Nutritional and ethical issues regarding vegetarianism in the domestic dog

W.Y. Brown

Animal Science, School of Environmental and Rural Science, University of New England, Armidale NSW 2351, Australia; wbrown@une.edu.au

Summary

Many dog owners wish to feed their dogs a vegetarian diet for the same ethical reason that they themselves are vegetarian. To meet this demand, there are an increasing number of vegetarian diets and recipes available for dogs. However, proof for their claims of nutritional adequacy is often lacking. There is little doubt that a dog's nutritional requirements can be met from a diet that does not contain meat; however, the difference between the amino acid profiles of plant and animal proteins must be considered. It has been shown that exercising dogs may develop anaemia when fed unbalanced plant-protein diets but will remain in good health if the meat-free diet is correctly balanced. Many plant ingredients contain high levels of non-starch polysaccharides and other anti-nutritive factors, which may reduce the availability of some nutrients. A diet devoid of animal ingredients is also likely to be of low palatability to dogs. All diets should be correctly formulated to meet nutrient requirements based on chemical analysis and predicted or measured apparent digestibility, should be sufficiently palatable to ensure adequate dietary intake and should maintain good health when consumed. If a vegetarian diet meets all of these criteria, then it is a suitable diet for the dog, irrespective of the owner's motivation for feeding a vegetarian diet.

Keywords: dog, vegetarian, plant protein, ethics

Introduction

The latest trends in human nutrition are often reflected in the marketing of dog and cat foods. This is probably due to the tendency of many pet owners to anthropomorphise their pets, and to the fact that pet foods must have human appeal to induce a dog owner to purchase them. Therefore, the increased popularity of vegetarianism among the human populace (White and Frank, 1994) offers a likely explanation for the increasing popularity of vegetarian dog and cat foods. Investigators examining this phenomenon revealed that dog and cat owners who choose to feed their pets a totally meat-free diet do so for the same ethical reasons that they themselves are vegetarian (Wakefield et al., 2006). But should these views and attitudes be applied to the canine?

There is little doubt that a carefully balanced diet that does not contain meat can meet the nutritional requirements of the dog. However, none of the currently available meat-free diets for dogs or cats base their claims of nutritional adequacy on recognised feeding protocols such as those of the Association of American Feed Control Officials (AAFCO, 2007). Furthermore, two commercial vegan diets for cats, which the manufacturers claim are nutritionally complete and balanced, were found to have multiple nutrient deficiencies (Gray et al., 2004).

There are many issues to consider when evaluating the suitability of a meat-free diet for dogs and cats. This review focuses on issues relevant to vegetarianism in the domestic dog. The topic is first viewed from a historical context by examining the phylogeny and ancestry of the dog. The potential to meet a dog's nutritional requirements using plant ingredients is then discussed in the light of available scientific evidence. Digestibility and palatability are considered and the question is raised of whether humans have the right to choose vegetarianism for their pets based on their own moral beliefs.

In this review, "vegetarian" and "meat-free" are synonymous. The inclusion of animal products such as eggs, milk and their derivatives is permissible in vegetarian diets although, in practice, these ingredients are used sparingly in commercial pet foods. "Vegan" diets, on the other hand, are devoid of all animal products.

Phylogeny and ancestry of the domestic dog

The domestic dog (*Canis familiaris*) is of the class *Mammalia*, order *Carnivora*, superfamily *Canoidea*. As a member of the *Carnivora*, it is often assumed that the dog is carnivorous. This is true of its closest relatives, the *Feloidea*, all of whom are flesh-eaters and are strictly carnivorous. In contrast to this, the *Canoidea* include families with diverse dietary habits, such as the herbivorous panda, the omnivorous bear and racoon,

and the carnivorous weasel.

Within the same genus as the domestic dog are four species of jackal, all of which are omnivorous, and the coyote (*C. latrans*), which is able to subsist on fruit and plant material when prey is scarce (Bradshaw, 2006). Also within this genus is the wolf (*C. lupus*), recently identified as the principal and perhaps sole ancestor of the domestic dog (Clutton-Brock, 1995). The diet of *C. lupus* consists primarily of meat in most of the areas that it currently inhabits (Bradshaw, 2006) and yet the stomach contents of 32 wolves culled from their natural habitat in Greece revealed that plant material (grasses and fruits) contributed substantially to their diet (Papageorgiou et al., 1994). The domestic dog is an opportunistic feeder and is able to adapt to a wide variety of foodstuffs when required. Feral dogs have been observed to subsist primarily on human refuse scavenged from open dump sites in Italy (Boitani et al., 1995) and there was little evidence of predation, which is consistent with the findings of other investigators (Scott and Causey, 1973; Nesbitt, 1975).

Morphologically, the dentition of terrestrial carnivores is characterised by a pair of bladelike carnassial teeth that are adapted to shearing meat, and prominent canines for holding prey and for puncturing and ripping flesh (Wayne, 1993). The post-carnassial molars, used for crushing and grinding, are well developed in omnivores but absent in obligatory carnivores such as the cat. The retention of these molars in the canids has allowed greater evolutionary flexibility in respect of their diet, which may account for the diverse dietary habits of contemporary canids. The nutritional requirements of the dog are also consistent with a more omnivorous diet than that of the carnivorous cat. The dog has a lower protein requirement than the cat and is able to convert β-carotene to active vitamin A and linoleic acid to arachadonic acid. This enables the dog to meet its requirements for vitamin A and arachadonic acid from plant sources, whereas the cat cannot (MacDonald et al., 1984). Moreover, the dog, but not the cat, is able to meet its taurine requirement from plant sulphur amino acids (MacDonald et al., 1984).

Animal vs plant proteins

Recommended daily allowances for the ten essential amino acids for dogs are listed in Table 1. Although all of these amino acids are present in plant material, typical amino acid compositions of animal proteins (Table 2) differ from those of plant proteins (Table 3). Lysine is often the first limiting amino acid in cereal-based dog foods (Brown, 1989). The requirement of growing dogs for lysine increases as the level of dietary protein increases (Milner, 1981). This is of concern as lysine can be damaged by heat processes involved in the preparation of pet foods, rendering it indigestible (Williams et al., 2006).

Recent reports suggest that taurine synthesis rates vary between dog breeds, but it is not clear whether the observed differences were caused by low intakes of sulphur amino acids relative to metabolic bodyweight, a low food intake (the dogs who developed a taurine deficiency were older and less active), or low feed bioavailability because of heat processing (Backus et al., 2006). Further research demonstrated that taurine synthesis rate is lower in large mongrel dogs than in beagles (Ko et al., 2007); however, the number of dogs used in the study was small (n = 6). These findings suggest that a high intake of methionine and cysteine may be required to prevent taurine deficiency in some dogs if the dietary intake of taurine is inadequate.

Soy

Soybean is the only plant protein source that has been extensively researched as a feed ingredient for dogs (Kendall and Holme, 1982; Zou et al., 1996; Cole et al., 1999; Bednar et al., 2000; Burkhalter et al., 2001; Clapper et al., 2001; Hill et al., 2001; Yamka et al., 2003; Biourge et al., 2004; Yamka et al., 2005). Soybean has attracted much attention because of its high protein content and its amino acid composition, which is similar to that of meat. However, soybeans contain high levels of non-starch polysaccharides (NSPs; the oligosaccharides, stachyose and raffinose) and other anti-nutritive factors (trypsin inhibitors, lectins, tannins and phytate), which limits the amount of soybean that can be included in the diet. Consequently, much of the scientific literature pertaining to plant proteins in dog diets has focused on improving the digestibility of soy products through processing. Research conducted with dogs has demonstrated that the apparent digestibility of soybean meal (Kendall and Holme, 1982; Yamka et al., 2005) and soy flours (Kendall and Holme, 1982) is higher than that of whole soybean. However, there were no differences in digestibility between low-phytate or low-oligosaccharide varieties of soybean and a conventional soybean variety (Zuo et al., 1996; Yamka et al., 2005). Some discrepancies are apparent in the literature pertaining to the digestibility of soybean products in dogs. Decreased digestibility was observed in one study in which soybean meal was included at levels greater than 15% (Yamka et al., 2003), whereas other investigators reported that the digestibility of soybean meal, soy flour and soy protein concentrate was excellent when included at levels greater than 30% (Clapper et al., 2001).

Alternative plant proteins

Several alternative plant proteins have been investigated for their potential inclusion in dog diets. The digestibilities of 21 different plant ingredients, including eight protein sources, were investigated by Kendall and Holme (1982). Four of the protein sources were soybean products, which contained 36–50% crude protein (CP) and had an apparent CP digestibility of 80–85%. The other four protein sources were rapeseed meal (37% CP), vital (wheat) gluten (83% CP), walnut meal (16% CP) and almond meal (30% CP); their

Table 1. Recommended daily allowance of crude protein (CP) and amino acids for dogs (g per kg $BW^{0.75}$) (NRC, 2006).

	CP	Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val
Adult dogs (maintenance)	3.28	0.11	0.06	0.12	0.22	0.11	0.11	0.15	0.14	0.05	0.16
Puppies (4–14 weeks of age) *	15.7	0.55	0.27	0.45	0.90	0.61	0.24	0.45	0.56	0.16	0.47
Puppies (older than 14 weeks of age) *	12.2	0.46	0.17	0.35	0.57	0.49	0.18	0.35	0.44	0.13	0.39
Bitches (late gestation and peak lactation)	24.6	1.23	0.54	0.87	2.46	1.11	0.38	1.02	1.28	0.15	1.60

* For 5.5 kg puppies and an expected mature BW of 35 kg.

Table 2. Amino acid composition of selected feed ingredients of animal origin (percentage as fed).

Ingredient	DM	CP	Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val
Animal proteins												
Meat meal, rendered[1]	94	54.1	3.82	1.11	1.60	3.41	2.91	0.77	1.93	1.83	0.36	2.40
Poultry (by-product) meal[1]	94	59.0	3.89	1.34	2.25	4.20	2.84	1.02	2.04	2.10	0.46	2.76
Fish meal[1]	91	61.1	4.11	1.64	2.91	4.43	4.42	1.67	2.54	2.59	0.69	2.48
Proteins of animal origin												
Milk, dried (skim)[1]	93	34.6	1.16	0.94	1.97	3.45	2.70	0.94	1.67	1.67	0.48	2.33
Egg, dried (whole)[1]	97	47.2	2.84	1.12	2.58	4.05	3.40	1.48	2.52	2.27	0.58	2.89
Egg, dried (white)[2]	94	81.1	4.41	1.83	4.58	6.84	5.52	2.79	4.74	3.69	1.00	5.16

[1](NRC, 2006) [2] (USDA, 2007)

Table 3. Amino acid composition of selected feed ingredients suitable for vegetarian diets (percentage as fed).

Ingredient	DM	CP	Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val
Maize, dried (whole grain)[1]	94	27.0	1.00	0.60	0.93	2.60	0.90	0.45	0.60	0.30	0.21	1.20
Maize gluten[1]	87	56.3	1.80	1.20	2.31	9.43	0.95	1.33	3.57	1.90	0.30	2.61
Soybean meal (without hulls)[1]	90	48.2	3.52	1.33	2.20	3.76	3.03	0.69	2.53	1.91	0.61	2.23
Adzuki beans, raw[2]	87	19.9	1.28	0.52	0.79	1.67	1.50	0.21	1.05	0.67	0.19	1.02
Chickpeas, raw[2]	89	19.3	1.82	0.53	0.83	1.37	1.29	0.25	1.03	0.72	0.19	0.81
Cowpeas, raw[2]	89	23.9	1.65	0.74	0.97	1.83	1.61	0.34	1.39	0.91	0.29	1.14
Mung beans, raw[2]	91	23.9	1.67	0.70	1.01	1.85	1.66	0.29	1.44	0.78	0.26	1.24
Pigeon pea, raw[2]	90	21.7	1.30	0.77	0.79	1.55	1.52	0.24	1.86	0.77	0.21	0.94
Flaxseed (linseed), whole[2]	93	18.3	1.93	0.47	0.90	1.24	0.86	0.37	0.96	0.77	0.30	1.07
Safflower seed meal [2]	94	35.6	3.85	1.00	1.58	2.54	1.17	0.63	1.77	1.29	0.40	2.26
Sesame seed flour, low-fat[2]	93	50.1	7.44	1.47	2.16	3.84	1.61	1.66	2.66	2.08	1.10	2.80
Sunflower seed flour[2]	93	48.1	5.07	1.33	2.40	3.50	1.98	1.04	2.47	1.96	0.74	2.78
Yeast, dried (brewers, Torula)[1]	93	47.9	2.60	1.40	2.90	3.50	3.80	0.80	3.00	2.60	0.50	2.90

[1](NRC, 2006) [2] (USDA, 2007)

respective apparent CP digestibility values were 75%, 96%, 45% and 73%. Of the eight protein sources, vital wheat gluten appears to be the most promising, as it has higher CP content and digestibility than soy products. Rapeseed meal was highly unpalatable, which renders it unsuitable for inclusion in diets for dogs. There are no other reports on the inclusion of wheat gluten in dog diets, but it has been included in diets for weanling pigs with excellent results (Richert et al., 1994).

More recently, maize gluten meal was identified as a highly digestible plant protein suitable for inclusion in diets for dogs (Yamka et al., 2004). Maize gluten meal is a by-product of the manufacture of maize syrup and maize starch, and consists of the dried residue that remains after removal of the bran, germ and starch from maize. Maize gluten meal is high in protein (60% CP) and when it was fed to dogs, the apparent CP digestibility improved as the inclusion level increased (Yamka et al., 2004). The inclusion levels tested ranged from 84–322 g/kg and the total tract CP digestibility increased from 84–91%.

Robinson (2001) identified copra meal, lupins and mung beans as potential plant proteins suitable for inclusion in dog foods. These feedstuffs were subsequently tested in dogs using extruded wheat-based diets, with encouraging results (Twomey, 2002). The inclusion level of these ingredients was about 15% (DM basis), and the apparent CP digestibility for diets containing lupins, copra meal or mung beans was 80%, 79% and 82%, respectively. The author of the report concluded that these plant protein sources represent practical alternatives to animal protein sources in extruded dog foods, as nutrient digestibility and faecal quality were similar to that of the control diet. The high NSP contents of lupins and copra meal probably accounts for their lower CP digestibility. Therefore, inclusion of lupins and copra meal in diets for dogs at levels greater than 15% may be problematic. Plant ingredients often contain large amounts of NSPs. Although soluble NSP represents a source of energy for the dog after its fermentation to short-chain fatty acids in the colon (Banta et al., 1979), the amount that can be ingested before faecal quality and nutrient digestibility are compromised is limited (Twomey et al., 2003).

Can meat-free diets sustain exercising dogs?

As exercise places additional demands on the body, dogs fed a meat-free diet may be at increased risk of developing sports anaemia. A study on dogs undergoing vigorous physical training reported a significant decrease in haemoglobin level and red blood cell count in dogs fed a diet containing vegetable protein, whereas dogs fed a diet containing animal protein showed no significant change (Yamada et al., 1987). These authors demonstrated that increased fragility of erythrocyte membranes was responsible for the decrease in haemoglobin level and red blood cell count and that this was associated with a change in the lipid composition of the blood. The change in lipid profile was characterised by a decrease in free cholesterol level associated with an increase in lysolecithin level during the exercise period. This change was pronounced in dogs fed the vegetable protein diet, but was not significant in dogs fed the animal protein diet. Yamada (1987) attributed this difference to the different amino acid composition of the two diets, in particular the lysine content, which was described as adequate in the animal protein diet (inferring that the vegetable protein diet was inadequate) and also to the lysine-to-arginine ratio, which was not reported. The source of protein in the vegetable protein diet was soybean meal, which comprised 53% of the diet. Nutrient digestibility values were not measured in their study; however, other studies have shown that nutrient digestibility is reduced when soybean meal is included at this level in dog diets (Yamka et al., 2003), which would decrease protein uptake. The diets in Yamada's study were not analysed for mineral content. It is possible that the vegetarian diet was lower in iron content than the animal protein diet, which may also have contributed to the anaemia.

Whereas Yamada's study highlighted the potential consequences of feeding a nutritionally inadequate meat-free diet to exercising dogs, a more recent study demonstrated the potential of a balanced meat-free diet for sustaining the health and fitness of racing dogs. Brown et al. (2009) hypothesised that exercising dogs would remain in good health and would not develop anaemia when fed a nutritionally balanced meat-free diet. To this end, 12 sprint-racing Siberian huskies were fed either a commercial diet recommended for active dogs (n = 6), or a meat-free diet formulated to the same nutrient specifications (n = 6). The commercial diet contained 43% poultry meal, which was replaced by maize gluten and soybean meal in the meat-free diet. The dogs were fed these diets for 16 weeks, which included 10 weeks of competitive racing. None of the dogs developed anaemia and the consulting veterinarian, who was blinded to the dietary treatments, assessed all dogs as being in excellent physical condition.

Creatine is an important component of the energy delivery process and, although not an essential nutrient for mammals, supplementation of diets with creatine has been shown to increase exercise potential in humans (Venderley and Campbell, 2006). As commercial dog foods provide very little creatine because of its degradation during heat processing (Harris et al., 1997), it has been suggested that an elevated dietary creatine intake (equivalent to that in a raw meat diet) may be important for exercising dogs. However, oral creatine supplementation did not increase muscle creatine concentration in caged beagles (Lowe et al., 1998) or racing greyhounds, and contrary to results for humans, creatine supplementation did not improve the performance of racing greyhounds (NRC, 2006). Therefore, it is unlikely that a lack of dietary creatine would have a detrimental effect on exercising dogs, provided that the dietary intakes of its precursors,

arginine and glycine, are adequate.

Ingredient quality and food processing

The quality of feed ingredients is an important consideration for all diets, whether of plant or animal origin, as exemplified by an incident in the USA in 2005 in which over 100 dogs died after consuming commercial dog foods containing mycotoxin-contaminated maize (Leung et al., 2007). Fungal invasion and subsequent toxin production may occur at any stage of the food production cycle, and higher concentrations of mycotoxins are more often associated with cereal by-products than raw cereals. Processing can also affect the digestibility and bioavailability of nutrients. This is of particular relevance to commercial dry dog foods, which are mainly cereal-based, and meat-free diets, which contain very high levels of cereal grains. Pet food manufacturers have the means to extrude cereal-based diets in a way that improves digestibility and therefore are better equipped to produce nutritionally adequate meat-free diets from plant ingredients than the dog owner. Pet owners who feed their dogs homemade vegetarian diets are more likely to successfully balance such diets when animal products such as eggs and dairy products are included in the formulation. However, as many dogs are lactose intolerant, milk products should be introduced gradually to determine their acceptability. It is also advisable that eggs be cooked before feeding, as consumption of too many raw eggs by dogs may result in biotin deficiency (Oliver and Greene, 1983).

Palatability

Although some individual dogs and some breeds of dogs will consume most foods that they are presented with, the palatability of diets devoid of animal ingredients is likely to be an issue for many dogs with more discriminating palates. It is interesting to note that a website promoting vegetarianism in dogs and cats also advertises 'vegetarian supplements', including flavour enhancers "to encourage dogs and cats to eat" and enzyme powders "to increase the absorption of vital nutrients". This seems to imply that palatability and nutrient digestibility are problems associated with the vegetarian and vegan diets they are promoting.

Clinical applications

In humans, well-balanced vegetarian diets may be useful in the prevention of certain diet-related diseases (Sabate, 2003). A meat-free diet may also benefit some dogs. The Dalmatian breed, which has a genetic predisposition to urate urolithiasis, may benefit from a meat-free diet because plant material has lower purine content than meat (Brown et al., 2003). As a high incidence of urate urolithiasis has also been observed in non-Dalmatian dogs with portal vascular anomalies (Kruger and Osborne, 1986), such dogs may also benefit from a nutritionally adequate meat-free diet.

Ethics and culture

The main reason that people choose to be vegetarian is a conscientious objection to killing animals. Other reasons are welfare concerns for animals raised in intensive animal industries, the belief that abstinence from meat will result in greater food availability for the world's poor and religious or health reasons. Some may question whether it is morally right for such people to impose their ethical views on their pets. Rather than subject their dogs and cats to a vegetarian or vegan existence, perhaps people with these views should restrict their choice of pets to one that is naturally herbivorous, such as a rabbit, horse or guinea pig. A similar argument is often raised when human parents impose their religious or moral beliefs on their children, particularly when the belief system differs from that of the ethnic majority or predominant culture. In either case, it would be wise to assess the situation without prejudice. In the case of dogs, vegetarianism should be viewed from a nutritional perspective: *1) Does the diet meet the animal's nutritional needs? 2) Is the diet sufficiently palatable to ensure adequate intake? 3) When fed the diet, is the animal in good health?* If the answer to all of these questions is yes, then any objections to the diet would have to be construed as being based on prejudice.

If we removed the elevated status that we in Western society generally afford to companion animals, a meat-free diet that is nutritionally adequate would be of little concern. Diets for production animals are routinely formulated on a least-cost basis, and feed ingredients of inferior quality are frequently used in this process. No consideration is given to whether the diet is consistent with the production animal's ancestral origins or whether animal producers have the right to impose their moral beliefs on their animals. When viewed in this context, an ethical objection to vegetarianism in dogs seems at odds with the general acceptance of the exploitation of animals for food production.

Conclusions

The nutritional adequacy of a diet, vegetarian or otherwise, should be based on the ability of the diet to meet nutritional requirements. Palatability and digestibility are key considerations. A large number of dogs are currently fed meat-free diets, and there is a small but growing niche market for vegetarian pet foods. The major pet food manufacturers are unlikely to enter this market until there is greater acceptance of this type of product. Should this eventuate, it is hoped that their participation will ensure that the nutritional adequacy of commercial vegetarian dog foods is validated by recognised feeding protocols and digestibility trials.

References

AAFCO (2007). *Official Publication 2007*. Association of American Feed Control Officials Inc. Atlanta, Georgia, USA.

Backus, R.C., Ko, K.S., Fascetti, A.J., Kittleson, M.D., MacDonald, K.A., Maggs, D.J., Berg, J. R. and Rogers, Q.R. (2006). Low plasma taurine concentration in Newfoundland dogs is associated with low plasma methionine and cyst(e)ine concentrations and low taurine synthesis. *Journal of Nutrition* 136, 2525–2533.

Banta, C., Clemens, E., Krinsky, M. and Sheffy, B. (1979). Sites of organic acid production and patterns of digesta movement in the gastrointestinal tract of dogs. *Journal of Nutrition* 109, 1592–1600.

Bednar, G.E., Murray, S.M., Patil, A.R., Flickinger, E.A., Merchen, N.R. and Fahey, G.C., Jr. (2000). Selected animal and plant protein sources affect nutrient digestibility and fecal characteristics of ileally cannulated dogs. *Arch Tierernahr* 53, 127–140.

Biourge, V.C., Fontaine, J. and Vroom, M.W. (2004). Diagnosis of adverse reactions to food in dogs: efficacy of a soy-isolate hydrolyzate-based diet. *Journal of Nutrition* 134, 2062S–2064S.

Boitani, L., Francisci, F., Ciucci, P. and Andreoli, G. (1995). Population biology and ecology of feral dogs in central Italy. In: *The Domestic Dog - its evolution, behaviour and interactions with people*, pp. 217–244 (ed. J. Serpell). Cambridge University Press, Cambridge, UK.

Bradshaw, J. (2006). The evolutionary basis for the feeding behavior of domestic dogs (*Canis familiaris*) and cats (*Felis catus*). *Journal of Nutrition* 136, 1927S–1931S.

Brown, R. (1989). Protein in dog foods. *Canine Veterinary Journal* 30, 528–531.

Brown, W.Y., Vanselow, B.A., Redman, A.J. and Pluske, J.R. (2009). An experimental meat-free diet maintained haematological characteristics in sprint-racing sled dogs. *British Journal of Nutrition (in press)*.

Brown, W.Y., Vanselow, B.A. and Walkden-Brown, S.W. (2003). One dog's meat is another dog's poison – nutrition in the Dalmatian dog. *Recent Advances in Animal Nutrition in Australia* 14, 123–131.

Burkhalter, T.M., Merchen, N.R., Bauer, L.L., Murray, S.M., Patil, A.R., Brent, J.L., Jr. and Fahey, G.C., Jr. (2001). The ratio of insoluble to soluble fiber components in soybean hulls affects ileal and total-tract nutrient digestibilities and fecal characteristics of dogs. *Journal of Nutrition* 131, 1978–1985.

Clapper, G.M., Grieshop, C.M., Merchen, N.R., Russett, J.C., Brent, J.L., Jr. and Fahey, G.C., Jr. (2001). Ileal and total tract nutrient digestibilities and fecal characteristics of dogs as affected by soybean protein inclusion in dry, extruded diets. *Journal of Animal Science* 79, 1523–1532.

Clutton-Brock, J. (1995). Origins of the dog: domestication and early history. In: *The domestic dog - its evolution, behaviour and interactions with people*, pp. 7–20 (ed. J. Serpell). Cambridge University Press, Cambridge, UK.

Cole, J.T., Fahey, G.C., Jr., Merchen, N.R., Patil, A.R., Murray, S.M., Hussein, H.S. and Brent, J.L., Jr. (1999). Soybean hulls as a dietary fiber source for dogs. *Journal of Animal Science* 77, 917–924.

Gray, C.M., Sellon, R.K. and Freeman, L.M. (2004). Nutritional adequacy of two vegan diets for cats. *Journal of the American Veterinary Medical Association* 225, 1670–1675.

Harris, R.C., Lowe, J.A., Warnes, K. and Orme, C.E. (1997). The concentration of creatine in meat, offal and commercial dog food. *Research in Veterinary Science* 62, 58–62.

Hill, R.C., Burrows, C.F., Ellison, G.W. and Bauer, J.E. (2001). The effect of texturized vegetable protein from soy on nutrient digestibility compared to beef in cannulated dogs. *Journal of Animal Science* 79, 2162–2171.

Kendall, P.T. and Holme, D.W. (1982). Studies on the digestibility of soya bean products, cereals, cereal and plant by-products in diets of dogs. *Journal of the Science of Food and Agriculture* 33, 813–822.

Ko, K.S., Backus, R.C., Berg, J.R., Lame, M.W. and Rogers, Q.R. (2007). Differences in taurine synthesis rate among dogs relate to differences in their maintenance energy requirement. *Journal of Nutrition* 137, 1171–1175.

Kruger, J.M. and Osborne, C.A. (1986). Etiopathogenesis of uric acid and ammonium urate uroliths in non-Dalmatian dogs. *Veterinary Clinics of North America Small Animal Practice* 16, 87–126.

Leung, M.C., Smith, T.K., Karrow, N.A. and Boermans, H.J. (2007). Effects of foodborne Fusarium mycotoxins with and without a polymeric glucomannan mycotoxin adsorbent on food intake and nutrient digestibility, body weight and physical and clinicopathologic variables of mature dogs. *American Journal of Veterinary Research* 68, 1122–1129.

Lowe, J.A., Murphy, M. and Nash, V. (1998). Changes in plasma and muscle creatine concentration after increases in supplementary dietary creatine in dogs. *Journal of Nutrition* 128, 2691S–2693S.

MacDonald, M.L., Rogers, Q.R. and Morris, J.G. (1984). Nutrition of the domestic cat, a mammalian carnivore. *Annual Reviews in Nutrition* 4, 521–562.

Milner, J.A. (1981). Lysine requirements of the immature dog. *Journal of Nutrition* 111, 40–45.

Nesbitt, W.H. (1975). Ecology of a feral dog pack on a wildlife refuge. In: *The Wild Canids*, pp. 391–395 (ed. M.W. Fox). Van Nostrand Reinhold, New York, USA.

NRC (2006). Physical activity and environment. In: *Nutrient requirements of dogs and cats*, pp. 300–

301. The National Academies Press, Washington DC, USA.

Oliver, J.E., Jr. and Greene, C.E. (1983). Diseases of the brain. In: *Textbook of veterinary internal medicine - diseases of the dog and cat* (2nd ed.) p. 499 (ed. S.J. Ettinger). W.B. Saunders, Philadelphia, USA.

Papageorgiou, N., Vlachos, C., Sfougaris, A. and Tsachalidis, E. (1994). Status and diet of wolves in Greece. *Acta Theriologica* 39, 411–416.

Richert, B.T., Hancock, J.D. and Morrill, J.L. (1994). Effects of replacing milk and soybean products with wheat glutens on digestibility of nutrients and growth performance in nursery pigs. *Journal of Animal Science* 72, 151–159.

Sabate, J. (2003). The contribution of vegetarian diets to health and disease: a paradigm shift? *American Journal of Clinical Nutrition* 78, 502S–507S.

Scott, M.D. and Causey, K. (1973). Ecology of feral dogs in Alabama. *Journal of Wildlife Management* 37, 253–265.

Twomey, L.N. (2002). *Dietary fibre and exogenous feed enzymes in dogs.* PhD thesis, Murdoch University, Murdoch, Australia.

Twomey, L.N., Pluske, J.R., Rowe, J.B., Choct, M., Brown, W., McConnell, M.F. and Pethick, D.W. (2003). The effects of increasing levels of soluble non-starch polysaccharides and inclusion of feed enzymes in dog diets on faecal quality and digestibility. *Animal Feed Science and Technology* 108, 71–82.

USDA (2007) National nutrient database for standard reference: http://www.ars.usda.gov/nutrientdata

Venderley, A.M. and Campbell, W.W. (2006). Vegetarian diets: nutritional considerations for athletes. *Sports Medicine* 36, 293–305.

Wakefield, L.A., Shofer, F.S. and Michel, K.E. (2006). Evaluation of cats fed vegetarian diets and attitudes of their caregivers. *Journal of the American Veterinary Medical Association* 229, 70–73.

Wayne, R.K. (1993). Phylogenetic relationships of canids to other carnivores. In: *Miller's anatomy of the dog* (3rd ed.) pp. 15–21 (ed. H. Evans). W.B. Saunders Co., Philadelphia, USA.

White, R. and Frank, E. (1994). Health effects and prevalence of vegetarianism. *Western Journal of Medicine* 160, 465–470.

Williams, P.A., Hodgkinson, S.M., Rutherfurd, S.M. and Hendriks, W.H. (2006). Lysine content in canine diets can be severely heat damaged. *Journal of Nutrition* 136, 1998S–2000S.

Yamada, T., Tohori, M., Ashida, T., Kajiwara, N. and Yoshimura, H. (1987). Comparison of effects of vegetable protein diet and animal protein diet on the initiation of anemia during vigorous physical training (sports anemia) in dogs and rats. *Journal of Nutrition Science and Vitaminology (Tokyo)* 33, 129–149.

Yamka, R.M., Jamikorn, U., True, A. and Harmon, D. (2003). Evaluation of soybean meal as a protein source in canine foods. *Animal Feed Science and Technology* 109, 121–132.

Yamka, R.M., Kitts, S.E. and Harmon, D.L. (2005). Evaluation of low-oligosaccharide and low-oligosaccharide low-phytate whole soya beans in canine foods. *Animal Feed Science and Technology* 120, 79–91.

Yamka, R.M., Kitts, S.E., True, A.D. and Harmon, D.L. (2004). Evaluation of maize gluten meal as a protein source in canine foods. *Animal Feed Science and Technology* 116, 239–248.

Zuo, Y., Fahey, G.C., Jr., Merchen, N.R. and Bajjalieh, N.L. (1996). Digestion responses to low oligosaccharide soybean meal by ileally-cannulated dogs. *Journal of Animal Science* 74, 2441–2449.