Cats and dogs versus pigs and poultry: a nutritional perspective

W.H. Hendriks

Institute of Food Nutrition and Human Health, Massey University, Private Bag 11–222, Palmerston North, New Zealand

Summary

Cats and dogs are the most popular companion animals world–wide. The dog is classified as an omnivorous–carnivore while cats are true carnivores. Due to their dietary habits throughout evolution both species have developed a specific nutrient metabolism with the cat showing a unique nutrient metabolism compared to omnivorous production animals. The essentiality of nutrients and requirements for protein of both species are discussed. Criteria for the formulation of diets for cats and dogs involve palatability of the product, marketing strategies and a complete and balanced diet. Commercially produced diets for cats and dogs are among the most intensively heat–treated animal diets with extrusion, baking, pasteurisation and sterilisation being the most widely used processes. The effect of heat processing on the nutritive value of pet foods is discussed. Currently premium dry dog foods and moist canned cat foods are over–formulated with respect to essential amino acids. Cost–savings are possible by substitution in the protein fraction with less expensive ingredients.

Introduction

Domestic dogs (*Canis familiaris*) and cats (*Felis catus*) are the most popular companion animals world–wide. Owning a pet has been recognised to have health and psychological benefits such as decreased loneliness, increased self–esteem, increased interaction with others and development of assertiveness. As a result pets are often used in therapy for functionally disturbed children, criminally insane prisoners and elderly people in nursing homes. Although the cat is a true companion, the dog serves as much more than merely a companion in our society. Dogs are actively used to aid blind and deaf people as well as those confined to wheelchairs. They play a vital role in search and rescue work and are frequently used to detect drugs and bombs at international airports. Furthermore, dogs are indispensable in the farming of sheep and assist police with law enforcement.

Domestication of the dog is believed to have occurred around 9000 BC, and that of the cat around 3000 BC (Röhrs 1987). Since that time, many new breeds of dogs and cats have appeared and currently there are approximately 150 different breeds of dogs and more than 100 different breeds of cats. Nowadays, domestic cats and dogs are often kept in an environment where they cannot obtain their food naturally and it is the responsibility of the owner to provide the animal with the nutrients it requires. It becomes imperative, therefore, that the food supplied is nutritionally balanced and meets the requirements of the animal. Failure to meet the nutritional needs of the animal for one or more essential nutrients may result in deficiency symptoms, disease or death.

Past presentations at this conference have seen an excellent review on nutrition of dogs in Australia (Costa 1997), research articles on dogs (Rowe *et al.* 1997) and cats (Harper and Siever–Kelly 1997), and an update on companion animal nutrition (Divola 1993). This contribution focuses on the nutrition of cats and dogs and some fundamental differences that exist between these species and the nutrition of the pigs and poultry.

Commercial pet foods: a short historical perspective

Commercially pet foods have increased in popularity ever since the first commercial ‘dog cake’ was developed in 1860, in England by James Spratt. This dog cake consisted of meat, vegetables, beetroot and wheat–meals. In 1908 the first dry biscuit type dog food was developed and marketed in the United States. Not until 1922 did the first canned dog food that consisted largely of horse and mule meat, become available (Corbin 1995). The development of extruder technology in the 1950s resulted in the introduction of expanded dry dog foods in 1957 and ultimately led to the disappearance of the true meal and kibble type dry dog food (Kallfelz 1985). It was not until 100 years after the first commercial dog food was produced that the first commercial cat food became available. Around 1960 one company began marketing tuna fish as cat food in a 6½ ounce can (Kallfelz 1985), something cat owners apparently had been waiting for.

In the 1940s, a new development occurred in the pet food industry, namely the production of commercial therapeutic diets. One of the first diets developed was a low protein ration for the feeding of dogs with chronic renal failure. Many other diets have since been developed to aid in the management of diseases/ conditions such as idiopathic chronic colitis, obesity, pancreatitis, hypertension, feline lower urinary tract disease, etc.

Global and Australian pet food market

The dollar value of the world pet food market has increased since 1993 by 22% to A$ 42 billion in 1997. In terms of volume sales, the world market was 14.6 million tonnes in 1997 with dog food accounting for 63% and cat food for 37% of total sales (Irwin 1998). Four large companies (Mars, Nestlé, Ralston Purina and Heinz) dominate the world pet food market, and between them account for around 60% of sales. From 1997 to 2002, the world pet food market is expected to grow by around 19% in volume terms and 42% in terms of current value. The market for cat food is expected to grow more rapidly as a result of the growing cat population in developing markets (Irwin 1998).

In 1997, 261,000 tonnes of dog food were sold in Australia, up 7.4% since 1993. Cat food sales were 118,000 tonnes, down 6.8% since 1993. Total value of the Australian pet food market is around A$ 700 million per annum with dog food accounting for 60% and cat food accounting for 40%. Australia was, furthermore, a major exporter of pet foods between 1991 and 1995 with the principal customer being Japan (Heyhoe 1997).

Criteria for diet formulation in companion animals

Humans have access to a wide variety of foods and will consume a number of food types to meet their nutrient requirements. Farm animals are fed compound diets formulated for efficient production and rarely live out their natural lives. Cats and dogs, on the other hand, are nowadays expected to live a long, happy and relatively disease free life similar to humans. However, unlike humans, cats and dogs are often kept in an environment whereby they cannot obtain their natural food and, as a result, rely on their owners to provide them with the nutrients they require.

Commercial pet food manufacturers focus much of their effort and a significant proportion of their research budget on diet formulation for palatability. A diet can be complete and balanced nutrition, but if the diet is not ingested it does not provide nutrients to the animal and, therefore, is of no value. The palatability of pet foods is influenced by many factors including food texture, food composition, ingredients, smell, taste, temperature, past experience of the animal, heat treatment, etc. Feeding their companion animal is one of the most rewarding services an owner can perform (Booles 1993). Seeing the enjoyment of their pet in consuming its diet gives the owner a strong sense of fulfilment and often determines whether that particular diet (or brand) will be purchased again. Little information is present in the literature on palatability testing for cats and dogs. Griffin (1996) and Tarttelin (1997) discussed the most commonly used palatability test in the pet food industry, the two–bowl, free choice method. Much of the data generated with these tests, however, is kept in–house and is not published by manufacturers, for obvious reasons.

The owner's perception of a diet is another important criterion in diet formulation as it also strongly determines the repurchasing of diets. The food purchased should be perceived by the pet owner as something that is good enough for their companion to eat. Attributes such as consistency, colour, smell, can head space and appearance of the product are important variables in formulating diets. A dark looking paste with an unpleasant smell will be perceived by the owner as being unnutritious food, although the diet might actually be highly palatable and provide complete and balanced nutrition.

Marketing strategy is another important criterion in formulating diets for companion animals. Different varieties of pet food are often produced by manufacturers, such as fish, lamb, beef, garlic and rabbit flavour. The variety and interest concept supposes that a cat or dog needs variety in their diet. Tarttelin (1997) noted that the concept of variety and interest is aimed solely at the purchaser of the product and not the consumer. O'Malley (1995) argued that the desire for variety is naturally present in cats and dogs to allow development of knowledge of available foods and increase the chances of survival in the wild. Nowadays, there are positive aspects in providing a pet with a variety of diets, as it is unlikely that nutrient deficiencies will occur on a variety of diets rather than the feeding of one highly palatable preferred product. Vitamin E deficiency has been noted in cats due to the sole feeding of highly palatable fish or fish–based diets (Koutinas *et al*. 1993). Additionally, marketing strategies influence diet formulation because commercial pet food manufacturers often produce different brands in different price categories. Super Premium foods are generally formulated using more expensive ingredients than Premium or Budget foods. Super Premium foods are sold in smaller size containers that are easier to open and have highly attractive labels. Budget foods on the other hand are produced using less expensive raw materials and contain less attractive labels. As well as the difference in price between these three categories, differences in the average nutrient composition of Super Premium, Premium and Budget foods can be found (Table 1).

One criterion, often not as apparent as other criteria used in diet formulation for companion animals but extremely important, is the formulation of complete and balanced diets. Nowadays a significant proportion of the research budget of commercial pet food manufacturers is spent on nutritional testing of produced diets. Morris and Rogers (1994) and Costa (1997) discussed the most widely used testing procedure for cat and dog foods, that of the American Association of Feed Control Officials (AAFCO). The reader is referred to these publications for a summary and a critical discussion of the AAFCO procedures.

Essentiality and requirements of nutrients for cats and dogs

The domestic dog and cat both belong to the order Carnivora. Many species within the order Carnivora, however, are far from meat eaters. The giant panda *(Ailuropoda melanoleuca*) for example eats almost solely bamboo, while brown bears (*Ursus arctos*) ingest an omnivorous diet of plant and animal material. Many scientists regard the domestic dog as an omnivorous–carnivore while the domestic cat is often referred to as a 'true' carnivore. This terminology is largely based on the metabolism of nutrients as the dog's metabolism resembles more that of the rat and pig, while the cat's metabolism shows specialisation towards a meat diet similar to other true carnivores such as the fox, mink, and ferret.

The following section will discuss some of the metabolic peculiarities of the cat and the dog as these differ from the metabolism of typical omnivores such as the pig, rat, and chicken.

Protein and amino acid metabolism

The ideal amino acid patterns for growing dogs, cats, pigs and chickens are presented in Table 2. The patterns are similar although the cat seems to require more sulphur–containing amino acids and leucine, while the requirement for tryptophan seems to be high in dogs. There are, however, several metabolic idiosyncrasies in the metabolism of amino acids in the cat and the dog not commonly seen in pigs and poultry.

Nine amino acids are dietary essential for most mammals. Arginine, however, is an essential nutrient for adult as well as growing cats and dogs (NRC 1985; 1986). Consumption of a diet devoid of arginine results in severe signs of ammonia toxicity in both species. Cats have been reported to die within three hours after the ingestion of a diet devoid of arginine (Morris and Rogers 1978). The cause of the essentiality of arginine in cats is the low activity of the enzymes ornithine amino–transferase and pyrroline–5–carboxylase involved in its synthesis. When cats and dogs are fed an arginine–free diet in which all other amino acids are present at normal levels, insufficient arginine is synthesised *in vivo* to maintain the urea cycle and subsequently causes hyperammonaemia.

Table 1 Average gross composition (g/kg dry matter) of budget, premium and super premium moist canned cat foods.

Fraction	Budget	Premium	Super premium
Crude Protein	382	506	550
Crude Fat	360	276	223
Carbohydrate[†]	172	102	139
Ash	86	115	88

From Hendriks and Tarttelin (1997).
[†]Estimated by difference as (100– crude protein–crude fat–ash).

Table 2 Ideal essential amino acid pattern for growth in cats, dogs, pigs, and chickens relative to lysine = 100.

	Ideal essential amino acid pattern			
Amino acid	Cat[†]	Dog[‡]	Pig[§]	Chick[¶]
Lysine	100	100	100	100
Methionine + cystine	94	76	60	72
Tryptophan	19	29	18	18
Threonine	88	91	65	74
Arginine	125	98	42	110
Isoleucine	63	70	60	73
Valine	75	70	68	82
Leucine	150	114	100	109
Histidine	38	35	38	32
Phenylalanine + tyrosine	106	139	95	122

From [†]NRC (1986), [‡]NRC (1985), [§]Baker and Czarnecki–Maulden (1991) and [¶]NRC (1994)

Taurine, 2–amino ethanesulphonic acid, is another amino acid regarded as an essential nutrient for the cat. The essentiality of this amino acid results from a combination of insufficient synthesis and a high metabolic demand. The metabolic basis for the lack of taurine synthesis lies in the transamination of cysteinesulfinate, an intermediate in the synthesis, rather then the decarboxylation leading to taurine (Edgar *et al*. 1998). Besides the low rate of synthesis, the obligatory use of taurine to conjugate bile acids results in a continuous loss of taurine from the body. Taurine is not an essential nutrient for the dog as this animal can synthesise sufficient to meet its requirements.

Cats, unlike dogs, excrete several unusual sulphur–containing amino acids in their urine: felinine, isovalthine and isobuteine. Although little is known of the latter two amino acids, rates of felinine excretion of 95 and 19 mg/day have been recorded for entire male and entire female cats, respectively (Hendriks *et al*. 1995a). The biological significance of felinine or the other sulphur–containing amino acids to the animal is still a matter for speculation but a function as a precursor to a pheromone seems likely (Hendriks *et al.* 1995b). The high excretion rates of felinine in entire male cats may have a significant effect on the daily sulphur amino acid requirement.

Another idiosyncrasy in the metabolism of amino acids is the high protein requirement of cats which is approximately 40–60 % higher than the requirements of the growing and adult dog and rat (Table 3). This is not caused by a higher requirement for essential amino acids, but rather a higher requirement for non–essential amino acids, a result of non–adaptive nitrogen metabolising enzymes in the liver of the cat which are permanently set to handle a high protein diet (Rogers *et al.* 1977).

Essential fatty acids

Arachidonic acid is an essential fatty acid for cats but not for the dog, rat, pig or chicken. Again the requirement for this nutrient originates from the lack of the activity of an enzyme in the metabolic pathway leading to its synthesis. In the cat, the activity of the Δ^6–desaturase enzyme is low or absent resulting in insufficient synthesis of arachidonic acid. Sinclair (1979) proposed an alternative pathway for synthesis involving Δ^5– and Δ^8–desaturase enzymes but it is still unclear whether this allows sufficient synthesis of arachidonic acid to meet the needs of the cat.

Vitamin metabolism

For pigs, chickens, rats and dogs vitamin A is a semi–essential nutrient because dietary ß–carotene can be converted by these animals to vitamin A. The cat, however, either lacks the enzyme dioxygenase to convert ß–carotene to retinol, or the activity of this enzyme is grossly deficient, making vitamin A an essential nutrient for the cat.

Most mammals derive their niacin (nicotinic acid) requirements from metabolism of the essential amino acid tryptophan. The cat, unlike the dog, rat and pig, is again unusual in this respect in that tryptophan cannot replace nicotinic acid in the diet and cats die within 20 days when fed diets high in tryptophan but lacking in nicotinic acid (Da Silva *et al.* 1952). The inability of the cat to utilise tryptophan for synthesis of nicotinic acid is not due to a deficiency in one of the enzymes involved in the synthesis of nicotinic acid but rather is due to a highly active alternative metabolic pathway. The latter results in insufficient tryptophan being available for the synthesis of niacin.

Recently, How *et al.* (1994) showed that cats and dogs are unable to synthesise sufficient vitamin D to meet requirements. Low concentrations of 7–dehydrocholesterol in the skin of cats and dogs results in insufficient vitamin D synthesis. Morris (1996) subsequently showed in cats that this inability is due to a high activity of the enzyme 7–dehydrocholesterol–Δ^7–reductase which catalyses the conversion of 7–dehydrocholesterol to cholesterol.

Mineral metabolism

There do not appear to be any idiosyncrasies in the dietary amounts of minerals required by cats and dogs (NRC 1985; 1986). However, minerals have long been recognised to be involved in the most important disorder

Table 3 Minimum dietary crude protein and total essential amino acid requirements (g/kg$^{0.75}$/day) for the growing and adult cat, dog and rat.

Nutrient	Growing			Adult		
	Cat	Dog	Rat	Cat	Dog	Rat
Crude protein	12.00	7.57	8.41	2.77	1.98	1.40
Essential amino acids						
Free base	3.43	4.11	3.09	(0.56)	0.60	0.44
Protein–bound	2.98	3.59	2.69	(0.49)	0.52	0.38
Difference†	9.02	3.98	5.72	(2.28)	1.46	1.02

From Hendriks (1996). Values between brackets are extrapolated.
†Crude protein minus total protein–bound essential amino acids.

affecting the lower part of the urinary system of cats and one of the most common conditions to afflict cats, urolithiasis or feline urological syndrome (FUS). Naturally occurring feline uroliths (urinary stones) may be composed of magnesium ammonium phosphate hexahydrate (struvite), calcium oxalate, ammonium phosphate, calcium phosphate, cystine and xanthine, with struvite being the most predominant form (Osborne *et al.* 1989). Strategies for preventing struvite formation in cats through dietary manipulation either target urinary pH or the excretion of magnesium in the urine. Lowering urinary pH to 6.0–6.4 by the addition of urinary acidifiers to diets is one of the most effective measures to prevent the formation of struvite crystals, and has become normal practice in commercial diets. Dry diets especially, which are more liable to cause formation of struvite in the cat, are formulated to include urinary acidifiers such as phosphoric acid, ammonium chloride, calcium chloride and methionine. In conjunction with urinary acidifiers, diets are often formulated to contain low magnesium levels, which is the primary mineral found in the struvite crystal. Buffington *et al.* (1985), however, showed that previous studies claiming that 'excessive' dietary magnesium causes struvite urolithiasis were the result of an error in the experimental design because the magnesium salt was added in a form which increased urinary pH. The importance of urinary magnesium concentration in the prevention of struvite formation in the cat, therefore, may be overemphasised. Recently, the importance of water in the prevention of FUS was noted by Markwell *et al.* (1998). These authors noted that more then half of cats classified as having idiopathic lower urinary tract disease may show no recurrence of this condition if maintained on a diet high in moisture content.

It is evident from the above that the dog more closely resembles an omnivore than the cat. However, the dog has still adapted its metabolism to the carnivorous component in its diet and for this reason the dog is characterised as an omnivorous–carnivore. The cat on the other hand has fully adapted to a carnivorous diet. The constant composition and high nutrient content of the cat's diet throughout evolution has resulted in several metabolic adaptations. All the nutrients which the cat cannot synthesise (taurine, arginine, arachidonic acid, vitamin A, vitamin D, niacin) can be found in a diet consisting of mammalian tissues.

Prepared cat and dog food

Dry, semi–moist and moist pet foods are manufactured from ingredients such as meats/offals (beef, fish, poultry, deer, lamb, etc.), cereal grains, meat by–products, fats/oils, vegetable protein concentrates, sugar, water, humectants, gelling agents, emulsifiers, colourants, vitamins, and minerals. The large numbers of ingredients contributes to the observed variability in the nutritional content of these types of diets (Hendriks and Tarttelin 1997). To increase shelf life, achieve a desired physical form, and(or) increase palatability, the unprocessed mixture is either extruded, baked, pasteurised or sterilised depending on the type of pet food that is manufactured. There is a plethora of information concerning the influence of various heat treatments on the protein quality of feeds for pigs and poultry (e.g. Van Barneveld 1993; Van der Poel *et al.* 1993; Voragen *et al.* 1995). Little information is available on the effects of heat treatments used in the manufacturing of pet foods which are among the most intensively processed of all animal foods.

Heat processing generally is believed to have a negative impact on the nutritive value of pet foods (NRC 1986; Lewis *et al.* 1987; Heinicke 1995). Loss of vitamins during the production of pet foods has been extensively documented (Roche 1981). Thiamine is particularly sensitive to heat and, as a precaution, compensatory amounts are added to pet foods to obtain adequate post–processing levels of thiamine in the product. Heat processing of a canned cat food, furthermore, has been noted to change the taurine status of cats because moist diets increase the microbial deconjugation of bile acids in the small intestine (Kim *et al.* 1996). Besides the negative effect on nutritive value, heat processing has been noted to decrease the palatability of moist diets for cats (Heinicke 1995; Hendriks *et al.* 1999).

Heat processing of pet foods can be expected to affect the protein fraction of the diet. Backus *et al.* (1995) found that heat sterilisation of a commercial canned moist cat food increased the apparent digestibility of the crude protein. It is possible that there was a decrease in digestibility in the small intestines but microbial deamination in the caecum and colon of the increased flow of amino acids, diffusion of ammonia across the mucosa reducing faecal N loss and thus resulting in increased apparent digestibility. In diets that have undergone processing or prolonged storage the ε–amino group of lysine can react with compounds present to produce nutritionally unavailable derivatives. Determination of unmodified lysine (reactive, available, lysine) before and after heat processing, therefore, may present a useful *in vitro* method to assess heat–damage to protein. Rutherfurd and Moughan (1997) found that the extrusion process used in the production of a dry cat food did not alter the digestibility of total and available lysine. Production of a moist cat food was associated with a 10% reduction in both digestibility values, indicating that heat damage to lysine may have occurred. Recently Hendriks *et al.* (1999) measured the effect of heat sterilisation on the protein quality of a canned cat food mixture using *in vitro* and *in vivo* assays. A standard recipe cat food was heat treated for different times and analysed for crude protein, amino acids, and reactive lysine, and fed to rats to determine the true ileal digestibility of amino acids. There were no changes in the gross composition of nutrients (crude protein, amino acids and reactive lysine) due to the heat treatment. However, the true ileal digestibility of amino acids generally decreased with increasing duration of heating (Figure 1). Amino acid nitrogen and proline digestibility increased with mild heat treatment but decreased with more severe heat processing. The reactive lysine content in the unheated and heat–treated diets was found to be about 10% lower than the total lysine content, a similar value to that found by Rutherfurd and Moughan (1997). The lower value was attributed to the relatively high proportion in the diet of collagen (from connective tissue) that naturally contains covalent cross–links involving lysine to maintain the native three–dimensional structure of the protein. Hendriks *et al*. (1999) concluded that cross–linking involving cystine is the likely mechanism for the decrease in the true digestibility of amino acids with increasing heat treatment.

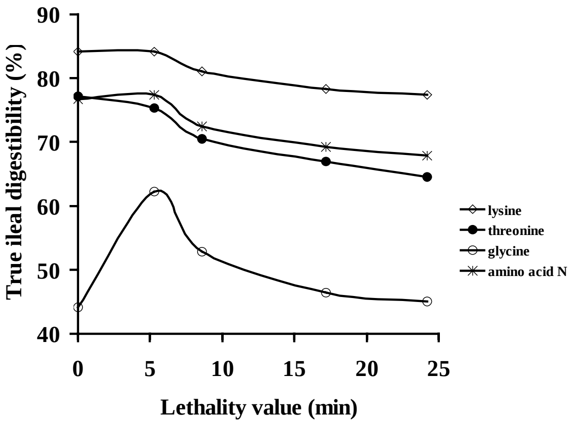

Figure 1 True ileal digestibility of lysine, threonine, glycine and amino acid nitrogen in a moist cat food heated to different lethality values (time equivalent of a heating process to destroy micro-organisms at the reference temperature of 121.1°C).

Over–formulation of commercial diets for cats and dogs

Feeds for production animals are formulated using data on the digestibility of nutrients of potential ingredients, and least–cost formulation to obtain the most cost–effective compound feed. Diets for cats and dogs, however, are formulated using criteria such as high palatability, appearance and nutritional completeness and balance. Formulation of diets based on these criteria will, in most cases, result in a nutrient content that is well in excess of the requirements of the animal. This fact is illustrated in Table 4 where the total and true ileal digestible content of essential amino acids for a dry dog food and moist canned cat food are compared to the nutrient requirements of adult dogs and cats. The essential amino acid requirements of adult cats were calculated from a computer–based factorial model developed from data presented by Hendriks (1996) and relate to a 4 kg adult male cat consuming a moist canned cat food. It must be noted that the latter estimates of requirements are not minimum values, but rather are optimum values for maintenance. As can be seen from Table 4, the premium dry dog food contains all amino acids in amounts well in excess of the dietary requirements. If the protein content were to be reduced in the diet, the first limiting amino acid is leucine as the true ileal digestible leucine content is only 50% above the dietary requirement. Arginine is the most abundant essential amino acid present in the dry dog food with the true ileal digestible arginine content more than 400% above requirement. The moist canned cat food also contains more than sufficient amounts of essential amino acids to meet the requirement of the animal. The true ileal digestible amino acid content of the moist cat diet is approximately 3.2 times the dietary amino acid requirement.

Table 4 Dietary amino acid contents of a dry dog food and a moist cat food and the dietary amino acid requirements of cats and dogs; all values are g/kg dry matter.

	Adult dog			Adult cat		
	Dry dog food[†]			Moist cat food[§]		
Amino acid	Total	True ileal digestible	Dietary requirement[‡]	Total	True ileal digestible	Dietary requirement[¶]
Lysine	11.2	9.7	5.1	36.2	29.4	7.6
Threonine	8.5	7.3	4.7	24.2	17.1	7.2
Arginine	28.1	25.6	5.0	35.1	28.5	8.2
Isoleucine	8.3	7.3	3.6	18.6	14.2	4.7
Valine	9.9	8.5	3.9	28.3	21.3	6.4
Leucine	17.4	15.4	5.8	44.0	35.1	9.2
Histdine	5.5	4.7	1.8	14.5	9.7	3.8
Phenylalanine + tyrosine	9.3	14.6	7.2	42.8	32.7	9.4

From [†]Sritharan (1998), [‡]NRC (1985), [§]Hendriks *et al.* (1999) and [¶]Hendriks unpublished.

As the two diets in Table 4 are typical examples of premium dry dog foods and moist canned cat foods (Table 1), it can be concluded that the majority of companion animal diets are over–formulated with respect to essential amino acids. Potential cost savings, therefore, are possible if less expensive ingredients can be incorporated in the protein fraction without affecting the formulation criterion of palatability.

Over–formulation of pet foods with respect to minerals has also been noted. Johnson *et al.* (1992) measured the iodine content of moist and dry cat foods in New Zealand and found a variation of more than a hundred–fold ranging from 47 to 5304 mg/kg as sold. This large variation in iodine content, as well as other minerals, has also been observed by Mumma *et al.* (1986) in dog and cat foods sold in America. The latter authors hypothesised that the variation in iodine content of commercial pet foods may be attributed to varying amounts of thyroids included. In a follow–up study, Tarttelin *et al.* (1992) fed adult cats diets containing high, medium or low iodine concentrations for a short time (2 wks) and measured urinary iodine excretion and serum free–thyroxine. The cats were found to closely regulate serum free–thyroxine levels and the latter authors found an inverse relationship between serum free– thyroxine and urinary iodine concentration. Further evidence that the cat is able to maintain normal levels of thyroid hormone when maintained on high and low iodine levels for longer periods (5 mo) was presented by Kyle *et al.* (1994).

References

Backus, R.C., Rogers, Q.R., Rosenquist, G.L., Calam, J. and Morris, J.G. (1995). Diets causing taurine depletion in cats substantially elevate postprandial plasma cholecystokinin concentration. *Journal of Nutrition* **125,** 2650–2657.

Baker, D.H. and Czarnecki–Maulden, G.L. (1991). Comparative nutrition of cats and dogs. *Annual Review of Nutrition* **11,** 239–263.

Booles, D. (1993). Foods fit for companion animals. In*: The Waltham Book of Companion Animal Nutrition*, pp. 1–3 (ed. I. Burger). Pergamon Press, Oxford.

Buffington, C.A., Rogers, Q.R. and Morris, J.G. (1985). Feline struvite urolithiasis: magnesium effect depends on urinary pH. *Feline Practice* **15,** 29–33.

Corbin, J. (1995). Pros and cons of palatability enhancers available: then and now. In: *Focus on Palatability*, pp. 48–55. Watt Publishing Co., Mt. Morris, Illinois, USA.

Costa, N.D. (1997). Nutrition of the dog: an Australian overview. In: *Recent Advances in Animal Nutrition in Australia 1997*, pp. 117–129. (eds. J.L. Corbett, M. Choct, J.V. Nolan and J.B. Rowe). University of New England, Armidale.

Da Silva, A.C., Fried, R. and de Angelis, R.C. (1952). The domestic cat as a laboratory animal for experimental nutrition studies. III. Niacin requirements and tryptophan metabolism. *Journal of Nutrition* **46,** 399–409.

Divola, C. (1993). Nutrition of companion animals: recent advances. In: *Recent Advances in Animal Nutrition in Australia 1993,* pp. 163–169 (ed. D.J. Farrell). University of New England, Armidale.

Edgar, S.E., Kirk, C.A., Rogers, Q.R. and Morris, J.G. (1998). Taurine status in cats is not maintained by dietary cysteinesulfinic acid. *Journal of Nutrition* **128,** 751–757.

Griffin, R.W. (1996). Palatability testing: Is it a valid test? *Petfood Industry* **38,** 4–6.

Harper, E.J. and Siever–Kelly, C. (1997). The effect of fibre on nutrient availability in cats of different ages. In: *Recent Advances in Animal Nutrition in Australia 1997*, pp. 110–116 (eds. J.L. Corbett, M. Choct, J.V. Nolan and J.B. Rowe). University of New England, Armidale.

Heinicke, R. (1995). Enhancing palatability of canned and semi–moist products. In: *Focus on Palatability*, pp. 56–68. Watt Publishing Co., Illinois, USA.

Hendriks, W.H. (1996). Protein Metabolism in the Adult Domestic Cat (*Felis catus*). PhD Thesis, Massey University, New Zealand.

Hendriks, W.H. and Tarttelin, M.F. (1997). Nutrient composition of moist cat foods sold in New Zealand. *Proceedings of the Nutrition Society of New Zealand* **22,** 202–207.

Hendriks, W.H., Tarttelin, M.F. and Moughan, P.J. (1995a). Twenty–four hour feline (*sic*) excretion patterns in entire and castrated cats. *Physiology and Behavior* **58,** 467–469.

Hendriks, W.H., Moughan, P.J., Tarttelin, M.F. and Woolhouse, A.D. (1995b). Felinine: a urinary amino acid of Felidae. *Comparative Biochemistry and Physiology* **112B,** 581–588.

Hendriks, W.H., Emmens, M. and Pluske, J.R. (1999). Heat processing changes the protein quality of canned cat foods as measured by a rat–bioassay. *Journal of Animal Science* **77,** 669–676.

Heyhoe, T. (1997). Export success. *Petfood Industry* **39,** 4–8.

How, K.L., Hazewinkel, A.W. and Mol, J.A. (1994). Dietary vitamin D dependency of cat and dog due to inadequate cutaneous synthesis of vitamin D. *General and Comparative Endocrinology* **96,** 12–18.

Irwin, A. (1998). Petfood world. *Petfood Industry* **40,** 62–68.

Johnson L.A., Ford, H.C., Tarttelin, M.F. and Feek, C.M. (1992). Iodine content of commercially–prepared cat foods. *New Zealand Veterinary Journal* **40,** 1820–1823.

Kallfelz, F.A. (1985). Nutrition and feeding of dogs and cats: past, present and future. *Cornell Veterinarian* **75,** 221–229.

Kim, S.W., Rogers, Q.R. and Morris, J.G. (1996). Dietary antibiotics decreases taurine loss in cats fed a canned heat–processed diet. *Journal of Nutrition* **126,** 509–515.

Koutinas, A.F., Miller, W.H., Jr., Kritsepi. M. and Lekkas, S. (1993). Pansteatitis (steatitis, 'yellow fat disease') in the cat: a review article and report of four spontaneous cases. *Veterinary Dermatology* **3,** 101–106.

Kyle, A.H.M., Tarttelin, M.F., Cooke, R.R. and Ford, H.C. (1994). Serum free thyroxine levels in cats maintained on diets relatively high or low in iodine. *New Zealand Veterinary Journal* **42,** 101–103.

Lewis, L.D., Morris Jr., M.L. and Hand, M.S. (1987). Small Animal Clinical Nutrition, III. Mark Association, Topeka, Kansas.

Markwell, P.J., Buffington, C.T. and Smith, B.H.E. (1998). The effect of diet on lower urinary tract diseases in cats. *Journal of Nutrition* **128,** 2753S–2757S.

Morris, J.G. (1996). Vitamin D synthesis by kittens. *Veterinary Clinical Nutrition* **3,** 88–92.

Morris, J.G. and Rogers, Q.R. (1978). Ammonia intoxication in the near–adult cat as a result of a dietary deficiency of arginine. *Science* **199,** 431–432.

Morris, J.G. and Rogers, Q.R. (1994). Assessment of the nutritional adequacy of pet foods through the life cycle. *Journal of Nutrition* **124**, 2520S–2534S.

Mumma, R.O., Rashid, K.A., Shane, B.S., Scarlett–Kranz, J.M., Hotchkiss, J.H., Eckerlin, R.H., Maylin, G.A., Lee, C.Y., Rutzke, M., Gutenmann, W.H., Bache, C.A. and Lisk, D.J. (1986). Toxic and protective constituents in pet foods. *American Journal of Veterinary Research* **47,** 1633–1637.

NRC (1985). *Nutrient Requirements of Dogs*. National Academy Press, Washington, DC.

NRC (1986). *Nutrient Requirements of Cats.* National Academy Press, Washington, DC.

NRC (1994). *Nutrient Requirements of Poultry*, 9th ed. National Academy Press, Washington, DC.

O'Malley, S. (1995). The role of variety in the diet. *Waltham Focus* **5,** 18–22.

Osborne, C.A., Sanna, J.J., Unger, L.K., Clinton, C.W. and Davenport, M.P. (1989). Analyzing the mineral composition of uroliths from dogs, cats, horses, cattle, sheep, goats, and pigs. *Veterinary Medicine* **84,** 750–764.

Roche (1981). *Rationale for Roche Recommended Vitamin Fortification. Dogs and Cats.* Department of Agriculture and Animal Health, Roche Chemical Division, Hoffmann–La Roche Inc., Nutley, NJ.

Röhrs, M. (1987). Domestication of wolves and wild cats: Parallels and differences. In: *Nutrition, Malnutrition and Dietetics in the Dog and Cat*, pp. 1–5 (ed. A.T.B. Edney), Proceedings of an International Symposium, Hanover., British Veterinary Association and Waltham Centre for Pet Nutrition, England.

Rogers, Q.R., Morris, J.G. and Freedland, R.A. (1977). Lack of hepatic enzymatic adaptation to low and high levels of dietary protein in adult cat. *Enzyme* **22,** 348–356.

Rowe, J.B., Choct, M., Brown, W. and Day, K. (1997). Variation in the carbohydrate composition of dog food. In: *Recent Advances in Animal Nutrition in Australia 1997*, pp. 242 (eds. J.L. Corbett, M. Choct, J.V. Nolan and J.B. Rowe). University of New England, Armidale.

Rutherfurd, S.M. and Moughan, P.J. (1997). Determining reactive lysine and the digestibility of reactive lysine in heat processed foods. *Proceedings of the Nutrition Society of New Zealand* **22,** 222–234.

Sinclair, A.J., McLean, J.G. and Monger, E.A. (1979). Metabolism of linoleic acid in the cat. *Lipids* **14,** 932–936.

Sritharan, K. (1998). The Rat as a Model Animal for Digestion in the Dog. MSc Thesis, Massey University, New Zealand.

Tarttelin, M.F. (1997). Gaining and maintaining market share in a competitive environment: Some views on long and short term pet food testing. *Proceedings of the Nutrition Society of New Zealand* **22,** 192–201.

Tarttelin, M.F., Johnson, L.A., Cooke, R.R., Ford, H.C. and Feek, C.M. (1992). Serum free thyroxine levels respond inversely to changes in levels of dietary iodine in the domestic cat. *New Zealand Veterinary Journal* **40,** 66–68.

Van Barneveld, R.J. (1993). Effect of Heating Proteins on the Digestibility, Availability and Utilisation of Lysine by Growing Pigs. PhD Thesis, University of Queensland. Australia.

Van der Poel, A.F.B., Huisman, J. and Hsaini, S. (1993). *Recent Advances of Research in Antinutritional Factors in Legume Seeds: Analytical Methods, Animal Nutrition, Feed (Bio) Technology*. EAAP Publication No. 70. Wageningen, The Netherlands.

Voragen, A.G.J., Gruppen, H., Marsman, G.J.P. and Mul, A.J. (1995). Effect of some manufacturing technologies on chemical, physical and nutritional properties of feed. In: *Recent Advances in Animal Nutrition*, pp. 233–246 (eds. P.C. Garnsworth and D.J.A. Cole). Nottingham University Press, UK.