# Nutrition of the dog: an Australian overview

N.D. Costa

Division of Veterinary and Biomedical Sciences, Murdoch University, Murdoch WA Australia 6150

## Summary

Forty-five percent of Australian households care for one or more pet dogs. Their nutrition presents the challenge of maintaining liveweight and health over a number of years. Commercial dog foods are formulated on the nutrient requirements specified by the Association of American Feed Control Officials (AAFCO) rather than NRC recommendations. Most commercial formulations for feeding dogs provide complete and balanced nutrition with safety margins of 10% or more for most nutrients rather than their minimum requirements. Allometric equations for determining daily energy requirements for dogs produce quite different outcomes in the amount of food required. Furthermore the balance of protein and fat as % ME has not been optimised. Wheat and meat and bone meal are the most commonly used ingredients in Australia for commercial dry foods for dogs. However, wheat and beef-based meat and bone meal are also frequently associated with adverse reactions and allergies to foods. Homemade diets are less likely to be associated with allergies and adverse reactions. Formulating dog foods with defined ratios of omega-6 and omega-3 polyunsaturated fatty acids of between 5: 1 and 10: 1 has been successful in increasing the relative concentration of some weakly or anti-inflammatory eicosanoids. Modulation of eicosanoid metabolism is proposed as a basis for treatment of some skin, gastrointestinal and renal disorders. Relatively high inclusions of dietary fibre (five percent or more) have improved stool consistency possibly through modified gastrointestinal structure and function. Prebiotics such as fructooligosaccharides are now being evaluated to enhance the actions of dietary fibre. This paper predicts that the trend of formulating to optimise health as well as supplying adequate nutrients will be extended in the future development of commercial dog foods.

## Dogs in Australia: setting the scene

The dog is man's oldest companion animal, probably beginning domestication about 12,000 to 14,000 years ago in Eurasia. Since that time many breeds have been developed for specific purposes such as hunting, herding and guarding. However, today, most dogs are kept mainly for companion purposes and almost 2.7 million households in Australia have a pet dog, giving rise to a total population of approximately 3.8 million dogs in this country (BIS Schrapnel 1996). Obviously dog numbers are related to the human populations in the various States of Australia, but expenditure per dog is particularly high in South Australia and the Territories. (Table 1).

**Table 1** Dog Populations and Expenditure on Dogs in the States and Territories of Australia

| | Dog Population (thousands) | Expenditure (A$ millions) | Expenditure per Dog (A$ per dog) |
|---|---|---|---|
| NSW | 1226 | 442 | 361 |
| Vic | 1012 | 334 | 330 |
| Qld | 691 | 225 | 324 |
| SA | 291 | 140 | 481 |
| WA | 345 | 111 | 321 |
| Tas | 123 | 41 | 333 |
| ACT | 60 | 25 | 417 |
| NT | 31 | 13 | 419 |

BIS Schrapnel 1996

Table 2 Dog Populations and Expenditure on Dogs in Developed Countries

| | Dog Population (millions) | Total Expenditure (US $ millions) | Expenditure per Dog (US $ per dog) |
|---|---|---|---|
| USA | 54.9 | 11,724 | 214 |
| Japan | 9.8 | 7,069 | 721 |
| France | 9 | 2,140 | 237 |
| UK | 7.2 | 2,610 | 363 |
| Italy | 6.1 | 870 | 142 |
| Germany | 5 | 2,994 | 599 |
| Spain | 3.2 | 259 | 81 |
| Australia | 3.8 | 1,038 | 273 |

Data from Petfood Industry (1997) and BIS Schrapnel (1996) ; conversion rate of 1.00 A$ ¯ 0.78 US $.

The number of dogs in Australia per head of population is comparable with the USA, European countries and Japan, and the expenditure on pet food and accessories for dogs by Australians is within the range of expenditures in those other developed countries. (Table 2 Euromonitor survey reported in Petfood Industry 1997).

Direct expenditure on the nutrition of dogs in Australia is more than A$6 19 million per annum (BIS Schrapnel 1996). Prepared dog foods accounted for more than 60% of all food fed to dogs in 1992 (Feed Grains Study 1995) and this trend of feeding commercial dog foods rather than home-made diets is expected to grow. Uncle Ben's of Australia (UBA) is the largest pet food manufacturer in the Australian market and their main brands of Pedigree PAL (the world's biggest pet food brand), Chum dog food and My Dog held 75.7% of the value of the canned market and 53.9% of the packet market in 1994 (Feed Grains Study 1995). UBA purchased more than 100,000 tonnes of feed grain in 1994, mainly as cereal grams but with small amounts of pulses and soybean meal. Overall demand for feed grain by the pet food area grew at 20% per annum during 1994 and 1995, and demand is expected to remain high (Feed Grains Study 1995).

## Feeding the dog compared with other domesticated species

It is important to remember that dogs have been used as the preferred animal model for nutritional studies for over a hundred years and this has provided some fundamental data on digestion and vitamin metabolism (as reviewed by Carpenter 199 1). However, this paper will present an overview of the nutrition of dogs that are kept as friends and companions. Feeding the pet dog differs from production feeding in a number of important ways. With beef cattle, prime lambs, pigs, and broiler chickens, there is a clear production end-point preferably achieved in the shortest time span possible. For dairy cattle and sheep in Australia, the aim of feeding is to produce milk or wool respectively. The nutrient requirement tables for these species reflect these production aims. Only the horse is similar to the dog, in that there is a large variation in liveweight between breeds reflected in the construction of NRC nutrient requirement tables for horses. Moreover, the purpose for keeping a horse is frequently for sport, often for companionship, and now only spasmodically for work. However, the horse has the advantage being a herbivore and can be sustained at maturity on 100% roughage diets. The dog, on the other hand is predominantly a carnivore, with a relatively high protein requirement (minimum 18%) at maturity.

There is a number ofnutritional aims and difficulties in feeding the pet dog. Firstly, the aim of feeding the pet dog is to sustain a relatively constant liveweight over a period of eight to fourteen years! Secondly most pet dogs are fed individually by one or two people, so the second aim of feeding is to reinforce a bond of companionship. As an offshoot of this bonding, the owner knows and often understands a great deal about the feeding habits and preferences of their pet dog. Finally the pet dog is kept until old age or disease makes it no longer desirable for both parties, so that feeding the older or geriatric dog is a problem that companion animal nutritionist must face. Different breeds of dogs age at different rates, and in general, larger breeds such as the Great Dane take longer to mature fully (24 months vs 12 months for Beagles), and yet they have a shorter life span than small to medium size breeds. Thus the nutrition of the companion animal draws as much information from other long-lived and well-researched species such as the human, as from the nutrition of production animals.

## Specification of nutrient requirements of dogs

Most commercial dog foods aim to comply with the concept of being 'complete and balanced'. A complete food may be defined as a nutritionally adequate feed for animals other than man, compounded by a specific formula to be fed as the sole ration and capable of maintaining life and/or promoting production without any additional substances being consumed except for water. The more balanced means having all known nutrients in the proper amount and concentration as specified by recognised authorities in the field for given set of physiological states for that species.

Formulating a 'complete and balanced' dog food requires at least three sets of information:

1 a set of nutrient requirement tables;
2 the chemical composition of the ingredients to be used; and
3 an appreciation of the bioavailability of the nutrients present in the dietary ingredients (Morris and Rogers 1994).

Two major American organisations have published tables of nutrient requirements for dogs: the NRC Nutrient Requirements of Dogs 1985, and the Association of American Feed Control Officials (AAFCO) who publish an annual volume including nutrient requirement tables for dogs. The NRC (1985) tables specify the minimum nutrient requirements of growing and adult dogs. In the introduction it is stated that 'caution is advised in the use of these requirement tables without the demonstration of nutrient availability, because in some cases requirements have been established on the basis of studies in which nutrients were supplied by highly purified ingredients where digestibility and availability were not compromised by the interaction of dietary constituents and effects of processing'. Since practical diets of both a commercial and 'homemade' nature are not free of these interactions and effects, and more importantly, no clear guidelines of bioavailability were published by the NRC, commercial manufacturers were either unable, or chose not, to use NRC 1985 as the basis for their claims of nutritional adequacy. In 199 1, the NRC requested that their recommendations not be used to substantiate claims of nutritional adequacy of manufactured feeds for dogs. As a consequence, the NRC nutrient requirement tables are now not widely used in the Australian petfood industry, with the major exception of the National Registration Authority (NRA) who use the NRC as the authority in determining registration of supplements. More importantly, the issue of bioavailability raised by the 1985 NRC Committee has still not really been addressed in current thinking about nutrient requirement tables.

Over the last four to five years, AAFCO have become the pre-eminent authority for specifying nutrient requirements of dogs, not only in the USA but in Australia, Japan and Europe also. Historically, AAFCO's primary function in the USA was to provide model laws, animal feed regulations and ingredient definitions, which the various States could use in their own feed laws and regulations for marketing of petfood across State borders in the USA. It is only since 1990 that AAFCO established a Canine Nutrition Expert Subcommittee to advise on nutrient requirement tables and testing procedures, its first report being released as the AAFCO Dog Food Nutrient Profiles in 1992 and updated each year. These tables do not report the published basis for their recommendations, as does the NRC, but they do include maximum as well as minimum amounts for nutrients that can be associated with toxicities (Table 3). The other major points of difference are the higher AAFCO specifications for iron, copper, zinc, iodine and vitamin E for adult dogs at maintenance. An essential part of the AAFCO (1993) protocol was the introduction of a feeding trial using the petfood as the major means of substantiating the claim of being 'complete and balanced'.

The test protocols for AAFCO specification are set out each year in their annual publication. The minimum testing protocol for adult maintenance for a dog food requires that it must be the only diet fed to a minimum of 8 healthy adult dogs (at least one year of age) for a minimum of26 weeks. Daily food consumption may be measured and recorded. Individual body weights must be measured at the beginning, then weekly until the end of the 26th week of the test. Ideally there should be no change in liveweight over the 26 weeks, but under the protocol liveweight cannot vary more than 1.9 times the standard error of the average percentage liveweight change. No animal under test can lose more 15% of liveweight. RBC number, haemoglobin packed cell volume, and serum alkaline phosphatase and albumin must be measured at the beginning and at the 26th week. Twenty-six weeks is a long time for any dog to be fed on only one food, so the feeds that pass these protocols are very palatable. The general health of all dogs undergoing AAFCO tests must be monitored by veterinarians through physical examination and blood tests. In addition to this protocol for maintenance, there are AAFCO protocols specified for pregnancy, lactation and growth. Successful completion of such a protocol can form the basis of a claim for nutritional adequacy of a commercial dog food. In the USA, there are a number of independent companies who can conduct such AAFCO trials but there is none in Australia. To undertake an AAFCO trial in Australia is a large commitment of resources and only large companies such as UBA have made an effort to screen their products.

## The problem of predicting daily energy requirement

The energy content of a food for dogs can be calculated using modified Atwater constants in the following equation (AAFCO 1997):

$$\text{ME (kJ/100g as fed)} = 14.64 \times \%\ \text{crude protein} + 35.56 \times \%\ \text{crude fat} + 14.64 \times \%\ \text{carbohydrate}$$

Carbohydrate is assumed to be equivalent to the nitrogen free extract and no agreed allowance has been made for any contribution to energy from fibre.

**Table 3** AAFCO minimum and maximum nutrient profiles for dog foods on a dry matter basis (1997).

| Nutrient | Units | Growth & Reproduction | Adult | Maximum |
|---|---|---|---|---|
| Protein | % | 22.0 | 18.0 | |
| Arginine | % | 0.62 | 0.51 | |
| Histidine | % | 0.22 | 0.18 | |
| Isoleucine | % | 0.45 | 0.37 | |
| Leucine | % | 0.72 | 0.59 | |
| Lysine | % | 0.77 | 0.63 | |
| Methionine–cystine | % | 0.53 | 0.43 | |
| Phenyalanine–tyrosine | % | 0.89 | 0.73 | |
| Threonine | % | 0.58 | 0.48 | |
| Tryptophan | % | 0.20 | 0.16 | |
| Valine | % | 0.48 | 0.39 | |
| Fat | % | 8.0 | 5.0 | |
| Linoleic acid | % | 1.0 | 1.0 | |
| Minerals | | | | |
| Calcium | % | 1.0 | 0.6 | 2.5 |
| Phosphorus | % | 0.8 | 0.5 | 1.6 |
| Ca:P ratio | | 1:1 | 1:1 | 2:1 |
| Potassium | % | 0.6 | 0.6 | |
| Sodium | % | 0.3 | 0.06 | |
| Chloride | % | 0.45 | 0.09 | |
| Magnesium | % | 0.04 | 0.04 | 0.3 |
| Iron | mg/kg | 80 | 80 | 3000 |
| Copper | mg/kg | 7.3 | 7.3 | 250 |
| Iodine | mg/kg | 1.5 | 1.5 | 50 |
| Zinc | mg/kg | 120 | 120 | 1000 |
| Manganese | mg/kg | 5.0 | 5.0 | |
| Selenium | mg/kg | 0.11 | 0.11 | 2 |
| Vitamins | | | | |
| Vitamin A | IU/kg | 5000 | 5000 | 250000 |
| Vitamin D | IU.kg | 500 | 500 | 5000 |
| Vitamin E | IU/kg | 50 | 50 | 1000 |
| Thiamin | mg/kg | 1.0 | 1.0 | |
| Riboflavin | mg/kg | 2.2 | 2.2 | |
| Pyridoxine | mg/kg | 1.0 | 1.0 | |
| Niacin | mg/kg | 11.4 | 11.4 | |
| Pantothenic acid | mg/kg | 10.0 | 10.0 | |
| Folic acid | mg/kg | 0.18 | 0.18 | |
| Vit $B_{12}$ | mg/kg | 0.022 | 0.022 | |
| Choline | mg/kg | 1200 | 1200 | |

Moreover, this equation is based on the assumption that the food is approximately 14.6kJ ME/g DM. If the energy density exceeds 16.7kJ ME /g DM, then the nutrient concentrations in the food must be increased in proportion to 14.6kJ ME /g DM factor. The definitive assessment of energy content is through digestibility trials, but more frequently most energy densities stated on labels for dog foods are predicted via this equation. As more commercial dry dog foods exceed energy densities of 14.6kJ then the balance of nutrients relative to predicted ME become more critical. The statement of 'complete and balanced' needs to be supported by AAFCO feeding protocols when used on high energy density feeds.

Energy requirements and the balance of nutrients to energy for dogs remains an issue of some contention. One of the major reasons for this difficulty is the unique range of liveweight in dogs, with Chihuahuas weighing approximately one kg, some giant breeds such as Newfoundlands and Great Danes nearly 100 kg, and St

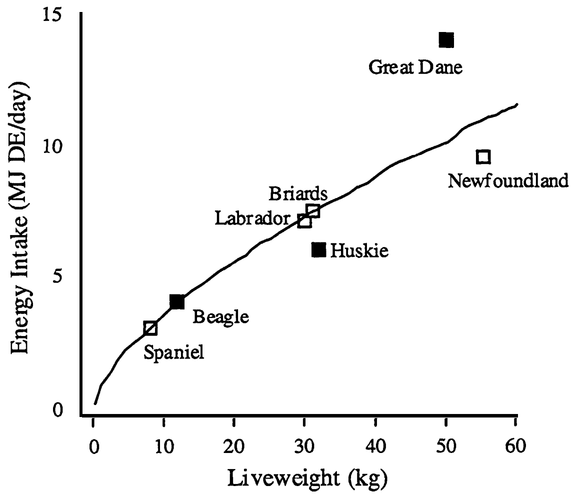


**Figure 1** Digestible energy intake of adult dogs at weight maintenance (Kienzle and Rainbird 1991).

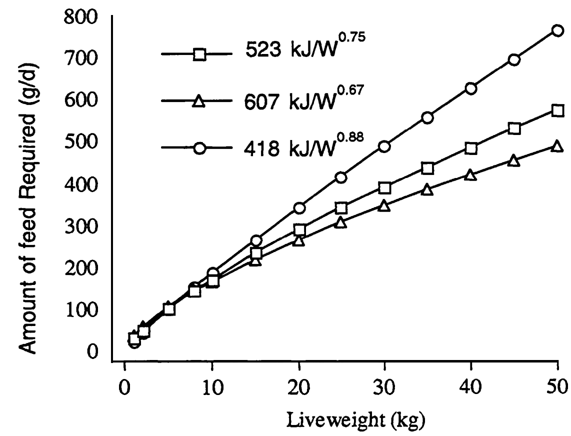


**Figure 2** Predicted Amount of Feed Required per Day by Dogs Fed High Energy Diets of 1.72 MJ ME per 100 g of feed.

Bernard dogs 115 kg (Burger 1994). Moreover, different breeds have quite different body composition and hair and coat production leading to differing daily energy needs at the same liveweight (Figure 1).

Deriving a single predictive allometric equation for the energy needs of dogs has proved somewhat difficult with most of the debate centring on the power function that should be assigned to the metabolic body weight for dogs (NRC 1985; Heusner 1991; Burger and Johnson 1991; Kienzle and Rainbird 1991; Burger 1994; Case et *al.* 1995). The power function suggested for resting adult dogs of weight range 5.8 – 48.8 kg (Burger 1994) was:

**Resting Energy Expenditure (REE)= 678 $W^{0.64}$ kJ/d**

**whereas the equation for moderately active dogs was:**

**Daily Energy Expenditure (DEE) = 523 $W^{0.75}$ kJ/d**

Both of these functions are in general agreement with the work of Heusner (199 1) who suggested a function of 0.67 but they are not in accord with the predictive equation of the NRC 1985 which proposes ME requirement = 100 $W^{0.88}$ kcal/day (4 18 $W^{0.88}$ kJ/day). The Heusner equations have different factors for activity in the general equation for ME requirement; the energy allowance for activity (kJ/day) = K x $W^{0.67}$ where K = 552 (inactive), 607 (active), and 837 for very active (Case, ***et al.*** 1995).

All of these equations assume that dogs adjust their food intake to match energy requirements but an increasing incidence of obesity has been reported (NRC 1985; Markwell *et al.* 1990). The difference in the amount of food fed daily is quite dramatic when dogs are fed on high rather than low energy diets, 16.7 vs. 14.6 kJ using the various predictive equations (Figure 2). It is preferable that dogs be meal-fed at least twice a day rather ***than*** fed ***ad libitum.*** Owners who follow advice based on either of the prediction equations, 523 $kJ/W^{0.75}$ or 418 $kJ/W^{0.88}$, could run the risk of overfeeding their dogs, especially if their dogs are larger breeds of 30 kg or more. On the other hand, manufacturers who use either of those two equations as the basis for their feeding guides on food labels run the risk of looking uncompetitive compared with companies that quite reasonably frame their recommendations on amounts to feed on the basis of 607 $kJ/W^{0.67}$. This problem of differences in the amount fed is exacerbated when comparing commercial ‘supermarket’ diets of 14.6 kJ ME /g DM and 12% fat content with high energy diets.

The fact that dogs live into old age exacerbates the problems of maintaining an appropriate dietary energy supply. Several studies have found that energy requirements decrease by the order of 20% with increasing age in dogs (Finke 199 1; Kienzle and Rainbird 199 1; Finke 1994). Moreover, the optimum contribution of protein to ME is a matter of speculation with Kronfeld *et al.* (1994) proposing that a protein concentration of 30–40% ME is best suited to the active dog. Deciding the best mix of nutrients and ingredients to optimise energy, protein, fat and fibre in the ageing dog remains a matter for investigation.

## Types of commercial dog food

Commercial pet foods can be categorised according to their moisture content. Dry dog foods in Australia usually contain 6–10% moisture and are most often extruded products based on cereals and animal proteins derived as by-products of meat processing in abattoirs. Extrusion is essential to gelatinise (and sometimes partially dextranise) the starches from cereal grains, and to kill bacteria in the ingredients. In addition, dry dog foods usually have 8–15% fat to aid palatability, but increasingly high energy ‘premium’ dry dogs are being formulated with fat content of 18–22%. The fat content in dry dog foods must be protected from rancidity by the use of antioxidants such as ethoxyquin, butylated hydroxytoluene (BHT), butylated hydroxyanisole (BHA), or vitamin E present as the various chemical forms of tocopherols. Semi-moist dog foods usually contain 14–25% moisture in Australia, and again are often extruded from similar ingredients to dry dog foods but with additional protection against mould and spoilage by using sucrose, glucose, propylene glycol, sorbic and propionic acids, and phosphoric acid. Dogs prefer sweet tastes to acid flavours (preferred by cats), and the sweetness of semi-moist dog foods can aid their palatability. Wet dog foods usually in cans, but increasingly now in 'knob' forms (the preferred form in the New Zealand market), contain 78–82% moisture. Wet dog foods are made from offal meats, particularly lung which remains intact during processing, muscle meat, and textured vegetable proteins made from soybean with very few cereal ingredients. Guar and carrageenan gums are often used to form a stable gel of these high moisture products. High heat and/or pressure during manufacture kills bacteria and preserves these wet foods.

## Ingredients commonly used in commercial dog foods

Wheat is the most commonly used cereal grain in dry dog foods in Australia with over 200,000 tonnes used annually (Feed Grains Study 1995). On the other hand, corn is the grain of choice in dog foods manufactured in the USA (Case *et al.* 1995). This is really a reflection of the availability and price of the two grains in their respective countries. The two grains have some important differences in carbohydrate composition and fibre constituents (Table 4) as well as in the structure of the starch granules (Bach Knudsen 1993). Extrusion gelatinises the starch in both grains, which a necessary prerequisite for availability of the carbohydrate in starch to the dog's digestive system (Case *et al.* 1995). However, the higher concentrations of soluble and insoluble non-cellulose polysaccharide (NCP) in wheat are associated with lower digestibilities than corn in dogs. In addition, wheat is more frequently associated with food allergies in dogs (Brown *et al.* 1995). Nevertheless, wheat is unlikely to be supplanted as the most commonly used grain in Australia because of its cost-effectiveness in commercial dog foods. Rice is more completely digested and absorbed in the small intestine of pigs (McDonald 1996), and rice flour and rice grain is now being used more widely in commercial dry dog foods, particularly for puppies. Rice and often potatoes are also used in dry formulations marketed as 'hypoallergenic' diets since these two carbohydrate sources are less frequently associated with adverse and allergenic reactions in skin and the gastrointestinal tract (Guilford 1994; Brown *et al.* 1995).

Meat and bone meal is the most commonly used protein supplement in dry dog foods in Australia with over 24,000 tonnes being used annually (AAS 1993). The proximate analysis of the three grades of meat and bone meal in Australia is presented in Table 5. This type of meal is usually a byproduct of a combination of animal sources rendered for tallow production but remains one of the major source of essential amino acids for dogs. However, meat and bone meals derived predominantly from beef are associated with a high proportion of allergenic and adverse reactions to commercial foods (Guilford 1994; Brown *et al.* 1995).

The protein quality of meat and bone meal is inversely related to the percentage of ash. The ash fraction represents bone (particularly bone chips), and possibly other material such as eartags and intraruminal 'bullets' (e.g. Co, Se), all of which make this fraction so variable. In fact, two reports on the use of meat and bone meal (AAS Report 1993; Allan 1994) have both stressed that the ash fraction of meat and bone meal is the single most variable component and the first limitation on the usefulness of meat and bone meal as a replacement for higher quality protein meals. However, the ash fraction does make a significant contribution to the mineral nutrition of dogs. Calcium concentrations can range from 1.2% to 16.4% with a mean of 12.3% inmeatmeal with a 50% crude protein specification. The variability in the concentrations of the trace minerals iron, zinc, copper and manganese can also be large. For instance, the range of iron concentrations over 489 samples of Australian meat and bone meals was 2 1.9 to 66080 ppm

**Table** 4 Carbohydrate composition (% DM) of wheat and corn grains (from Bach Knudsen 1993)

| Carbohydrate component | Wheat | Corn |
|---|---|---|
| Total sugar | 1.9 | 2.0 |
| Starch | 65.1 | 69.0 |
| Cellulose | 2.0 | 2.2 |
| Total NSP | 11.9 | 9.7 |
| Soluble NCP* | 2.5 | 0.9 |
| Insoluble NCP | 7.3 | 6.6 |
| ß–glucan | 0.8 | 0.2 |
| Insoluble : Soluble NSP | 3.8 | 9.8 |

* Non–cellulose polysaccharide.

**Table 5** Average analysis of Australian meat and bone meals of various crude protein contents (AFIC.

| Component (% DM) | 45% Crude Protein | 50% Crude Protein | 55% Crude Protein |
|---|---|---|---|
| Moisture | 9.28 | 9.27 | 9.40 |
| Ash | 36.61 | 34.07 | 27.70 |
| Crude Protein | 47.02 | 51.00 | 54.96 |
| Crude Fat | 13.37 | 12.37 | 14.72 |
| NFE | NA | 6.68 | 11.38 |
| Crude Fibre | 0.84 | 2.41 | 3.8 |

DM with a mean of 3993 ppm DM for meat and bone meal with a 50% crude protein specification (AFIC 1987). From discussions with pet food manufacturers, the variation in the iron is probably due to metal filings being abraded from machinery during rendering and thus being included in the final product sold to petfood manufacturers. Elemental iron, such as that present in the filings, would not be available for absorption by animals but could constitute a risk as an oxidant of fats in the meal. Magnets can extract this type of impurity and should be part of any high quality rendering process. Interestingly, some heavy metal contaminants such as cadmium and mercury have been found in meat and bone meals. The reason is for this contamination is not clear but one possibility is the inclusion of contaminated offal such as liver and kidney (see Langlands *et al.* 1988) in the final mix for rendering.

The 'generic' lines of dry dog food have expanded the use of meat and bone meal in the short term because this section of the petfood market is growing rapidly. There are a number of companies in each State competing in this area of the market. Price is the key factor and both in perception and price, meat and bone meal is the preferred protein meal. Atypical generic line of dry dog food contains a minimum of 20% crude protein and 8% crude fat and the main source of protein is usually meat and bone meal which can account for 40-50% of the total crude protein and 25% of the crude fat. Fifty percent or more of the remaining fat is derived from tallow. It is these two components which determine the palatability of generic lines of dog feed. Generic dog foods are always on the borderline of producing a zinc-responsive problem of coat condition because of their high calcium (often greater than 2.0%) and high wheat (often 35% or more) content. Calcium is a competitive inhibitor of zinc absorption, and the phytates in wheat are effective at binding zinc, thereby also decreasing its absorption.

Beef meats and offal, particularly lungs are used in wet dog food formulations, and included in some extruded products. Lungs are preferred because they not only hold their shape after pressure cooking, but also they readily absorb colouring compounds. These characteristics ensure that the final product has a 'meaty and chunky' look. Beef proteins are implicated in skin and gastrointestinal tract allergies and adverse reactions to a greater extent than any other source of animal protein (Guilford 1994; Brown *et al.* 1995). This could be because beef is more frequently used compared with meat and meals from other animal sources. On the hand, beef could be more susceptible to Maillard reactions during cooking which has been proposed as one possible reason for the higher incidence of adverse reactions to commercial foods (Guilford 1994).

Chicken meat and poultry meal are increasingly used in both dry and wet formulations to increase palatability and protein quality. Poultry meal is higher in protein and less variable in protein quality than meat and bone meal (65–68% versus 52–58% respectively) because it does not contain the coarse ash components common in meat and bone meal. As a consequence, poultry meal can be ground through very fine-mesh screens during processing which to the human eye produces a better looking extruded food.

Meals produced solely from lamb and mutton are now being used in commercial dry food formulations and promoted as hypoallergenic because they are less frequently associated with adverse and allergenic reactions (Guilford 1994, Brown *et al.* 1995). Lamb is often included in homemade diets used in the nutritional management of food allergies in dogs (Brown *et al.* 1995).

Soybean meal and textured vegetable protein from soybean are often used in dry and wet formulations respectively. Soybean protein is of high quality but like beef and wheat is frequently associated with food allergies (Guilford 1994; Brown *et al.* 1995). This could be an index of its use rather than any intrinsic allergenic property of soy protein. Textured soy protein keeps its shape under pressure cooking (like lungs) and is a preferred protein in wet formulations.

Tallow is often added to dry food formulations, both within the extruded premix and sprayed onto the product post–extrusion, to increase energy density and improve palatability of dry dog foods. The colour of poor quality tallows varies with season as chlorophylls are extracted in this fraction during rendering and this 'greenness' affects the colour of extruded, dry dog feeds. Vegetable oils such as sunflower and safflower oils are often included in dry and wet formulations to improve the content of linoleic acid (Cl 8:2 ω6), an essential fatty acid for dogs (Table 3). The proportion of linolenic acid (Cl 8:3 ω 3) and the total omega-3 fatty acids as well as omega-6 series based on linoleic acid is now seen as important to the properties of dry and wet dog foods. The composition of some commonly used animal fats and vegetable oils is listed in Table 6.

Vitamins and trace minerals are often included in commercial dog foods on the assumption that the ingredients themselves contain little or none of these. Allowances are made for those vitamins such thiamin and folic acid where significant losses occur during processing at high temperature and pressure. Thiamin mononitrate is the preferred form of thiamin for manufacturing because it is less susceptible to loss on cooking. No allowances are made in these inclusions for breed differences in requirements or for sensitivities to particular trace minerals. For instance, copper storage diseases can occur predominantly as an inherited autosomal recessive disorder in Bedlington Terriers and West Highland White Terriers, and in Doberman Pinchers and Cocker Spaniels although the mode of inheritance is not known in these two breeds (Thornburg *et al.* 1984). Copper accumulation in the liver begins shortly after birth with toxic concentrations of 2000 ppm dry weight of liver (normal range for dogs is 200-400 ppm dry weight) reached at varying ages but usually between *4* and 8 years of age, depending on intake and other interactions. A zinc-responsive disorder often presenting as skin lesions occurs in Alaskan Malamutes, Siberian Huskies, and occasionally Great Danes and Doberman Pinchers (Kunkle 1980, Fadok 1982). Dogs with this affliction require zinc supplementation, as 80 mg Zn per day, throughout their lives (Kunkle 1980).

Antioxidants are included in dry and some semi–moist dog foods to protect against rancidity of fats. Ethoxyquin, a synthetic antioxidant, is the most effective antioxidant (Coelho 1995). However, some breeders and owners suspect that ethoxyquin is associated with reproductive and other problems in dogs despite the fact that ethoxyquin has been tested as safe (Dzanis 199 1). Over the last few years, dry dog foods have been marketed as containing 'natural' vitamin E protection of fats rather than ethoxyquin (Coelho 1995). The comparative effectiveness of antioxidants in protecting against fat rancidity in mixed fat is shown in Table 7. Note the additions of other protective agents such as ascorbic acid to re–reduce the antioxidant, EDTA and citric acid to chelate potential oxidant divalent actions such as iron, and phosphoric acid to maintain low pH.

Although synthetic antioxidants such as ethoxyquin are clearly more potent in their action, some purchasers of dry dog food are beginning to show a preference for 'natural foods' with high concentrations of fat of higher unsaturation. This presents a challenge to pet food industry to establishing the concentrations of tocopherols needed in proportion to content of fat and its degree of unsaturation to ensure a long (9-12 months) shelf-life under a range of temperatures of storage using the tocopherols.

## Home-made diets for dogs

Most homemade diets are based on meat (Khonke and Hoskins 1994). Carbohydrate is often added in the form of cooked pasta or rice. Vitamins such as vitamin E and A and trace minerals such as calcium and zinc can be deficient in these diets. Nevertheless, complete and balanced diets can be formulated from home ingredients if appropriate combinations of meat, meat and bones, vegetables and pasta, vegetable oils, and vitamin and mineral supplements are used. Some of those most commonly used ingredients are listed in Table 8 along with their energy, protein, fat, Ca and P contents.

All-meat diets containing no bone material or providing no access to bones represents the greatest dietary risk from home-made diets for growing or adult dogs due to the severe deficiency of calcium, and phosphorus, as well as a skewed Ca:P ratio of approximately 1:20. Such diets result in nutritional secondary hyperparathyroidism (Hazewinkel 1989). As a result there are a wide range of supplements available on the market to supply calcium in particular, but also phosphorus to correct these deficiencies and imbalances. The AAFCO minimum level on a dry matter basis for calcium is 0.8% for growth and reproduction

**Table 6** Fatty acid composition of some animal fats, vegetable oils and fish oil

| Source | Saturated fat | Oleic Acid ω 9 | Linoleic Acid ω 6 | α–Linolenic Acid ω 3 | ω 6: ω 3 Ratio |
|---|---|---|---|---|---|
| Safflower Oil | 9 | 14 | 77 | 0 | >100:1 |
| Sunflower Oil | 11 | 23 | 66 | trace | >100:1 |
| Soybean Oil | 15 | 23 | 54 | 8 | 6.75:1 |
| Corn Oil | 14 | 32 | 52 | 2 | 26:1 |
| Canola Oil | 7 | 63 | 20 | 10 | 2:1 |
| Olive Oil | 14 | 76 | 10 | trace | >100:1 |
| Palm Oil | 51 | 39 | 10 | trace | >100:1 |
| Butter | 57 | 36 | 5 | 2 | 2.5:1 |
| Tallow | 50 | 45 | 4 | 1 | 4:1 |
| Menhaden Fish Oil* | 25.3 | 16.8 | 2.5 | 3.1 | 1:11.6 |

* Menhaden fish oil contains 35.3% of C20 and C22 ω 3 fatty acids.

**Table** 7 Activity of several synthetic and naturally derived antioxidants in mixed fat (Coelho 1995).

| Antioxidant | Equivalence: Before processing | Equivalence: post–extrusion |
|---|---|---|
| ethoxyquin + Lecithin + EDTA + Citric acid | 100 | 100 |
| ethoxyquin | 90 | 90 |
| BHT + BHA + Ascorbic + EDTA | 65 | 62 |
| BHA + EDTA + Phosphoric + Mono & Di–glycerides | 65 | 56 |
| BHA | 45 | 41 |
| Mixed tocopherols + Citric + Ascorbic + Lecithin + EDTA | 34 | 20 |
| BHT | 32 | 30 |
| Delta –tocopherols | 25 | 15 |
| Mixed tocopherols | 22 | 13 |
| Gamma–tocopherol | 20 | 12 |
| Beta–tocopherol | 16 | 10 |
| Alpha–tocopherol | 10 | 5 |

**Table 8** Composition of some feeds commonly fed in home–made diets shown as average values for 100g as fed (after Khonke and Hoskins 1994).

| Ingredient | ME (kJ) | Protein (g) | Fat (g) | Ca (mg) | P (mg) |
|---|---|---|---|---|---|
| Beef, very lean | 515 | 22.4 | 4.6 | 7 | 180 |
| Beef, medium lean | 880 | 18.9 | 15 | 8 | 170 |
| Beef, fatty | 1380 | 15 | 30 | 6 | 130 |
| Chicken, lean (no skin) broiler | 450 | 19.3 | 5 | 7 | 200 |
| Chicken, skin | 946 | 16.1 | 17.1 | 10 | 160 |
| Chicken, whole,no feathers, minced | 1046 | 21.2 | 19.4 | 200 | 270 |
| Chicken, necks, minced | 975 | 13.2 | 18.6 | 800 | 500 |
| Horse, meat | 544 | 19.3 | 7 | 200 | 291 |
| Kangaroo, meat | 418 | 21.6 | 0.6 | n/a | n/a |
| Sheep, lamb, leg | 1004 | 17.9 | 18.7 | 6 | 170 |
| Sheep, mutton whole carcase, no bones | 1393 | 14.6 | 30.5 | 7 | 180 |
| Veal, lean average | 430 | 19 | 2.6 | 8.3 | 216 |
| Rabbit, raw | 544 | 21.9 | 4 | 22 | 200 |
| Heart, beef | 418 | 18.2 | 3 | 5 | 200 |
| Liver, beef | 650 | 20 | 8.6 | 6 | 200 |
| Lungs, sheep, beef | 530 | 13.3 | 8.8 | 1.28 | 144 |
| Fish, white, steamed | 385 | 20.9 | 0.9 | 42 | 190 |
| Fish, oily, raw | 500 | 20.3 | 4 | 20 | 250 |
| Milk, whole | 272 | 3.3 | 3.5 | 120 | 95 |
| Eggs, raw with shell | 615 | 12.3 | 10.9 | 9546 | 220 |
| Cheese, cheddar | 1700 | 26 | 33.5 | 800 | 520 |
| Bread, wholemeal | 900 | 8.8 | 2.7 | 23 | 230 |
| Bread, white | 975 | 7.8 | 1.7 | 100 | 97 |
| Wheatbix | 1420 | 11.4 | 3.4 | 33 | 300 |
| Pasta, boiled/drained | 490 | 4.3 | 0.6 | 8 | 47 |
| Rice, white, boiled/drained | 515 | 2.2 | 0.3 | 1 | 34 |
| Potatoes, boiled | 335 | 1.4 | 0.1 | 4 | 29 |
| Peas, boiled/drained | 280 | 5.8 | 0.4 | 83 | 170 |
| Carrots, boiled/drained | 79 | 0.6 | | 37 | 17 |
| Polyunsaturated cooking oil | 3700 | 0 | 100 | 0 | 0 |
| Brewer's yeast | 1172 | 39 | 1 | 110 | 1800 |

and 0.5% for adult maintenance, and a maximum level of 2.5%. Most commercial diets from reputable companies contain 1.1 to 1.8% calcium per kg dry matter. Calcium absorption from the small intestine is predominantly a saturable, carrier-mediated process dependent on 1,25 dihydoxycholecalciferol (Fraser 1995), but in neonates and young animals, there is second non-saturable, diffusion transfer dependent on the concentration of calcium in the lumen of small intestine (Allen 1982). Oversupplementation with calcium in Great Dane puppies (3.3% Ca in the diet) significantly elevated calcium absorption and retention, showing that young dogs of this breed were unable to protect themselves from chronic excessive calcium intake (Hazewinkel *et al.* 1991).

Food allergies and adverse reactions to food are less frequent in dogs fed on homemade diets (Guilford 1994; Brown *et al.* 1995). In fact, specialists in food allergies maintain that the ideal 'hypoallergenic' diet is a home-made diet (Guilford 1994; Brown *et al.* 1995) with the recipes for some elimination and maintenance diets based on lamb and rice or fish and potato listed in the article by Brown *et al.* (1995). The basis for using these protein and carbohydrate sources is novelty rather than any intrinsic property of lamb, fish, and rice. Given the greater availability of lamb in Australia, it remains to be shown whether lamb would be as effective in Australia as in the USA. There is no published work to substantiate that lamb is less allergenic than beef for dogs in Australia where meat and bone meal is often derived from lamb.

Some veterinarians strongly advocate homemade diets in preference to commercial dog foods (Billinghurst 199 1, Lonsdale 1997). Both recommend diets of meaty bones or chicken carcass or chicken wings for dogs, in order to provide complete nutrition and optimal dental hygiene. In fact they go further than just recommending homemade diets because they also claim that commercial diets are in fact harmful to the health of dogs. While there is evidence that wet diets, and some extent dry diets, are associated with increase incidence of plaque and gingivitis, the evidence that these types of homemade diets are healthier is lacking. Diets composed of meaty bones or chicken containing fresh bones will have sufficient energy, protein, fat, calcium and phosphorus but will be deficient in at least vitamins A and E. What is needed to resolve this issue is a lengthy trial, at least six–months like AAFCO maintenance trials, where diets composed entirely of either meaty chicken carcasses (or meaty bones) or commercial dog feeds are compared for their effects on liveweight maintenance and general health in a group of adult dogs of known genetic background.

## The dietary ratio of omega-6 to omega-3 fatty acids and skin disease

The modem commercial diet for dogs aims not only to provide an optimal supply of nutrients but also to treat or prevent clinical disease. This is particularly so for the prevention and treatment of skin disease through appropriate ratios of omega-6 and omega-3 polyunsaturated fatty acids. The concept has been extended to control and treatment of kidney and liver disease, but this will not be discussed in this paper.

Traditionally, medical management of skin disorders has been accomplished most frequently with systemic glucocorticoids. Although this mode of treatment is highly effective in managing many hypersensitivity disorders, the serious side effects of systemic glucocorticoid therapy stimulated the use of alternative methods that will allow the avoidance, or at least a reduction in glucocorticoid administration. Direct supplementation with omega-6 and omega-3 fatty acids has been shown to useful in the treatment of various inflammatory disorders including atopy and other allergic skin disorders (Codner and Thatcher 1993; White 1993). The unique metabolic feature of the skin is that it lacks delta-6 and delta-5 desaturase enzyme activity and thus is incapable of making arachidonic acid from linoleic acid or eicosapentaenoic acid from alpha–linolenic acid (White 1993). Skin can elongate gamma–linolenic acid to dihomoGLA and eicosapentaenoic acid to docosahexaenoic acid. Thus diets must either contain these longer polyunsaturated fatty acids or have sufficient precursors for the liver to desaturate and elongate them and transport them to the skin.

Arachidonic acid is the substrate for proinflammatory eicosanoids, producing prostaglandins from the 2–series via the cyclooxygenase pathway or leukotrienes of the 4–series and hydroxyeicosatetraenoic acids (HETEs) via several lipoxygenase pathways. These products are pro–inflammatory mediators of inflammation. The effects of prostaglandins on the skin include alteration of vascular permeability, potentiation of vasoactive substances such as histamine, modulation of lymphocyte function and potentiation of pain and itch. Prostaglandins and leukotrienes potentiate each other. The effects of leukotrienes on the skin are to alter vascular permeability, to activate neutrophils, to modify lymphocyte function, and to cause potent neutrophilia and eosinophil chemotaxis.

Eicosapentaenoic acid competes with arachidonic acid for 5–lipoxygenase and 15–lipoxygenase enzymes, resulting in production of leukotriene $B_5$ and 15–hydroxyeicosapentaenoic acid (15–HEPE). Both metabolites apparently have inhibitory effects on the production of leukotriene $B_4$. In addition EPA has a higher affinity for cyclooxygenase but is a poor substrate. By competing for this enzyme, EPA can limit the production of pro–inflammatory prostaglandin $E_2$. Docosahexaenoic acid is a strong inhibitor of cyclooxygenase but not the lipoxygenase pathway and produces a hydroxy fatty acid that can inhibit the formation of leukotriene $B_4$ in *vitro* (White 1993; Bauer 1994).

The beneficial effect of omega–6 and omega-3 fatty acid supplementation has been documented in multiple double-blind, placebo controlled and open uncontrolled studies which indicate a reduction in swelling, erythema, scaling, pruritus and an improvement in overall coat condition in approximately 20% of atopic dogs with greater than 50% reduction in clinical signs in these patients (Bond and Lloyd 1992a and 1992b; Scott *et al.* 1992). Some commercial diets for dogs are formulated now to provide ratios of omega–6 to omega–3 fatty acids of between 5.0: 1 .0 and 10.0: 1 .0 in order to generate optimal proportions of pro-inflammatory and anti-inflammatory eicosanoids (Reinhart 1996). Vaughn and Reinhart (1996) showed that this approach of direct incorporation of omega-6 to omega-3 fatty acids into formulated feed rather than as supplements can alter eicosanoid metabolism. Diets formulated to ratios of omega–6 to omega-3 fatty acids of 5.0: 1 .0 and 10: 1 .0 were associated in dog skin with significant increases in the synthesis of anti-inflammatory leukotriene 5, and reduced rates of synthesis of pro-inflammatory leukotriene 4. The risks and side effects of fatty acid delivery through dietary formulation are few, and none was reported in the study by Vaughn and Reinhart (1996). As further support for this concept, Schick *et al.* (1996) reported improvement in clinical signs of pruritis associated with inhalant allergies or adverse reactions to food or a combination of both in fourteen of 28 dogs after eight weeks on a diet with a ratio of 4.2: 1 .0 for the omega–6 : omega-3 fatty acids.

Incorporating the appropriate ratio of omega–6 : omega-3 fatty acids in the commercial food is preferable to direct supplementation. Nevertheless, no blind studies have confirmed the correct ratio or the appropriate dosage offering the best potential therapeutic response. Moreover, there has not been any direct confirmation that modifying this ratio has led to substitution of arachidonic acid with eicosapentaenoic acid in the sn-2 position of phospholipids in plasma membrane of skin. Another area that still needs investigation is the effect of combining the fatty acids with other substances such as vitamins, minerals and cofactors. Certain vitamins and minerals can serve as cofactors in the metabolism of essential fatty acids, but it remains to be seen if supplementation of these nutrients above the AAFCO recommendations will benefit the ameliorating affects of the omega–6 and omega-3 fatty acids if the dog is already being fed a nutritionally balanced and complete diet. Further to this, should AAFCO now be recommending a base amount of omega-3 fatty acid and some range of ratio of omega–6 : omega-3 fatty acids in future listings?

## Dietary fibre and the good stool

The type of fibre included in modem commercial diets and the role of that fibre is the subject of considerable research and marketing. This area of companion animal nutrition has expanded rapidly and the list of responses influenced by dietary fibre has also increased (Sunvold 1996). Fibre exerts its influence on the gastrointestinal structure and function through the three major means:

- physical effects such as viscosity of guar gums and soluble fibre;
- metabolic effects through fermentation to short–chain volatile fatty acids; and
- ecological effects of the microbial population favoured by the source of fibre (Sunvold 1996; Pluske *et al.* 1997).

The effect of fibre on a number of gastrointestinal conditions in dogs is discussed elsewhere in this volume (Pluske *et al.* 1997). The main effect of fibre likely to be observed by owners is a beneficial effect on stool consistency (Sunvold 1995). In fact, many premium dry foods for dogs contain relatively large concentrations of fibre (4.5 – 10% DM) for what is a monogastric animal with retention times of 2 1 to 3 3 hours for food in the gut (Sunvold 1995).

The overall aim of inclusions of fibre in commercial diets for healthy dogs is to promote stool consistency, reduce stool odour, and establish and maintain a 'beneficial' microflora in the small and large intestine. Nondigestible oligosaccharides, and fructooligosaccharides in particular, have been proposed as an important aid to these aims for dietary fibre. Fructo–oligosaccharides (FOS) are part of a new group of compounds termed prebiotics, defined as nondigestible food ingredients that can beneficially affect the host by selectively stimulating the growth and/or activity of one or a limited number of bacterial species already present in the colon and thus improving the health of the host (Gibson and Roberfroid 1995). Prebiotics offer opportunities for pet food manufacturers because compounds such as FOS can survive extrusion whereas the use of probiotics is precluded by the processing. *Bifidobacteria* selectively ferment fructooligosaccahrides, and large increases in numbers of Bifidobacteria relative to decreases in *Bacteroides, Clostridia*, and *Fusobacteria* are observed in healthy humans consuming 15 g per day of fructooligosaccharides for 15 days (Gibson and Roberfroid 1995). Supplementation of chicken-base kibble diets with 1% FOS was associated with large decreases in aerobic/facultative anaerobic bacteria in healthy German Shepherd dogs that suffered from asymptomatic, spontaneous small intestinal bacterial overgrowth (Willard *et al.* 1994). However, Willard (1996) urges caution in recommending FOS supplementation as a prebiotic for dogs because of the large variability in both background microflora and response in dogs from his and other studies. Nevertheless, inclusion of FOS in diets, notably with defined ratios of insoluble and soluble fibre, improved stool consistency and decreased stool odour in dogs fed chicken and corn–based dry diets (G Mahon pers. comm.). The interaction between prebiotics and fibre sources obviously warrants further investigation.

## References


Allan, G. (1994). Preliminary evaluation of meatmeal in aquaculture diets for silver perch *(Bidyanus bidyanus)* Final Report *MRC Project M. 561.*

Allen, L.H. (1982). Calcium bioavailability and absorption: a review. *American Journal of Clinical Nutrition 35,* **783-808.**

*Association of American Feed Control Officials* ( *1993). Official Publication. AAFCO* Inc.: Atlanta, Georgia, USA.

*Association of American Feed Control Officials* ( 1997). pp. 137-140. In: Official Publication. AAFCO Inc.: Atlanta, Georgia, USA.

Australian Agribusiness Services (AAS) (1993). The meatmeal and tallow industry and its markets. Main Report *MRC Project M. 258*

Australian Feeds Information Centre (AFIC) *Australian Feed Composition Tables* (Ed H.T. Ostrowski–Meissner). AFIC-CSIRO: Sydney.

Bach Knudsen, K.E. (1993). Carbohydrates and lignin in feedstuffs. In: *44th Annual Meeting of the E.A.A.P., Commission of Animal Nutrition.* pp. 1-8

Bauer, J.E. (1994). The potential for dietary polyunsaturated fatty acids in domestic animals. *Australian Veterinary Journal* **71**, **342–345.**

Billinghurst, I. In: Give your dog a bone. I. Billinghurst, PO Box 703 Lithgow **NSW.**

BIS Shrapnel (1996). *Contribution of the Pet Care Industry to the Australian Economy.*

Bond, R. and Lloyd, D.H. (1992a). A double-blind comparison of olive oil and a combination of evening primrose oil and fish oil in the management of canine atopy. *Vetinerary Record* **131, 558-560.**

Bond, R. and Lloyd, D.H. (1992b). Randomized single–blind comparison of an evening primrose oil and fish oil combination and concentrates of these oils in the management of canine atopy. *Vetinerary Dermatology* **3**, 215–219.

Brown, C.M., Armstrong, P.J. and Globus, H. (1995). Nutritional management of food allergies in dogs and cats. *Compendium of Continuing Education of Practising Vetinerarians* **17**, 637–658.

Burger, I.H. (1994). Energy needs of companion animals: matching food intakes to requirements throughout the life cycle. *Journal of Nutrition* **124**, 2584S–2593 S.

Burger, I.H. and Johnson, J.V. (1991). Dogs large and small: the allometry of energy requirements within a single species. *Journal of Nutrition* **121,** S 18–S2 1.

Carpenter, K.J. (1991). Contribution of the dog in the science of nutrition. *Journal of Nutrition* **121,** S 1–S7.

*Case,* L.P., *Carey,* D.P. and Hirakawa, D.A. (1995). *Canine and Feline Nutrition.* Mosby-Year Book Inc.: St. Louis, Missouri.

Codner, E.C. and Thatcher, C.D. (1993). Nutritional management of skin disease. *Compendium of Continuing Education of Practising Vetinerarians* **15,** 411–423.

Coelho, M. (1995) Ethoxyquin: science vs marketing. *Petfood Industry* **37**, 8–20.

Dzanis, D.A. (1991) Safety of ethoxyquin in dog foods. Journal of Nutrion **121,** S **163-S 164.**

Euromonitor excerpted (1997). *Petfood Industry* **39**, 62.

Fadok, VA. (1982). Zinc-responsive dermatosis in a Great Dane: a case report. *Journal of American Animal Hospital Association* **18**, 409–4 14.

Feed Grains Study (1995) Vo12 pp 86 produced by Meyers Strategy Group in conjunction with Australian Bureau of Agricultural and Resource Economics and ACE Consulting.

Finke, M.D. (199 1). Evaluation of the energy requirements of adult kennel dogs. *Journal of Nutrition* **121,** S22–S28.

Finke, M.D. (1994). Energy requirements of adult female beagles. *Journal of Nutrition* **124**, 2604S–2608S.

Fraser, D.R. (1995). Vitamin D. *Lancet 345,* 104–107.

Gibson, GR. and Roberfroid, M.B. (1995). Dietary modulation of the human colonic microbiota: introducing the concept of prebiotics. *Journal of Nutritin* **125**, 1401–1412.

Guilford, W.G. (1994). Adverse reactions to foods: a gastrointestinal perspective. *Compendium of Continuing Education of Practising Vetinerarians* **16, 957-969.**

Hazewinkel, **H.A.W.** (1989). Nutrition in relation to skeletal growth abnormalities. *Journal of Small Animal Practice* **30**, 625–630.

Hazewinkel, **H.A.W.,** Van Den Brom, W.E., Van 'T Klooster, A. Th., Voorhout, G. and Van Wees, A. (1991). Calcium metabolism in Great Dane dogs fed diets with various calcium and phosphorus levels. *Journal of Nutrition* **121,** S99–S106.

Heusner, A.A. (1991) Body mass, maintenance and basal metabolism *in* dogs. *Journal of Nutrition* **121,** S8–S **17.**

*Khonke,* **J.** and Hoskins, R. (1994). *In: Talking greyhounds.* Vetsearch International Sydney. pp. 80-92

Kienzle, E. and Rainbird, A. (1991). Maintenance energy requirements of dogs: what is the correct value for the calculation of metabolic body weight *in* dogs? *Journal of Nutrition* **121,** S39–S40.

Kronfeld, D.S., Ferrante, P.L. and Grandjean, D. (1994). Optimal nutrition for athletic performance, with emphasis of fat adaptation in dogs and horses. *Journal of Nutrition* **124**, 2745S–2753S.

Kunkle, GA. (1980). Zinc-responsive dermatoses in dogs. In *Current veterinay therapy VII: small animal practice.* pp 472–476 (Ed. Kirk R.W. ). W.B. Saunders: Philadelphia.

Langlands, J.P., Donald, GE. and Bowles, J.E. (1988). Cadmium contamination *Australian Journal of Experimental Agriculture* **28**, 29 1–297.

Lonsdale, (1997) http://www.zeta.org.au/%7Elonsdale/

Markwell, P.J., Erk, W., Parkin, GD. (1980). Obesity in the dog *Journal of Small Animal Practice* **31**, 533–537.

McDonald, D.E. (1996). *Dietay nonstarch polysaccharides in the weanerpig: interactions with postweaning diarrhoea.* Honours thesis. Murdoch Unversity Murdoch WA Australia 6 150.

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.

National Research Council (1985). *Nutrient requirement of dogs.* National Academy Press: Washington, DC.

Pluske, J.R., Pethick, D.W., Durmic, Z., McDonald, D.E., Mullan, B.P. and Hampson, D.J. (1997). Diseases and conditions in animals arising from incomplete digestion and absorption of carbohydrates. In: *Recent Advances of Animal Nutrition in Australia.* (Eds. J. Nolan and M. Choct). University of New England Press: Armidale, Australia.

Reinhart, GA. (1996). Review of omega-3 fatty acids and dietary influences on tissue concentrations. In: *Proceedings of the I996 Iams International Nutrition Symposium,* pp 235-242 (Eds. D.P. Carey, S.A. Norton and S.M. Bolse). Orange Frazer Press: Ohio, USA.

Schick, M.P., Schick. R.O. and Reinhart, GA. (1996). The role of polyunsaturated fatty acids in the canine epidermis: normal structural and functional components, inflammatory disease state components, and as therapeutic components. In: *Recent Advances in Canine and Feline Nutritional Research; Proceedings of the 1996 Iams International Nutrition Symposium.* pp. 267-275 (Eds. D.P. Carey, S.A. Norton and S.M. Bolse). Orange Frazer Press: Ohio, USA.

Scott, D.W., Miller, W.H., Decker, GA. and Wellington, J.R. (1992). Comparison of the clinical efficacy of two commercial fatty acid supplements (EfaVet and DVM Derm Caps), evening primrose oil, and cold water marine fish oil in the management of allergic pruritus in dogs: a double-blinded study. *Cornell Veterina y* **82**, 3 19-329.

Sunvold, GD. (1996). Dietary fiber for dogs and cats: a historical perspective. In *Recent Advances in Canine and Feline Nutritional Research; Proceedings of the 1996 Iams International Nutrition Symposium*, pp. 3-14 (Eds. D.P. Carey, S.A. Norton and S.M. Bolse). Orange Frazer Press: Ohio, USA.

Sunvold, GD., Fahey, GC., Merchen, N.R., Titgemeyer, E.C., Bourquin, L.D., Bauer, L.L. and Reinhart, GA. (1995). Dietary fiber for dogs IV: in vitro fermentation of selected fiber sources by dog fecal inoculum and in vivo digestion and metabolism of fiber-supplemented diets. *Journal of Anim. Science.* **73**, 1099–1 109.

Thornburg, L.P., Polley, D. and Dimmitt, R. (1984). The diagnosis and treatment of copper toxicosis in dogs. *Canine Practice* **11**, 36–39.

Vaughn, D.M. and Reinhart, GA. (1996). Influence of Fatty acid ratios on tissue eicosanoid production and blood coagulation parameters *in* dogs. In: *Recent Advances in Canine and Feline Nutritional Research; Proceedings of the I996 Iams International Nutrition Symposium,* pp.243–255 (Eds. D.P. Carey, S.A. Norton and S.M. Bolse). Orange Frazer Press: Ohio, USA.

White, P.D. (1993) Essential fatty acids: use in management of canine atopy *Compendium of Continuing Education of Practising Vetinerarians* **15**, 45 1-457.

Willard. M.D., Simpson, M. B., Delles, E.K., Cohen, N.D., Kolp, D., Fossum, T.W. and Reinhart, GA. (1994). Effects of dietary supplementation of fructo–oligosaccharides on small intestinal overgrowth in dogs. *American Journal of Vetinera y Research 55, 654-659.*

Willard, M.D. (1996). Effects of dietary fructo–oligosaccharide supplementation on canine small intestinal small intestinal bacterial populations. In: *Recent Advances in Canine and Feline Nutritional Research; Proceedings of the 1996 Iams International Nutrition Symposium,* pp. 45-50 (Eds. D.P. Carey, S.A. Norton and S.M. Bolse). Orange Frazer Press: Ohio, USA.