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Plant-Based Diets for Dogs and Cats: Review of Current Perspectives

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1. INTRODUCTION

World population growth has been increasing since the Industrial Revolution and more rapidly within the last 50 years due to technological advances. Based on the Population Division of the United Nations Department of Economic and Social Affairs (UNDESA), the world population will increase from 7.7 billion in 2019 to 9.7 billion in 2050 (UNDESA, 2019). Scientists have voiced increased concern regarding environmental sustainability with respect to the food production industry and claim that in order to maintain sustainability, significant changes need to be made (Aiking, 2011; Bruinsma, 2009). With pet ownership also increasing, especially in developing countries (Okin, 2017), the compounding effect of human and pet food production on the environment needs to be addressed. Plant-based food industry has demonstrated a significantly smaller use of the planet's resources as compared to animal-based food industry (Reijnders, 2003), which is a contributing factor to an overwhelming rise in vegetarianism and veganism over the last several years (Christopher et al., 2018; Pendergrast, 2016). Consequently, interest in plant-based diets for dogs and cats has also increased (Okin, 2017), which has fueled the scientific community to address how and if plant-based diets are possible for dogs and cats. This emerging field has seen mixed results and controversial views, specifically focusing on the idea of nutrient deficiencies that can arise from plant-based diets. This points to a need for more research and information on the topic, especially given the serious impact to the environment as well as psychological impact for meat-abstaining pet owners.

The following paper aims to review up-to-date literature on the topic of plant-based diets for dogs and cats, and deconstruct and examine the findings in this field. Specific questions of interest focus on how the pet food industry impacts the environment, what motivates pet owners to seek out plant-based diets for their pets, how can nutritional requirements for dogs and cats be met through a plant-based diet, what are the concerns surrounding plant-based diets for dogs and cats, what are the existing controversies in the area of plant-based diets for dogs and cats, and what can be expected as this field continues to grow.

2. METHODS

To address these questions the current review examined studies that have looked at current and predicted environmental effects the pet food industry, pet owner motivations for plant-based diets, including potential psychological effects, nutritional requirements for dogs and cats, plant-based diets in dogs and cats, and issues in the area of manufacturing plant-based diets for pets.

The literature review is organized into four primary sections. The first section discusses the environmental implications of animal-based pet food production, along with humanization of pets and projected long term effects of the environment. The second section provides a brief history and current trends in plant-based diets as well as social trends regarding pet owner attitudes, and examines various motivations of pet owners in providing plant-based diets to their pets. The third section provides information on the nutritional requirements for dogs and cats, specifically focusing on issues and concerns that need to be addressed in pet food. The fourth section reviews existing plant-based diets in the areas of commercial, homemade, and natural food, where to find it and how it should be administered properly. This section also includes a review of labeling and informational issues that must be considered by pet owners. Both content analysis and feed trial studies were included in the current review. Areas where more research and data is needed is also discussed.

3. ENVIRONMENTAL EFFECTS OF FOOD PRODUCTION

In recent decades the human population growth made a big jump and it will keep increasing at a high rate (Cohen, 2003; UNDESA, 2019). The production of resources had to accompany this trend in order to provide enough means for the population to survive. During this period, the technology advances have been tremendous which allowed for food production to be more efficient. Despite that, the environmental impact of food production and consumption has increased greatly (Tilman, 2001; Reijnders, 2003; Okin, 2017).

Currently, humans appropriates an estimate of 32-35% of all primary production to raising plants on land, the food sector being the main factor in appropriation. Such claims of the biomass have created a massive impact on nature. There has created a substantial increase

in the extinction of species, moreover, by now half of the usable fresh water is appropriated by humankind (Rojstaczer, 2001). Energy consumption and waste production are also great concerns of the current agricultural practices. Extrapolation of current practice suggests that in the next 50 years, 10 trillions of hectares will be used and nitrogen and biocides emissions might increase by 2.4 to 2.7 times (Tilman, 2001). This means that there will be less space available for people and nature, such as forests which will ultimately decrease the quality of the air. Moreover, the increased number of nitrogen and biocides will affect the balance of the ecosystems, leading to overgrowth of some species and extinction of others.

Even though improvements in agricultural practices are important in reducing the impact of food production, the potential impact of changing the dietary choices must not be neglected (Goodland, 1997). A dietary change that has been gaining popularity and can have a great impact on the environment is the reduction of animal product consumption. For the same amount of protein produced by soybeans, meat requires 6-17 times more land use, 4.4-26 times more water, 6-20 times more fossil fuel, 7 times more phosphate rock, 7 times more emissions of acidifying substances, 6 times more emissions of biocides and over 100 times more emissions of copper. Production of vegetables is also considerably more environmentally friendly than meat. It is estimated that with all things considered, a vegetarian meal has an environmental impact 1.5 to 2 times less than a regular meal (Reijnders, 2003). This demonstrates the significant differences that meat based diets have on the environment as compared to plant-based diets.

A considerable percent of the global food production is pet food production. In United States for instance, dogs and cats consume as much dietary energy as 62 million Americans which corresponds to around one fifth of the United States population (Okin, 2017). In Australia, it was estimated that in 2006, each cat consumed around 13.7 kg of fish, making it close to 2 million tons of fish used in the production of cat food. Applying such values to the rest of the world would mean that cats consume around 2.5 million tons of fish per year (de Silva & Turchini, 2008). It is important to note that a large percentage of pet food is by-products from human food. AAFCO defines by-product as secondary products produced in addition to the principal product (AAFCO, 2019). Pets are considered secondary consumers because they consume food production byproducts that might not be used for food production (Swanson et al., 2013). It has been argued and is widely accepted that pet food production has

a negligible global effect because the byproducts used in pet food would not serve a purpose otherwise. However, based on the information from AAFCO's manual on the ingredients in pet food, meat and poultry products that humans do consume, are also utilized in addition to by-products (AAFCO, 2019). Because there is not enough data on what percentage of animal-based products used in pet food is also used by human, calculating the actual impact of the pet food industry on the environment has been difficult (Okin, 2017; Swanson et al., 2013). This is complicated by the fact that animal by-product consumption differs culturally. Additionally, there is not enough information on what percentage of animal by-products can be used by humans in other useful ways. Even if only one quarter of the animal products in the United States derived to pet food production was usable for humans, it could feed 26 million people (Okin, 2017). Furthermore, pet ownership is increasing throughout the world, making the effects of the pet food industry even more relevant. In China for example, the pet population grew by 20% between 1999 and 2004. During this time period, the pet ownership increased from 240,799,000 to 291,315,000 (Zuang, 2005). Consequently, the market for pet care products has been growing an annual average rating of 4% in terms of value, reaching a value of 49 billion dollars in 2003. Pet food represents 80% of the global pet industry market (Combelles, 2004).

The humanization of pets is another factor of importance to consider when looking at resource use for animal-based diets. Pet owners are regarding their pets more like humans, recognizing in them human characteristics and treating them as such (Kumcu & Woolverton, 2014; Swanson et al., 2013). A major reason for this is the fact that younger people are starting their families later than older generations, relying on pets as a major source of companionship. This is seen in the quality of food fed to pets. There is a trend towards increasing the use of premium ingredients in pet food (Okin, 2017). Such higher quality products include ingredients that could be used for human food products, directly competing with it. As this trend grows, the competition with humans will also increase. This means that food that is usually destined for human consumption will be utilized for feeding animals, contributing to food scarcity for both humans and pets.

The humanization of pets is accompanied by a greater movement throughout the world about humanization of animals. The shift of people regarding animals more highly means that people consume lower amounts of animal products. There has been a trend of increasing

numbers of people that abstain from consumption of animals, which can be complete or partial (Bertuzzi, 2017; Christopher et al., 2018; Pendergrast, 2016). Flexitarian, a term used to describe a vegetarian oriented consumer that does not consider him/herself a vegetarian but prefers vegetarian products (de Boer & Aiking, 2011). This movement shapes the products consumed by society, including the ones destined for pets.

4. MOTIVATIONS OF PLANT-BASED DIETS

4.1 Current trends in vegetarianism and veganism.

The vegetarian/vegan movement is largely a response to the effects of the meat production industry on the environment and animal welfare. This trend has been documented through multiple studies over the past several decades. A study on vegetarian and vegan trends found that the number of people abstaining from meat has increased significantly in western countries, citing environmental and animal protection and health as the main reasons (Beardsworth & Keil, 1991). In more recent years, this trend has shown more drastic increases, with number of vegans over the age of 15 in the UK increasing 360% in the last decade (Vegan Society, 2016). Similarly, over the last decade Germany has seen an increase of individuals identifying as vegan by 350% (Castricano & Simonsen, 2016). This trend is also seen in the USA, with consumer reports showing the number of vegans has increased by 600% between 2014 and 2017 (Report Buyer, 2017). Effects of this trend are also seen at the institutional and systemic level, with the American Medical Association House of Delegates issuing a policy for hospitals to begin serving plant-based diets (PCRM, 2017), supporting research that has been released by the World Health Organization (IARC, 2015). These dietary social changes further underscore the need for more research on plant-based diets, for both humans and pets.

4.1.1 Vegetarian's Dilemma

The *vegetarian's dilemma* is a form of cognitive dissonance, which is psychological discomfort and distress that occurs when an individual's behavior is inconsistent with their cognitions. Because human beings strive for internal consistency, they will use one of three ways to reduce that distress. The methods for decreasing cognitive dissonance include changing behaviors to be consistent with beliefs/cognitions, changing beliefs/cognitions to be more in line with behaviors, or coming up with an alternate rationalization of

beliefs/cognitions to reduce the internal conflict (Festinger, 1957). The term vegetarian's dilemma was first coined by Hank Rothgerber (2013) to describe the cognitive dissonance, or internal conflict, that meat abstainers experience when feeding their pets a meat-based diet. Meat abstainers have been found to have more positive attitudes towards animals (Herzog et al., 1991; Preylo & Arikawa, 2008), more empathy (Fillipi et al., 2010) and concern for animal suffering (Ruby et al., 2011; Kenyon & Barker, 1998; Rozin et al., 1997), and are more likely than meat eaters to own pets (Rothgerber, 2013; Dodd et al., 2019). Specifically, vegetarian's dilemma refers to the conflict between feeding pets an animal-based diet that may be best for their health and the welfare of animals in and negative environmental effects of the meat production industry that creates these diets. Rothgerber (2015) suggests that there are several ways through which to mitigate this conflict. First, to simply feed pets a plant-based diet (change behavior to fit the beliefs). However, there are multiple issues regarding the availability and nutritional content of current plant-based diets, which will be discussed in greater detail in the Food Types section. Another method for resolving the vegetarian's dilemma and reduce the associated distress is to deny that animals have emotional and cognitions similar to humans and feed them an animal-based diet (change the beliefs to fit the behavior). The problem with this method is that it denies the very reasons many meat abstainers choose to exclude meat products from their diets (Fillipi et al., 2010; Ruby et al., 2011; Kenyon & Barker, 1998; Rozin et al., 1997; Dodd et al., 2019). The last method by which to resolve the vegetarian's dilemma is to rationalize feeding pets an animal-based diet, while abstaining from meat, simply because their health and well-being requires animal protein (alternate rationalization of beliefs). This method uses a limited choice approach and tended to be moderately popular among meat abstaining pet owners (Rothgerber, 2013). The method utilized for reducing distress of vegetarian's dilemma highly depends on the motivations behind pet owners decisions to abstain from meat and whether their pets are dogs or cats (Dodd et al., 2019).

4.2 Ethical vs. Health Meat Abstainers

4.2.1 Ethical

Ethical meat abstainers, a category that includes ethical vegetarians and vegans, are motivated by an ideology that tends to be philosophically and spiritually driven, wherein they oppose animal suffering and believe that modern means of animal production are inhumane.

Furthermore, ethical meat abstainers are motivated by humanistic values, and tend to hold the belief that animals have primary and secondary emotions similar to humans. Previous research has demonstrated that it is these beliefs, and not beliefs about health benefits or appropriateness of animal-based diet, that account for the increased guilt reported by ethical meat abstainers (Rothgerber, 2013). Ethical meat abstainers are more likely to resolve the vegetarian's dilemma through behavior and are more likely to feed their pets a plant-based diet. (Rothgerber, 2013; Rothgerber, 2015).

A sub-category under ethical meat abstainers is that of individuals who abstain from meat on the basis of religion. Religions like Buddhism, Seven-day Adventism and Hare Krishna promote avoidance of meat (Nath, 2010). In one study, around one fourth of meat abstainers cited religion as the major reason to avoid the consumption of meat (Spencer et al., 2007). Religious and cultural practices may also have an effect on what pet owners feed their pets. An example of how religious and cultural practices interact with food choice can be seen in India, where cows are sacred and are not consumed. This widespread cultural practice likely affects the extent to which beef based products are used in pet food.

4.2.2 Health

Health meat abstainers are motivated by an ideology that tends to be more internally focused, are driven by more normative values, and tend to be more closely related to the mainstream ideas on animal welfare in animal-based food production. Their primary concerns are personal health, fitness and energy. Furthermore, due to the internal and personal focus of their motivation, health meat abstainers, as well as combination ethical/health meat abstainers, tend to experience less guilt than ethical meat abstainers and vegan when feeding their pets an animal-based diet, and are less likely to abandon that diet (Rothgerber, 2013). The most common method for health vegetarians in resolving distress of vegetarian's dilemma was to deny that animals have emotional and cognitive states similar to humans (Rothgerber, 2013; Rothgerber, 2015).

5. NUTRITIONAL REQUIREMENTS AND CONCERNS

In order to understand the nutritional needs of dogs and cats, it is crucial to understand their evolutionary history. Dogs were domesticated from wolves approximately 33,000 years ago (Ovodov et al., 2011). The ancestral dogs depended on human food scraps in order to

survive and developed biological adaptations accordingly. Divergence of dogs from wolves has been shown in the ability to subsist on lower protein diets and to metabolize carbohydrates, to the extent that they developed specific genes to digest starch. Therefore, contrary to their wolf ancestors, dogs are biologically omnivores (Axelsson et al., 2013) which allows them to meet their nutritional needs through a plant-based diet.

The domestication of cats happened approximately 10,000 years ago (Driscoll et al., 2007). While cats played the role of companions, it was their role as pest controllers (Driscoll et al., 2009) that allowed them to continue to choose a similar diet to wild cats (Buff et al., 2014). Therefore, cats did not have any significant evolutionary pressure to change their diet. Due to this, meeting all the nutritional needs of cats through a plant-based diet is much more challenging. In order to evaluate the plausibility and applicability of plant-based diets for dogs and cats the protein content, taurine, L-carnitine, fatty acids, vitamin A, vitamin D, vitamin B12, calcium, phosphorus, palatability and urinary pH need to be considered. Nutritional requirements for dogs and cats as well as species-specific concerns are described in detail below.

5.1 Dogs

Protein Content

When addressing the protein requirements for dogs in any diet, two issues must be addressed: quantity and quality. Regarding protein requirement for dogs, quantity refers to the amount of protein and quality refers to the presence of required amino acids. Depending on the various stages of life such as growing, reproducing or maintenance, dogs have different nutritional needs, therefore, the diet has to be formulated accordingly. The maintenance protein needs for an adult dog with typical exercise levels are 18% of metabolizable energy with sufficient amount of the right amino acids. The protein requirements of growth and reproduction stages are 22% of metabolizable energy (Case, 2011). Nowadays, most of the dog protein needs are met through the use of products from animal sources. Reasons for such practices to have such high popularity have to do with the nature of dogs, it being ingrained in the culture and it being a cheap and effective way to meet the dog's nutritional needs. Due to continued advances in food production, plant-based sources of protein are being used and are gaining popularity (de Boer & Aiking, 2011).

When it comes to protein quantity, multiple plant-based protein sources are being investigated and some used already, such as soy. Plant-based alternatives have been proven to have high enough content of protein to easily satisfy the quantitative needs in a diet for a dog. Some have total protein levels comparable to animal products such as brewer's yeast, soy protein concentrate, and gluten meal which have respectively 59, 76, and 60 grams of protein per 100 grams of product. Animal product protein content range between 50 grams to 80 grams of protein per 100 grams. Examples of the most used products include cattle by-product meal with 52 grams of protein and chicken by-product meal with 53 grams of protein (Dodd et al., 2018).

Nevertheless, protein quantity available in food is not the only concern related to the quantitative characteristic of the food. Once ingested, the proteins are digested and the absorption of the amino acids varies for different products. Factors affecting the availability of amino acids include high food dry matter intake, fiber levels, low quality of protein and presence of anti-nutritive factors (Hand & Lewis, 2010).

Soy is the most popular and well-studied plant-based protein source because of its high protein content and good protein availability. However, it also has the presence of anti-nutritives, which are natural or synthetic compounds that interfere with the absorption of nutrients. Soybeans contain anti-nutritive factors such as trypsin inhibitors, lectins, tannins and phytate and increased amounts of non-starch polysaccharides such as stachyose and raffinose (Dodd et al., 2018). Processing soy products has been shown to resolve some of these anti-nutritive related limitations. Apparent digestibility of soybean meal and soy flour in dogs has been determined to be higher than whole soybean (Kendall & Holme, 1982). Nevertheless, more research is needed in this area as there are currently inconsistent findings. For instance, decreased digestibility was found in studies where soybean meal was present in levels greater than 15% (Yamka et al., 2003). In contrast, in another study of soybean digestibility it was observed that the digestibility of soy protein concentrate, soy flour and soybean meal was excellent in levels higher than 30% (Clapper et al., 2001). One possible explanation for the different findings is that other factors such as dog age or the other contents in the food could have affect digestibility levels.

Other plant-based protein sources that have been researched and have shown some promise include wheat gluten, maize gluten, copra meal and lupin and mung beans (Yamka et

al., 2004; Twomey et al., 2002). Wheat gluten meal has been shown to have higher crude protein content and digestibility than soy products (Kendall & Holme, 1982). Although, more conclusive research was done with pigs, which demonstrated excellent results (Richert, et al., 1994), there is a need to replicate these findings with dogs. Maize gluten is high in protein and has been shown to be a highly digestible plant-based protein. The more maize gluten added to dog diet, the higher crude protein digestibility (Yamka et al., 2004). In another study, copra meal, lupins, and mung beans were tested in dog diets with promising results. The author concluded that these protein sources represented practical alternatives to animal protein sources and showed nutrient digestibility and fecal quality similar to the control diet, which was animal based (Twomey et al., 2002).

As stated above, findings demonstrate that attaining adequate protein from plant-based sources is possible, several studies have examined this in dogs. Semp (2014) conducted a study that measured protein levels in the blood of dogs, where 20 dogs were fed a vegan diet and 20 dogs were fed a conventional diet. The serum total protein of all the dogs fed a vegan diet were within normal range, between 5.4 and 7.6 g/dl and a mean value of 6.3 g/dl, while in the conventional diet group, 2 dogs were not within reference range. The serum albumin was also measured in this study, but only in the group fed a vegan diet. Out of the 20 dogs fed plant-based, all individuals presented albumin values within the reference range, between 2.8 and 4.3 g/dl and mean value of 3.3 g/dl (Semp, 2014).

The qualitative characteristic of plant-based protein for dog food requires higher attention and knowledge. Dogs have 10 essential amino acids: arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine (Hand & Lewis, 2010). Presence of all amino acids in sufficient amount is crucial for the health of the dogs. Taurine is also an important amino acid that can more accurately be classified as semi-essential, which is discussed below.

One of the concerns about plant-based dog food is the fact that many protein sources have an incomplete amino acid profile. Compared to animal products, which usually contain the 10 essential amino acids in sufficient quantities, plant-based sources are usually low in some amino acids (Dodd et al., 2018). There are a few solutions to this concern. One way of addressing this issue is choosing plant sources that have good amino acid profile. For example, soy is a protein source that has a good amino acid composition except for the sulfur-containing

amino acids (Brown, 2009). It is also possible to combine different protein sources to complete the amino acid profile. It is a process that requires extensive knowledge in order to be done properly because it can lead to amino acid imbalances if not done correctly. One example of this is combining corn protein, which is low in lysine and tryptophan, with soybean meal which has high levels of both amino acids. When the combining is rightfully done, it can result in food with high quality protein (Gillen, 2008). Another solution to address this problem is to add amino acids individually to the food (Hand & Lewis, 2010). By knowing the amino acid missing in a feed, it can be added to it individually, successfully completing the amino acid profile.

Studies that have examined both quantity and quality of protein in dogs have looked at dogs with vigorous intensity exercise. In one study where dogs performing high intensity exercise, with some fed a meat-based diet and others a plant-based diet, the plant-based group developed significant decreases in hemoglobin levels and in red blood cell count (Yamada et al., 1987). The authors concluded that the cause of this was the increased fragility of the erythrocytes' membrane. The authors attributed the cause of such differences to the different amino acid profile in both diets. The plant-based diet had inadequate lysine content and poor lysine-to-arginine ratio. Although the source protein used in the plant-based diet was soy, which has a similar amino acid profile to meat, this study did not take digestibility into account. More recently, more research was done on high intensity performing dogs that included the digestibility issue, and found different results. They investigated 12 sprint racing sled dogs, half were fed a diet with poultry meal as the protein source and half were fed a diet with maize gluten and soybean meal as protein source. The subjects were fed these diets for 16 weeks and healthy hematological results were maintained throughout the study (Brown et al., 2009). The consulting veterinarian who was blinded to the dietary treatments determined that the dogs were in excellent condition.

Taurine

Taurine is a sulfur containing amino acid with a different profile from other amino acids in the way that it is found throughout the body. In dogs it has many important functions, so adequate levels must be maintained. It is a semi-essential amino acid so it can be produced endogenously. The great majority of sources of taurine are animal-based but synthesis in laboratory is also possible.

The major difference between taurine and other amino acids is where it is found in the body. Unlike other amino acids which are incorporated into proteins, taurine can be found free flowing through the body with the highest concentrations in skeletal muscle, cardiac muscle, central nervous system and platelets (Tenaglia & Cody, 1988). The function of taurine is not completely understood and only some of its functions have been discovered. It is known that taurine is involved in conjugation of bile acids, detoxifying of xenobiotics, antioxidation, stabilization of neural membranes, reduction in platelet activation, reproduction and maintenance of myocardial function. Due to the multiple functions of taurine, it is imperative that it is maintained in the body at the required levels, as taurine deficiency in dogs is associated with complications, the most critical being dilated cardiomyopathy (Sanderson, 2006).

In dogs, taurine is a semi-essential nutrient, meaning that it is an absolutely necessary nutrient to exist in the required levels in the body but it does not necessarily need to be obtained from diet. Dogs have the ability to synthesize taurine in the liver from other amino acids. Hepatic synthesis is done using the enzyme cysteine sulfonic acid decarboxylase and the sulfur containing amino acids methionine and cysteine (Jacobsen et al., 1964). Therefore, meeting the taurine requirements for dogs can be done in two ways: supplying the feed with enough taurine or supplying the feed with enough methionine or cysteine so that the nutritional needs of these amino acids is met and there is enough extra for taurine to be produced in the liver.

When it comes to vegetarian diets for pets, taurine is a controversial topic because it is typically sourced from animals. Taurine is also found in high levels in seafood such as mussels and salmon, and in moderate levels in turkey products. In non-animal sources, taurine is present in a few fungi and plants with levels too small to meet the nutritional needs of a dog (Spitze et al., 2003). Synthesis of taurine in laboratory settings is also an option that has been gaining popularity. Laboratory made taurine is simple and easy to produce, offering very viable source of taurine that can be added to canine diet (Bondareva et al., 2008).

Taurine deficiency has been a concern with plant-based diet because of limited sources. Nevertheless, there are other aspects affecting the taurine nutrition. High levels of fiber in diet, especially fermentable, enhance bile acid excretion and microbial degradation of taurine conjugated bile acids (Ko & Fascetti, 2016), which lowers the availability of taurine in

the food. Also, it has been shown that when given high enough levels of sulfur containing amino acids, dogs maintain adequate levels of taurine even in taurine depleted diets (Pion et al., 1998).

Due to the tragic consequences of taurine deficiency in dogs, such as cardio and reproductive issues, steps should be taken to guarantee such outcomes do not occur. There are easy ways to ensure proper taurine level that owners feeding dogs plant-based diets should be informed about. Owners can and should request blood samples when visiting the veterinarian in order to measure taurine levels. Evaluating plasma and whole blood taurine has been shown to accurately measure the levels of taurine in a dog's body. Taurine can also be safely added to the diet on a regular basis in order to ensure adequate levels. No side effects have been seen in dogs fed high levels of taurine, which is cheap and available (Sanderson, 2006).

L-Carnitine

L-Carnitine has a similar structure to amino acids but the amino group is not free and so it is not used in the synthesis of proteins. It can be obtained from the diet or synthesized in the , using iron, vitamin C and vitamin B6 cofactors (Bremer 1983). One of the most important functions of L-carnitine is the transport of long chain fatty acids into the mitochondria to be used as energy. The normal heart obtains close to two thirds of the total energy production from oxidation of long-chain fatty acids (Neely & Morgan, 1974). Issues in this process are associated with poor prognostic diseases, especially those related to heart function such as dilated cardiomyopathy (Sanderson, 2006).

Most sources of L-carnitine are animal-based, however, some plant sources also exist. Furthermore, plant-based sources can provide enough L-carnitine, but due to its great importance to the body, maintenance of adequate levels must be assured. Laboratory made L-carnitine is another good and efficient way to add L-carnitine to the diet. Deficiencies can be diagnosed through plasma level measurements of L-carnitine (Sanderson, 2006). Control is especially important when transitioning the dog to a plant-based diet. Supplementing L-carnitine in diet is a relatively safe process. The most extreme side effect found when feeding dogs large amounts of L-carnitine was diarrhea. The biggest issue about supplementation is the price, despite it being abundantly available. Some research has been done on L-carnitine levels in plant-based fed dogs. A study of 7 dogs had their L-carnitine levels measured with 4

dogs having normal values and 3 dogs having elevated values (Semp, 2014). Therefore, it is possible to provide enough L-carnitine to dogs fed a plant-based diet.

Fatty Acids

Dogs have fatty acid requirements that must obligatory be met through diet. They require omega-3 and omega-6 polyunsaturated fatty acids which have critical cellular development and physiological functions. For non-reproducing or lactating adults, either male or female, the only needed essential omega-3 polyunsaturated fatty acid is the alpha linolenic acid, while the only needed omega-6 polyunsaturated fatty acid is linoleic acid. Other needed longer chain of polyunsaturated fatty acids can be synthesized from alpha linolenic acid in non-reproducing adults. For reproducing adults or puppies, direct dietary DHA is required and must be present in the diet (Case, 2011).

Alpha linolenic acid can be found in terrestrial plants and seeds in high amounts, enough to meet requirements in a dog's diet, however, DHA is only found in small amounts in terrestrial plants (Sarter et al., 2015). Presently, most of DHA used in feed production originates from fish oil. A plant-based solution to this is the use of algae (Dodd et al., 2018). Many algae are known for containing high levels of DHA that can be extracted, added to the diet and effectively meet dog's requirements.

Vitamin A

Vitamin A plays an essential role in growth, reproduction, immune function and maintenance of healthy epithelial tissues (Hand & Lewis, 2010). Deficiency is associated with poor prognostic diseases such as blindness but it usually does not develop in dogs. As omnivorous animals, dogs have the ability to synthesize active vitamin A from precursor vitamin A carotenoids (Deming & Erdman, 1999). This is very important because the preformed version of vitamin A is exclusively found in animal products (Dodd et al., 2018). Nevertheless, dietary carotenoids are only absorbed half as efficiently as preformed dietary vitamin A because they are hydrophobic and need bile salts for micellar solution (Hand & Lewis, 2010). Laboratory synthesized vitamin A is another viable option for supplementation in a dog's diet.

Vitamin D

Vitamin D is a precursor of the hormone calcitriol which plays a very important role in calcium homeostasis ensuring proper mineralization of the skeleton especially in growing

dogs. In most animals there are 3 potential sources of vitamin D: dietary ergocalciferol (vitamin D₂), dietary cholecalciferol (D₃) and endogenous synthesis in the skin when exposed to sunlight. Dogs have negligible synthesis of vitamin D in the skin due to having high enzymatic catabolism of vitamin D precursors (Hazewinkel & Tryfonidou, 2002). In most animals, vitamin D₂ is not as effectively used as vitamin D₃. In dogs, there is an uncertainty about the efficiency of vitamin D₂ but it is accepted that it moderately contributes to the maintenance of vitamin D (Hand & Lewis, 2010). Nevertheless, the addition of vitamin D₃ to dog's diet is recommended in case of deficiency.

Commercially, vitamin D₂ is derived from fungi and yeast while vitamin D₃ originates usually from animal products such as fish oils and sheep lanolin (Dodd et al., 2018). There are also plant-based sources of vitamin D₃ such as Solanaceae or Fabaceae families and algae, which are mainly used in human products (Jäpelt & Jakobsen, 2013). In pet foods, vitamin D₃ is mostly animal derived, so vitamin D is a very concerning aspect in plant-based diets for dogs. Owners feeding a plant-based diet should monitor serum calcidiol concentrations to ensure no vitamin D deficiency occurs.

Vitamin B12

The vitamin B₁₂, also known as cobalamin, is required in many crucial metabolic processes through the body such as DNA synthesis. Deficiency, if not corrected, is associated with poor prognostic disease (e.g. neurological problems). Possible causes of deficiency include low level in the diet or problems in absorption. Cobalamin is transported through the intestinal lining with a transport protein which in dogs originates primarily in the pancreas, and to a smaller degree in the stomach. Out of the vitamin B complex, cobalamin is the only vitamin that is not present in plant products. It is produced by microbes in the soil or in fermented organic substances. Some animals obtain cobalamin from intestinal microbial production, however in dogs, this process happens too distal in the intestines to be absorbed (Hand & Lewis, 2010). Animal products can have high amounts of vitamin B₁₂ and so they can be a viable source of cobalamin. Currently, however, most commercial foods use cobalamin that is synthetically derived from microbial fermentation (Semp, 2014). Therefore, non-animal effective sources of B₁₂ are available.

Calcium

Calcium is a very important nutrient in dogs' health as it plays many important functions. Calcium plays a crucial role in blood clotting, blood pressure and cell communication. Deficiencies in calcium cause disorders such as demineralization in bones and, with time, osteoporosis (Cline, 2012). In order to maintain adequate levels of calcium, the levels of phosphorus in feed must be considered. If the ratio of calcium to phosphorus is unbalanced, even if the animal receives appropriate amount of calcium, the calcium levels will be unbalanced and cause disease.

Meeting a dog's calcium requirements through a plant-based diet is possible as there are multiple non animal-based sources of calcium. There are many natural sources of calcium such as spinach, turnip, broccoli and tofu (Miller, 1989) which can provide the calcium needed to fulfill a dog's nutritional requirements. Moreover, laboratory synthesized calcium sources also exist such as calcium carbonate, which originated from limestone and can safely be added to a dog's food and provide calcium levels required for proper health (Aldrich, 2010).

Phosphorus

Phosphorus serves multiple important functions in a dog's body including structural make up of DNA, RNA and bones. Therefore, deficiencies will lead to severe complications such as slow growth and bone deformities. Phosphorus has an important relationship with calcium and both must be provided in a balanced ratio in order to maintain adequate phosphorus levels in the body (Grandjean & Butterwick 2009).

Phosphorus is a very abundant mineral and is present in many foods such as bones and flesh. There are also plant-based sources with high levels of phosphorus, including legumes and cereals. Plant sources have an additional obstacle when it comes to providing phosphorus because a percent of phosphorus is present in phytate form which non-ruminant mammals cannot naturally digest making it unavailable for absorption. The phosphorus in phytate may become available for absorption if it is broken down by phytase, an enzyme that breaks down phytate. Legumes have low levels of phytase which makes their phosphorus contribution to dogs poor. On the other hand, cereals have high levels of phytase which makes them a reliable source of phosphorus when feeding dogs a plant-based diet (Steiner et al., 2007).

Palatability

Palatability is always a concern in any diet because it can affect the amount of food the animal consumes. Most dogs do not have problems in consuming enough food but there are

some exceptions. Dogs that are more selective need palatable food in order to assure proper consumption. Little research has been done on plant-based food palatability. In one study comparing plant-based diet and conventional diet in racing dogs, the authors noted that all dogs, regardless of the diet fed, consumed the food promptly (Brown et al., 2009). However, palatability was not directly studied and authors inferred palatability from the dogs eating quickly. If it is a problem, there are plant-based palatability increasing supplements that can be easily purchased.

Urinary pH

Urinary pH in dogs fed vegetarian diets is one of the concerns that must be taken into consideration and controlled. Plant products are known to be relatively low in acidic amino acids which can cause an acidifying effect in urine. Moreover, plant-based proteins tend to have higher pH than animal source proteins, contributing further to the alkalization of urine (Knight & Leitsberger, 2016). Such changes in pH predisposes dogs to crystallisation of certain urinary salts, forming stones in the urinary system which may cause partial or complete urinary obstruction, dysuria or hematuria (Blood & Studdert, 1996). Complications like these can be quite serious if not detected early and are left untreated. Changes in the pH also affect the normal flora of the urinary tract which predisposes dogs to infections. A range of 5-7 pH is needed in dogs to avoid previously mentioned complications (Knight & Leitsberger, 2016).

Due to the possible fast development of complications once urine pH is improper, control of it is fundamental. The pH can be tested with urinary strips which are cheap and easy to obtain. Urine can be easily collected by owners at home using a few different methods, for instance, by the use of foil disposable containers. Control is especially important when transitioning to a plant-based diet. During the adaptation period, measurement should be done weekly to ensure proper transitioning. Once the switch to a plant-based diet is successful, measurements should be done monthly to ensure proper health (Knight & Leitsberger, 2016).

There are multiple ways to correct high pH values in urine if detected. Many natural products create urine acidifying effects such as peas, rice, oats, lentils corn, brussel sprouts, yeast and asparagus (Peden, 1999). There are also a great variety of specific pet food supplements, that can be easily purchased, which are effective urine acidifiers. Nevertheless, much awareness is needed when correcting urine pH because urine can be over acidified causing metabolic acidosis and mineral imbalances.

Some research has been done with plant-based diets in dogs which has shown promising results. The urine was measured of 19 dogs fed a plant-based diet, one presented pH values above the healthy normal value, with the rest in normal range. The dog showing inadequate values was examined by a veterinarian and showed no clinical signs or problems in the urinary tract (Semp, 2014). The authors proposed that inappropriate storage of the laboratory sample might have been the root of the different value.

5.1.1 Plant-based diets for special conditions

There have been some associations between plant-based diets and health improvements in dogs, though further research needs to be done for more accurate conclusions. Some suggest that plant-based diet improves coat condition, allergy control, weight control and overall health and vitality (Knight & Leitsberger, 2016). Owners have reported their plant-based fed pets to be in good condition but it is unclear if it is rooted in diet.

Some diseases in dogs have been shown to be maintained or prevented more effectively on plant-based diets. For example, urolithiasis which affects many breeds and Dalmatians in particular. It is said that the low level of purine in plant-based diets decreases the incidence of uroliths (Brown et al., 2003). The degree of incidence of congenital porto systemic shunt has been shown to be much lower in dogs fed soy proteins compared with meat proteins. The cause of this is the lower production of NH₃ on a soy protein diet (Proot et al., 2009).

5.2 Cats

Protein Content

Similarly to dogs, the protein requirements of cats is evaluated in terms of quantity and quality. The protein requirement for a cat is 22.75% of metabolizable energy for maintenance of an adult and 26.25% of metabolizable energy for reproduction and growing stages (Case, 2011). Concerning protein quality, cats have 11 essential amino acids and enough quantity of each must be present in the feed for proper health. Cats' protein requirements have been met throughout history with products of animal sources. Similarly to dogs, some of the reasons for this pattern have to do with the carnivorous nature of cats and high availability and cheap prices of animal products, as they are mostly originated from byproducts of human food industry. Therefore, meeting the protein requirements with animal products is natural and

generally safe and efficient. Straying away from such practices is controversial and frowned upon. Nevertheless, it is possible to meet a cat's protein requirements through a plant-based diet.

When it comes to quantitative protein requirements, multiple plant-based options are available. Cats have higher protein needs than dogs so the inclusion of high protein plant-based products in their diet is even more fundamental. As it was previously discussed with dogs, there are multiple sources of plant-based proteins capable of meeting cats' quantitative requirements. Further research needs to be done on this topic in order to find the best and most easily available plant-based protein sources. Some of the possible protein sources showing great potential for their high protein content and usefulness are brewer's yeast, soy protein concentrate and gluten meal (Dodd et al., 2018).

Despite the fact that more research is needed in this subject, some research has been done with plant-based protein for cats with good results. In order to evaluate the protein levels in the body, the total serum protein and serum albumin levels must be measured. Low levels of such parameters are related to inadequate protein level intake. One study investigated a sample of 15 cats fed a vegan diet and 20 cats fed a conventional diet. All cats on a vegan diet reported serum total proteins in normal range, between 5.9 and 8.7 g/dl, with a mean of 7.3 g/dl while in the conventional diet group, one cat presented serum total proteins lower than the reference range. Concerning serum albumin levels, all cats in the vegan group had levels within the reference range, between 2.8 and 4.3 g/dl, and with a mean value of 3.3 g/dl. The values of serum albumin level for the conventional diet group were not reported in the study (Semp, 2014).

Addressing the qualitative protein content of cat food is more complicated than in dog food. Cats have 11 essential amino acids: arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, valine and taurine (Hand & Lewis, 2010). When feeding cats a plant-based diet, taurine is clearly the most controversial because of its importance and the fact that it is mostly present in animal sources, therefore, it will be discussed in its own section below. The other 10 amino acids are abundantly found in plant sources and offer no major concern. Similarly to dogs, there are a few ways to ensure complete amino acid profile in cat feed such as choosing complete amino acid sources or

combining protein sources that complement each other (Gillen, 2008). Another possibility is to add the missing amino acid individually to the food (Hand & Lewis, 2010).

Taurine

Taurine in cats is an essential amino acid, therefore, its presence in the feed is absolutely necessary for deficiencies not to happen. Taurine plays a much more fundamental role in cat nutrition, compared to dogs. In cats, taurine is an essential nutrient, meaning no endogenous synthesis. The daily need of taurine for cats is 10 mg/kg of body weight (Hand & Lewis, 2010). Compared with dogs, cats have very low levels of the enzyme cysteine sulfonic acid decarboxylase, which is responsible for the synthesis of taurine from sulfur containing amino acids (Jacobsen et al., 1964). There are likely other factors affecting the endogenous synthesis of taurine because there are species with low levels of the enzyme cysteine sulfonic acid decarboxylase that can still synthesize taurine, such as humans.

The deficiency symptoms of taurine in cats are similar to those previously discussed in dogs. The most common diseases are dilated cardiomyopathy, reproductive problems and retinal degeneration. However, the consequences of taurine deficiency in cats are faster occurring and more severe than in dogs. Therefore, it is perhaps the most controversial aspect of feeding a cat a plant-based diet.

Despite the lack of consistent plant-based sources of taurine, there are other options other than animal products. Laboratory synthesized taurine is a very effective way to supplement cat diets. It is a safe and cheap solution that can easily be obtained. Because for cats deficiencies happen more often and faster, it is essential to ensure adequate taurine levels. Therefore, it is advisable for cats in a plant-based diet to get their blood taurine level tested by a veterinarian every six months.

Some research has been done on cats' taurine levels in vegetarian diets, with mixed results. One study looked at the health of 8 vegetarian cats in Germany, Switzerland and Belgium. The cats presented many nutritional deficiencies, one displayed retina atrophy and two displayed reduced frequency of estrus, all possible symptoms of taurine deficiency (Kienzel & Engelhard, 2001). Nevertheless, other studies showed some good results for vegetarian cats. One study measured the taurine levels of 17 cats that have been fed a vegetarian diet for over 1 year. Plasma taurine concentrations which was only available for 15 of the cats, had one sample yielding a value less than the reference range and no values were

less than the critical range. Blood taurine was obtained from the 17 cats, 3 of them showed values less than the reference range but above the critical range (Wakefield et al., 2006). There are some limitations to this study such as the fact that the owners were recruited through websites which might not provide a completely unbiased sample. Nevertheless, it shows that maintaining adequate levels of taurine in a vegetarian cat is possible.

L-Carnitine

L-carnitine is also an important requirement in cats, though not as fundamental as it is to dogs. It plays a similar role in cats, being the most important function the transport of long-chain fatty acids. Deficiency of L-carnitine is associated with poor prognostic diseases, such as heart and liver complications (Beynen, 2018). Cat supplementation can be effectively done through the use of laboratory synthesized L-carnitine. As levels can be measured through blood analysis, owners should do regular veterinary check up to ensure adequate safety and health.

Fatty Acids

Fatty acids are an essential nutrient in cats that must be obtained from the diet. Just like in dogs, it has a fundamental function in cellular development and physiological functions (Case, 2011). For maintenance of an adult cat, the required fatty acids are arachidonic acid and DHA (Bauer, 2008). Growing or reproductive cats have other requirements such as linoleic acid and alpha linoleic acid, which can also be found in plant sources (Sarter et al., 2015). DHA can easily and effectively be obtained from algae (Dodd et al., 2018). Arachidonic acid is usually found in animal tissue but it also exists in large quantities in certain algae such as *Parietochloris incisa* (Bigogno, 2002). Therefore, there are plant-based sources for all types of fatty acids.

Vitamin A

Vitamin A is more important nutrient when considering plant-based diet for a cat. As obligate carnivores, cats do not have the ability to metabolize vitamin A from precursor vitamin A carotenoids (Dodd et al., 2018). Therefore, the inclusion of preformed vitamin A in cats' diet is absolutely necessary. The only viable non animal-based source of vitamin A must be synthetically made. Synthetically made analogs are efficient ways to supplement cat diets, making vitamin A a nonissue in plant-based diets. It is highly advised to have regular check ups at the veterinarian in order to detect any deficiency as early as possible.

Vitamin D

The functions of vitamin D in cats is similar to other animals. Like dogs, cats do not have the ability to produce endogenous vitamin D due to the high catabolic activity of the vitamin precursors. Vitamin D2 is also a negligible source in cats because its usage is very inefficient (Hazewinkel & Tryfonidou, 2002). This leaves vitamin D3 as the only reliable source of vitamin D. However, they are only used in human products making it a big concern for cats fed plant-based diet (Japelt & Jakobsen, 2013). Blood samples are a must in order to detect deficiency and avoid serious complications.

Vitamin B12

Cobalamin plays a similar role in cats as in dogs. It is involved in fundamental metabolic processes throughout the body such as DNA synthesis. Deficiencies can be severe and cause complications such as neural damage. In cats, the intrinsic factor responsible for the absorption of vitamin B12 is in totality produced in the pancreas (Hand & Lewis, 2010). Similarly to dogs, the intestinal microbial production of B12 is too distal to be absorbed and so cats need dietary B12. Cobalamin sources can be animal products or synthetically derived from microbial fermentation (Dodd et al., 2018). The latter is in accordance with plant-based values. Most of the cobalamin in commercial pet food originates from microbial fermentation (Semp, 2014). Some research has been done on the level of cobalamin in cats fed a plant-based diet. One study looked at the cobalamin levels of 17 vegetarian cats and all had concentrations within reference ranges (Wakefield et al., 2006), showing that cats may obtain adequate levels of vitamin B12 from plant-based diets.

Calcium

Calcium has a very similar function in cats as it has in dogs. In cats, calcium is responsible for major functions such as blood clotting and bone mineralization (Cline, 2012). Naturally, deficiencies in calcium will cause disorders which can progress and have high severity if left unchecked. Calcium deficiency disorders include osteoporosis and poor growth (Grandjean & Butterwick, 2009). A balanced calcium to phosphorus ratio is also very important in cats and any imbalance will cause changes in the calcium level, even if provided with adequate amounts in the diet.

Meeting the calcium requirements for cats through a plant-based diet is possible as there are many sources. Tofu, broccoli and leafy greens such as spinach and collard greens are high in calcium and can be used to provide calcium for a cat's diet (Miller, 1989). Moreover,

laboratory synthesized sources are available such as calcium carbonate (Aldrich, 2010). Calcium carbonate originated from limestone is a very safe and efficient way of providing the required calcium to a cat's diet (Aldrich, 2010).

Phosphorus

Phosphorus plays similar roles in cats as it does in dogs, such as structural function of bones, DNA and RNA. Similarly, phosphorus deficiencies will lead to structural malformations in cats (Grandjean & Butterwick 2009). Providing phosphorus in a balanced ratio with calcium is also crucial for the phosphorus be absorbed and maintained in cats.

As it was mentioned in the dog section, there are reliable plant-based sources of phosphorus which can provide the required phosphorus levels for cats. As non-ruminant animals, cats cannot break down phytate. Therefore, phosphorus sources like legumes are bad sources for cats. On the other hand, cereals have high levels of phytase which breaks down phytate making the phosphorus available for absorption (Steiner et al., 2007). Hence, cereals are reliable sources of phosphorus when feeding cats a plant-based diet.

Palatability

Palatability can also be an issue in cats. Research about the palatability of plant-based cat food is very limited so there is no data on how cats react to it. Nevertheless, there are multiple plant-based palatability increasing supplements available for purchase online. Notably, such supplements are usually sold on the same websites as plant-based commercial foods, which might indicate that there are some issues with palatability.

Urinary pH

Similarly with dogs, plant-based diets raise the pH of urine in cats due to the lower levels of acidic amino acids and more alkaline characteristic of plant-based proteins (Knight & Leitsberger, 2016). However, urinary pH in plant-based diets is an even greater concern in cats because they are more susceptible to urinary problems. Possible issues are urinary stone formation resulting in feline urological syndrome characterized by partial or complete urinary obstruction, dysuria and hematuria (Blood & Studdert, 1996). Complications are fast developing and life threatening. PH must be maintained between 5.5 and 7 to ensure urinary system health.

The reasons for cats' higher susceptibility urinary problems has to do with the diameter of the urethra. Cats have very small urethra diameters, increasing the chances of a stone

blocking the urine flow. Male cats have the smallest diameter and are especially susceptible to complications. Therefore, control of feline urinary pH is crucial. It should be done weekly when transitioning to a plant-based diet and monthly once established (Knight & Leitsberger, 2016).

Many dietary supplements are also available for acidifying cat urine, ranging from natural products (e.g. asparagus, peas, brown rice, oats, lentils and yeast) to specific pet food supplements (Peden, 1999). Nevertheless, much caution must be taken when correcting urinary pH because inadequate low urine pH values can lead to metabolic acidosis and other complications.

5.2.1 Plant-based diets for special conditions

The benefits reported to a plant-based diet for cats are similar to the ones reported to dogs. Such diets have been associated with good coat condition, allergy control, lower ectoparasites and weight control (Knight & Leitsberger, 2016). However, further research needs to be done in order to determine for certain the benefits of plant-based diet in cats.

6. FOOD TYPES

Food is a basic need that is crucial for survival but it is also very significant in many other ways. The primary function of feeding is to obtain nutrition, maintain health and prevent diseases. As it is such an important part of life, it is associated with many other aspects of society such as religion and group identity, order or bonding. The individual identity is also greatly influenced by the approach taken to feed, for example, individuals who are wary of processed foods tend to also be more skeptical of commercial foods. Such values are also applied to the feeding of pets, reflecting owners approach to food (Michel, 2006).

Feeding a cat or a dog a plant-based diet is one of the ways that the owner's relationship to food is manifested. The relationship of the owner with food is reflected in their choice to feed their pet either a commercial food, homemade or natural diet. Some people are more selective with the types of nutrients used, for example choosing raw foods. Although there is not much data on food type breakdown, one study found that among dog owners, 86.8% were classified as commercial feeders and 10.0% were classified as noncommercial feeders (Michel et al., 2008). Understanding the underlying motivations and the different unconventional diets of pet owners is threefold. First, it can assist manufacturers in creating

products that will be healthy and profitable. Second, it will create a more effective and efficient dialogue between pet owners and veterinarians to ensure pet safety and active owner participation and communication (Michel, 2006). Lastly, it will inform research in the field of plant-based diets for dogs and cats.

6.1 Commercial plant-based foods

Commercially prepared food is the most convenient way to feed a pet when it comes to simplicity and price. They are made according to established nutrient requirements by AAFCO for the respective species. There are currently a few different plant-based commercial pet food brands that can be purchased in stores or online. There are plant-based dry and wet food options both available for cats and dogs. Commercial food manufacturers make use of natural, processed and laboratory synthesized ingredients.

Theoretically, it is possible to feed cats and dogs with a commercial plant-based feed. The nutrient requirements not met through natural ingredients can be met with laboratory synthesized supplements, ensuring nutritional completeness. Manufacturers are required to follow the AAFCO regulations and are knowledgeable in the food manufacturing process which provides some assurance of nutritional completeness. However, many problems can happen which can affect the food quality. Commercially made foods, including plant-based, have been shown to have nutritional content not meeting the AAFCO requisites.

6.1.1 How to do them safely and adequately

Dogs:

Providing adequate nutrition for a dog through commercially made plant-based food is possible but requires caution. The most concerning nutrient is vitamin D. In commercial made food the mostly used vitamin D form is ergocalciferol, vitamin D2. As it was previously described, the rate of use of vitamin D2 is uncertain in dogs and plant-based vitamin D3 form exist but are only used in human foods (Japelt & Jakobsen, 2013). Therefore, deficiency may occur in commercial plant-based feed. Vitamin B12 also must be taken into consideration, despite food manufacturers usually using the laboratory synthesized form when producing commercial diets, they may not add it in adequate amounts. Other nutrients required are used by commercial plant-based manufacturers. However, discrepancies have been found between the content and the labels. Therefore, it is crucial to use a plant-based commercial feed that has

been proven to be nutritionally complete through research. Regular veterinary checks are also strongly advised in order to avoid possible deficiencies.

Cats:

In theory, presently it is possible to adequately feed a cat through a commercially plant-based diet but there are many challenges. The major concern is vitamin D because the form used in plant-based commercial diets is the ergocalciferol, D2 supply (Japelt & Jakobsen, 2013). As it was previously discussed, cats do not absorb this vitamin D form. Therefore, deficiencies may happen in commercial plant-based diet. Supplementation can be done using plant-based vitamin D3 supplements similarly to dogs. Taurine is another concern mostly because of the severe consequences of deficiencies. As plant-based ingredients have very low taurine, it is not naturally added to the diet. Therefore, laboratory synthesized taurine must be added which has been proven to be insufficiently done by some plant-based commercial feed manufacturers (discussed below). Supplementation may be done by the owners as taurine is easy to find and inexpensive. Moreover, there are no major consequences of high levels of taurine in the diet. Concerning B12 vitamin, food manufacturers usually add the laboratory synthesized form to the diet, nevertheless, much attention must be taken to its level due to the catastrophic consequences that deficiencies can have.

There are non-animal sources to all nutrients required by cats, though some might be harder to obtain. The major issue is finding a commercial plant-based food that is nutritionally complete. Some commercial plant-based foods for cats have been shown to be nutritionally adequate but many have shown many deficiencies. Therefore, finding one is the biggest obstacle. There is also a lack of research and feed analysis control making the task of finding a complete commercial plant-based diet for cats even more challenging. For owners attempting to follow such a diet plan, regular veterinary checks and close monitoring are absolutely necessary in order to ensure nutritional adequacy. 6.1.2 Label/Information issues.

There are major concerns related to labels not matching the content of commercial made diets, ranging from nutrients missing to presence of animal products. Nevertheless, labelling inaccuracies are not limited to plant-based commercial diets. Nutritional mislabeling has been seen in both animal-based and plant-based diets and nutritional inadequacies and inconsistencies have been demonstrated (Knight & Leitsberger, 2016). Inadequacies are dangerous in all diets but plant-based fed pets can be particularly affected as there are some

nutrients that are more vulnerable to deficiencies when obtained from non animal sources (e.g.vitamin D, vitamin B12, taurine).

There has been some research investigating the content of commercially available plant-based pet foods. A study examining the fundamental claim that the diet is plant-based, tested 6 dry feeds and 8 wet feeds for molecular structure of animal DNA. Results demonstrated inconsistencies in the claim that diets were plant-based, showing that mammalian DNA was detected in all 6 dry feeds and in 1 out of the 8 wet feeds. The diets were intended for cats and dogs for different maintenance levels, with findings of DNA from bovine, ovine and porcine origin (Kanakubo et al., 2016).

Other studies have looked at the nutritional completeness of plant-based foods based on AAFCO standards. A study that examined two different vegan diets for cats found deficiencies in protein levels, some amino acids like taurine and methionine, arachidonic acid, calcium and phosphorus, vitamin A, vitamin B6, vitamin B12 and niacin. Furthermore, the two diets had concerning low levels of taurine, being 0.06 and 0.09, which does not meet the AAFCO taurine requirement value of 0.25, although it was labeled as such (Gray et al., 2004). A cat fed one of these diets would suffer from multiple deficiencies with very severe health consequences. These findings were replicated in a study of a larger sample of plant-based commercial feeds for dogs and cats. The study examined the content analysis of 24 plant-based diets for cats and dogs, 13 dry and 11 wet feeds, and determined that only 8 complied with the AAFCO requirements (Kanakubo et al., 2015). It should be noted that out of the 24 diets, 3 were veterinary therapeutic diets and all 3 complied with the nutritional requirements. These findings demonstrate the gross nutrient deficiencies in commercially available plant-based diets. However, if pet owners do decide to feed their pets a plant-based commercial diet, choosing a veterinary approved diet has a higher chance of avoiding deficiencies. This study was done in 2015 and some manufactures of the feed examined have since responded to the study. Some stated that the results obtained were a fluke while others promised to improve manufacturing methods in order to assure that inaccuracies do not happen again (Knight & Leitsberger, 2016). More research and feed analysis is needed to assure proper nutritional status of commercial plant-based feed. It is possible to meet the nutritional needs for cats and dogs through commercial diet but manufacturers need to be more exact. For now, in order to avoid deficiencies in pets, choosing veterinary therapeutic diets is advisable.

6.2 Home-made foods

As previously discussed, the relationship between humans and dogs developed with dogs feeding on food leftovers. Home-prepared food have been the basis of dog feeding since the domestication of dogs. Commercially prepared foods have only been around in the last few decades and they are still widely considered unconventional in many countries. Other than the lack of availability of commercially made foods, there are a few reasons that lead people to choose homemade diets for their pets. Some people worry about the wholesomeness and nutritional value of ingredients used in commercial feeds (Michel, 2006). Others do it because of palatability concerns and wanting to bond with pets through food preparation. Sometimes this type of diet can also be used for diagnosis or therapeutic reasons.

The term homemade diet means a diet prepared by the owner and it can include natural ingredients, processed foods, laboratory made, and supplementation. As it can include many types of ingredients, it is possible to obtain all the nutrients necessary for cats and dogs. However, it can be a challenging process, possibly creating nutritional deficiencies and severe complications in the health of the pets. The difficulty also differs for dogs and cats. Finding a homemade diet recipe that has been proven to be complete is absolutely crucial for achieving nutritional completeness.

6.2.1 How to do them safely and adequately

Dogs:

A complete homemade plant-based diet for dogs is easier to formulate as compared to cats. Possible nutritional concerns for a dog fed a homemade plant-based diet are vitamin A and vitamin D. Because there are basically no viable plant-based ingredients for vitamin D that can be added to the feed, supplements must be used. For vitamin A it may be safer to add the preformed form, instead of the provitamin carotenoid, because of the uncertainty of the rate of conversion. Fatty acids may also have to be purchased individually in order to meet a dog's nutritional requirements. Laboratory synthesized taurine should also be added for safety as some breeds can not reliably synthesize it endogenously. Laboratory synthesized vitamin B12 must be added in order to provide adequate levels. The rest of the nutrients can reliably be obtained from natural ingredients and following a complete recipe will ensure nutritional completeness.

Cats:

Maintaining a cat on a homemade plant-based diet is possible but challenging. The most important factor is the addition of laboratory synthesized taurine as there is no reliable plant-based source. Similarly for vitamin A, preformed laboratory synthesized must absolutely be added as there is no plant-based source. For vitamin D, supplements must be used as cats do not absorb vitamin D₂. When it comes to fatty acids, they must be obtained as supplements from special sources such as algae. Vitamin B₁₂ supplementation must absolutely be added in order to meet dietary requirements for cats. The rest of the nutrition can be obtained from natural ingredients. Therefore, using a recipe that has been proven to provide adequate nutrition through nutritional analysis.

6.2.2 Label/Information issues.

Nutritional incompleteness of homemade diets is a major concern for all types of homemade diets, including plant-based. One study looked at the nutritional profile of many homemade diets recommended by veterinarians in North America and discovered multiple deficiencies. Nutritional inadequacies were detected in 28 of the 46 recipes for dogs and 18 of 39 recipes for cats (Roudebush & Cowell, 1992). Similar results were found in a study that examined 49 maintenance diets and 36 growth diets. Mineral deficiencies were found in 86% of the diets, protein deficiencies in 55% and vitamin deficiencies in 62% (Lauten et al., 2005). Therefore, specialized knowledge is crucial when formulating homemade diets, especially plant-based ones. It is absolutely necessary to find a diet that has been proven to be nutritionally complete and veterinary checks must be done in order to ensure proper health of the pet. These findings underline the importance of checking nutritional content of homemade food for completeness.

6.3 Natural foods

The usage of natural foods is a trend followed by some owners. The AAFCO defines natural ingredients as one that is derived in its totality from plant, animal or mined sources and a natural product as a product that is made up of only natural ingredients (AAFCO, 2019). The choice of natural based foods comes from concern about the additives used which might have a carcinogenic effect or contribute to the development of dietary hypersensitivities and autoimmune disorders (Dzanic, 1991). Naturally, there are some people who want to feed their pets a plant-based and natural way which can be quite challenging.

6.3.1 How to do them safely and adequately

Dogs:

It is impossible to meet all nutritional requirements of a dog through a natural plant-based diet. Some nutrients are close to impossible to obtain this way. Moreover, some nutrients would have to be obtained through endogenous synthesis, like taurine, which is not very safe way to ensure adequate levels.

Cats:

It is impossible to feed a cat with proper nutrition through a natural plant-based diet. There are no reliable sources for some very important nutrients such as vitamin A and taurine.

6.3.2 Label/Information issues.

Although natural kibble exists, there are currently no requirements or overseeing body for pet food manufacturers to insure labeling accuracy.

6.3.3. Raw Foods

It should be noted that similar issues of natural foods are also present in plant-based raw diets for pets. Doing it completely raw excludes laboratory made nutrients which is the only way of obtaining certain nutrients, if the diet is to be completely animal free. Raw plant-based diets may have some advantages such as increased safety, as raw animal-based products have been associated with contagious diseases such as salmonella and toxoplasma (Michel, 2006). Nevertheless, the disadvantages of nutritional concerns far outweigh the possible benefits it may bring.

7. CONCLUSION

The current paper sought to conduct a comprehensive review of nascent yet burgeoning field of plant-based diets for dogs and cats. This topic has been gaining interest over the past several decades due to increases in environmental sustainability concerns, humanization of animals, and a fast growing trend of more individuals choosing a plant-based diet. The current paper reviewed existing literature on the motivations, plausibility, and availability of plant-based diets for dogs and cats.

A review of the studies on the motivations of individuals choosing a plant-based diet for themselves as well as their pets, has shown that the main motivators include animal and environmental welfare, ethical/moral reasons, and health reasons. In regards to environmental welfare, increases in human population as well as pet ownership have compounded the effects

of animal-based food production on the environment, which is projected to get much worse in the coming decades. Scientists have suggested that to maintain sustainability while accommodating population growth, food production will need to shift to plant-based, which has a significantly smaller effect on the environment. Furthermore, there has been a global trend of increased concern towards animals, especially pets. A major effect of this movement is global reduction of animal product consumption. It should be noted that a consequence of the humanization of pets, there has been an increase in the quality of the products fed to them. As a result of this, the pet food industry will be competing for higher nutritious products that are usually used for human consumption, which will create more waste and lead to more animal-based production.

Ethical motivations are often closely connected to environmental and animal welfare concerns, with ethical meat-abstainers often citing environment and cruelty to animals as the main reasons. Individuals who choose to abstain from meat based on religious reasons are also included in this category. Ethical meat-abstainers tend to suffer from what has been termed the vegetarian's dilemma, which is psychological distress over the conflict of feeding their pets an animal-based diet and their own beliefs. Contrastingly, health meat-abstainers choose their diet based on health benefits to self, with a much smaller focus on the environment and animal welfare. Although, motivations for meat abstaining is discussed categorically in this paper, it should be noted that motivations are not mutually exclusive, and many individuals fall on a continuum (e.g. flexitarians) of which products they choose to avoid and for which reasons, with many shifting over time.

As a result of the issues discussed above, there has been a rise in the number of people choosing to abstain from meat over the past 30 years, and a drastic increase of these practices in the past five years, with more and more people choosing plant-based diets. Finding a safe solution for such demand is crucial for the wellbeing of the owners and pets. It is crucial to find ways to feed people and pets that are more sustainable and efficient. The substitution of animal products by plant-based products is one of the ways to address this issue.

Based on existing research, feeding cats and dogs through a plant-based diet is possible as all nutrients required can be found either in plant-based products or synthesized from non-animal-based materials in the laboratory. Palatability is also not a problem as there are many palatability enhancing supplements so cats and dogs can consume and maintain plant-based

diets without developing deficiencies. Nevertheless, this way of feeding pets poses many challenges, especially for cats. Plant-based sources for some nutrients exist but have not yet been implemented widely in pet food. The major nutrient deficiencies concerns for dogs are vitamin D, vitamin A and vitamin B12. For cats, taurine, vitamin D, vitamin A and vitamin B12. The biggest obstacle to feeding a pet a plant-based diet is finding a diet that has been proven to be nutritionally complete. Many commercial feeds and homemade diets have been shown to be deficient in many nutrients which is very dangerous, especially to cats. Determining which plant-based foods are complete is also very challenging because this area of research is still developing and more data is needed. Moreover, in many countries the pet food options available for owners is very limited. In some countries even conventional commercial food options are not available for pets, much less plant-based options. This issue is further compounded by the fact that there does not exist federal organizations that monitor that pet food labeling is consistent with the contents. Therefore, even if in theory it is possible to feed cats and dogs plant-based, it is not viable to everyone, either because of lack of knowledge or products available.

When adopting a plant-based diet for the pet, it is absolutely crucial to have veterinary assistance. By checking the status of the body and doing blood analysis, a veterinarian can detect any possible complications related to the plant-based diet before any severe complications develop and ensure the safety of the pet. The veterinarian might also have valuable knowledge on plant-based nutrition and how to do it with the means available in the country. Knowledge of the complete diets available in a particular location is crucial to the success of plant-based nutrition for the pet and utilizing veterinary expertise can be a very valuable source. Owners may contact the different veterinary clinics in the area to find one with knowledge and experience on the subject. The author believes that it is possible to feed a dog adequately through a plant-based diet as long as it is veterinary prescribed with routine monitoring. However, for cats, the author does not recommend a plant-based diet, although it will likely be possible in the future.

7.1 Limitations and Future research.

There is research indicating the success of plant-based diets to fulfill nutritional requirements in dogs and cats. However, more research is necessary in order to get more exact

results and information about the details of such a diet type. Most of the studies supporting a plant-based diet for cats and dogs are only based on studies evaluating nutritional values of food through lab analysis. There are very few studies of plant-based diets for dogs and cats that are based on feed trials. Nevertheless, this is also true for research on available pet foods currently on the market. Only basing the success of a pet food on nutritional analysis may not take into consideration aspects which ultimately affect how nutrients are absorbed and utilized by dogs and cats and their ability to function. For improving the nutritional adequacy and consistency of the food fed to pets, it is imperative that future research tests pet food through nutritional analysis and feed trials. It is especially important that it is done so for plant-based diets, as it is a growing field. By doing so, people will have the realistic choice to feed their pets a plant-based diet that is educated and safe. This will help alleviate the psychological distress that many meat-abstainers feel when faced with providing adequate nutrition to their pets and their own beliefs.

Additionally, another aspect that needs to be improved in the pet food industry is food labeling. Many studies have shown big discrepancies between food content and labels. This can cause serious problems to pets, as it is the example of taurine for cats. In order to assure nutritional adequacy and consistency of diets, it is imperative that pet foods match the nutritional label, especially in plant-based diets. In the future, measures must be taken to improve the quality control of the continued manufacturing of pet food. Doing so, will provide the opportunity for every owner to feed a plant-based diet to their pet with assurance of nutritional completeness.

ABSTRACT

There is a rise on plant based diets throughout the world which has also been applied to pets which comes as a response to the heavy strain put on the environment by animal agriculture. Food scarcity is already a major problem in the world and will only be aggravated by the expected population growth in the future. The plant based diets for pets is a growing field of research which has recently been developed. The current paper reviewed existing literature in the field of plant-based diets in order to examine the motivations, plausibility and availability of these diets for dogs and cats. Findings indicate that the choice to abstain from meat is motivated by environmental strain of the meat industry, humanization of animals, and psychological distress of meat abstaining pet owners. After a discussion of nutritional requirements and a thorough review of studies on content analysis and feeding trials, the paper concludes that plant based diets are possible for dogs and cats. Nevertheless, at this time, extensive knowledge and continuous monitoring is required to ascertain the safety and health of the diet, especially for cats.

It is the belief of the author that plant-based food for dogs can be adequate as long it is veterinary prescribed and with routine monitoring. For cats the author does not recommend a plant-based diet although in the future most likely it will be a possible. Limitations and future directions are also discussed.

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