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STANDARD ARTICLE

Evaluation of phosphorus, calcium, and magnesium content in commercially available foods formulated for healthy cats

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Abstract

Background: High dietary phosphorus (P) and low calcium-to-phosphorus ratio (Ca:P) are associated with kidney damage in cats. There are no established guidelines for dietary P maximum for cats.

Objectives: To quantify crude protein, P, Ca, and magnesium (Mg) concentrations in cat foods and compare among food formats (dry, canned, raw), primary protein ingredients, protein concentrations (low, moderate, high), grain-free versus grain-containing foods, foods intended for adult maintenance versus all life stages, and cost.

Samples: Eighty-two commercial nonprescription cat foods.

Methods: Descriptive study. Mineral concentrations were measured using inductively coupled argon plasma-optical emission spectroscopy. Crude protein was measured using the Dumas nitrogen combustion method. Mineral and crude protein concentrations were compared among food categories.

Results: Twenty-seven foods contained ≥3.6 g P/1000 kcal metabolizable energy (ME), of which 7 exceeded 4.8 g/1000 kcal ME. Thirteen foods had low Ca:P ratio (≤1.0). The low-protein diet group had no products ≥3.6 g P/1000 kcal ME, which was significantly different compared to the high-protein diet group (52% of products had ≥3.6 g P/1000 kcal ME; $P = .01$). No significant differences in P content and Ca:P ratio were found among other diet categories. Canned foods had significantly lower Mg compared to dry ($P < .001$) and raw ($P = .007$) foods. Declared minimum P and Ca were significantly lower than analyzed concentrations ($P = .0005$ and $P = .003$, respectively).

Conclusions and Clinical Importance: The high number of foods with high P and low Ca suggest that pet food regulatory reform should be considered.

KEYWORDS
adult, calcium, commercial, diets, feline, foods, phosphorus

1 | INTRODUCTION

Chronic kidney disease (CKD) is common in geriatric cats.[1-3] Evidence suggests that high dietary phosphorus (P), particularly inorganic P,

Abbreviations: Ca, calcium; Ca:P, calcium-to-phosphorus ratio; CKD, chronic kidney disease; ME, metabolizable energy; P, phosphorus.

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may be a contributing factor in the development of CKD in adult cats. One study evaluated adult healthy cats fed a home-cooked diet supplemented with inorganic P (monophosphate) and containing 3.0 g P/1000 kcal of metabolizable energy (ME) with a low calcium-to-phosphorus (Ca:P) ratio of 0.4 for 4 weeks. The study diet resulted in transient changes in renal function including decreased endogenous creatinine clearance, glucosuria, and microalbuminuria.[4] In another study,[5] adult cats fed extruded dry foods containing P in excess of 3.6 g/1000 kcal ME and with low Ca:P ratio (<1.0) resulted in decreased glomerular filtration rate, increased serum creatinine concentration, renal echogenicity changes on ultrasonography, and nephrolithiasis within 28 weeks in comparison to adult cats fed a control food with 1.2-1.3 organic P per 1000 kcal ME. The same report documented more significant renal impairment in cats fed an extruded diet with 4.8 g P/1000 kcal ME and a Ca:P ratio of 0.6 for 4 weeks. Additionally, dietary magnesium (Mg) intake impacts P and Ca bioavailability in people and cats, but little is known about the metabolic mechanism involved in cats.[6,7]

Dietary minimum requirements for dietary P, Ca, and Mg in cats are established as well as regulatory minimums for commercial cat foods (Appendix). Currently, no dietary Ca and P maximums are cited in widely accepted nutrition guidelines for cats including the National Research Council (NRC),[8] the Association of American Feed Control Officials (AAFCO),[9] and the European Pet Food Industry Federation (FEDIAF).[10] Despite established maximum dietary Ca and P guidelines for growing dogs provided by AAFCO, a study evaluating the total amount of P and Ca in commercially available dry foods formulated for adult maintenance showed that some products exceeded these amounts.[11]

A gap in information exists regarding the typical intake of P, Ca, and Mg by pet cats, because a large-scale evaluation of these minerals in commercial cat foods has not been reported. Therefore, our objective was to quantify the P, Ca, and Mg concentrations in commercially available cat foods. Our primary aim was to compare mineral concentrations among different food formats (dry, canned, and raw foods), primary protein ingredient categories (poultry, fish, beef, and nontraditional), protein concentration categories (low, moderate, and high), and food cost. Our secondary aim was to compare analyzed P and Ca concentrations with the minimum amounts reported on product labels. We hypothesized that commercial cat foods would have total P of ≥3.6 g P/1000 kcal ME and Ca:P ratios ≤1.0, and that this finding would be more frequent in canned foods and in foods containing nontraditional protein ingredients. We hypothesized that there would be an inverse relationship between food cost and mineral concentration and that the analyzed P and Ca concentrations would be higher than the minimum concentration reported by the manufacturer.

2 | MATERIALS AND METHODS

In this descriptive study, cat foods labeled for adult maintenance (1+ years) or all life stages were identified at local pet food stores (n = 3) and a grocery store (n = 1) in the Fort Collins, Colorado area. The foods (dry, n = 66; canned, n = 77; raw, n = 34) were grouped according to food format (dry, canned, or raw) and an online randomization tool was used to select 82 products that then were purchased. Raw food was defined as any food containing uncooked fresh, dehydrated, or frozen animal products. The percentage Ca and P "as fed" minimum concentration was recorded from the product label when available. The cost of the food per ounce and the AAFCO nutritional adequacy statement from the product label for each food were recorded.

2.1 | Sample preparation

All samples were aliquoted and stored in numbered containers before analysis. The aliquots were coded so that laboratory technicians were blinded to food identity and other labeling information. Dry samples were stored at room temperature and analyzed within 2 weeks after purchase. High-moisture frozen and canned foods were thawed if needed, aliquoted, and shipped on ice overnight. All samples were sent to a commercial laboratory (Midwest Laboratory, Omaha, Nebraska) validated for pet food analysis.

2.2 | Food analysis

Each food sample was homogenized before analysis. Food analysis using previously validated methods[12] included proximate analysis (crude protein, crude fat, crude fiber, moisture, and ash concentrations) as well as Ca, P, and Mg concentrations. The carbohydrate content (percentage) of the foods was calculated as 100 minus crude protein, crude fat, crude fiber, ash, and moisture. Measured crude protein, P, Ca, and Mg percentages were converted to g/1000 kcal ME using modified Atwater factors[13] for protein, fat, and carbohydrate to allow for comparisons among study foods. Calcium, P, and Mg concentrations were analyzed using inductively coupled argon plasma-optical emission spectroscopy using Association of Analytical Communities (AOAC) official method 985.01. Moisture, ash, crude protein, crude fat, and crude fiber were measured using AOAC official method 930.15, AOAC official method 942.05, AOAC official method 990.03 (Dumas nitrogen combustion method), AOAC official method 954.02, and AOAC official method Ba 6a-05 (Ankom filter bag technique), respectively.

2.3 | Statistical analysis

Data were analyzed using Prism (Version 8.1.0, Graph Pad Software Inc, La Jolla, California). Data sets were assessed for normality using the Shapiro-Wilk test. The analyzed P, Ca, and Mg concentrations (g/1000 kcal ME) and Ca:P ratio were compared among food formats (dry, canned, and raw [freeze- or air-dried and frozen]) and primary protein ingredient categories (poultry, fish, beef, and nontraditional [lamb, duck, quail, rabbit, venison]) using 1-way analysis of variance (ANOVA) with Tukey's post hoc analysis or Kruskal-Wallis with Dunn's multiple comparisons test. The analyzed percentage crude protein was compared among food formats, and the analyzed P concentration was compared among low-protein (<80 g/1000 kcal ME), moderate-protein (80-120 g/1000 kcal ME), and high-protein foods (>120 g/1000 kcal ME) using the Kruskal-Wallis test with Dunn's multiple comparisons test. Protein concentration categories (low, moderate, high) were arbitrarily selected according to the distribution of the products in the sample pool. A Mann-Whitney test or Student *t* test was performed to compare the analyzed crude protein, mineral concentrations, and Ca:P ratio between grain-free and grain-containing foods and between foods intended for all life stages or those for adult maintenance. A Student *t* test was performed to compare the declared minimum P and Ca "as fed" concentration on the food claim label to the analyzed percentage concentration. The percentage of foods with an analyzed P ≥3.6 g/1000 kcal ME, analyzed P ≥4.8 g/1000 kcal ME, Ca:P ratio ≤1.0, and Ca:P ratio ≥2.0 for each food format, for each primary protein ingredient category, for each protein concentration category, for grain-free and grain-containing foods, and for foods intended for all life stage and those for adult maintenance based on the AAFCO nutritional adequacy statement was calculated and Fisher's exact test was performed to determine differences among these categories. A Spearman correlation was used to analyze the relationship between the measured P concentration and food cost per ounce as well as between analyzed crude protein and P concentrations. For all analyses, a value of $P < .05$ was considered significant.

3 | RESULTS

3.1 | Food description

A total of 82 foods were purchased from local stores in the following formats: canned, n = 30 samples; dry, n = 30 samples; raw, n = 22 samples. Freeze- or air-dried (n = 11 including 2 with dry kibble containing dehydrated pieces) and frozen (n = 11) products comprised the raw group. A full list of products is provided in Supplemental Information. According to food label information, 81/82 foods had an AAFCO nutritional adequacy statement with 1 canned food labeled as cat food but having no AAFCO statement. The nutritional adequacy claims were based on formulation to meet the AAFCO Nutrient Profiles for 68/81 foods (28 foods for adult maintenance and 40 foods for all life stages), based on feeding trials for 4/81 foods (3/4 for adult maintenance and 1/4 for all life stages), and established as family members under AAFCO Pet Food Product Families procedures for 9/81 foods. Regarding the primary protein ingredient as listed first on the ingredient list, 27 foods (33%) had poultry (chicken, turkey, poultry by-product), 16 foods (20%) had fish (salmon, tuna, mackerel, unspecified fish), 12 foods (15%) had beef, and 27 foods (33%) had a nontraditional protein source (duck, lamb, quail, rabbit, or venison). Most foods (61/82; 74%) were labeled as grain-free. According to the ingredient lists, 67% (20/30) of dry foods, 83% (25/30) of canned food products, and 18% (4/22) of raw foods contained a P additive or preservative including dicalcium phosphate, dipotassium phosphate, l-ascorbyl-2-polyphosphate, phosphoric acid, sodium acid pyrophosphate, sodium hexametaphosphate, sodium phosphate, sodium tripolyphosphate, tetrasodium pyrophosphate, or tricalcium phosphate.

3.2 | Crude protein analysis

No significant difference was found in analyzed crude protein concentrations among food formats (Table 1), among primary protein ingredient categories, between grain-free and grain-containing foods, and between foods intended for all life stages and those intended for adult maintenance. The analyzed crude protein concentration for 3 foods (range, 50.3-64 g/1000 kcal) was below the AAFCO Cat Food Nutrient Profile minimum value for adult maintenance (and therefore also for growth and reproduction; Appendix Tables A1 and A2). Of the 82 samples, 9 (11%) were low protein foods, 54 (66%) were moderate protein foods, and 19 (23%) were high protein foods.

3.3 | Mineral analysis

The analyzed P, Ca, and Mg concentrations (g/1000 kcal ME) and the calculated Ca:P ratio for each food format are summarized in Table 1. No significant difference was found in analyzed mineral concentrations and Ca:P ratio among the primary protein ingredient categories or between grain-free and grain-containing foods. Low-protein foods (median, 1.8; range, 0.6-3.0 g/1000 kcal ME) had significantly lower analyzed P concentration compared to moderate-protein (median, 3.0; range, 1.6-5.8 g/1000 kcal ME) and high-protein foods (median, 3.6; range, 1.9-5.2 g/1000 kcal ME; $P < .001$). No significant difference

TABLE 1 Analyzed crude protein, phosphorus, calcium, and magnesium concentrations and calculated calcium-to-phosphorus ratio in each diet format. Data represented as median (range)

	Crude protein g/1000 kcal ME	Phosphorus g/1000 kcal ME	Calcium g/1000 kcal ME	Calcium-to-phosphorus ratio	Magnesium g/1000 kcal ME
All samples n = 82	100.5 (50.3-172.9)	3.0 (0.6-5.8)	3.9 (0.3-8.7)	1.3 (0.5-1.7)	0.3 (0.05-0.5)
Dry n = 30	95.2 (79.6-125.3)	3.1 (1.8-4.9)	3.9 (1.8-7.4)	1.3 (0.8-1.6)	0.3 (0.1-0.5)[a]
Can n = 30	103.4 (50.3-172.9)	2.8 (0.6-5.8)	3.3 (0.3-8.7)[a]	1.3 (0.5-1.7)	0.2 (0.05-0.49)[b]
Raw n = 22	106.2 (64.1-163.4)	3.1 (1.2-5.2)	4.6 (1.0-8.2)[b]	1.4 (0.8-1.6)	0.3 (0.1-0.5)[a]

Note: Rows with different superscript letters are significantly different from one another ($P < .05$).
Abbreviation: ME, metabolizable energy.

was found in the analyzed P concentrations of moderate and high protein foods (P = 1.0).

Of the 81 foods with AAFCO nutritional adequacy statements, 3 foods had analyzed P concentrations (0.6, 0.9, 1.2 g/1000 kcal ME) and Ca concentrations (0.3, 0.8, 1.0 g/1000 kcal ME) below the AAFCO Cat Food Nutrient Profile minimum value for adults (Appendix). All 81 foods had analyzed Mg concentration above the AAFCO Cat Food Nutrient Profile minimum value for adults (Appendix). Fifty of these foods (62%; 50/81) had a nutritional adequacy claim for all life stages, of which multiple products did not meet the AAFCO Cat Food Nutrient Profile minimums for growth and reproduction (Appendix), including 4 for P (range, 1.2 to 1.8 g/1000 kcal ME), 4 for Ca (range, 1.0 to 2.1 g/1000 kcal ME), and 11 for Mg (range, 0.1 to 0.2 g/1000 kcal ME). One diet with P (1.2 g/1000 kcal ME) and Ca (1.0 g/1000 kcal ME) concentrations below the AAFCO minimum for growth and reproduction underwent feeding trials for all life stages according to the AAFCO nutritional adequacy statement. The 1 cat food that lacked an AAFCO nutritional adequacy statement had P (0.6 g/1000 kcal ME) and Ca (0.3 g/1000 kcal ME) concentrations below and a Mg concentration (0.5 g/1000 kcal ME) above the AAFCO Cat Food Nutrient Profile minimum value for adult cats.

Twenty-seven foods (33%; 27/82) contained P concentrations ≥3.6 g/1000 kcal ME, and 7 of those exceeded 4.8 g/1000 kcal ME (range, 3.6-5.8 g/1000 kcal ME). Two of the 3 diets that underwent feeding trials for adult maintenance according to the AAFCO Nutritional Adequacy Statement had a P concentration of 3.6 g/1000 kcal. Although no significant difference was found in the P concentration between foods intended for adult maintenance (median, 3.0; range, 0.89-5.8 g/1000 kcal ME) and those for all life stages (median, 3.0; range, 1.2-5.2 g/1000 kcal ME; P = .21), the majority (68%; 19/28) of foods with P concentration ≥3.6 g/1000 kcal ME were in the latter category. Thirteen foods (16%) had a Ca:P ratio ≤1.0 (range, 0.5-1.0). None of the 82 study foods had Ca:P ratio >2.0. Twenty-six of 81 foods (32%) had an analyzed Mg concentration >0.32 g/1000 kcal. The Ca concentration, Mg concentration, and Ca:P ratio were not significantly different between foods intended for adult maintenance and those for all life stages.

The percentages of foods with P ≥3.6 g/1000 kcal ME, P ≥4.8 g/1000 kcal ME, and Ca:P ≤1.0 in each food category are summarized in Table 2. The low protein group had a significantly lower proportion of foods (0%) with P ≥3.6 g/1000 kcal ME in comparison to the high protein food category (52%; P = .01). No significant difference was found in proportions of foods with high P concentration (≥3.6 g or ≥4.8 g/1000 kcal ME) and low Ca:P ratio ≤1.0 among food formats, primary protein ingredient categories, and between grain-free foods and grain-containing foods.

Eighteen of 82 (22%) food labels declared a percentage minimum P; the mean claimed value (0.82% ± 0.34%) was significantly lower

TABLE 2 The percent of diets with Ca:P ≤ 1.0, P ≥ 3.6 g/1000 kcal ME, and P ≥ 4.8 g/1000 kcal ME in each diet format, in grain-free and grain-containing diets, in AAFCO nutritional profile categories, in protein ingredient categories, and in protein concentration categories

	Ca:P ≤ 1.0	P ≥ 3.6 g/1000 kcal ME	P ≥ 4.8 g/1000 kcal ME
All samples n = 82	16% (13/82)	33% (27/82)	9% (7/82)
Diet format			
Dry food n = 30	10% (3/30)	33% (10/30)	7% (2/30)
Canned food n = 30	30% (9/30)	23% (7/30)	3% (1/30)
Raw food n = 22	5% (1/22)	45% (10/22)	18% (4/22)
Grain inclusion/exclusion			
Grain-free n = 61	16% (10/61)	38% (23/61)	11% (7/61)
Grain-containing n = 21	14% (3/21)	19% (4/21)	0% (0/21)
AAFCO nutritional profile			
Adult maintenance n = 31	19% (6/31)	25% (8/31)	3% (1/31)
All life stages n = 50	14% (7/50)	38% (19/50)	12% (6/50)
Primary protein ingredient			
Poultry n = 27	11% (3/27)	22% (6/27)	4% (1/27)
Fish n = 16	31% (5/16)	31% (5/16)	0% (0/16)
Beef n = 12	25% (3/12)	42% (5/12)	25% (3/12)
Nontraditional n = 27	7% (2/27)	41% (11/27)	11% (3/27)
Protein concentration categories			
Low protein n = 9	33% (3/9)	0% (0/9)[a]	0% (0/9)
Moderate protein n = 54	13% (7/54)	31% (17/54)	9% (5/54)
High protein n = 19	16% (3/19)	52% (10/19)[b]	11% (2/19)

Note: Rows with different superscript letters are significantly different from one another (P < .05).
Abbreviations: Ca, calcium; Ca:P, calcium-to-phosphorus ratio; ME, metabolizable energy; P, phosphorus.

than the analyzed concentration (1.0% ± 0.37%; P = .0005). Likewise, 19/82 (23%) food labels declared the percentage minimum Ca; the mean claimed value (1.06% ± 0.50%) was significantly lower than the analyzed concentration (1.36% ± 0.56%; P = .003). Three food labels declared percentage maximums P and Ca concentrations on the package label claim and had analyzed P and Ca concentrations below the label claims.

A correlation was found between the analyzed crude protein and P concentrations (P < .00001; r = 0.43). No correlation was found between the analyzed P concentration and the cost per ounce of the foods (P = .38).

4 | DISCUSSION

As expected, our study found that commercial cat foods contain a highly variable amount of total P and Ca and therefore also have variable Ca:P ratios. The analyzed P in foods ranged from below the established AAFCO minimum requirement for maintenance to amounts that have been experimentally shown to cause renal dysfunction in healthy cats (range, 0.63-5.75 g/1000 kcal ME). Of concern, 33% of all study diets (27/82) had a P content ≥3.6 g/1000 kcal. It was hypothesized that canned foods and nontraditional protein food categories would have a higher proportion of foods with total P ≥3.6 g P/1000 kcal ME and Ca:P ratios ≤1.0 because of P-containing salts and additives used for hydration or higher bone ash, respectively, but this hypothesis was not confirmed in our study. As expected, the high-protein food category had a higher proportion of foods with a total P content previously shown to cause renal dysfunction in healthy cats (P ≥3.6 g/1000 kcal ME).[5] The analyzed P and crude protein concentrations were correlated, which supports that a substantial amount of dietary P is provided by protein sources and associated bone ash rather than added inorganic P salts. Conversely, an inverse Ca:P ratio might indicate a higher proportion of added P salts in some foods. Of the 82 study foods, 7 foods (9%) contained concentrations of total P (≥4.8 g/1000 kcal) that previously were demonstrated to cause a rapid decline in renal health in adult cats when most of the P was provided by inorganic P sources.[5] Of these 7 foods with total P ≥4.8 g/1000 kcal ME, most (4/7; 57%) were raw foods, which is possibly attributable to these foods being high in protein and possibly bone derivatives, the main source of organic P in pet food. We hypothesized that food cost would negatively correlate with dietary P concentrations, but we did not find a correlation between food pricing and analyzed P concentrations. Therefore, we cannot conclude that less expensive foods, which might include raw materials of lesser quality and higher ash content, are higher in P than higher priced products. The limitation to this observation is that the cost of the final product may have little to do with the cost of the raw materials.

Excessive intake of inorganic P has been documented to induce renal damage in humans,[14,15] rodent models,[16] dogs,[17] and cats.[4,5,18] Phosphate nephropathy in people may result in chronic renal insufficiency.[19,20] Acute phosphate nephropathy on histopathology is characterized as acute tubular injury with accumulation of Ca and phosphate crystals within tubular lumens. In the chronic phase, the predominant finding is tubular atrophy and interstitial fibrosis with mild lymphoplasmacytic interstitial inflammation.[21] These histopathological findings are similar to those found in cats with CKD.[22] High P-containing foods might be involved in the etiology of CKD in cats considering that CKD cats have significantly higher P and protein intakes before diagnosis compared to age-matched control cats without CKD.[23]

Diets with a low Ca:P ratio (<1.3) can have several adverse effects on parathyroid hormone regulation and bone density. In animal models, a low Ca:P ratio diet caused nutritional secondary hyperparathyroidism, loss of bone, and osteopenia.[24,25] In women, habitual consumption of diets with low Ca:P ratios caused higher serum parathyroid concentrations and increased bone resorption.[26] In our study, a small proportion of the adult cat foods (13/81; 16%) had a low Ca:P ratio (≤1.0). Of these 13 diets, 4 diets (31%) had a Ca content below the AAFCO minimum based on the designated nutrient profile for the diet (adult maintenance or all life stages) and 3 diets (23%) had a P content ≥3.6 g/1000 kcal. None of the 13 diets with low Ca:P ratio had both a low Ca concentration and a P content ≥3.6 g/1000 kcal. This finding shows that some diets have acceptable Ca and P content, yet still have low Ca:P ratios. In addition to avoiding excessive P dietary content in cat foods, manufacturers should monitor the Ca:P ratios in commercial diets to avoid ratios <1.0 that may cause mineral bone disorders in healthy cats or exacerbate renal secondary hyperparathyroidism in cats with unidentified renal disease.[27]

Although there are no globally accepted established dietary maximums for P and Ca in cats by AAFCO, NRC, or FEDIAF; the NRC 2006 publication does state expected safe upper limit (SUL) ranges for Ca and P.[8] The SUL for P in cats is stated, as expected, in a range of 2.5-3.5 g/1000 kcal, for a reasonable Ca:P ratio between 0.5 and 1.5 and high P bioavailability. In our study, 33% of foods exceeded 3.5 g/1000 kcal. The NRC stated that the SUL for Ca in cats may be between 2.6 and 4.6 g/1000 kcal. This statement is based on feeding studies performed in growing cats in which changes in food intake and bone density were noted with high Ca intake.[28,29] In our study, 32% (26/82) of foods had a Ca content ≥4.6 g/1000 kcal (range, 4.7-8.7 g/1000 kcal). Of the 26 foods with a Ca content ≥4.6 g/1000 kcal, 85% (22/26) also had a P content ≥3.6 g/1000 kcal. Despite these suggested ranges, the NRC did not establish maximums for either Ca or P, which may be falsely interpreted as indicating no need for dietary maximums for these nutrients.

For both Ca and P, the analyzed concentration often exceeded the minimum concentration declared on the food label claim when converted to a calorie basis. Although this finding was expected, some owners when comparing foods may refer to the package label when seeking diets with a lower P content. Based on this finding, minimum values on food packages cannot be used to accurately estimate "as fed" amounts of Ca and P, and thus utilizing the label to identify foods low in P or Ca is not feasible.

Both organic and inorganic P are present in cat food. Organic P is present in the raw materials used for the manufacturing of pet food (eg, protein meal, bone ash, or plant phytates). Inorganic P often is added in the form of P-containing palatants, salts added for pH stabilization, hydration agents, calcium chelation for dental health, and for processing.[30] Although the amount of added inorganic P likely varies among products, the proportion of inorganic P of the total P in cat food potentially is not negligible. Although preliminary attempts have been made, no reliable method currently exists to distinguish between organic P and inorganic P in pet food analysis.[31] This limitation precludes our ability to differentiate the sources of P in the foods assessed in our study.

Multiple factors contribute to determining absorption of P from the gastrointestinal tract. These include the P source, the amount of 25-hydroxyvitamin D, and the relative amounts of P and Ca in the food products.[32-36] Previous studies have shown that organic P salts experience decreased absorption compared with inorganic P in cats.[37] Although the adverse health effects of high dietary P have been demonstrated,[4,5] there are no published studies to date evaluating the safety in cats of foods with high organic P. Also, the absorption of phosphorus in any form is impacted by other minerals, notably Ca, where a high Ca:P ratio decreases P absorption.[35,36] Increased dietary Mg (>0.32 g/1000 kcal ME) decreases intestinal P absorption by 13% compared with an intake of 0.04 g/1000 kcal ME in cats.[7] Our study found that 32% of analyzed foods provided dietary Mg at >0.32 g/1000 kcal ME. This observation indicates that the risks of high dietary load of P are likely partially mitigated by dietary Mg in some diets. However, the test diets in a previous study[5] had Mg content of 0.18 g/1000 kcal ME and 0.28 g/1000 kcal ME, but evidence of kidney injury was present at the end of the feeding period in the cats fed a high P diet.

Our study had several limitations. Products with low popularity may have been overrepresented because all products were weighted equally during randomization. Acquiring accurate sales data would have been difficult, and therefore our survey represents products that are available for the cat owner as a consumer, rather than an epidemiological survey of dietary P intake in the feline population. Potential variability among lot numbers was not evaluated in our study. Evaluation of >1 lot number for each food product may help determine product variability and repeatability of the protein and mineral content in pet foods. Additionally, our study did not evaluate the bioavailability of dietary nutrients in cats, the source or form of P, the content of vitamin D, and the clinical consequences of the findings. We cannot conclude with certainty that any of the tested foods would cause kidney injury to healthy cats, even if fed long term.

Despite these limitations, we demonstrated that the concentrations of P and Ca in many commercially available cat foods are highly variable. Recently published findings[5] indicating that excess P may cause sustained kidney damage and decreased renal function, along with our finding raise concern regarding the typical intake of P, Ca, and Mg in cats. A change in existing regulatory guidelines with regard to P maximums in foods formulated for cats should be considered in light of potential safety issues potentially impacting a subset of pet cats.

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CONFLICT OF INTEREST DECLARATION

Authors declare no conflict of interest.

OFF-LABEL ANTIMICROBIAL DECLARATION

Authors declare no off-label use of antimicrobials.

INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE (IACUC) OR OTHER APPROVAL DECLARATION

Authors declare no IACUC or other approval was needed.

HUMAN ETHICS APPROVAL DECLARATION

Authors declare human ethics approval was not needed for this study.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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APPENDIX A

TABLE A1 Current nutritional guidelines for minimum concentrations of protein, phosphorus, calcium, and magnesium in diets formulated for adult maintenance in cats. The dietary maximums have not been determined

	Adult maintenance			
	NRC 2006[8] minimum requirement	NRC 2006[8] recommended allowance	AAFCO 2019[9] minimum concentration	FEDIAF 2019[10] minimum recommended (based on intake of 100 kcal/body weight(kg)$^{0.67}$
Protein (g/1000 kcal ME)	40	50	65	62.5
Phosphorus (g/1000 kcal ME)	0.35	0.64	1.25	1.25
Calcium (g/1000 kcal ME)	0.4	0.72	1.5	1.48
Magnesium (g/1000 kcal ME)	0.05	0.1	0.1	0.1

Abbreviations: AAFCO, Association of American Feed Control Officials; FEDIAF, European Pet Food Industry Federation; ME, metabolizable energy; NRC, National Research Council.

TABLE A2 Current nutritional guidelines for minimum concentrations of protein, phosphorus, calcium, and magnesium in diets formulated for growth and reproduction in cats. The dietary maximums have not been determined

	Growth and reproduction			
	NRC 2006[8] minimum requirement	NRC 2006[8] recommended allowance	AAFCO 2019[9] minimum concentration	FEDIAF 2019[10] minimum recommended
Protein (g/1000 kcal ME)	45	56.3	75	70/75
Phosphorus (g/1000 kcal ME)	1.2	1.8	2.0	2.1
Calcium (g/1000 kcal ME)	1.3	2.0	2.5	2.5
Magnesium (g/1000 kcal ME)	0.04	0.1	0.2	0.13

Abbreviations: AAFCO, Association of American Feed Control Officials; FEDIAF, European Pet Food Industry Federation; ME, metabolizable energy; NRC, National Research Council.