Comparison of corn gluten meal and meat meal as a protein source in dry foods formulated for cats

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Objective—To compare the nutritional value of corn gluten meal (CGM) and meat meal (MM) as a dietary source of protein in dry food formulated for adult cats.

Animals—8 healthy adult cats (4 males and 4 females).

Procedure—Diets containing CGM or MM as the main protein source were each fed for a 3-week period in a crossover study. Digestibility and nutritional balance experiments were conducted during the last 7 days of each period. Furthermore, freshly voided urine was obtained to measure urinary pH, struvite crystals, and sediment concentrations.

Results—Daily food intake and dry-matter digestibility were significantly higher for the MM diet. Fecal moisture content also was higher for the MM diet. Apparent nitrogen (N) absorption and N retention were higher for the MM diet, even when values were expressed as a percentage to account for differences in N intake. Urinary pH, struvite activity product, number of struvite crystals in urine, and urinary sediment concentrations were not different between diets. Retention of calcium, phosphorus, and magnesium was lower for the CGM diet, and cats lost body calcium and magnesium when fed the CGM diet.

Conclusions and Clinical Relevance—Meat meal was superior to CGM as a protein source in dry foods formulated for cats, because dry-matter digestibility and N utilization were higher for the MM diet. In addition, net loss of body calcium and magnesium for the CGM diet suggests that mineral requirements increase when CGM is used as a protein source. (*Am J Vet Res* 2002;63:1247–1251)

Cats are carnivores with several metabolic characteristics. Cats require relatively high amounts of specific amino acids, essential fatty acids, and vitamins that are abundant in animal tissues,[1-3] but commercial dry foods formulated for cats generally contain 40 to 60% cereal as a starch source needed for extrusion processing. Moreover, other vegetable ingredients are also often included in commercial foods as inexpensive protein sources. Nutritional evaluation of the digestion of vegetable ingredients in cats is required, but only limited information is available.

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As an initial step in the nutritional evaluation of plant protein in dry foods formulated for cats, nutritional values of **corn gluten meal (CGM)** and **fish meal (FM)** were examined as the major protein source for healthy adult cats.[4] Results of that study revealed that apparent digestibility and **nitrogen (N)** balance did not differ between CGM and FM. Corn gluten meal is commonly used as an ingredient of commercial dry food formulated for cats because it contains amounts of crude protein as high as those found in FM or **meat meal (MM)**. In addition, unlike most plant sources of protein, CGM contains higher concentrations of sulfur-containing amino acids that produce acidic urine when fed to cats.[5] Urine acidification is desirable for the prevention of struvite uroliths that are likely to develop in young adult cats fed dry foods.[6,7] In the study reported here, we performed a nutritional evaluation to compare CGM and MM as sources of protein in dry foods formulated for cats.

Materials and Methods

Animals—Eight healthy adult cats (4 sexually intact males and 4 sexually intact females) that weighed between 3.20 and 4.92 kg (mean **body weight [BW]**, 3.92 kg) were used in the study. Cats were considered clinically normal on the basis of results of physical examinations. All cats were housed separately in metabolic cages in a temperature-controlled room (mean ± SD, 24 ± 2 C) with artificial light provided from 6 AM to 6 PM daily. Cats were provided care in accordance with established principles.[8]

Diet—Two extruded dry diets were used. Dietary ingredients, dietary composition determined by chemical analyses, and base excess calculated from dietary composition were recorded for each diet (**Appendix 1 and 2**). Each diet contained > 45% corn, and MM or CGM was the major protein source. Crude protein from MM and meat-and-bone meal accounted for 77 and 3%, respectively of the total crude protein for the MM diet. For the CGM diet, crude protein from CGM was 80% of the total crude protein. It was our intention that **sodium (Na)**, **calcium (Ca)**, **phosphorus (P)**, and **chloride (Cl)** contents would be identical between the 2 diets; this would be accomplished by the addition of NaCl as well as Ca and P salts. Both diets contained concentrations of crude protein, acid-ether extract, Ca, P, and **magnesium (Mg)** that were at or above amounts recommended by the **Association of American Feed Control Officials (AAFCO)** for maintenance.[9] Dietary base excess[10] calculated as 2[Ca] + 2[Mg] + [Na] + [K] – 2[P] – 2[methionine] – [Cl] was slightly lower for the CGM diet. A positive relationship between dietary base excess and urinary pH has been described,[11] but the difference in dietary base excess between the MM and CGM diets was too small to cause a clear difference in urinary pH.[10]

Procedure—Cats were used in a crossover study. Cats

were randomly assigned to be fed 1 of the diets for a period of 3 weeks. After an interval of 5 days, the cats were then fed the other diet for a period of 3 weeks. Although the AAFCO recommends a precollection or adaptation period of 5 days followed by a 5-day period for collection of feces, which is then used to determine digestibility of dog and cat foods, it was suggested in another study[12] that cats require a longer adaptation period than dogs. To measure availability of nutrients in cats, it is recommended that diets be fed for a period of 3 weeks.[13] Diets and water were available ad libitum throughout the study. Fresh food was provided daily at 4 PM. Intake of food and water was recorded each day, and BW was measured weekly.

For the last 7 days of each dietary period, feces and urine were collected daily at 4 PM. Urine was collected in a bottle containing 10 ml of 10% (vol:vol) sulfuric acid to prevent loss of ammonia and to prevent electrolytes from forming crystals, except when freshly voided urine was collected. In addition, we collected the first urine voided after 5 AM on each of the last 7 days of each dietary period and used it to measure urinary pH, number of crystals, and sediment concentrations.

Analysis of samples—Amino acid concentrations of each diet were determined by use of an amino acid analyzer.[a] Samples were treated with performic acid for 16 hours, and then they were hydrolyzed with 20% (wt:vol) hydrochloric acid for 16 hours at 135 C. Feces excreted for the sampling period were pooled for each cat. Aliquots of pooled feces were dried at 135 C for 2 hours[14] or oven dried at 70 C for 5 days prior to chemical analysis. Daily excretion of nutrients in feces was calculated from nutrient contents in air-dried feces and dry-matter contents of pooled and air-dried feces.

Urine samples collected during the sample collection period were pooled for each cat and stored at –20 C until analyzed. Urinary N and nitrogenous compounds were analyzed as described elsewhere.[4] Analysis of urinary minerals and calculation of **ammonium ion (NH_4^+)**, **phosphoric acid ion (PO_4^{3-})**, and struvite activity product were performed as described elsewhere.[15] For convenience, struvite activity product was expressed as the **negative logarithm of struvite activity product (pSAP)**. Urinary pH was measured by use of glass pH electrodes.[b] Number of struvite crystals in urine was counted by use of light microscopy.

The amount of sediment in freshly voided urine was determined by use of the following procedure. After centrifugation[c] (12,000 × g for 20 minutes at 4 C), sediment was air dried at 45 C for 24 hours, and the resulting dried sediment was weighed. Sediment was further fractionated by extraction with 1 N HCl for 24 hours at 25 C, and the HCl-insoluble sediment was measured as described previously. The amount of HCl-soluble fraction of the urine was determined by subtracting the amount of HCl-insoluble sediment from the total amount of sediment. Similar to other studies,[16-18] protein of 95 to 100 kd was detected by use of sodium dodecyl sulfate-polyacrylamide gel electrophoresis. Protein was evident in urinary sediment and the HCl-insoluble fraction of the sediment, but it was not detected in the HCl-soluble fraction. In view of the extraction procedure, the HCl-soluble sediment is believed to be the mineral fraction of urinary sediment. Acidification of urine can cause struvite crystals to solubolize,[7] and D,L-methionine supplementation of dry food can result in urinary acidification and a decrease in the amount of HCl-soluble sediment but not the amount of HCl-insoluble sediment.[19]

Data analysis—Data were analyzed by use of an ANOVA,[20] using a computer-based statistical program.[d] The model included diet, cat, and period. Results were considered significant at $P < 0.05$.

Results

All cats appeared to be healthy and did not manifest clinical abnormalities throughout the study. Change in BW, daily intake of food and water, urine volume, dry-matter digestibility, and fecal moisture content were determined for each diet (**Table 1**). Changes in BW for the CGM diet had a negative value in contrast to a positive value for the MM diet; however, the difference between diets was not significant ($P = 0.13$). Daily food intake was significantly higher for the MM diet, probably because of the higher palatability of MM than CGM. Daily water intake was higher, but not significantly so ($P = 0.16$), for cats when fed the MM diet. Dry-matter digestibility also was higher for the MM diet. Fecal moisture content for cats when fed the CGM diet (63.2%) was comparable with the value (63.7%) reported in another study.[4] Although feces of cats for the MM diet were not loose or diarrheic, fecal moisture content was higher, but not significantly so ($P = 0.08$), for the MM diet, compared with the CGM diet.

The N balance was determined for the MM and CGM diets (**Table 2**). Consistent with daily food intake, daily N intake for the MM diet was significantly higher than for the CGM diet. In contrast, fecal and urinary excretion of N for cats when fed the CGM diet was comparable with values for cats when fed the MM diet. As a result, apparent N absorption and N retention for the MM diet were significantly higher than for the CGM diet. When N balance was expressed as a percentage of N intake to account for differences in N intake, N retention was still higher for the MM diet.

Table 1—Mean values for several variables in 8 cats fed a commercial dry diet containing meat meal (MM) and a commercial dry diet containing corn gluten meal (CGM)

Variable	MM	CGM	SEM	*P*
Change in BW (g/d)	14.8	–18.1	9.5	NS
Food intake (g/kg of BW/d)	21.2	16.1	1.1	0.02
Water intake (ml/kg of BW/d)	42.5	36.0	2.7	NS
Urine volume (ml/kg of BW/d)	15.1	12.5	1.4	NS
Dry-matter digestibility (%)	79.3	71.6	0.9	0.001
Fecal moisture content (%)	65.3	63.2	0.7	NS

BW = Body weight. NS = Not significant at a value of $P < 0.05$.

Table 2—Mean values of nitrogen (N) balance in 8 cats fed a commercial dry diet containing MM and a commercial dry diet containing CGM

Variable	MM	CGM	SEM	*P*
N (g/kg of BW/d)				
Intake	0.91	0.70	0.05	0.03
Feces	0.21	0.21	0.18	NS
Urine	0.44	0.39	0.02	NS
Absorbed	0.70	0.49	0.03	0.004
Retained	0.26	0.10	0.02	0.001
Percentage of N intake				
Feces	22.3	29.7	1.0	0.002
Urine	48.9	55.7	2.3	NS
Absorbed	77.7	70.3	1.0	0.002
Retained	28.8	14.6	2.0	0.003
Percentage of N absorbed that was retained	37.0	20.2	3.0	0.008

See Table 1 for key.

The increase in N retention was attributed to the decrease in N excretion in feces and urine.

Relative urinary N of the nitrogenous compounds expressed as a percentage of total urinary N in cats when fed diets containing MM or CGM was calculated (**Table 3**). More than 80% of the total urinary N was excreted in the form of urea. Although it was not significantly different, the percentage of urea N in relation to total urinary N for the CGM diet was 3% less than that for the MM diet. In contrast, the percentage of urinary ammonia N was 4% higher for the CGM diet, which was significantly different from the percentage for the MM diet. As a result, the sum of the percentages of urea N and ammonia N was quite comparable for the 2 diets. The percentage of creatinine was significantly higher for the MM diet.

Urinary pH, urinary concentration of struvite constituents, pSAP, number of urinary struvite crystals, and urinary sediment concentration in cats were determined for the MM and CGM diets (**Table 4**). Although urinary concentrations of Mg were higher for the MM diet and urinary concentrations of NH_4^+ were higher for the CGM diet, the differences were minimal, and pSAP was similar for the 2 diets. In addition, urinary pH, number of struvite crystals, and urinary sediment concentrations were not significantly different between the diets. Urinary pH of all cats was < 6.7, which is a critical value for formation of struvite crystals.[7] In fact, there were few struvite crystals in the urine.

Table 3—Urinary N excretion of nitrogenous compounds relative to the total N in 8 cats fed a commercial dry diet containing MM and a commercial dry diet containing CGM

Nitrogenous compound (%)	MM	CGM	SEM	*P*
Urea	85.8	82.5	1.4	NS
Ammonia	10.0	14.1	0.8	0.02
Creatinine	4.6	3.3	0.2	0.004
Creatine	0.08	0.07	0.02	NS
Total	**100.5***	**99.9***	**1.7**	**NS**

*Total did not equal 100% because of rounding of values.
See Table 1 for remainder of key.

Table 4—Urinary pH, urinary concentrations of struvite constituents, negative logarithm of struvite activity product (pSAP), urinary struvite crystals, and urinary sediment in 8 cats fed a commercial dry diet containing MM and a commercial dry diet containing CGM

Variable	MM	CGM	SEM	*P*
pH	6.11	6.14	0.06	NS
Magnesium (m*M*)	3.12	1.98	0.30	0.04
Ammonium ion (m*M*)	227.50	348.90	14.60	0.002
Total phosphorus (m*M*)	143.60	136.40	8.30	NS
Phosphoric acid ion ($\times 10^{-3}$ m*M*)	0.15	0.16	0.04	NS
pSAP	10.17	10.11	0.12	NS
Struvite crystals (No./µl of urine)	1.20	0.70	0.40	NS
Sediment (mg/ml of urine)				
HCl-soluble	6.55	5.75	0.56	NS
HCl-insoluble	1.38	1.35	0.11	NS
Total	**7.92***	**7.10**	**0.66***	**NS**

*Total value was affected because of rounding of values.
See Table 1 for remainder of key.

Mineral balance was determined for cats when fed the MM and CGM diets (**Table 5**). Daily intake of Ca, P, and Mg was higher for the MM diet than for the CGM diet. For Ca balance, Ca was primarily excreted in the feces, and fecal excretion of Ca was similar between the 2 diets, leading to less Ca retention for the CGM diet. In fact, Ca retention for the CGM diet had a negative value, indicating net Ca loss. For P balance, fecal excretion was comparable between the 2 diets. Although urinary P excretion was higher for the MM diet than for the CGM diet, the extent of the difference was smaller than that of P intake, and the urinary P-to-P intake ratio was similar for the 2 diets. As a result, P retention for the MM diet was higher than that for the CGM diet. Similar to Ca excretion, the main route of excretion for Mg was via the feces. Fecal excretion of Mg for the CGM diet was more than Mg intake, leading to net Mg loss. In contrast, Mg retention for the MM diet had a positive value, although fecal and urinary excretion of Mg was higher for the MM diet than for the CGM diet.

Discussion

Commercial dry foods formulated for cats generally contain cereals as a starch source necessary for extrusion processing. Furthermore, plant ingredients are also used as a protein source because of their low cost. In the study reported here, we performed a nutritional evaluation of CGM and MM, both of which are often used as protein sources for commercial dry foods. Cats consumed more of the MM diet than the CGM diet, resulting in higher intakes of N and some macrominerals. In addition, the MM diet provided higher digestibility and utilization of nutrients. These 2 effects led to higher retention of nutrients in cats when fed the MM diet. Analysis of our results suggests that animal-origin MM is nutritionally superior to plant-origin CGM as a dietary protein source for adult cats.

The CGM diet had a deleterious effect on protein

Table 5—Mineral balance in 8 cats fed a commercial dry diet containing MM and a commercial dry diet containing CGM

	Calcium balance				Phosphorus balance				Magnesium balance			
Variable	**MM**	**CGM**	**SEM**	***P***	**MM**	**CGM**	**SEM**	***P***	**MM**	**CGM**	**SEM**	***P***
Intake (g/kg of BW/d)	225.5	173.7	12.1	0.03	180.8	138.8	9.7	0.03	16.1	9.5	0.8	0.001
Feces (g/kg of BW/d)	197.0	196.5	16.2	NS	89.6	87.2	6.2	NS	12.7	9.7	0.8	0.04
Urine (g/kg of BW/d)	0.10	0.09	0.03	NS	58.7	46.6	3.3	0.05	1.0	0.5	0.1	0.03
Retained (g/kg of BW/d)	28.3	–22.9	7.6	0.004	32.5	5.0	4.1	0.004	2.4	–0.7	0.6	0.02
Feces (% of intake)	87.7	113.4	4.5	0.007	49.7	63.3	2.4	0.008	79.2	102.8	4.6	0.02
Urine (% of intake)	0.05	0.04	0.01	NS	32.6	33.7	1.0	NS	6.3	5.7	0.5	NS
Retained (% of intake)	12.3	–13.4	4.5	0.007	17.6	3.0	2.5	0.007	14.5	–8.5	4.9	0.02

See Table 1 for key.

nutrition. The N balance analysis suggested that this deterioration resulted from lower digestibility and lower utilization of absorbed N, although the reason why the CGM diet had lower digestibility of crude protein is unclear. Lower utilization of absorbed N in cats when fed the CGM diet indicates the lower biological value of CGM protein, compared with the biological value for MM. The ratio of urinary ammonia N to total urinary N was higher for the CGM diet than the MM diet, although the ratio of the sum of urea N plus ammonia N to total N was similar for the 2 diets. Analysis of these results suggests lower activity of the urea cycle in cats for the CGM diet. Arginine content was lower in the CGM diet than in the MM diet (Appendix 1). Unlike other mammals, cats readily develop arginine deficiency, because arginine synthesis for the urea cycle is lower in the kidneys of cats,[2,21,22] and arginine is a dietary essential even in adult cats.[23] Thus, the MM diet should be better than the CGM diet for maintaining activity of the urea cycle in adult cats.

Compared with results for the MM diet, cats lost body Ca and Mg when fed the CGM diet, although the dietary mineral contents met the nutrient contents proposed by the AAFCO.[6] Analysis of the results of the study reported here indicated that dietary mineral requirements increase when CGM is used as a protein source. Lower bioavailability of minerals in plant-origin ingredients is recognized in monogastric animals including rats, pigs, and chicks, because these ingredients contain substantial amounts of phytic acid and oxalic acid that disturb absorption of minerals.[24-27] In addition, it is possible that the bioavailability of minerals was better for the MM diet than for the CGM diet. In rats, bioavailability of minerals from meat-and-bone meal is better than that from inorganic mineral supplements.[28]

The dietary protein source did not affect urinary pH, pSAP, number of urinary struvite crystals, or sediment concentrations in urine. These results suggest that both diets had a similar effect in preventing formation of struvite crystals. Diets for true carnivores have a urine-acidifying effect, because high amounts of sulfur-containing amino acids are contained in meat.[5] Oxidation of these amino acids results in the excretion of sulfate in the urine and a concomitant decrease in urine pH.[29] In contrast, a diet containing a large amount of cereal grains can result in alkaline urine, because potassium salts that are abundant in most vegetable ingredients usually contribute to the production of alkaline urine when metabolized.[30,31]

However, CGM is unusual in that it is a cereal protein that has a strong acidifying effect on urine when fed to cats.[5] Unlike most plant protein sources, CGM contains high amounts of sulfur-containing amino acids. In the study reported here, the CGM diet contained higher amounts of methionine and cystine than the MM diet (Appendix 2). Solubilization of struvite crystals relates to struvite activity product, (ie, $[Mg] \times [NH_4^+] \times [PO_4^{3-}]$), and complete solubilization is achieved at a pH below 6.7.[7] Urinary pH was < 6.7 for both diets, and only a few struvite crystals were detected in the urine. The urinary HCl-insoluble fraction contained an organic substance similar to the Tamm-Horsfall glycoprotein,[18] which may act as an organic matrix needed for the development of struvite uroliths in cats.[16,17] Excess acidification of urine increases the risk of Ca oxalate urolithiasis.[11,32] However, it is unlikely that the diets used in the study reported here caused the production of Ca oxalate uroliths, because Ca oxalate crystals were not seen in the urine (data not shown), and because urinary excretion of Ca was low (< 1% of Ca intake).

In another study[4] conducted by our laboratory group, we documented that FM was nutritionally equivalent to CGM as a dietary protein source for adult cats with regard to apparent digestibility of nutrients and N balance. However, FM was suggested to be a better protein source than CGM for the prevention of struvite urolithiasis, because organic materials in the urinary sediment increase in cats fed the CGM diet. Considering the results of that study and the results of the study reported here, we recommend the use of a mixture of MM and FM as dietary protein sources for healthy adult cats from the aspect of health and nutrition. Because most commercial dry foods use a combination of plant and animal proteins, effects of currently available dry foods on nutritional status of cats are not definitive. Nevertheless, it is reasonable to support the notion that animal-origin ingredients are better than plant-origin ingredients in dry foods formulated for cats.

[a]MLC-203, Atto, Tokyo, Japan.
[b]HM-30S, Toa, Tokyo, Japan.
[c]H1500FR, Kokusan, Tokyo, Japan.
[d]SAS, release 8.2, SAS Institute Inc, Cary, NC.

References

1. MacDonald ML, Rogers QR, Morris JG. Nutrition of the domestic cat, a mammalian carnivore. *Annu Rev Nutr* 1984;4:521–562.

2. Morris JG, Rogers QR. Comparative aspects of nutrition and metabolism of dogs and cats. In: Burger IH, Rivers JPW, eds. *Nutrition of the dog and cat*. Cambridge, UK: Cambridge University Press, 1989;35–66.

3. Baker DH. Comparative nutrition of cats and dogs. *Annu Rev Nutr* 1991;11:239–263.

4. Funaba M, Tanaka T, Kaneko M, et al. Fish meal vs. corn gluten meal as a protein source of dry cat food. *J Vet Med Sci* 2001;63: 1355–1357.

5. Case LP, Carey DP, Hirakawa DA. Feline lower urinary tract disease. *Canine and feline nutrition*. St Louis: Mosby Year Book Inc, 1995;357–371.

6. Lewis LD, Morris ML. Diet as a causative factor of feline urolithiasis. *Vet Clin North Am Small Anim Pract* 1984;14:513–527.

7. Buffington CA, Cook NE, Rogers QR, et al. The role of diet in feline urolithiasis syndrome. In: Burger IH, Rivers JPW, eds. *Nutrition of the dog and cat*. Cambridge, UK: Cambridge University Press, 1989;357–380.

8. National Research Council. *Guide for the care and use of laboratory animals*. Washington, DC: National Academy Press, 1996.

9. Association of American Feed Control Officials. *Official publication*. San Diego, Calif: Association of American Feed Control Officials Inc, 2001.

10. Kienzle E, Schuknecht A, Meyer H. Influence of food composition on the urine pH in cats. *J Nutr* 1991;121:87S–88S.

11. Markwell PJ, Buffington CT, Smith BH. The effect of diet on lower urinary tract diseases in cats. *J Nutr* 1998;128:2753S–2757S.

12. Nott HMR, Rigby SI, Johnson JV, et al. Design of digestibility trials for dogs and cats. *J Nutr* 1994;124:2582S–2583S.

13. Edney ATB. Biological trial procedures in dog and cat nutrition. In: Edney ATB, ed. *The Waltham book of dog and cat nutrition*. Oxford, UK: Pergamon Press, 1988;121–128.

14. Association of Official Analytical Chemists. *Official methods*

of analysis. 16th ed. Arlington, Va: Association of Official Analytical Chemists, 1995.

15. Funaba M, Hashimoto M, Yamanaka C, et al. Effects of a high-protein diet on mineral metabolism and struvite activity product in clinically normal cats. *Am J Vet Res* 1996;57:1726–1732.

16. Rhodes DCJ, Hinsman EJ, Rhodes JA, et al. Urinary Tamm-Horsfall glycoprotein concentrations in normal and urolithiasis-affected male cats determined by an ELISA. *Zentralbl Veterinarmed [A]* 1992;39:621–634.

17. Buffington CA, Blaisdell JL, Sako T. Effects of Tamm-Horsfall glycoprotein and albumin on struvite crystal growth in urine of cats. *Am J Vet Res* 1994;55:965–971.

18. Yamate T, Funaba M, Iriki T, et al. A preliminary study on fractionation of urinary protein in healthy cats. *J Pet Anim Nutr* 2001;4:78–80.

19. Funaba M, Yamate T, Narukawa Y, et al. Effect of supplementation of dry cat food with D,L-methionine and ammonium chloride on struvite activity product and sediment in urine. *J Vet Med Sci* 2001;63:337–339.

20. The GLM procedure. In: *SAS/STAT user's guide, release 6.11*. Cary, NC: SAS Institute Inc, 1996;891–996.

21. Morris JG. Nutritional and metabolic responses to arginine deficiency in carnivores. *J Nutr* 1985;115:524–531.

22. Levillain O, Parvy P, Hus-Citharel A. Arginine metabolism in cat kidney. *J Physiol* 1996;491:471–477.

23. National Research Council. *Nutrient requirements of cats*. Washington, DC: National Academy Press, 1986.

24. Kikunaga S, Ishii H, Takahashi M. The bioavailability of magnesium in spinach and the effect of oxalic acid on magnesium utilization examined in diets of magnesium-deficient rats. *J Nutr Sci Vitaminol (Tokyo)* 1995;41:671–685.

25. Hirabayashi M, Matsui T, Yano H, et al. Fermentation of soybean meal with *Aspergillus usamii* reduces phosphorus excretion in chicks. *Poult Sci* 1998;77:552–556.

26. Matsui T, Nakagawa Y, Tamura A, et al. Efficacy of yeast phytase in improving phosphorus bioavailability in a corn-soybean meal-based diet for growing pigs. *J Anim Sci* 2000;78:94–99.

27. Kamao M, Tsugawa N, Nakagawa K, et al. Absorption of calcium, magnesium, phosphorus, iron and zinc in growing male rats fed diets containing either phytate-free soybean protein or soybean protein isolate or casein. *J Nutr Sci Vitaminol (Tokyo)* 2000;46:34–41.

28. Miura T, Nakano M. Calcium bioavailability of a total bone extract (TBE) and its effects on bone metabolism in rats. *Biosci Biotechnol Biochem* 1998;62:1307–1312.

29. Kane E, Douglass GM. The effects of feeding a dry commercial cat food on the urine and blood acid-base balance of cat. *Feline Pract* 1986;16:9–13.

30. Harrington JT, Lemann J. The metabolic production and disposal of acid and alkali. *Med Clin North Am* 1970;54:1543–1554.

31. Chan JCM. Nutrition and acid-base metabolism. *Fed Proc* 1981;40:2423–2428.

32. Kirk CA, Ling GV, Franti CE, et al. Evaluation of factors associated with development of calcium oxalate urolithiasis in cats. *J Am Vet Med Assoc* 1995;207:1429–1434.

Appendix 1

Dietary ingredients of 2 commercial dry diets fed to 8 adult cats

	Diet	
Ingredients (g/kg of diet)*	**MM**	**CGM**
Meat meal	285	0
Meat-and-bone meal	20	0
Corn gluten meal	0	366
Corn	569	477
Cellulose powder	15	15
Beef tallow	35	50
Vitamins and minerals†	20	20
NaCl	0	3
$Ca(PO_4)_2$	16.5	32
H_3PO_4	9.5	7
Flavor‡	30	30

*Determined on an as-fed basis. †One kilogram of the vitamin and mineral mixture contained 22,500 IU of vitamin A, 35 g of vitamin E, 2.2 g of vitamin B_1, 2.3 g of vitamin B_2, 1.6 g of vitamin B_6, 8.5 mg of vitamin B_{12}, 20 g of nicotinic acid, 5 g of pantothenic acid, 22 mg of biotin, 185 g of chlorine, 10 g of inositol, 450 mg of folic acid, 600 mg of manganese, 6.5 g of iron, 33 mg of cobalt, 420 mg of copper, 500 mg of iodine, and 500 mg of taurine. ‡Spray-dried fish extract.

MM = Meat meal. CGM = Corn gluten meal.

Appendix 2

Composition of 2 commercial dry diets fed to 8 adult cats

	Diet	
Component	**MM**	**CGM**
Metabolizable energy (kcal/100 g)	344.0	371.0
Crude protein (% of dry matter)	32.6	32.5
Acid ether extract (% of dry matter)	9.1	10.0
Crude fiber (% of dry matter)	2.5	2.6
Nitrogen-free extract (% of dry matter)	50.5	48.4
Sodium (% of dry matter)	0.33	0.36
Potassium (% of dry matter)	0.34	0.22
Calcium (% of dry matter)	1.17	1.19
Phosphorus (% of dry matter)	0.94	0.95
Magnesium (% of dry matter)	0.08	0.07
Chloride (% of dry matter)	0.33	0.29
Amino acids (% of dry matter)		
Arginine	1.80	0.99
Cystine	0.30	0.56
Histidine	0.49	0.61
Isoleucine	0.81	1.13
Leucine	1.94	4.52
Lysine	1.31	0.55
Methionine	0.44	0.63
Phenylalanine	0.98	1.73
Threonine	0.89	0.98
Tryptophane	0.25	0.17
Tyrosine	0.73	1.52
Valine	1.27	1.32
Base excess (mmol/kg of dry matter)*	121.0	85.0

*Base excess was calculated as 2[Ca] + 2[Mg] + [Na] + [K] – 2[P] – 2[methionine] – [Cl].