FEEDS AND FEED ADDITIVES, PET FOODS

1. Introduction

All pet foods sold in the United States are subject to scrutiny by both competitors and feed control officials, including the Food and Drug Administration (FDA), Association of American Feed Control Officials (AAFCO), U.S. Department of Agriculture (USDA), Federal Trade Commission (FTC), American Animal Hospital Association (AAHA), American Veterinary Medical Association (AVMA), and Pet Food Institute (PFI). A European group organized to assure fair trade and free circulation of products through Europe (FEDIAF) also monitors every aspect of U.S. pet foods and follows American trends. More is known about the nutrition of dogs and cats than is known about the nutrition of humans.

Pet foods are different from other animal feeds. Most pet foods are processed in highly sophisticated plants using equipment, sanitation, and quality control exceeding standards observed in many plants producing human-grade foods. Pet foods may be stored for up to a year following manufacture before being consumed. This possible delay in the consumption of pet foods requires more careful ingredient selection, preservation of freshness with antioxidants (qv), packaging and processing to avoid insect infestations and rancidity, and careful storage. Pet foods may contain expensive ingredients to provide desirable promotional and marketing copy.

Pets are fed a wide range of commercial foods, which vary on a dry basis from 15 to 60% protein and 5 to 50% fat. Some pet foods are expensive, nutrient-rich foods that contain twice as much nutrition density as needed. Although small quantities of a high calorie food may be consumed, approximately equivalent nutrition may be obtained by pets consuming larger quantities of a less concentrated food. For example, dogs may consume foods containing up to twice as much protein as they require; the excess digested protein is metabolized, the protein used as energy, and the nitrogen excreted, causing no problems in normal dogs. The protein content of cat foods is much higher than that required by dogs and more realistically conforms to the amounts that cats actually require for growth, gestation, lactation, and maintenance. Most pet foods are carefully balanced to meet the pet's needs without nutrient deficiencies or significant excesses.

The first pet food, a baked mixture of meat, vegetables, and wheat flour, was produced in the late 1800s. Early canned dog foods were composed mostly of meat from horses or dead stock. In the 1950s, high quality, nutritionally balanced, oven-baked, and pelleted dog foods became popular with dog owners and provided the most economical and satisfactory sources of dog nutrition. The extrusion process for pet foods was developed in 1954 and by 1957 extruded dog food had become the nation's leading dry pet food.

2. Types of Commercial Pet Foods

Pet foods are produced in canned, semimoist, and dry forms. Canned pet foods contain approximately 78 to 82% water and have a strong appeal to both pets

and owners. Semimoist foods have moisture contents of 25 to 50%. Dry-type foods contain 10 to 12% moisture and supply about 90% of the nutrition consumed by dogs and 72% of the nutrition eaten by cats.

Therapeutic foods have been developed to meet the needs of pets that have nephritic failure, allergies, thyroid problems, geriatric difficulties, and obesity. Most of these therapeutic diets are dispensed by veterinarians, though some are available in pet food outlets and human-food stores stocking pet foods. Treats are usually snacks that may be nutritionally complete or may provide a tasty morsel as a reward. The number of treat products has escalated rapidly.

2.1. Canned and Semimoist Foods. Canned and dry foods are nutritionally comparable on a moisture-free basis. Some canned foods are basically dry foods to which gravy, moisture, and flavor enhancers have been added. Almost all animals tend to prefer moist foods to dry, and canned foods are desirable for geriatric dogs and cats, particularly those having gum and dental deterioration. Canned foods can be gulped by dogs and consumed quickly by cats.

Semimoist foods usually contain about 30% moisture and provide pets with a meat-like food. This meat-like appearance has been the primary basis for the popularity of semimoist pet foods.

2.2. Dry Foods. Dry foods are concentrated sources of nutrition and provide the most economical nutritional value because water in canned foods is expensive. Dry foods tend to scrape the teeth as pets eat, minimizing tartar deposition. When dry food is moistened prior to being consumed, tartar accumulates in a manner comparable to deposits observed with canned foods. Approximately 95 to 98% of dry-type cat and dog foods are made by the extrusion process; the remainder is made by pelleting or baking.

Pelleted Pet Food. Pelleted pet foods for dogs are processed and sold in relatively small quantities. These are seldom used for cats. In the pelleting process, slightly moistened ingredients are placed between rollers and huge dies containing thousands of holes. As the die rotates, rollers with tremendous pressures push the food mixture through the die holes and scrapers or cutters on the external surface of the die then cut or shear the pelleted particles into desirable lengths. The temperature, moisture, and time during pelleting are too low to gelatinize carbohydrates (qv) and carbohydrate ingredients are precooked in an extruder or baked prior to pelleting. Outdated bread, cookies, and other pastries are often recycled as the ingredients for pelleted foods. Moistened pelleted foods become sticky or soggy and disintegrate rapidly. Pellets are much more dense than extruded pet foods, and pelleted and extruded bags of equal weight are considerably different in size. Pelleted foods can be made in square, round, or oval pellets depending on the die holes and in different lengths depending on the position of cutters. Extruded foods, by contrast, can be made in many more shapes and sizes.

Extruded Food. Extrusion is an extremely versatile method of producing pet foods. The concept of extrusion for pet foods is based on expeller screw pressing of oil seeds. An adaptation to remove the oil-escape orifices of the screw press resulted in an extruder that produced elevated temperatures and high pressure through internal friction. An experimental extruder was used first in an attempt to produce human cereals. In 1954, the machine successfully produced a formed dog food with the carbohydrates dextrinized. The food was highly palatable, did

not disintegrate into a mush in the dog's mouth, and had an attractive appearance. The first extruder produced quantities on the order of kilogram per hour whereas modern extruders produce many tons per hour.

During the extrusion process, ingredients, primarily dry, are blended into mixtures that normally do not include labile nutrients. The blend is moistened to approximately 30% moisture and then heated in a conditioning chamber prior to extrusion. Fresh meat and moist ingredients including animal by-products also may be added in the conditioning chamber. The heated and moistened mixture then enters the commercial extruder, ie, an immense enclosed screw with flights arranged in progressively restricted capacities, thus producing an enormous amount of heat by friction, up to 150°C, and pressures of nearly 6.89 MPa (1000 psi). After a few seconds moving through the extruder, the food is forced through forming dies and out into the room environment. The sudden release of pressure lets the entrapped moisture produce an expansion similar to exploding popcorn. Orifices within the die can produce almost any form, including stars, fish, chunks, and pellets of many sizes. Following extrusion, the food is moved by conveyor or negative air pressure to large ovens and spread in thin layers for drying. The moisture is reduced to about 10%, and the food is cooled. Additional fats, vitamins, and flavor enhancers are then added and the food packaged.

Extrusion processing is highly automated. Some extruders may process over 9 t/h, and in one Ralston Purina plant 30 extruders were operating in a single location. With computer assistance, one person can operate many different extruders, and several different foods can be produced simultaneously. These may be different formulations or different colors and shapes to be packaged singly or combined into one variety pack. The differences in variety may be attributable only to added colors or different shapes.

The heat and pressure of extrusion cooks (gelatinizes) carbohydrates and helps prevent diarrhea and flatulence. Extruding also inactivates several types of trypsin inhibitors found in legumes; most antivitamins, such as avidin; and some mineral-binding factors. Extrusion destroys the 13 different species of proteinase inhibitors found in the raw potato (1). It destroys thiaminase found in fish spleen, liver, and intestines; and inactivates lipoxidase present in raw soybeans which can oxidize carotene. Canned foods are processed in retorts using elevated temperatures and pressure which also gelatinizes carbohydrates.

3. Pet Food Formulation

Weights of adult cats in normal physical condition vary from 2 to 6 kg, which is contrasted with the 1 to 100 kg encountered in adult dogs of different breeds. Dogs have proportionately longer digestive tracts and can digest foods more efficiently than cats. This difference in digestibility helps account for the requirement by cats for higher protein diets.

Animal food ingredients are selected to provide desirable contributions of nutrient availability, digestibility, droppings condition, palatability, processing characteristics, ethical desirability, and economics. Modern commercial pet foods contain about 50 nutrient and nonnutrient additives. Each nutrient is supplied at a near-optimum bioavailable level. Some nutrients have a symbiotic

relationship with other nutrients, whereas some combinations are antagonistic, eg, an excess of zinc may be antagonistic to the availability of dietary copper. Copper is a part of many biological functions and closely linked with iron metabolism. A copper deficiency may decrease iron transport, produce anemia and bone disorders, and impair hemoglobin synthesis. Copper levels recommended for and tolerated by most strains of dogs may be toxic to some lineage of Bedlington terriers (2), with inborn errors of metabolism resulting in excess levels of copper accumulated in the liver and often death. High levels of copper have been used in some dog foods, but generally low levels are added to dog and cat foods to minimize copper accumulation in susceptible strains of dogs.

Ingredients used in pet foods are usually high in nutritional quality but generally not desirable as human foods primarily because they do not conform to human taste or processing expectations. By-products such as rendered proteins and fat converted into pet foods may have a derivation unappealing to humans, yet after processing may actually be more free of microorganisms and toxins than foods consumed by humans.

3.1. Nutritive Ingredients. Nutrients include amino acids (qv), fats, carbohydrates, fibers, minerals, and vitamins (qv). Some ingredients, such as niacin, supply only niacin, whereas salt provides both essential sodium and chlorine. Meat and bone meal may contain all of the nutrients, but not the correct quantities and ratios needed by dogs and cats, and the minimum required level of some nutrients for some species may be toxic to others. Nutrient concentrations in ingredients may be given in absolute amounts, as determined by chemical or physical laboratory procedures which have little direct nutritional application, because there may not be a relationship to bioavailability, ie, the amount of a nutrient absorbed from the digestive tract and available for the animal's use. An allowance must be made for the bioavailability of specific nutrients, and absorption alone is not proof that nutrients are bioavailable. Some peptides are absorbed and excreted in the urine without being utilized (3). Utilization of some nutrients depends on the dietary concentration. Calcium from calcium carbonate at low dietary levels is utilized efficiently, but at high dietary calcium concentrations increased quantities of calcium are excreted in the feces. Thus the bioavailability of calcium tends to be correlated with the quantity of the chemical component, dietary concentration, and grind or particle size. The iron in minerals such as ferric oxide and ferrous carbonate is not readily available; that from ferrous sulfate is highly available. Phosphorus in phosphoric acid, animal muscle, or organ tissue is highly available; plant phosphorus is poorly available to dogs and cats. Acidulants including phosphoric acid are used in cat foods to produce an acidic urine and help prevent urinary calculi, primarily struvite (magnesium ammonium phosphate hexahydrate) deposition. Too much phosphoric acid may produce a urinary pH of less than 6.5. This excess urinary acidity produces hypokalemia unless dietary potassium is increased to provide ample dietary potassium quantities.

Proteins. Proteins (qv) supply amino acids (qv), palatability enhancement, and, when present in more than required amounts, energy as the proteins are degraded and nitrogen compounds excreted. Dogs and cats can consume and meet amino acid requirements in the form of pure amino acids with complete success. However, animal tissue cannot differentiate between pure, plant, or animal

sources of those amino acids, and those amino acids can be obtained much more economically from either plant or animal proteins.

Huge amounts of concentrated proteins, available as oilseed plant by-products from the brewing, distilling, starch, and oil industries, provide excellent sources of amino acids for pets. Horses, sheep, cattle, swine, and poultry also use oilseeds efficiently and provide intense competition for the use of these plant proteins. Plant proteins are heated during processing to inactivate enzymes that could otherwise be detrimental. Some plant proteins, such as soybean meals, contain enough relatively indigestible oligosaccharides, including stachyose [470-55-3] and raffinose [512-69-6], to limit usage in pet foods. Microorganisms in the large intestine associating with stachyose and raffinose produce undesirable skatoles, indoles, and flatulence. Accompanying fiber concentrations in most plant proteins act like thousands of tiny sponges in the digestive tract, absorbing large amounts of water. This helps prevent constipation, but decreases fecal dry matter and increases fecal volume. The extra fecal volume is undesirable in kennel and pet management.

Soybean products that have been processed to remove a portion or all of the carbohydrates and minerals are used to make textured vegetable proteins which can be formed into various shapes and textures (see SOYBEANS AND OTHER OILSEEDS). Many canned dog foods utilize the textured vegetable protein chunks with added juices, flavor enhancers, vitamins, and minerals to produce canned dog foods that have the appearance of meat chunks. Similarly, those proteins can be combined with uncolored ingredients to imitate marbling and form pet foods with chunk-meat appearance. This processing is commonly used in semimoist pet foods.

Plant proteins from single sources, such as soybean meal, may be abundant in specific amino acids that are deficient in some cereal grains. Thus a combination of soybean meal and corn with their amino acid symbiosis may provide an excellent amino acid profile for dogs. Plant protein mixtures alone do not meet the amino acid needs for cats, because taurine [107-35-7] is not generally present in plant proteins.

Plant proteins are less expensive than animal proteins and are used in formula quantities at the greatest extent possible while still retaining the maximum desirable food characteristics. Plant proteins are extremely important in the nutrition of pets.

In the United States, more than 16.3×10^9 kg of human-inedible raw materials are available each year, and the rendering industry is a valuable asset in diverting these into valuable ingredients for use primarily in animal foods (4). The three largest meat packers are responsible for nearly four-fifths of all red meat production (5) and enormous amounts of rendered meat meal and animal fat. Three broiler producers account for about 40% of the total broiler production. The world's largest processor of poultry by-products, produces more than 450,000 t of poultry meal, feather meal, and poultry fat each year. It also produces more than 100,000 t of fish meal, fish oil, and fish products each year. Fish meal, meat and bone meal plus feather meal and poultry by-product meal are the primary sources of animal proteins used by the pet food industry (6).

New Zealand rendering industries have low temperature rendering systems with cooking (rendering) temperatures ranging from 75 to 100°C for two to ten minutes with separation of liquid and solid phases. This produces high

quality animal protein by-products with the least amount of nutrient degradation, yet permits destruction of most microorganisms and fat separation from the protein solids (7). This method of processing retains higher than normal levels of arginine, lysine, and other amino acids with less nonnitrogen protein. This processing helps account for the popularity of New Zealand sheep by-products, primarily lamb meal, gaining popularity in U.S. pet foods.

Milk and egg products are highly desired in pet foods since they supply the highest quality amino acid profiles with nearly 100% digestibility. Most milk protein concentrates are used for human foods, but some are available to pets (see MILK AND MILK PRODUCTS). An enormous quantity of whole eggs (qv) derived from egg graders, egg breakers, and hatchery operations are handled as dehydrated, liquid, or frozen ingredients.

Meat derived from crippled, old, discarded, injured animals, and those that have recently died (designated as 4-D beef), as well as USDA rejected meats, are used in canned pet foods. Fresh meats of human-grade also are used, including wing-tips, gizzards, livers, necks, backs, and meat still attached to bones. Edible meat removed by deboning machines from backs, necks, and bones in USDA inspected plants are used primarily for soup and meat-filled human foods; the excess is used in pet foods. Those parts that are not deboned are sold fresh and frozen to the pet food industry. These meat products (qv) are shipped in sealed-containers marked USDA inedible or denatured with charcoal or dye to prevent any use as nonanimal food.

Fats and Oils. Fats and oils from rendering animal and fish offal and vegetable oilseeds provide nutritional by-products used as a source of energy, unsaturated fatty acids, and palatability enhancement. Fats influence the texture in finished pet foods. The use and price of the various melting point fats is determined by the type and appearance of the desired finished food appearance.

Large quantities of fat are used from the fast food industry; these fats may have dissolved plastics from restaurant wrappers which can restrict spray nozzle orifices as the fats cool during spraying on pet foods (see FATS AND FATTY OILS).

Vegetable oils which have become increasingly desirable in human foods because of the high levels of polyunsaturated fatty acids, are generally too expensive to be used in pet foods. An excess of vegetable oils in the nutrition of show dogs tends to produce less-firm fat deposition, which may be objectionable in conformation competition. Canned dog foods may have extremely high levels of fat, especially those containing 4-D meat sources; they may exceed 50% fat on a dry matter basis.

Carbohydrates and Plant Products. The world supply of excess grains provides desirable sources of carbohydrates (qv) and fibers (qv) for animals, including pets. Most grains are relatively low in proteins and, unless processed for starch or alcohol, are generally ground whole and used in animal feeds. Thus the contribution of the accompanying protein, vitamins, minerals, and fibers can be accounted for advantageously during pet food formulation.

Corn, wheat, and rice are the most desirable common grains and are used extensively in pet foods. Oats and barley often tend to have excess fiber, which can be objectionable. However, barley is a preferred grain for moisture absorption and form in canned foods because the turgid white form is desired in some canned dog foods. Milo has enormous variations in tannin content which

can influence digestibility and acceptability, thus limiting its use in pet foods (see WHEAT AND OTHER CEREAL GRAINS).

Fibers and Fiber Sources. Fibers are present in varying amounts in food ingredients and are also added separately (see DIETARY FIBER). Some fibers, including beet pulp, apple pomace, citrus pulp, wheat bran, corn bran, and celluloses are added to improve droppings (feces) form by providing a matrix that absorbs water. Some calorie-controlled foods include fibers, such as peanut hulls, to provide gastrointestinal bulk and reduce food intake. Peanut hulls normally have a high level of aflatoxins. They must be assayed for aflatoxin and levels restricted to prevent food rejection and undesirable effects of mycotoxins.

Normally, fecal moisture increases and dry matter digestibility decreases with added dietary fibers. When 500 grams of common dog foods sold in food stores are consumed, about 300 grams of droppings containing 30% dry matter are produced. For the inclusion of 12% dietary beet pulp, 500 grams of food can produce up to 800 grams of feces having 19 to 20% dry matter content.

3.2. Nonnutrient Additives. Nonnutritional dietary additives provide antioxidants to preserve freshness, flavor enhancers to stimulate food selection, color to meet the owner's expectations, pellet binders to minimize fine particles, mycostats to minimize mold growth, and ingredient-flow enhancers. Pet foods do not include coccidiostats, antibiotics, added hormonal materials, and fly-larval insecticides used in other animal feeds.

Antioxidants. Naturally occurring and synthesized antioxidants are added to help protect and spare vitamin E, selenium, vitamin C, taurine, xanthophylls, and other nutrients with antioxidant properties that are needed to protect cell membranes against peroxidation and the destructive effects of free radicals. Vitamin E's most potent biological form, α-tocopherol [59-02-9], is unavailable in adequate quantities to meet demands for human foods. There is speculation that vitamin E may impede the formation of low density lipoproteins (LDL) in humans and ameliorate atherosclerotic effects (8,9). Controversy has developed relating to a synthesized antioxidant, ethoxyquin [91-53-2]. Owners of dogs that perhaps have genetic or management problems have pointed to ethoxyquin as the cause of the undesirable problems observed with their dogs. That unsubstantiated association has stimulated activism for the removal of ethoxyquin, which spares other dietary antioxidants.

Early cat foods without antioxidants produced steatitis, ie, yellow fat disease, when the food contained quantities of fish, particularly tuna, and high levels of polyunsaturated oil. Early (1950s) shipments of Peruvian fish meal often spontaneously combusted, and ships' fish-meal cargo sometimes ignited. Ethoxyquin, considered the most highly effective antioxidant, combined with fish meal immediately after rendering, eliminates the combustion hazard. Because pet foods have such a long shelf life, ethoxyquin has been the choice of antioxidants because of efficacy, durability, and economics. Although ethoxyquin has been used in dog foods for almost 40 years with excellent success, additional extensive long-term testing of ethoxyquin in beagles is under way. Natural tocopherols are expensive and, because of the increasing demand in human diets, may become almost unavailable for pet nutrition.

Flavor Enhancers. Competition for the dog owner's money places enormous emphasis on instant acceptance of foods by pets. This has created an

industry to supply flavor enhancers for dog and cat foods having aromas that appeal to owners. Different types of spices, essential oils (qv), amino acids, natural extractives, and synthetic flavoring substances have been used. Dogs and cats tend to prefer fats and fatty acids, amino acids, onion and garlic, hydrolysates, and most meat and fish flavors. Many flavor chemists have researched flavor enhancers (10), eg, they have identified and elucidated a series of factors contributing to high quality beef flavors, and have identified the distinctive beef flavor as a peptide chain of eight amino acids that develops as beef ages (see FLAVORS).

Newer flavor enhancers include hydrolyzed animal and plant proteins. Hydrolyzed proteins are used in dry-type dog and cat foods to provide enhanced acceptability. These are highly effective either sprayed on as a liquid or dehydrated and dusted on the outside of the pet food after extrusion and drying. Inclusion of flavor enhancers at the pre-extruder conditioner and heating just prior to extrusion significantly decreases flavor enhancement. That flavor loss apparently is a result of changes associated with high pressures and temperatures during extrusion, plus flavor loss during flashing as the extrudate is released from the high pressure into the atmospheric conditions.

Color Additives. Color additives, for the benefit of dog and cat owners, help simulate food richness, which is evaluated in many different ways. The addition of color helps minimize variations in appearance associated with batch difference in food ingredients and fineness of grind. Cats and dogs are practically color blind; colors have little influence on them.

Other Nonnutrient Additives. Mycostats are included in most dry-type and semimoist pet foods to prevent mold development. When pet food packages are stacked against cold surfaces, internal moisture within the bag migrates toward those cold surfaces. That concentration of water along the periphery is conducive to growth of any viable fungi, thus producing mold. Small quantities of fungistats help prevent mold growths.

Additional nonnutrient additives include sequestrants to provide ingredient separation and stabilizers such as gums. Spices, essential oils, oleoresins, synthetic flavorings, and adjuvants are also used in pet foods.

3.3. Cat Specific Additives. Cats are more sensitive to some nutritional deviations than are dogs. A dietary deficiency of arginine [7004-12-8] is more severe in cats than in dogs. This difference is associated with the higher dietary protein in cat foods. An arginine-free diet, intentionally produced with purified ingredients, was designed to evaluate arginine requirements of cats. Graded levels of arginine were added to the basal diet to determine requirements. It was observed (11) that an arginine deficiency in the cat produces ammonia toxicity. Accumulation of ammonia in the blood appears within three hours following consumption of a single arginine-free meal and is accompanied by emesis, hyperactivity, ataxia, tetanic spasms, and other abnormalities. Although severe deficiencies of arginine are unlikely to be encountered, arginine and taurine are most likely to be the limiting indispensable amino acids.

Taurine. Taurine is a sulfonic amino acid derived from methionine and cystine and functions in many biological systems. Although taurine is plentiful in most mammalian tissues as a free acid, the cat's synthesis of taurine is insufficient to meet its biological needs (12). The cat's synthesis of taurine by the cysteine sulfinic acid pathway is limited by the low activity and concentration

of cysteine sulfinic acid decarboxylase. Taurine scavenges strong oxidants, including free radicals. Taurine deficiency has caused abnormal reproduction by queens and abnormal development of kittens, eg, abortion and resorption of fetuses, stillbirths, low neonatal weights, and abnormal brain and neurological development have been observed with taurine-deficient queens (13). Ocular lesions, associated with feline central retinal degeneration (FCRD), terminating in blindness develop in growing kittens and are the initial observable signs of deficiencies associated with taurine (14,16). Cats have been used in long-term studies to determine that no FCRD abnormalities occur with purified diets containing 375 mg of taurine kg/diet; 400 mg taurine/kg diet is recommended for growing kittens (17). Taurine also is associated with dilated cardiomyopathy (18), a relaxation of the heart wall muscles that decreases cardiac efficiency; prolonged taurine deprivation can cause death.

The taurine status of cats is easily measured using assays for blood or serum taurine levels. Serum taurine levels of 50 nmol/mL are generally considered adequate. Because heat processing during canning inactivates considerably more taurine or forms an inhibition against taurine uptake by the feline, less taurine is required in dry foods than in canned foods. The Feline Nutrition Expert Subcommittee of the Association of American Feed Control Officials (AAFCO), in the nutrient profiles for complete and balanced cat foods (19), suggests 0.1% taurine in extruded food and 0.2% in canned foods as a result of the extra loss of taurine during the canning processing.

Feather meal, first hydrolyzed and then oxidized, produces cysteic acid [13100-82-8] an excellent precursor for taurine in cats (20). Hydrolyzed feather meal may supplement the taurine provided by other dietary animal proteins and help replace part or all of the synthetic taurine in cat food formulations with considerable cost savings.

Phosphoric Acid. Cats generally consume about two-thirds as much water per unit of food dry matter intake as do dogs (21). This water conservation is often associated with feline urine obstruction, primarily formed by the deposition of struvite (magnesium ammonium hexahydrate) in the urinary tract. Dietary magnesium in amounts required for growth is near the concentration which also precipitates in the urinary tract and may cause obstruction. To provide safe levels of dietary magnesium and also prevent feline urinary syndrome (FUS), ingredients such as phosphoric acid [7664-38-2], which acidulates the urine, are added at carefully controlled levels to produce an acidic urine of approximately pH 6.5. This keeps practically all struvite in suspension in the urine. Relatively high levels of dietary potassium are required with low urine acidity to prevent hypokalemia.

Other Additives. Cats cannot convert tryptophan to niacin (22), or carotene to vitamin A in sufficient amounts to meet their needs (23). These deviations, as compared with other animals, need not produce problems because added dietary sources of niacin and vitamin A provide the needs of cats.

3.4. AAFCO Nutrient Profiles. Pet food products provide package claims of "complete and balanced for specific physiological states" to provide the pet owner with confidence and to assure that pets receive nutritionally desirable foods. Before the promulgation and acceptance of the Association of American Feed Control Official (AAFCO) Nutrient Profiles (Table 1), a number

Table 1. **AAFCO Nutrient Profiles[a], 2006**

Nutrient	Dog foods			Cat foods		
	Growth and reproduction, min	Adult maintenance, min	Maximum suggested level	Growth and reproduction, min	Adult maintenance, min	Maximum suggested level
proteins, %	22.0	18.00		30.0	26.0	
arginine	0.62	0.51		1.25	1.04	
histidine	0.22	0.18		0.31	0.31	
isoleucine	0.45	0.37		0.52	0.52	
leucine	0.72	0.59		1.25	1.25	
lysine	0.77	0.63		1.20	0.83	
methionine–cystine	0.53	0.43		1.10	1.10	
methionine				0.62	0.62	1.50
phenylalanine–tyrosine	0.89	0.73		0.88	0.88	
phenylalanine				0.42	0.42	
taurine						
extruded				0.10	0.10	
canned				0.20	0.20	
threonine	0.58	0.48		0.73	0.73	
tryptophan	0.20	0.16		0.25	0.16	
valine	0.48	0.39		0.62	0.62	
fat[b], %	8.0	5.0		9.0	9.0	
linoleic acid	1.0	1.0		0.5	0.5	
arachidonic acid				0.02	0.02	
minerals, %						
calcium	1.0	0.6	2.5	1.0	0.6	
phosphorus	0.8	0.5	1.6	0.8	0.5	
Ca:P ratio	1:1	1:1	2:1			
potassium	0.6	0.6		0.6	0.6	
sodium	0.3	0.06		0.2	0.2	
chloride	0.45	0.09		0.3	0.3	
magnesium	0.04	0.04	0.3	0.08	0.04	
iron,[c] mg/kg	80	80	3,000	80	80	
copper,[d] mg/kg	7.3	7.3	250	5	5	
manganese,[e] mg/kg	5.0	5.0		7.5	7.5	

zinc, mg/kg	120	120	1,000	75	75	2,000
iodine, mg/kg	1.5	1.5	50	0.35	0.35	
selenium, mg/kg	0.11	0.11	2	0.1	0.1	
vitamins						
vitamins A, IU/kg	5,000	5,000	250,000	9,000	5,000	750,000
vitamin D, IU/kg	500	500	5,000	750	500	10,000
vitamin E,[f] IU/kg	50	50	1,000	30	30	
vitamin K,[g] mg/kg				0.1[g]	0.1	
thiamine,[h] mg/kg	1.0	1.0		5.0	5.0	
riboflavin, mg/kg	2.2	2.2		4.0	4.0	
pantothenic acid, mg/kg	10	10		5.0	5.0	
niacin, mg/kg	11.4	11.4		60	60	
pyridoxine, mg/kg	1.0	1.0		4.0	4.0	
folic acid, mg/kg	0.18	0.18		0.8	0.8	
vitamin B_{12}, mg/kg	22.0	22.0		0.02	0.02	
biotin,[i] mg/kg				0.07[j]	0.07	
choline,[i] mg/kg	1,200	1,200		2,400[j]	2,400	

[a]Presumes and energy density of 14.64 kJ ME/g DM (metabolizable energy/gram dry matter), as determined in accordance with Regulation PF9, which is based on the 'modified Atwater' values of 14.64, 35.57 and 14.64 kJ/g for protein, fat, and carbohydrates (nitrogen-free extract, NFE), respectively. Rations greater than 16.73 kJ/g should be corrected for energy density; rations less than 14.64 kJ/g kcal/g should not be corrected for energy. To convert kJ to kcal, divide by 4.184. Rations of low-energy density should not be considered adequate for growth or reproductive needs based on comparison to the Profiles alone.

[b]Although a true requirement for fat *per se* has not been established, the minimum level was based on recognition of fat as a source of essential fatty acids, as a carrier of fat-soluble vitamins, to enhance the palatability, and to supply an adequate caloric density.

[c]If the mean urine pH of cats fed *ad libitum* is not below 6.4, the risk of struvite urolithiasis increases as the magnesium content of the diet increases.

[d]Because of very poor bioavailability, iron from carbonate or oxide sources that are added to the diet should not be considered as components in meeting the minimum nutrient level in cats.

[e]Because of very poor bioavailability, copper from oxide sources that are added to the diet should not be considered as components in meeting the minimum nutrient level.

[f]For cats, add 10 IU vitamin E above minimum level per gram of fish oil per kilogram of diet.

[g]Vitamin K needs to be added to cat food only when diet contains greater than 25% fish on a dry matter basis.

[h]Because processing may destroy up to 90% of the thiamin in the diet, allowances in formulation should be made to ensure the minimum nutrient level is met after processing.

[i]Biotin needs to be added to cat food when diet contains antimicrobial or antivitamin compounds.

[j]In cat food, methionine may substitute for choline as methyl donor at a rate of 3.75 parts for 1 part choline by weight when methionine exceeds 0.62%.

of references were used for complete and balanced recommendations (17,24,25). The Canine Nutrition Expert (CNE) subcommittee was formed to establish new profiles for complete and balanced dog foods. The AAFCO–CNE nutrient profiles are considered the AAFCO-recognized authority on canine nutrition (26). Dog foods bearing the label claim of nutritional adequacy by reference to the AAFCO dog food nutrient profile must meet all of the minimum and maximum levels for nutrients as established by the CNE subcommittee or must meet successful feeding test criteria based on published feeding protocols (27). The Feline Nutrition Expert (FNE) subcommittee was appointed following the development of AAFCO–CNE recommendations to compile profiles for complete and balanced cat foods. These AAFCO–FNE nutrient protocols for cats were published, and include protocols for adequate testing of pet food products, which are monitored by AAFCO (26). The AAFCO nutrient profiles for both adult dogs and cats offer maximum suggested nutrient levels; excess nutrient levels can be as harmful as deficiencies. Also, separate nutrient levels for the stages of growth of kittens and puppies and reproduction are additional features. The AAFCO nutrient profiles for dogs and cats are given in Table 1.

4. Economic Aspects

In 2005, dog and cat food sales in the U.S. reached a new record high of \$14.3 $\times 10^9$ (see Table 2). Table 3 gives pet food product sales history (29). It has been estimated that there are as many as 15,000 different brand labels and package sizes of pet foods, marketed by 3000 manufacturers (30).

Pet food purchases are based on the satisfaction of the owner, and pet food proliferation is enormous with accompanying advertising descriptors including natural, lite, low calorie, high calorie, low protein, and high protein. New therapeutic series, sizes, densities, colors, and attractive packaging have also added to the proliferation.

Commercial flavor enhancers for pet foods have become big business. Flavor enhancers, primarily so-called digests, provide high acceptance of pet foods and enable the pet to select one food over another. Commercial companies compete with flavors based on the types that pets like. However, owner objections minimize the use of some acceptability enhancers such as some fish products, onions, and garlic.

Digest is the most widely used flavor enhancer. Digests are mostly hydrolyzed proteins and fats, primarily of animal origin. When meat or animal

Table 2. **U.S. Cat and Dog Food Sales, \$ $\times$ 10^6 2004–2005**[a]

Type	2004	2005
dog food	7,520.0	7,819.8
cat food	4,435.6	4,582.3
dog treats	1,681.2	1,731.6
cat treats	217.0	234.4
Total	*13,853.8*	*14,368.1*

[a]Ref. 28.

Table 3. **Pet Food Product Sales History**[a,b]

Food	1981[c]	1995	1997	1999	2000	2001	2002
dry dog food (includes soft dry)	1,698.0	2,905.0	3.981.0	4,496.0	4,657.0	4,955.0	5,201.0
canned dog food	790.0	1,129.2	1,240.3	1,283.0	1,301.0	1,340.0	1,379.7
dog treats	214.0	1,165.1	1,148.6	1,185.0	1,265.0	1,370.0	1,475.0
semi-moist dog food	281.0	101.8	103.2	98.0	85.0	84.0	80.3
Total Dog Food	*2,983.0*	*5,301.1*	*6,473.1*	*7,060.0*	*7,308.0*	*7,749.0*	*8,136.0*
canned cat food	730.0	2,009.9	1,535.0	1,610.0	1,545.0	1,615.0	1,652.0
dry cat food	524.0	1,612.9	1,753.0	1,946.0	2,087.0	2,235.0	2,344.0
moist cat food	191.1	109.0	94.6	85.1	77.5	64.0	53.0
cat treats	n/a	100.5	109.6	109.0	125.0	145.0	167.0
Total Cat Food	*1,445.1*	*3,832.3*	*3,492.2*	*3,750.1*	*3,834.5*	*4,059.0*	*4,216.0*
Total Dog and Cat Food	*4,427.1*	*9,133.4*	*9,965.3*	*10,812.1*	*11,142.5*	*11,808.0*	*12,352.0*

[a]From Ref. 29

[b]All Figures in U.S. dollares $\times 10^6$

[c]Figures prior to 1991 include retail grocery sales only. From 1991 on, figures include estimated retail sales from all points of sales, This data was compiled by Davenport Company and printed in Petfood Industry Magazine.

by-products are subjected to acids or enzymes and disintegrate into components, some have potent attraction to both dogs and cats. Digests are sprayed or dusted on the outside of many dog and cat foods, and are much more effective as palatability enhancers than are those same digests added with the other ingredients and processed through pelleting or extrusion machines.

Cost per kilogram of dog food ranges from ca $0.30 to $30/kg of dry matter; demands exist for pet foods in each range. Some of the highest quality pet foods are manufactured by companies conducting an enormous amount of applied research and producing only foods that are sold relatively inexpensively through private label channels and not with their own labels.

5. Labeling

Most of the 50 United States require under state animal food laws and regulations that pet food labels be regulated and approved. Pet food labeling is regulated at two levels. FDA regulations require proper identification of the product, net quantity, name and place of manufacturer or distributor, a proper listing of all ingredients from most to least based on weight (21 CFR 501.4). Many regulations are based on a model established by The Association of American Feed Control Officials (AAFCO). The FDA has also put into place policies for making health claims on pet food labels, such as maintenance of urinary tract health, low magnesium, reduces hairballs and plaque and tartar (31).

Some of the information on a label is required and some is optional. All labels regardless of size should carry the mandatory information. Other information not mentioned above include nutritional adequacy statements, which is proof of the complete and balanced status of a pet food. This can be achieved in either of two ways. One is to compare the nutrient content of the product and determine by calculation or laboratory analysis done by following AAFCO profiles. Second, is to conduct animal feed studies using AAFCO testing protocols. If the product does not contain complete and balanced nutrition, the label should state “not to be fed as a sole diet.” Snacks and treats do not require nutrition adequacy statements (31).

Although not required, some manufacturers list a toll-free number for consumer information.

A pet food company selling a product that does not meet a particular state’s regulations can be subject to a warning, fine, removal of the product from stores and prohibited from marketing in that state until violations are corrected.

6. Safety of Pet Food

The FDA regulation of pet food is similar to that of other animal feed. The Federal Food, Drug, and Cosmetic Act requires that pet food, like human food, be pure, safe, and wholesome to eat, produced under sanitary conditions, contain no harmful substances, and be truthfully labeled. In addition, canned pet foods

must be processed in conformance with the canned food regulations to ensure that the pet food is free of viable microorganisms (CFR, part 113) (31).

There is not a requirement that pet foods products have premarket approval by the FDA. However, the FDA ensures that the ingredients in pet food are safe and have an appropriate function. Many ingredients such as grains, poultry, etc, are considered food and require no premarket approval. Other substances, such as vitamins, minerals, colorings, flavorings, and preservatives may be generally recognized as safe (GRAS) and must have approval as food additives (21 CFR pts 7, 74, 81, 573, and 582).

6.1. Bovine Spongiform Encephalopathy (BSE). With the exception of cats, no pets (companion animals) are known to be susceptible to the organism that causes BSE in cattle. No evidence of BSE has been found in dogs, horses, birds, or reptiles. Approximately 90 cats in the UK and several cats in other countries have been diagnosed with the feline version of BSE, or FSE. Before it was recognized that cats were susceptible to the BSE infectious agents, cats were exposed to the BSE agent through commercial pet food or through scraps provided by butchers.

The number of reported cases of FSE has been declining since 1994 after bans were implemented in those countries (31).

Currently in the United States, animal products that are prohibited from cattle feed are acceptable as pet food. Such products include meat and bone meal. However the FDA believes that safeguards put into place to prevent BSE in the U.S. have always protected cats. To date, no case of FSE has been found in the U.S. Safeguards are revisted continually (31).

6.2. Salvage and Distressed Pet Food. Salvage pet food is defined as a product that is still under the control of the original manufacturer and will not be offered for retail sale. Examples are start-up and over-run products, unpelleted pet food, pt food fines, and other products not suitable for packaging for retail sale. Distressed pet food is defined as product that is no longer available for retail sale. Examples are dented cans, torn bags, or product past its sell-by-date. Salvage or distressed products offered for sale must be accompanied by a label listing ingredients, guaranteed analysis for crude protein, crude fat and fiber, and include all other label requirements for animal feed. Distressed products that may contain mammalian material are prohibited from use in feed for ruminant animals must carry a "no feed to cattle" label and detailed record-keeping. Such requirements have been put in place a an additional layer of protection against BSE (32).

BIBLIOGRAPHY

"Feeds, Animal," in *ECT* 1st ed., Vol. 6, pp. 299–312, by H. M. Briggs, Oklahoma Agricultural and Mechanical College; in *ECT* 2nd ed., Vol. 8, pp. 857–870, by H. M. Briggs, South Dakota State University; "Pet and Livestock Feeds," in *ECT* 3rd ed., Vol. 17, pp. 90–109, J. Corbin, University of Illinois; "Feeds and Additives (Pet Foods)" in *ECT* 4th ed., Vol. 10, pp. 330–314, by J. Corbin, University of Illionis at Urbana-Champaign. "Feeds and Feed

Additives, Pet Foods" in *ECT* (online), posting date: December 4, 2000, by J. Corbin, University of Illinois at urbana-Champaign; in *ECT* 5th ed., Vol. 10, pp. 848–861, by J. Corbin, University of Illinois at Urbana-Champaign;

CITED PUBLICATIONS

1. R. Bernard, *Cornell Vet.* **32**, 29 (1942).
2. D. C. Tinedt, I. Sternlieb, and S. A. Gilberson, *J. Am. Vet. Med. Assoc.* **175**, 269 (1979).
3. J. E. Ford and C. Shorrock, *Br. J. Nutr.* **26**, 311–322 (1971).
4. P. Brown and co-workers, *J. Infectious Diseases* **161**, 467 (1990).
5. F. Burton, *Render* **19**(4), 7 (1990).
6. F. Burton, *Render* **15**(3), 7, 25 (1986).
7. F. Burnham, *Render* **15**(3), 10 (1986).
8. M. Stampfer, *The Champaign-Urbana (Illinois) News-Gazette*, 4A (Nov. 18, 1992).
9. D. Steinberg and co-workers, *New Engl. J. Med.* **310**, 915–924 (1989).
10. R. W. Hitzman, *Identification and Elucidation of Factors Contributing to High Quality Beef Flavors*, Ph.D. dissertation, University of Illinois, Urbana, 1986.
11. J. G. Morris and Q. R. Rogers, *J. Nutr.* **106** (abstr. 63) (1976).
12. I. Burger and K. Earle, *Waltham International Focus* **2**(2), 9–13 (1992).
13. J. A. Sturman and co-workers, *J. Nutr.* **116**, 655–667 (1986).
14. K. C. Hayes, A. R. Rabin, and E. L. Berson, *Am. J. Pathol.* **78**, 505–515 (1975).
15. P. A. Anderson, *Significance of Indispensable Amino Acids, Choline, and Taurine in Feline Nutrition*, Ph.D. dissertation, University of Illinois at Urbana-Champaign, 1979.
16. Q. R. Rogers and J. G. Morris, *3rd Annual Pet Food Inst. Technical Symposium*, Sept. 24, 1982, Kansas City, Mo., 1982.
17. National Research Council, *Nutrient Requirements of Cats*, National Academy Press, Washington, D.C., 1986.
18. P. D. Pion and co-workers, *Science* **237**, 764–768 (1987).
19. D. A. Dzanis, *FDA Veterinarian* **7**(6), 1–2 (Nov./Dec. 1992).
20. Q. R. Rogers, personal communication, 1992.
21. H. N. Waterhouse and D. S. Carver. *Proc. Animal Care Panel* **12**, 271 (1962).
22. B. Ahmad, *Biochem. J.* **25**, 1195 (1931).
23. M. Ikeda and co-workers, *J. Biol. Chem.* **240**, 1395 (1965).
24. National Research Council, *Nutrient Requirements of Dogs*, National Academy Press, Washington, D.C., 1974.
25. Ref. , 1978 ed.
26. D. A. Dzanis, *FDA Veterinarian* **6**(5), 1, 2, 4 (Sept./Oct. 1991).
27. Association of American Feed Control Officials, official publication, AAFCO, Inc., Atlanta, Ga., 2006.
28. *Pet Food and Pet Care Products in the U.S.*, Euromonitor International, 2005.
29. *PFI Reference Desk*, The Pet Food Institute, Washington, D.C., 2006.
30. R. H. Brown, *Feedstuffs* **64**(52), 5 (1992).
31. *Pet Foods*, Center for Veterinary Medicine, U.S. Food and Drug Administration, www/fda/gov/cvm/petfoods.htm, 2006.
32. *Handling of Salvage and Distressed Pet Foods*, The Pet Food Institue, Washington, D.C., 2002.

GENERAL REFERENCE

Official Publication of Association of American Feed Control Officials, 1993, Association of American Feed Control Officials, Georgia Department of Agriculture, Capitol Square, Atlanta, Ga.

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