RENDERED PRODUCTS IN PET FOOD

Greg Aldrich, Ph.D.
President, Pet Food and Ingredient Technology, Inc.

Summary

Globally, in 2005, pet food and products were a $53 billion industry—and the market is growing. In the United States, dog and cat food sales alone account for $14.5 billion with exports of nearly $1 billion. The global total for pet food and supplies for all pet animals is now approaching $40 billion annually. These rising sales are driven, in part, by increasing ownership of pets with more than 140 million dogs and cats and an estimated 200 million specialty pets, such as fish, pocket pets, and exotic animals. It is also moved by the trend that more people consider their pets as members of the family as demonstrated by everything from birthday and holiday celebrations, family photos, health insurance, burial plots, and preparation of special meals. Pet foods are now more than ever considered packaged goods that are co-mingled with other family food items. The top five pet food companies, over 65 percent of the market, are owned by household names like Mars, Nestle, Proctor & Gamble, Colgate-Palmolive, and Del Monte. Traditional retail outlets such as grocery and farm/feed stores have lost some market share to big-box mass market stores, warehouse clubs, and pet specialty stores, but grocery stores remain the largest outlet.

Pet food choices have become almost limitless with options for different price points, life-stage, shapes and sizes, package type, ingredient preferences, breed, size, and disease condition. Pet foods are also becoming more "humanized" and tracking human food trends. Nutrition research is showing that companion animals have some unique dietary requirements, e.g., arginine in the dog and cat, the aminosulfone taurine, and pre-formed vitamin A for the cat. Emerging nutritional benefits from omega-3 fatty acids, carotenoids, dietary fiber, mineral balance, and how meat proteins and fats are connected to optimal nutrition are actively under investigation. Rendered protein meals such as meat and bone meal, poultry by-product meal, and fish meal are almost universally used in pet foods. Generally, they provide high quality protein with a good balance of amino acids. Nutrient availability and (or) dietary utilization can be hampered by excessive heat treatment, dilution of essential amino acids with connective tissue, high levels of ash, and oxidation. Rendered fats and oils like tallow, lard, poultry fat, and fish oil provide a supplementary source of energy, flavor, texture, and nutrients in pet foods.

Balancing for essential and conditionally essential fatty acids has become a key driver for selection of specific fats in the diet. Application and oxidation issues are the most common challenges faced in their use. Much of the information for pet food ingredients has been gleaned from livestock and human nutrition research. There is a fundamental need to develop these databases specifically for pets in order to address their unique nutritional idiosyncrasies and to support this growing and

continually segmenting industry. Raw, fresh, human edible, and alternative protein sources are competing to supply the protein and fat needs in pet foods. Opportunities for various rendered ingredients especially those that are able to retain their species identity and maintain control over processing conditions while retaining nutrient quality, will be welcome.

The Pet and Pet Food Industry

Size, Growth, and Demographics

Globally, pet food and pet care product sales were nearly $53 billion in 2005 (Kvamme, 2006). In the United States, pet food sales totaled $14.4 billion in 2005 with 54 percent from dog and 32 percent from cat foods (Euromonitor, 2005) with an annual expected growth of three to four percent. Exports were just over $900 million in 2005 (U.S. Bureau of the Census Trade Data, 2006). Pets live in 70 percent of American homes, with 15 percent of those homes owning both a cat and dog (Pet Food Institute, 2003).

Specifically, there were an estimated 81.4 million cats in 37.7 percent of households and 63 million dogs in 43.5 percent of households in the United States in 2005 (Euromonitor, 2005). Other species of pets, defined as specialty pets, such as rodents, reptiles, rabbits, ferrets, exotic birds, and fish account for almost 200 million more household pets. In addition, to many people the horse is considered a pet with the total number of horses in the United States at 9.2 million and with affiliated goods and services accounting for an estimated $39 billion (American Horse Council, 2002).

More people are considering their pets as members of the family by celebrating their birthdays, including them in holiday rituals, providing them with special television programs, including them in family photos, and preparing special meals for them. Many pet owners spend large sums of money for veterinary care, pet health insurance, medications, cremation, and even burial. An increasing number of pet owners are adding pets in their wills and treating them as a second family after children are grown and have left the home, spoiling their pets with special and premium foods, treats, and toys as if they were wayward grandchildren. But all is not frivolous excess; pets are also becoming increasingly valuable as service animals, as therapy aids, and as an emotional and stressful release in an increasingly complex world. There is a bond and interdependence between man and companion animals that will not soon diminish.

Pet Food Companies

The pet food industry in the United States is dominated by five major companies that account for over 65 percent of the market. These big five are owned by multi-national conglomerates that have a primary emphasis in personal care, dry goods, and (or) other consumables (Kvamme, 2006). These companies include: Mars (Pedigree, Whiskas, and Royal Canin), Nestle (Purina, Friskies), Proctor & Gamble (Iams, Eukanuba), Colgate-Palmolive (Hills Science Diet, Hills Prescription Diet), and Del Monte (9-Lives, Gravy Train, Kibbles 'N Bits, Nature's

Recipe, Meow Mix, and Milk Bone). The remaining 35 percent of the market is made up of pet food-exclusive companies, numerous regional brands, and new smaller brands and companies. Some of these latter are supplied by a strong cadre of private-label pet food manufacturers and toll-packers. Consolidation, mergers, and acquisitions continue to play a part in the evolution of the industry; however, unlike other food sectors, this is not the only avenue left for growth. In short, the pet food industry is a very dynamic, growing, and maturing industry where new ideas from non-traditional sectors will continue to emerge and new market opportunities will be available.

Channels to Market

The retail availability of pet foods has expanded across a number of platforms. Big-box mass market stores, warehouse clubs, and pet specialty stores have become market channels in addition to traditional outlets such as grocery and farm/feed stores. Estimated market share of each category in 2002 was grocery (37.4 percent), mass market (16.4 percent), pet specialty (17.2 percent), farm/feed (5.4 percent), vet/kennel (5.0 percent), and other (18.6 percent) (Knudson, 2003). Alternative channels to market via non-traditional retail, direct marketing, catalog, and web-based sales of pet foods are also becoming prominent. Sales through these alternative channels accounted for approximately 12 percent of the total market with annualized growth in 2004 of just over eight percent (Packaged Facts, 2006). The activity in this segment is quite fragmented, generally strong, and expected to continue growing.

Trends in Companion Animal Products and Feeding Practices

There are a number of different factors that motivate consumers to choose certain foods for their pets. Some are driven by cost, some nutrition, some performance, and still others by their pet's preference. The choices seem to be almost limitless. Today there are foods for different life-stages (e.g., maintenance, gestation/lactation, growth; or puppy, kitten, adult, senior), price points (e.g., value, premium, super premium), formats (e.g., kibbles, soft-moist, wet, raw), and packaging styles (e.g., can, retortable pouch, stand-up pouch, paper or plastic bag, re-sealable bag, tray). Pet owners are deciding on foods according to their own ingredient biases (i.e., natural, wheat-free, hypoallergenic), the breed and size of pet they own (e.g., toy breed, large breed, Dalmatian, Persian), nuisance factors (e.g., hairball, multi-cat), and their pet's predisposition to disease (e.g., joint health, senior, struvite, weight loss, renal disease). Pet foods are also becoming more "humanized" (i.e., gourmet, heat and eat, fruits and vegetables) and are tracking human food trends (e.g., raw, organic, holistic, low-carb). While the number of brands and market segments seem almost limitless and the differentiation unstoppable, there are some general principles by which all are judged. These are palatability, digestive and stool consistency, and the influence of the diet on the pet's general appearance (i.e., skin and coat) and behavior (i.e., vigor).

With this much variety, finding raw materials with the right mix of name appeal, nutrition, functional properties, availability, and cost can be a big challenge for the pet food manufacturer, and this challenge will continue to increase. In many cases, the ingredient statement is driving the decision-making process. This is probably best exemplified in the promotion by some pet food companies that their foods are made with "human-grade" ingredients. While no definition exists for such a claim, it is telling about the humanization underway in the pet food market and the lengths that manufacturers will go to meet the pet owner's perception of quality.

Companion Animal Nutrition

Dog and Cat Nutrition

The dog is not a furry pig or an oversized rat, nor is the cat a small dog. While some similarities exist among the species, from a purely nutritional perspective, requirements of the dog and cat take on some unique differences. While these differences are briefly summarized below, the reader is referred to recent texts and literature reviews specifically on dog and cat nutrition and digestive physiology for a more thorough understanding of the topic (Smeets-Peeters et al., 1998; Case et al., 2000; Morris, 2002; Zoran, 2002; NRC 1985, 1986, and 2006).

The dog, while considered to be an omnivore, tends very closely to the carnivorous dietary and nutritional inclinations of the cat. The cat is considered to be an obligate carnivore and has a very substantial requirement for high quality proteins and meat-predominant amino acids. For example, besides the standard array of amino acids, dogs and cats have a dietary requirement for arginine. Cats have an elevated requirement for sulfur amino acids like methionine and a dietary requirement for the aminosulfone taurine. Interestingly, it has recently been discovered that some dogs may require dietary taurine as well (Fascetti et al., 2003). Further, both dog and cat commercial diets are often limiting in tryptophan unless adequate amounts of meat proteins are provided.

In addition to a requirement for linoleic acid, like the dog and many other species, cats also require arachadonic acid. More recently it has been observed that cats and dogs have a conditional requirement for dietary forms of omega-3 fatty acids such as eicosapentaenoic and (or) docosahexaenoic acids. Cats also have a requirement for pre-formed vitamin A as they lack the enzyme systems necessary to cleave β-carotene into vitamin A. Ironically, both cats and dogs have been reported to mount an enhanced immune system response when supplemented with carotenoids such as β-carotene and lutein (Chew and Park, 2004). Cats require dietary biotin, but dogs do not, and neither have a dietary requirement for inositol or vitamin C.

Neither the dog nor the cat has a true requirement for dietary carbohydrates, but both species have a need for metabolic glucose. This need for metabolic glucose can be met through conversion of amino acids in the gluconeogenic pathway. The cat, due to its carnivorous make-up, is in an almost constant state of converting dietary protein to glucose through this pathway.

Though carbohydrates are not absolutely required, they can be utilized in the diet if properly cooked, albeit more efficiently by the dog than the cat. Most of the dietary carbohydrates come from grains and, to a limited degree, tubers. These carbohydrates are also an essential part of making the kibble. While dogs and cats do not require fiber, there is growing evidence that adding moderate levels (three to seven percent) of soluble and (or) fermentable fiber provides benefit to the animal's lower gastrointestinal health, and for the owner this results in more consistent and less odorous stools.

Besides the standard requirement for macro and trace minerals in the diet, mineral nutrition can become an issue for dogs, and especially cats, if the animal is predisposed to renal and (or) urinary tract diseases. Specifically, elimination of excess dietary minerals by the pet can exacerbate conditions such as renal failure and urolithiases. For this reason, low ash, low magnesium, and low phosphate diets have been developed. This area will likely continue to evolve as we better understand the relationship between excess mineral nutrition and disease etiology.

Beyond meeting nutritional deficiencies, research is active in areas such as athletic and working dog nutrition, obesity and diabetes, aging, organ failure (e.g., renal disease), inflammatory diseases like osteoarthritis and dermatitis, and many, many others. Nutrition research for the canine athlete is an area of growing interest. Working dogs in occupations such as search and rescue, bomb sniffing, drug sniffing, guiding, and herding must have nutrition that supports their purpose in order to perform at optimum efficacy. Sporting dogs such as sled dogs, racing greyhounds, upland game hunting dogs, and agility dogs have tremendous nutrient demands at peak activity. This is nutrition well beyond the minimum. From this research it has been learned that the canine athlete has a tremendous oxidative capacity and benefits from a diet that includes animal-based proteins and fatty acids from animal and marine sources (Reynolds, 1996). Besides the benefits to the dog and (or) cat, a great deal of companion animal nutrition research has been beneficial to human nutrition and medicine as well.

Required versus Optimal/Needs versus Wants

The nutrient requirements reported in the 1985 National Research Council *Nutrient Requirements of Dogs*, the 1986 National Research Council Nutrient Requirements of Cats, and the recently released 2006 National Research Council *Nutrient Requirements of Dogs and Cats*, as well as the Association of American Feed Control Officials (AAFCO) 2006 nutrient profiles for dogs and cats are the guidelines to meet when formulating diets. Each is published with overages factored in to account for the wide variability among animals and dietary ingredients. Further, most pet owners are more concerned with issues of longevity and health than with saving a fraction of a cent to meet only the minimum. Thus, pet foods are not formulated to the "minimum" as is customary in livestock feeds; rather, most are "optimized" to some level of nutritional support that meets or exceeds the pet food company's perceived notion of "the best nutrition" for the dog or cat. Vast differences of opinion occur among the companies due to their own research findings, nutritional philosophies, and investment in a certain franchise "position." As just one example, there is a great disparity about whether a senior dog should be fed a low, medium, or high amount of protein. Each company has a strong opinion backed by internal and external research to support their particular position, but little consensus has yet been reached—much like in human foods where brands such as Weight Watchers, Jenny Craig, and the Atkins Diet compete.

Other Companion Animal Species

Horses, rabbits, ferrets, rodents, birds, and numerous other companion animal species are fed commercial foods. Aside from horses and rabbits, these are considered specialty pets. Formulation of diets for these species, if it is fair to lump them into one category, is mostly driven by convenience and ingredient bias rather than lowest cost. While cost of production for performance horses and production rabbits may be a cost of production issue, for those animals considered to be pets it is not as much of an issue. Horse and rabbit feeds are primarily vegetative in nature (i.e. a grain, protein, fat, mineral, and vitamin mix intended to complement a forage diet). The ferret is an exception in this group. Nutritionally it is very much like the cat and has a very high requirement for quality proteins and little to no fiber. Thus, rendered ingredients play a prominent part of its diet. Numerous pocket pets or rodents (e.g., rats, mice, gerbils, hamsters, and guinea pigs) are found in homes today and their commercial foods are most often based on grains and vegetable proteins. Formula considerations for these pets are most often based on nutrient recommendations for laboratory research animals. Only a limited amount of rendered ingredients are used in these rodent diets. Exotic and pet birds, such as the macaw, parrot, finch, etc., are often offered commercial foods. They have nutrient requirements much like those of domesticated fowl (i.e., chicken and turkey), without the need for cost efficiency. The issue, like that for dogs and cats, is on longevity and health. The diet must be visually appealing to the owner and the bird and be nutritionally sound. Pigments (e.g., xanthophylls) are often added to maintain the plumage coloration. Rendered ingredients are not typically part of the ingredient mix for these birds.

General Degree of Research

Compared to funding for livestock or human nutrition research, dog and cat nutrition is a secondary consideration at best. For the most part, there is no direct governmental funding for companion animal nutrition research. Most of the research has been funded either by pet food companies, ingredient suppliers, or special interest groups such as breed associations and foundations. Indirectly, funding has been provided through interest in using the dog and (or) cat as a research model for human nutrition. This has proven beneficial in a limited number of cases. Activist groups have had a negative influence on the level of bureaucracy necessary to initiate research and thus funding for companion animal research has diminished. This has not occurred as a result of financial inability, but rather the "fear" of reprisal from radical groups and how they may distract from public relations and advertising campaigns of today's multi-conglomerate pet food companies. The offset to this has been a general increase in funding from ingredient suppliers and trade groups. While substantial progress has been made in the past several years, there continues to be a need for fundamental research regarding ingredient composition, nutrient availability, and the effects on the two when combined in a processed pet food (Fahey, 2004).

Pet Food Production and Processes

To talk about pet foods without a brief discussion of the processes by which they are made would only give a fraction of the picture regarding pet foods and nutrition. Today, many pet foods are processed not just for the nutrition of the pet, but for their convenience to the pet owner as well. This convenience is the culmination of several factors: (1) foods that are nutritionally balanced by experts for pet owners who may or may not have the knowledge of dog/cat nutrition themselves, (2) foods in a form and format that is easy to use, (3) foods that are virtually waste-free, and (4) foods that minimize the hassles of storage, spoilage, infestation, etc. In many respects, the popularity of modern pet ownership is the product of very successful, wholesome, and convenient commercial pet foods.

There are three basic formats in pet foods and treats: baked, wet canned (including retort packed), and extruded. Except for foods fed to small and exotic pets and companion horses, little to no pelleted or granular meal commercial pet foods are sold. Some of the first pet foods sold commercially (ca. 1860) were produced by a baking process similar to that still used for cracker and biscuit production today (Corbin, 2003). The process involves mixing stiff dough that is based primarily on wheat flour. The dough is pressed into "shape" on a rotary mold. The molded pieces are conveyed through a long tunnel-oven on a chain belt and cooked by direct application of heat. The resulting product at the end of baking is a dry (hot) brittle biscuit, pellet, or wafer. Producing a product that will hold its shape depends on a high amount of grain flour like wheat, which contains gluten protein. The gluten protein acts as the glue that holds the shape of the piece and helps it resist breaking. Through the cooking process, the piece does not expand, but some texture is created by the cross-linking of proteins. The process, relative to other standard pet food production methods, is slow and costly. To the positive, baking does create baked flavors that most dogs appreciate; but, generally speaking, baking does not produce cat-friendly foods. The process can use either fresh/frozen meats or meat protein meals and (or) vegetable protein meals as the protein source.

Canned meats and fish were the route by which several of today's prominent pet food companies got their start. The first canned pet foods were introduced in the 1920s and have been a prominent part of the industry ever since. Hermetically sealed retorted pet food in a can, pouch, or tray provides a convenient, easy to serve, appetizing meal and (or) treat to many dogs and cats, though the term "canned" is not used much currently in marketing. Detractors cite the cost penalty of purchasing high amounts of water, the potential for spoilage, and dental build-up as negatives. Conversely, canned foods are commonly recommended as part of a urolithiasis (urinary tract obstruction) treatment regime in cats in order to get them to consume more water. Canned pet foods rely on fresh/frozen meats and limited amounts of grains. Small amounts of animal fats are used, but only under special circumstances are rendered meals employed.

In the mid 1950s, the first extruded pet foods were produced. This was a technological breakthrough for the pet foods of that day which were loose granular "meals" of inconsistent quality and nutritional content. The extrusion process allowed for the forming of a textured piece that was readily accepted by the dog and simultaneously held the nutrients together so that the full complement of intended nutrients was provided in each bite. It also provided cooking (gelatinization) of the starch in the grains (Riaz, 2003), which improved digestibility and decreased the intermittent diarrhea and flatulence associated with undigested starch in the lower bowel. In addition, the process served to sterilize ingredients that might otherwise be heavily inoculated with pathogenic bacteria. The drawback was the effect that the additional cooking had on proteins, vitamins, and other heat-labile nutrients, especially ingredients like rendered protein meals that had already been heat processed once (Murray et al., 1998). Additionally, these previously heat-processed ingredients lost most of their functional properties and did not contribute to the expansion of the piece upon exit from the extruder. To compensate, specialized starches, vegetable proteins, and (or) spray-dried proteins may be added to achieve the form, texture, and density desired. The other negatives have been resolved by corrective formulation, special protection technologies (e.g., encapsulation), selection of specialized ingredients that resist the effects of extrusion processing (e.g., phosphorylated vitamin C), and more refined processing controls. Rendered protein meals often account for a majority of the protein used in extruded pet foods, whereas fats, oils, flavors, and other heat-labile ingredients may be surface applied post-extrusion and drying.

Most extruded pet foods are sold at a moisture content of less than 12 percent; however, there is a significant market for higher moisture products (20 to 28 percent moisture). These soft-moist and (or) semi-moist foods are cooked as a dough prior to extrusion and simply "formed" by the extruder. They are not dried to control microbial growth, but rather, fungal growth is controlled by managing water activity with humectants and mold-inhibitory preservatives (Rokey, 2003). Humectants like dextrose, propylene glycol, glycerin, and emulsifiers (e.g., lecithin) tie-up water preventing its use by mold spores. Organic acid preservatives like potassium sorbate, sorbic acid, benzoate, and others have been shown to be very safe and inhibit mold growth at very low doses. In addition to fresh/frozen meats, rendered meals and animal fats play a prominent part of these intermediate moisture products.

Utilization of Rendered Ingredients in Pet Foods

Market, Volume, and Trends

No easily obtainable figures are available to provide specifics on the amount of rendered products used in pet foods. However, through some estimates and assumptions it may be possible to determine a reasonable volume. If one were to assume the average cost per pound for all pet food sold was $0.60/lb, then based on total sales of pet food ($14.5 billion in 2005), the total tons produced each year would be in the neighborhood of 12 million. If rendered ingredients were 20 percent of these 12 million tons across all products (protein meals, fats, other), then the pet food industry would consume around 2.4 million tons per year. This represents roughly 25 percent of the total U.S. production of rendered materials during the same period (Swisher, 2005). This indicates substantial reliance and connectedness between the pet food industry and the rendering industry. This dependence for the pet food industry is for a vital supply of animal-based proteins and fats to meet the demands of their customers; for the rendering industry, it is an important outlet for their products with a tremendous value-added upside. Increasing the understanding of opportunities and limitations between the two industries will provide increased value to both, with the pet owner and their pets as the ultimate winners.

Protein Meals

Pet food companies write very specific purchasing requirements for their ingredients, including rendered products. AAFCO definitions are the "starting place" for these specifications.

Meat and Bone Meal and Meat Meal: Meat and bone meal has been a staple protein in pet foods and is still used by a great many today. However, its popularity has declined in recent years due to several issues. Probably the biggest issue is that meat and bone meal is no longer considered "label friendly." What this means, specifically, is that the nomenclature is too generic for today's discerning consumer. Consumers have been taught to distrust something simply called "meat." A strictly beef or strictly pork meat and bone meal would likely be more acceptable to consumers, but these were not commonly available until recently. These meals are now often available for a higher price and are widely used in pet food. Adding to the challenges are its association with livestock feed rather than human food, recurring issues with bovine spongiform encephalopathy (BSE), inspections and record keeping for all ruminant meats, and concerns with disease outbreaks such as foot and mouth disease. These issues continue to place downward pressure on the popularity of meat and bone meal.

Nutritionally, meat and bone meal remains a good source of animal-based protein with a fairly consistent protein level of 50 percent (Parsons et al., 1997; Pearl, 2004). This is an adequate level for traditional pet food diets with protein levels between 18 percent and 26 percent. Like many other animal-based proteins, methionine, cystine, and the total sulfur amino acids are likely the first to become limiting. Fat composition ranges from 10 percent to as high as 25 percent, depending upon supplier. The fatty acid profile can vary some and resembles the composition of the animal from which the meal originates, e.g., beef fatty acids are proportionally more saturated than pork fatty acids. Incidentally, one will often find measurable quantities of omega-3 fatty acids in meat and bone meal of ruminant origin. Due to the more saturated nature of the fatty acids in meat and bone meal it is inherently more resistant to oxidation than many of the other rendered meat meals. The higher level of ash (around 25 percent) in meat and bone meal can be a challenge to formulate with versus some other protein meals. The AAFCO specifications indirectly restrict ash by setting limits on calcium and phosphorus levels and their ratio. Typical levels of calcium and phosphorus in meat and bone meal are 7.5 percent and 5.0 percent, respectively, and they are readily available. However, this level of minerals becomes problematic when formulating higher protein (greater than 30 percent) and low ash foods like those for cats.

Increasing levels of ash in meat and bone meal have not been shown to lower protein digestibility (Johnson et al., 1998; Shirley and Parsons, 2001). However, this may not be directly due to the effect of ash on digestibility (Johnson and Parsons, 1997), but rather due to the amount and quality of connective tissue present. Low quality collagen affects protein quality where a lower proportion of essential amino acids and a higher proportion of nonessential amino acids such as hydroxyproline (Eastoe and Long, 1960) may be to blame for lower digestibility. The requirement (AAFCO) for pepsin indigestible residue of less than 12 percent partially serves to control this. Processing systems and excessive temperatures have also been shown to negatively affect the amino acid digestibility of meat and bone meal (Wang and Parsons, 1998; Batterham et al., 1986). But on the whole, the digestibility of meat and bone meal for companion animals is comparable to that of lamb meal and poultry by-product meal (Johnson et al., 1998). In dog and cat diets, meat and bone meal has not been reported to negatively affect the intestinal flora, stool consistency, or stool volume. However, beef is often blamed for food hypersensitivities so meat and bone meal is one of the first ingredients removed in an "elimination" diet regimen. Regardless of this special circumstance, the palatability, acceptability, and utilization of meat and bone meal-containing diets by both dogs and cats are quite good.

<u>Lamb Meal</u>: Lamb meal has been a popular ingredient in dog and cat diets for the better part of the last 15 years. Initially it was considered a novel ingredient in diets for animals with food-related allergies (hypersensitivity). Lamb meal and rice diets were some of the fastest growing products offered in the pet food aisle—to the point that lamb meal supply was outstripped by the demand. "Lamb meal analogs" made of other protein meals were rumored to have entered the market, but tight controls due to BSE and scrapie issues and new DNA typing technology (Krcmar and Rencova, 2003) have all but made this an issue of the past.

Some domestic lamb meal is available; however, much of the lamb meal used in pet foods is derived from the lamb meat industry in Australia and New Zealand. Most of this lamb meal is rendered in a "low temperature" rendering process. Theoretically, the quality of the meal may be better because heat damage to the proteins is minimized. However, data to support or refute this hypothesis are lacking. Lamb meal is a species-specific category of meat meal, but, very little data are available in the public domain on the ingredient itself. Analytically, lamb meal mirrors the nutrient composition of meat (and bone) meal. Likewise, the protein quality of lamb meal is reported to be roughly comparable to meat and bone meal and about 75 percent of chicken by-product meal (Johnson and Parsons, 1997; Johnson et al., 1998). In the study by Johnson et al. (1998), ileal digestibility of the essential amino acids lysine and threonine and the nonessential sulfur amino acid cystine were quite low in the lamb meal-containing diets. This may be due to contamination of the lamb meal with high levels of wool. Wool is high in sulfur amino acids like cystine, but its nutritional availability is low. This poor availability of cystine, a taurine precursor, may explain the taurine-associated dilated cardiomyopathy in certain breeds of dogs fed an otherwise nutritionally complete diet based on lamb meal and rice (Fascetti et al., 2003).

Effects of lamb meal in dog or cat diets on palatability, shelf-life, or appearance are lacking in the literature. Anecdotally, lamb meal is not considered to be the most palatable of the meat meals due to the "mutton-fat" aroma. Cats prefer other meat meals over lamb meal. Concerns about rancidity and short shelf-life of lamb meal products may result from the long journey that it takes from "down under" and (or) prooxidants inherent to rendered lamb. In addition, high levels of lamb meal in a product can lead to a gray color. If the meal contains appreciable levels of contamination from wool, complaints about "hairs" may be heard from customers, especially in baked products like biscuits and treats.

Poultry (By-product) Protein Meals: Poultry protein meals are a popular, high quality protein source used in pet food. The pet food industry consumes an estimated 23 percent of the rendered poultry proteins produced each year (Pearl, 2003). However, the ability to make one homogenous statement about this ingredient ends there. Due to some inconsistent rules regarding ingredient nomenclature, an evolving pet food customer base, and pressures within the poultry industry, a series of names and classifications of poultry protein meals has emerged. To start, the rendered poultry proteins are defined by AAFCO differently than the meat meals. This has created some controversy in the pet food industry and resulted in a whole layer of confusion and misdirection for the consumer. By definition, poultry by-product meal (Section 9.10) differs from poultry meal (Section 9.71) only by the inclusion of "heads, feet, and entrails" (AAFCO, 2006). Further, they can be labeled specific to their "kind" and many renderers have accommodated. Thus, there are numerous products available in the market under this umbrella: poultry by-product meal, chicken by-product meal, chicken meal, turkey by-product meal, and turkey meal. No duck or goose meal is known to have been developed as of this writing. Adding to this confusion, there are several different grades of rendered poultry products available. "Feed grade" poultry by-product meal is seldom used in pet food because it contains a higher level of ash and lower protein content. Standard pet food grade poultry by-product meal contains less than 14 percent ash and low-ash poultry meal and (or) poultry by-product meal contains less than 11 percent ash. The latter is available in limited quantities at a premium price and typically reserved for low-ash cat formulas. One further split has been the request by certain customers for poultry protein meals that are preserved against oxidation by natural compounds (natural antioxidant systems) rather than the traditional synthetic antioxidants.

Among these various names, grades, and inferences regarding quality or lack thereof, there is very little in the way of direct comparisons between "meal" and "by-product meal" available in the literature. Of studies that are available, the results are mixed. For example, Bednar et al. (2000) reported that protein digestibility was better for poultry meal than for poultry by-product meal. However, protein quality of pet food grade chicken meal did not differ from chicken by-product meal in a chick assay (Aldrich and Daristotle, 1998). From this report, data on individual chicken pieces indicated that the protein quality of feet, bone, and cartilage was poorer than other parts utilized in rendered poultry by-product meal. This appears to be independent of ash level (Johnson et al., 1998; Johnson and Parsons, 1997; Yamka et al., 2003) and would indicate that regardless of whether or not the "by-product" qualifier was present or not, the amount of cartilage and connective tissue had a bigger impact on the quality of the protein. Adding to this, the more extensively the protein meal is processed in rendering, the further the quality can be eroded (Wang, 1997). To make matters worse, there is substantial variation in the nutrient composition of poultry protein meals (Locatelli and Hoehler, 2003). Controlling this variation becomes something that the pet food company must actively manage to assure a consistent finished product. Most manage this by establishing strong relationships with select suppliers.

In general, poultry protein meals are well utilized by dogs and cats and make up the biggest share of proteins in many of the premium pet foods. The fatty acid profile complements dog and cat nutrient requirements very well. Additionally, they contain an enriched level of the essential linoleic acid. Palatability of poultry protein meals is very good in both dogs and cats and in many instances serves as the standard by which other ingredients are measured.

<u>Turkey (By-product) Protein Meals</u>: Turkey protein meal-containing pet foods are becoming more popular, thus the ingredient warrants a separate description. However, nutritional information on rendered turkey is not easily obtained nor is the ingredient constantly available. Most of the turkey to be rendered is lumped in with chicken then processed and labeled as poultry (by-product) meal. There are only a few companies that produce or trade turkey protein meals. Turkey protein meals are a slightly darker golden brown color with a "richer" aroma when compared to chicken protein meals.

The nutrient composition of turkey protein meal is usually considered to be somewhat better than meat and bone meal, which has allowed some pet food companies to use turkey protein meal as a modest upgrade to meat and bone meal as a leading protein source. The nutrient profile of turkey meal is slightly less favorable than that of pet food grade chicken protein meal. For example, turkey protein meal ranges from 62 to 65 percent protein and ash level ranges from 18 to 25 percent, whereas, pet food grade chicken protein meal typically exceeds 65 percent protein with less than 17 percent ash. This may be due to the more efficient removal of meat and other soft materials for the human edible and (or) hot dog markets, i.e. 78 percent of turkey ends up in the grocery meat case versus 72 percent of chicken. Thus, the raw material finding its way to rendering is, in general, lower in protein and fat and higher in bone (i.e., ash). The amino acid and fatty acid profile of turkey meal is very similar to that of chicken meal. Contrary to conventional wisdom, the tryptophan level in turkey meal is not greater than that found in chicken meal so it may not have a sleep inducing or calming effect as is so often rumored. No direct feeding tests of turkey meal to dogs or cats are available in the literature. However, *in vitro* digestibility and amino acid profiles are similar enough to chicken by-product meal to suggest that turkey meal nutritional utilization would be similar. Palatability, acceptability, utilization, and stool quality of turkey protein meal-containing diets is very good when fed to either cats or dogs. However, the ingredient does not appear to have any unique nutritional features from that of chicken or poultry protein meals aside from its name in marketing campaigns.

Fish Meal: Fish meal is an increasingly common ingredient in pet foods. While there are a few exclusionary diets in which fish meal is the feature protein ingredient, by and large, fish meal is added only secondarily as a protein source. Fish meal, relative to most other protein meals, has a high level of protein with a correspondingly high protein digestibility. Typical fish meals contain upwards of 19 percent ash which can be problematic for cat, puppy, large breed, or therapeutic diets. Besides being a source of high quality protein, fish meal also contains about eight to 12 percent fat which is rich in omega-3 fatty acids including eicosapentaenoic acid (EPA; 20:5n3) and docosahexanoic acid (DHA; 22:6n3). Thus, in most diets its primary purpose is to serve as a vehicle to deliver fatty acids. There are indications that these longer chain omega-3s may be needed. While the more direct method for the inclusion of these fatty acids would be through fish oils, the use of fish meal serves an additional purpose. Stabilizing the more highly unsaturated oils, like fish oil, can be quite difficult, especially when surface applied to pet foods. However, for reasons not fully understood, the volatile omega-3 fatty acids found in fish meal seem to be easier to stabilize in a pet food application than those in the surface applied oil. This is doubly true for those companies attempting to utilize marine oils simultaneous to claiming to be naturally preserved. For insurance and to comply with maritime laws, antioxidant preservatives may be used when the situation warrants.

The predominant fish meals available and used by the pet food industry in the United States are Gulf and Atlantic menhaden meals, capelin and herring meals from the North Atlantic, and mackerel meal from Chile. Freshwater fish meals, such as catfish from the Mississippi delta region, are also found in some pet foods. There can be substantial compositional differences in the fatty acid profile, stability, and ash levels among the many fish species (Palstinen et al., 1985; Pike and Miller, 2000). Further, the different fish meals are not necessarily interchangeable as they can dramatically affect palatability. The cat seems to be more sensitive than the dog to changes in the origin of the meal. There are very little data in the literature on the nutrient utilization of fish meal by dogs and cats. This is one case where utilizing nutrient availability data from aquaculture and swine is probably appropriate and applicable. Results from these species would suggest that fish meal is a very high quality protein source for cats and dogs with few negatives aside from compositional considerations like ash and stability.

Fats and Oils

In the diet, fat provides a concentrated source of energy, essential fatty acids, a route for fat soluble vitamin absorption, texture, aroma, and flavor. Fat, in and of itself, will increase the palatability of a diet up to a certain point in cats, and without limit in dogs. Addition of fat to the diet to meet label guarantees will often reach 10 percent of the formula. While energy and essential fatty acids are a concern nutritionally, maintaining food stability is a primary issue. Dietary oxidized fat has been associated with lower metabolizable energy values (Pesti, 2002), slower puppy growth, suppressed immunity, and lower dietary and serum linoleic acid concentrations (Turek et al., 2003). Choosing the right fat source and method to retain freshness are important.

Tallow: Tallow was one of the original fats applied to early commercial pet foods and there are several companies that still use it today. Most of the animal fat sold as tallow comes from federally inspected animals and facilities and has regulated quality and composition, something many other fats and oils cannot claim. Although other animal fats can be found in tallow, it is, practically speaking, derived from beef because it is a dominant meat in North America and Europe. Because of the saturated nature of the fatty acids (i.e., saturated fats are solid at higher temperatures) in fat from beef animals, it most often meets the definition of tallow—a titer of 40, or a melting point of 40ºC.

For many, the "harder" fats like tallow carry a poor nutritional connotation due to the negative association of saturated fats with transport lipoproteins, cholesterol, and coronary heart disease. This is really a human nutritional issue as coronary heart disease is not a prevalent health concern for dogs or cats. Dogs and cats are considered to be "HDL species" meaning they have a preponderance of the "good" HDL in their circulation. The fatty acids in beef tallow are about 50 percent saturated, with a small amount of linoleic acid (LA; 3.0 percent) and linolenic acid (ALA; 0.6 percent) and none of the longer chain omega-3 fatty acids (EPA or DHA). Mutton tallow has a similar level of saturation (47 percent), but with a slightly higher level of LA (5.5 percent) and ALA (2.3 percent). Since beef tallow is considered a "saturated" fat and is a common fat source encountered by dogs and cats, it often serves as the baseline or "control" treatment in fatty acid research.

Tallow digestibility is high (i.e., apparent fat digestibility of 97 percent or better) and comparable to other fat sources like chicken fat and lard. Among the different fat sources, beef tallow is well known for being one of the more palatable. Mutton or lamb tallow is not quite as palatable, possibly due to the aroma. Animal fat from tallow has even been shown to benefit "olfactory acuity scores" (Altom et al., 2003), which may translate to beneficial effects during hunting. Tallow is also considered to be more shelf-stable than less saturated fats and requires less antioxidant addition to achieve shelf-life goals. Tallow also contains a small level of conjugated linoleic acid that is now showing promise as a potent natural element in the fight against cancer. Tallow is a good "platform" to provide energy and flavor, but a balanced diet may require a complementary oil enriched with linoleic acid and (or) omega-3 fatty acids.

Lard/Choice White Grease: Lard and choice white grease are also common animal fats used in pet foods. They are derived primarily from pork and are most often labeled generically as animal fat. Like tallow, most of the lard used in pet food comes from federally inspected facilities and a portion of the available supply is human edible. Thus, pet food companies may partially compete in the human edible market for this ingredient. Due to its abundance, the cost is not typically beyond that of other fat sources.

The proportion of essential fatty acids such as linoleic acid can range between 3 percent and 16 percent (Firestone, 1999). To some degree, this can be influenced by the diets the pigs were fed prior to slaughter. Lard is relatively easy to stabilize due to a preponderance of palmitic and oleic acids. Lard and choice white grease are semi-solid to viscous liquid at room temperature. It can solidify during colder weather so transportation and handling can be an issue. Further, it must be coated on foods when they are hot in order to get adequate penetration. Digestibility of lard is high and comparable to other fats. Palatability is good in both cats and dogs.

<u>Poultry Fat</u>: Poultry and, more specifically chicken fat, has become a very popular fat source in pet foods. Poultry fat use in pet foods is probably more than 10 percent to 20 percent of the 888 million pounds of poultry fat that was produced in 2003 (U.S. Census Bureau).

There are several different sources by which poultry fat is obtained: rendered, rendered-refined, and low-temperature blanched. They differ with regard to quality, consistency, and cost, and they may differ ever so slightly in minor nutrients (e.g., carotenoids), palatability, and stability. Stabilizing chicken fat in bulk storage is not a big challenge; however, when added to pet food, stability can become an issue. The potency of preservative application must consider the food and its handling and packaging. Further, the condition of the fat at the time preservatives are added is critical, i.e., the lower the moisture content, peroxide value, free fatty acid level, and impurities, the better. The trade-off is cost, availability, flavor, and aroma.

Chicken fat is a good source of the essential linoleic acid (19.5 percent; USDA-ARS, 2006) and about double that of lard. Chicken fat fits very well in dog and cat diets because it is well accepted by both, having a flavor that is preferred over many other fats. Chicken fat is comparable to other fat sources such as tallow or pork fat in digestibility and overall contribution of metabolizable energy to the diet.

<u>Fish Oil</u>: The majority of omega-3 fatty acid research in dogs and cats was conducted with the longer chain omega-3s from fish oil (e.g., EPA and DHA). These oils are derived primarily from pelagic fish like menhaden, anchovy, herring, and mackerel. This family of fish is typically found in the lower-latitude temperate to sub-tropical coastlines. They are known to have a strong oily taste and aroma not appreciated by most people; but while this doesn’t appear to be a big problem for dogs, some cats may show a preference for one fish oil over another. Most fish oils are added to the surface of the pet food post-extrusion and drying. The application of fish oil to meet the desired omega-3 fatty acid level is typically less than one to two percent of the formula. This small amount can be challenging to accurately meter without properly designed equipment. Surface application can also lead to palatability concerns.

The fatty acid profile of the different fish oils can vary substantially. Most of the fish oil used in the pet food industry is cold pressed and (or) refined. While the more processed oils add to the cost, the trade-off is improved handling, animal acceptability, and shelf life. Stabilizing bulk fish oil against oxidation requires very little to no preservative; the same goes for oil in canned pet foods. However, application onto the surface of a dry extruded kibble can become an oxidation issue. The most effective antioxidant preservative is ethoxyquin; however, natural antioxidant systems based on tocopherols can be effective.

Once ingested, the utilization of fish oil is similar to other fat sources. The omega-3 fatty acids appear in the circulation within hours of ingestion and pass along their benefits for weeks.

Other Rendered Ingredients

There have been numerous attempts to bring spent hen meal into pet food. However, no "label friendly" name has been developed. Until a suitable approach can be found, it is unlikely that a rendered spent hen meal will be used. Feather meal, while rich in desirable amino acids like methionine and cystine, is seldom, if ever, found in pet foods. This is likely due to issues with labeling and translation to the pet owner. Further, digestibility and utilization of the sulfur amino acids is not adequate to justify its use. Recent research would indicate that while blood meal is a good protein source, from a protein quality perspective, there are issues with its palatability in dogs (Dust et al., 2005). This may limit its use for anything other than a very specialized application like enteral or parenteral prescription diets. Joint cartilage and bone typically represent materials that are not desirable due to the high degree of connective tissue and low level of essential amino acids. However, there are a couple of applications in the pet food industry that may benefit from these fractions. Specifically, there has been an effort to introduce more "natural" sources of chondroprotectives like glucosamine and chondroitin sulfate into the diet. These have been traditionally sourced from China as extracts from bovine trachea (chondroitin sulfate) and crustacean shells (glucosamine). Naturally occurring and measurable levels can be found in bone cartilage and has been marketed by at least one company. Additionally, there is a move, albeit small, to develop foods which rely upon more holistic ingredients—for this purpose steamed bone meal provides calcium, phosphorus, and a host of other trace minerals.

There are likely more opportunities to extract specific nutrients from rendered materials. The dependence will be upon the creativity of the product developers and the economic incentives these opportunities present.

References

AAFCO. 2006. Association of American Feed Control Officials. Official Publication.

Aldrich, C.G., and L. Daristotle. 1998. Petfood and the economic impact. Proc. California Animal Nutrition Conference, Fresno, CA. pp. 140-148.

Altom, E.K., G.M. Davenport, L.J. Myers, and K.A. Cummins. 2003. Effect of dietary fat source and exercise on odorant-detecting ability of canine athletes. *Res. Vet. Sci*. 75:149-155.

American Horse Council. 2005. National Economic Impact of the U.S. Horse Industry.

APPMA. 2006. Industry statistics and trends. www.appma.org/press_industrytrends.asp. Accessed Mar. 16, 2006.

Batterham, E.S., R.E. Darnell, L.S. Herbert, and E.J. Major. 1986. Effect of pressure and temperature on the availability of lysine in meat and bone meal as determined by slope-ratio assays with growing pigs, rats and chicks and by chemical techniques. *Br. J. Nutr.* 55:441-453.

Bauer, J.E. 2004. Fatty acid research review. Proc. Petfood Forum 2004, Chicago, IL. Petfood Industry, Watt Publishing Co., Mt. Morris, IL. pp. 116 – 140

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

Brown, S.A., C.A. Brown, W.A. Crowell, J.A. Barsanti, C. Kang, T. Allen, C. Cowell, and D.R. Finco. 2000. Effects of dietary polyunsaturated fatty acid supplementation in early renal insufficiency in dogs. *J. Lab. Clin. Med*. 135:275-286.

Case, L.P., D.P. Carey, D.A Hirakawa, and L. Daristotle. 2000. *Canine and Feline Nutrition: A Resource for Companion Animal Professionals.* 2nd ed. Mosby Inc., St. Louis.

Chew, B.P., and J.S. Park. 2004. Carotenoid action on the immune response. J. Nutr. 134:257S-261S.

Corbin, J. 2003. The history of petfood. *Petfood Technology*. J.L. Kvamme and T.D. Phillips, ed. Watt Publishing Co., Mt. Morris, IL. pp. 514-516.

Davenport, G., R. Kelley, E. Altom, and A. Lepine. 2001. Effect of diet on hunting performance of English pointers. *Vet. Therapeutics*. 2:1-14.

Dust, J.M., C.M. Griseshop, C.M. Parsons, L.K. Karr-Lilienthal, C.S. Schasteen, J.D. Quigley III, N.R. Merchen, and G.C. Fahey Jr. 2005. Chemical composition, protein quality, palatability, and digestibility of alternative protein sources for dogs. *J. Anim. Sci*. 83:2414-2422.

Eastoe, J.E., and J.E. Long. 1960. The amino-acid composition of processed bones and meat. *J. Sci. Food Agric.* 11:87-92.

Euromonitor. 2005. The petfood report: New products are coming from the premium segment with a promise of healthcare benefits. *Petfood Industry*, November 2005. pp. 41-43.

Fahey, G.C., Jr. 2004. Research needs in pet nutrition. Proc. Petfood Forum 2004. Chicago, IL. pp. 69-75.

Fascetti, A.J., J.R. Reed, Q.R. Rogers, and R.C. Backus. 2003. Taurine deficiency in dogs with dilated cardiomyopathy: 12 cases (1997-2001). J. Am. Vet. Med. Assoc. 223:1137-1141.

Firestone, D. 1999. *Physical and Chemical Characteristics of Oils, Fats, and Waxes*. AOCS Press.

Freeman, L.M., J.E. Rush, J.J. Kehayias, J.N. Ross Jr., S.N. Meydani, D.J. Brown, G.G. Dolnikowski, B.N. Marmor, M.E. White, C.A. Dinarello, and R. Roubenoff. 1998.

Nutritional alterations and the effect of fish oil supplementation in dogs with heart failure. *J. Vet. Intern. Med*. 12:440-448.
Fuller, H.L. 1996. Utilizing rendered products: poultry. *The Original Recyclers*. D.A. Franco and W. Swanson, ed. The Animal Protein Producers Industry, The Fats and Proteins Research Foundation, and The National Renderers Association. pp. 107-128.
Johnson, M.L., and C.M. Parsons. 1997. Effects of raw material source, ash content, and assay length on protein efficiency ratio and net protein ratio values for animal protein meals. *Poult. Sci.* 76:1722-1727.
Johnson, M.L., C.M. Parsons, G.C. Fahey Jr., N.R. Merchen, and C.G. Aldrich. 1998. Effects of species raw material source, ash content, and processing temperature on amino acid digestibility of animal by-product meals by cecectomized roosters and ileally cannulated dogs. *J. Anim. Sci*. 76:1112-1122.
Kearns, R.J., M.G. Hayek, J.J. Turek, M. Meydani, J.R. Burr, R.J. Greene, C.A. Marshall, S.M. Adams, R.C. Borgert, and G.A. Reinhart. 1999. Effect of age, breed and dietary omega-6 (n-6):omega-3 (n-3) fatty acid ratio on immune function, eicosanoid production, and lipid peroxidation in young and aged dogs. *V et. Immuno. Immunopath*. 69:165-183.
Kilpatrick, J.S. 2003. Fish processing waste: Opportunity or liability. Advances in Seafood Byproducts: 2002 Conference Proceedings. P. J. Bechtel, ed. Alaska Sea Grant College Program, University of Alaska Fairbanks, Fairbanks. pp. 1-10.
Knudson, W.A. 2003. The pet food report. Accessed Mar. 26, 2006. www.aec.msu.edu/Product/documents/working 1-12031.pdf.
Krcmar, P., and E. Rencova. 2003. Identification of species-specific DNA in feedstuffs. *J. Agric. Food Chem*. 51:7655-7658.
Kvamme, J. 2006. Top 10 profiles of petfood leaders. *Petfood Industry*, January. pp. 6-15.
Locatelli, M.L., and D. Hoehler. 2003. Poultry byproduct meal: Consider protein quality and variability. *Feed Management*. 54(7):6-10.
Morris, J.G. 2002. Idiosyncratic nutrient requirements of cats appear to be diet-induced evolutionary adaptations. *Nutr. Res. Rev.* 15:153-168.
Murray, S.M., A.R. Patil, G.C. Fahey Jr., N.R. Merchen, and D.M. Hughes. 1998. Raw and rendered animal by-products as ingredients in dog diets. *J. Anim. Sci.* 75:2497-2505.
National Research Council. 1985. *NRC Nutrient Requirements of Dogs*. National Academy Press, Washington DC.
National Research Council. 1986. *NRC Nutrient Requirements of Cats*. National Academy Press, Washington DC.
National Research Council. 2006. *NRC Nutrient Requirements of Dogs and Cats*. National Academy Press, Washington DC.
Packaged facts. 2006. www.packagedfacts.com/pub/1087709.html. Accessed Mar. 31, 2006.
Palstinen, T., K. Punnonen, and P. Uotila. 1985. he fatty acid composition of 12 North-European fish species. *Acta. Med. Scand*. 218:59-62.
Parsons, C.M., F. Castanon, and Y. Han. 1997. Protein and amino acid quality of meat and bone meal. *Poult. Sci*. 76:361-368.
Pearl, G. 2003. President, Fats and Protein Research Foundation, personal communication.
Pearl, G. 2004. Tech Topics: Meat and bone meal usage in modern swine diets. *Render*. 33(2):50-53,57.
Pesti, G.M., R.I. Bakalli, M. Qiao, and K.G. Sterling. 2002. A comparison of eight grades of fat as broiler feed ingredients. *Poult Sci*. 81:382-390.
Pet Food Institute. 2003. petfoodinstitute.org/reference_pet_data.cfm. Accessed Mar. 25, 2006.

Pike, I.H., and E.L. Miller. 2000. Fish Advantages: Fish meal and oil as a source of omega-3 fatty acids in petfood. *Petfood Industry*, October. pp. 18-22.
Riaz, M.N. 2003. Extrusion Basics. *Petfood Technology*. J.L. Kvamme and T.D. Phillips, ed. Watt Publishing Co., Mt. Morris, IL. pp. 347-360.
Reynolds, A.J., C.R. Taylor, H. Hoppelar, E. Wiebel, P. Weyand, T. Roberts, and G. Reinhart. 1996. The effect of diet on sled dog performance, oxidative capacity, skeletal muscle microstructure, and muscle glycogen metabolism. Recent Advances in Canine and Feline Nutritional Research. Proc. of the 1996 Iams International Nutrition Symposium. D.P. Carey, S.A. Norton, and S.M. Bolser, ed. Orange Frazer Press, Wilmington, OH. pp. 181-198.
Rokey, G. 2003. Semi-moist/semi-expanded petfoods. *Petfood Technology*. J.L. Kvamme and T.D. Phillips, ed. Watt Publishing Co., Mt. Morris, IL. pp. 376-379.
Scott, D.W., W.H. Miller Jr., G.A. Reinhart, H.O. Mohammed, and M.S. Bagladi. 1997. Effect of an omega-3/omega-6 fatty acid-containing commercial lamb and rice diet on pruritus in atopic dogs: Results of a single-blinded study. *Can. J. Vet. Res*. 61:145-153.
Shirley, R.B., and C.M. Parsons. 2001. Effect of ash content on protein quality of meat and bone meal. *Poult. Sci.* 80:626-632.
Smeets-Peeters, M., T. Watson, M. Minekus, and R. Havenaar. 1998. A review of the physiology of the canine digestive tract related to the development of in vitro systems. *Nutr. Res. Rev*. 11:45-69.
Swisher, K. 2005. Market Report 2004: A roller coaster year and hope for the future. *Render*. 34(2):10-16.
Turek, J.J., B.A. Watkins, I.A. Schoenlein, K.G.D. Allen, M.G. Hayek, and C.G. Aldrich. 2003. Oxidized lipid depresses canine growth, immune function, and bone formation. *J. Nutr. Biochem*. 14:24-31.
USDA-ARS. 2006. USDA National Nutrient Database for Standard Reference. www.nal.usda.gov/fnic/foodcomp/search/. Accessed Mar. 25, 2006.
U.S Bureau of the Census Trade Data. 2006. U.S. exports of pet foods. www.fas.usda.gov. Accessed Mar. 25, 2006.
Waldron, M.K., A.L. Spencer, and J.E. Bauer. 1998. Role of long-chain polyunsaturated n-3 fatty acids in the development of the nervous system of dogs and cats. *J. Am. Vet. Med*. Assoc. 213:619-622.
Wang, X. 1997. Effect of processing methods and raw material sources on protein quality of animal protein meals. Ph.D. Thesis, University of Illinois, Urbana, IL.
Wang, X., and C.M. Parsons. 1998. Effect of raw material source, processing systems, and processing temperatures on amino acid digestibility of meat and bone meals. *Poult. Sci*. 77:834-841.
Yamka, R.M., U. Jamikorn, A.D. True, and D.L. Harmon. 2003. Evaluation of low-ash poultry meal as a source in canine foods. *J. Anim. Sci.* 81:2270-2284.
Zoran, D. 2002. The carnivore connection to nutrition in cats. *J. Am. Vet. Med. Assoc.* 221:1559-1567.