Alternatively, improvements in ingredient quality and manufacturing process to optimize nutrient digestibility and bioavailability can have a positive impact on pet health and nutritional sustainability. Although the cooking process that occurs during extrusion or retort increases starch and protein digestibility, excessive temperature, pressure, or processing time leads to decreased protein and amino acid digestibility.

Strategies to improve the sustainability of pet foods involve a coordinated effort among all employees within a pet food business, including ingredient buyers, formulators, and nutritionists. Sustainability change within the pet food industry will involve education and awareness not only

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within the industry, but also among consumers, including the competing environmental, social, and economic aspects of pet foods that exist. As methods, research, and new technology are discovered or as sustainability science becomes clearer, regulators and consumers will desire more sustainable products for their pets. Initiating the discussion is one step to help move the industry toward improving the sustainability of pet ownership.

Conclusions

Sustainability in terms of the world's food supply is of great importance. Nutritional, ecological, and economic concerns exist, not only for the human food supply, but for pet foods as well. Because the pet food system is largely based on byproducts and is interlinked with livestock production and the human food system, it is quite unique with regard to sustainability. Moreover, consumer perception and the anthropomorphism of pets have had an increasingly important effect on dietary aspects of commercial pet foods, including ingredient selection and nutrient composition. Formulation of diets to provide nutrients in excess of physiological requirements, the use of ingredients that compete directly with the human food system, or overfeeding by owners resulting in food wastage and obesity are common challenges in optimizing the sustainability of the pet food system and pet ownership. With increasing research and knowledge in sustainable practices, advances in technology, and increasing awareness and demand by consumers, there is an increasing ability to make an impact on pet food sustainability. Pet food professionals have the opportunity to influence the sustainability of pet foods through product design, manufacturing processes, public education, and policy change. A coordinated effort that includes all parts of the pet food industry, including ingredient buyers, formulators, and nutritionists, can improve the sustainability of pet foods and pet ownership.

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