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Comparison of carbohydrate content between grain-containing and grain-free dry cat diets and between reported and calculated carbohydrate values

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Abstract

Objectives The aim of this study was to compare the carbohydrate content of grain-containing and grain-free dry cat diets and compare major protein and carbohydrate sources of these diets.

Methods This was a cross-sectional study of 77 randomly selected dry cat diets (42 grain-containing, 35 grain-free). Reported carbohydrate values were compared between grain-containing and grain-free cat diets. A subset of 25% of diets from each category (grain-containing and grain-free) was analyzed and nitrogen-free extract was calculated as an estimate of carbohydrate content. These calculated values were compared with reported values from the manufacturer. Animal- and plant-sourced ingredients were also compared between grain-containing and grain-free diets.

Results Mean reported carbohydrate content of the grain-free diets (n = 35) was lower than the grain-containing diets (n = 41; 64 ± 16 vs 86 ± 22 g/1000 kcal; $P < 0.001$). Reported carbohydrate values were higher than analyzed nitrogen-free extract (n = 20; 79 ± 30 vs 73 ± 27 g/1000 kcal; $P = 0.024$). Poultry ($P = 0.009$) and soy ($P = 0.007$) were less common in grain-free diets than in diets containing grain. The alternative carbohydrate sources of chickpeas, lentils, peas, potato, sweet potato and cassava/tapioca were more common ($P < 0.05$) in grain-free diets than in diets containing grain.

Conclusions and relevance This sample of grain-free diets had lower mean reported carbohydrate content than grain-containing diets, but there was considerable overlap between groups and individual diets' carbohydrate/nitrogen-free extract content varied widely.

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Introduction

The popularity of grain-free pet diets has increased in recent years. From 2012–2014, the percentage of grain-free cat food purchased more than doubled, going from 4% to 9% of total cat food purchased.[1] Based on our personal experience, as well as from discussions with other veterinarians, this percentage has likely continued to increase since 2014. Reasons for this increase are unknown but may be related to manufacturers' marketing efforts and unsubstantiated consumer beliefs about the role of grains or carbohydrates in pet foods and the ability of cats to metabolize carbohydrate.

Instead of grains, grain-free diets typically contain alternate carbohydrate sources such as white potato, peas and other legumes, sweet potato or tapioca. It is unclear whether grain-free diets differ in their total carbohydrate content compared with grain-containing diets. Information on carbohydrate content, which is not found on the label, must be obtained from manufacturers and may be based on total starch, total sugars or, more commonly, nitrogen-free extract (NFE). NFE is calculated by

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subtracting the measured percent crude protein, crude fat, crude fiber, moisture and ash from 100 and assuming the remainder is carbohydrate.

In addition to concerns regarding carbohydrates, some cat owners have reported to the authors that they choose grain-free diets because of the perception that food allergies are common in cats and that grains are a common allergen. In fact, food allergies are reported to be uncommon in cats.[2] When they do occur, they are most commonly associated with an animal-source protein such as beef, chicken, fish or dairy protein rather than to plant ingredients such as wheat, corn or rice.[3,4] Whether grain-free diets contain fewer of the most commonly reported food allergens in cats (ie, beef, fish, chicken or dairy) has not been reported.

To begin to address these issues, the first objective of this study was to determine whether the manufacturer-reported carbohydrate content of grain-free dry cat diets was lower than that of grain-containing diets, with the hypothesis that there would be no difference in the carbohydrate content between grain-containing and grain-free diets. Second, since carbohydrate values reported by manufacturers could encompass a number of different types of assays and methods, reported carbohydrate values were compared with calculated NFE in a subset of grain-free and grain-containing cat diets. Our hypothesis was that there would be no significant difference between reported carbohydrate and calculated NFE values. Finally, animal-sourced and plant-sourced ingredients were compared between grain-free and grain-containing diets, with the hypothesis that there would be no significant difference in the most commonly reported food allergens in grain-free vs grain-containing diets.

Materials and methods

Diet selection

A list of dry cat diet manufacturers was created from all diets offered for sale on two popular internet pet food retailers' websites (petfooddirect.com; chewy.com). For the purposes of the study, an individual manufacturer was defined by having a unique main corporate address, which was assumed to have common management and manufacturing sites, even if they produced multiple products sold under different names. All manufacturers with corporate headquarters outside of the USA were excluded. Since some manufacturers sell both mass-market and 'premium' brands of diets (which may use different ingredients and formulations), we recorded whether each manufacturer had diets sold on the mass market (eg, grocery stores, superstores/big-box stores), only in specialty stores (eg, pet supply stores, pet boutique stores) or both.

Procedures

For each manufacturer, a list of all flavors and varieties of dry adult cat diets that were available for sale on the sites was compiled. The list included all diets that were marketed as being for adult maintenance and included diets with an Association of American Feed Control Officials (AAFCO) nutritional adequacy statement indicating that the diet had passed feeding trials or was formulated to meet the AAFCO Nutrient Profile for adult cat maintenance or all life stages.[5] Diets that were marketed specifically for kittens were excluded. Any diets with labels that contained wording implying special needs, such as 'indoor', 'urinary tract health', 'breed specific' or 'hairball control' were also excluded. The final list included 224 diets.

Ingredient lists of all eligible diets were reviewed and grains were defined as any food made from wheat, rice, oats, corn, barley or another cereal grain. As per the US Department of Agriculture definition of the word 'grain', this included both the whole-grain products (which include the entire grain kernel of the bran, the germ and the endosperm), as well as refined-grain products that have been milled to remove the bran and germ.[6] The diets were categorized as containing grains if there was a grain or grain-derived product in the ingredient list (grain-containing group) and as 'grain-free' (grain-free group) if they did not contain any recognizable grains or grain-derived ingredients on the ingredient list *or* were marketed as being 'grain-free' by the manufacturer, even if there was a grain in the ingredient list.

Of the 224 diets identified, some were from the same manufacturer. To ensure that one manufacturer's diets were not over-represented, a computerized randomization scheme was used to select one diet from each manufacturer for each diet group (grain-free vs grain-containing). In addition, if a manufacturer sold diets in both mass-market and specialty stores, one diet from each of these categories was selected in the grain-containing and grain-free groups. Therefore, from an individual manufacturer, between one (one grain-containing or one grain-free) and four (two grain-containing and two grain-free) diets were selected for the study for a total of 77 diets.

For each diet included in the study, manufacturers' customer service lines were contacted and asked to provide 'carbohydrate content' on a metabolizable energy basis (in g/1000 kcal). If the manufacturer could only provide the carbohydrate content on an as-fed percent basis, the energy density (kcal/kg) was also obtained from the manufacturer and the as-fed carbohydrate content was converted to a g/1000 kcal value. If the manufacturer could only provide the carbohydrate content on a dry matter basis, the moisture content was obtained and the carbohydrate content was converted to g/1000 kcal.

From the complete list of diets included in the study (n = 77), a subset of approximately 25% (n = 20) was selected using a random number generator from the

grain-containing and grain-free diet groups (grain group: n = 11; grain-free group: n = 9). Each of these diets was purchased online. Each diet was mixed thoroughly, and 250 g samples were removed, repackaged and coded so that the laboratory personnel were blinded to the identity of the samples during diet testing. All of the diet samples were shipped to a commercial laboratory (Midwest Laboratories, Omaha, NE, USA) regularly used by the pet food industry for diet analysis. A single proximate analysis that included moisture, crude fat, ash, crude protein and crude fiber was run on each diet sample. The percentage NFE was then calculated by the laboratory using the formula NFE = 100 – (crude protein + crude fat + crude fiber + moisture + ash). The energy density of the diet was calculated using modified Atwater factors and used to convert these values to g/1000 kcal.[7] The NFE values were then compared with the manufacturer-reported carbohydrate content.

To assess ingredients, each diet's ingredient list was reviewed and major animal and plant sources of protein and carbohydrate in the diet were recorded. Fats such as fish oil, animal fat and vegetable oils were not included in the analysis. Ingredients that followed the vitamins and minerals in the ingredient list were deemed to be present in only trace amounts and were also excluded. To facilitate analysis, some of the animal-sourced ingredients were grouped into larger categories if they were rare (eg, calamari was grouped with clam in the seafood category), if they were derived from the same proteins (eg, cheese and yogurt both coming from milk) or if it was not clear which specific species were contained in each ingredient (eg, 'poultry' or 'fish' or 'meat' could include multiple species that were all individually included in other diets). As such, the 'poultry' category included the following ingredients: poultry, chicken, turkey, pheasant and duck. The 'fish' category included the following ingredients: fish, salmon, whitefish, ocean fish, trout, herring, menhaden and tuna. The 'dairy' category included the following ingredients: whey, yogurt, milk, cheese and cottage cheese. The 'seafood' category included the following ingredients: mussel, crab, clam and calamari. The 'meat' category included the following ingredients: meat, meat meal and animal digest. Overall, there were 12 animal-sourced ingredients or categories. There were 42 different major plant-sourced ingredients and these were not further grouped. These main protein categories and individual carbohydrate ingredients were compared between grain-containing and grain-free diets.

Statistical analysis

Data distributions were evaluated graphically, and since all data were normally distributed, data are presented as mean ± SD. The carbohydrate content reported by manufacturers was compared between grain-containing and grain-free diets using an independent *t*-test. For the subgroup of diets that underwent nutrient analysis, the calculated NFE vs reported carbohydrate content was compared using a paired *t*-test. Major protein categories and carbohydrate ingredients in each diet were compared between grain-containing and grain-free diets using χ^2 tests. Data were analyzed with commercial statistical software (Systat 13.0 [Systat Software] and SPSS version 22 [IBM]), and $P < 0.05$ was considered significant.

Results

Of the 77 diets included in the study, three manufacturers were unable to provide information on carbohydrate content on an energy basis. Two of these manufacturers provided dry matter carbohydrate values from a typical analysis (average dry matter carbohydrate content or maximum dry matter carbohydrate content) and average moisture levels from which carbohydrate content on an energy basis was calculated. The third manufacturer did not respond to repeated requests over several months to provide the carbohydrate content of the diet, resulting in a total study population of 76 diets for the carbohydrate content comparison between grain-containing and grain-free diets. When the subset of diets was randomly selected for diet analysis, in anticipation of being able to get the requested information from all manufacturers, this diet was counted in the calculation of the 25% subset of grain-containing diets. Without reported carbohydrate content, this product could only be included in the ingredient evaluation as an ingredient list was available on the manufacturer's website. Therefore, a total of 77 diets were included in the ingredient comparison portion of the study.

The manufacturer-reported carbohydrate content of the grain-containing diets (n = 41; 86 ± 22 g/1000 kcal) was significantly higher than that of the grain-free group (n = 35; 64 ± 16 g/1000 kcal [$P < 0.001$]; Figure 1). When diets typically sold in specialty stores were compared with mass-market diets, reported carbohydrate content was higher in the mass market (n = 12, 93 ± 17 g/1000 kcal) than in the specialty diets (n = 64, 72 ± 22 g/1000 kcal; $P = 0.003$), all inclusive of grain-free and grain-containing diets (Figure 2).

For the subgroup of 20 grain-containing and grain-free diets for which NFE content was calculated from analysis, the reported carbohydrate content (79 ± 30 g/1000 kcal) from the manufacturers was significantly higher than the NFE calculated from analysis (73 ± 27 g/1000 kcal; $P = 0.024$) The calculated NFE content of the grain-containing diets (n = 11; 90 ± 19 g/1000 kcal) was higher than that of the grain-free diets (n = 9; 52 ± 20 g/1000 kcal; $P < 0.001$).

The grain-containing diet group contained eight categories of animal-sourced ingredients and 35 unique plant-sourced ingredients. In the grain-free diet group,

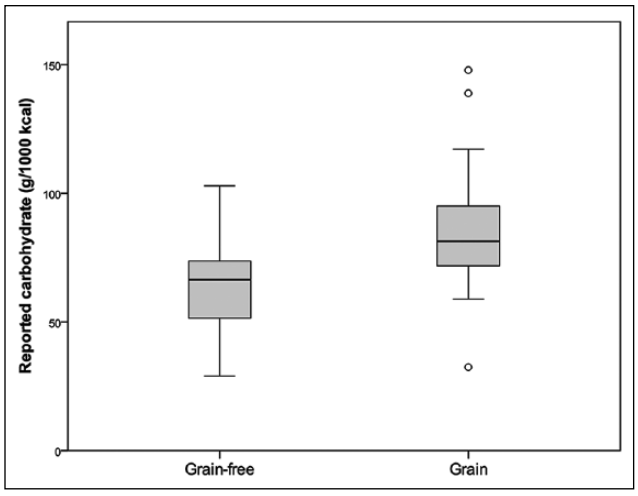

Figure 1 Box and whisker plot of the carbohydrate content of grain-free and grain-containing dry feline diets. Each box represents the interquartile range (25th–75th percentiles), the horizontal line in each box represents the median value, the whiskers indicate the range of observed values that fall within ± 1.5 times the interquartile range, and circles represent outliers

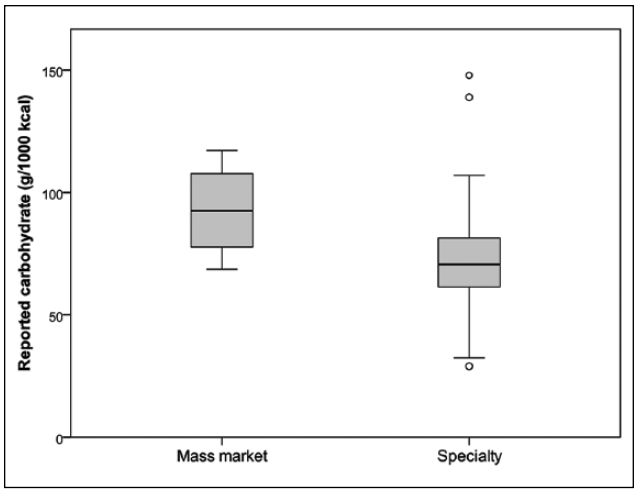

Figure 2 Box and whisker plot of the carbohydrate content of dry feline diets available in mass market retailers as compared with specialty retailers. Each box represents the interquartile range (25th–75th percentiles), the horizontal line in each box represents the median value, the whiskers indicate the range of observed values that fall within ± 1.5 times the interquartile range, and circles represent outliers

Table 1 Comparison of animal-sourced ingredients in grain-containing (n = 42) and grain-free (n = 35) dry cat diets

Protein source	Number of grain diets	Number of grain-free diets	*P* value
Beef	0	2	0.203
Dairy*	4	5	0.724
Egg	26	17	0.259
Fish†	30	25	1.000
Lamb	3	0	0.246
Meat‡	3	0	0.246
Pork	2	4	0.402
Poultry§	40	25	0.009
Rabbit	0	2	0.203
Seafood¶	4	1	0.369

*Included whey, yogurt, milk, cheese and cottage cheese
†Included fish, salmon, whitefish, ocean fish, trout, herring, menhaden and tuna
‡Included meat, meat meal and animal digest
§Included poultry, chicken, turkey, pheasant and duck
¶Included mussel, crab, clam and calamari

10 categories of animal-sourced ingredients and 32 unique plant-sourced ingredients were identified, one of which was a grain by the US Department of Agriculture definition.[6] Tables 1 and 2 show ingredients that were present in more than one diet of the total 77 diets. Other ingredients – venison, bison, avocado, apricot, artichoke, chia, papaya and zucchini – were each only present in either one grain-free diet and no grain-containing diets or one grain-containing diet and no grain-free diets and were excluded from statistical analysis. The most common animal-sourced ingredient category in the grain-containing diets was poultry, while poultry and fish tied as the most common ingredients in the grain-free foods. The most common plant-sourced ingredients in the grain-containing diets were rice, flax and cranberry vs pea, cranberry and potato in the grain-free diets. Poultry ($P = 0.009$), which included chicken, a commonly reported food allergen, was significantly more common in the grain-containing diets than in the grain-free diets. For the plant-sourced ingredients, all grains and soy were significantly more common ($P < 0.05$) in grain-containing diets than grain-free diets, while chickpea, lentil, pea, potato, sweet potato and cassava/tapioca were significantly more common ($P < 0.05$) in the grain-free diets.

Table 2 Comparison of plant-sourced ingredients in grain-containing (n = 42) and grain-free (n = 35) dry cat diets

Carbohydrate source	Number of grain diets	Number of grain-free diets	*P* value
Alfalfa	6	10	0.162
Apple	9	11	0.435
Barley	13	1	0.002
Beet	14	9	0.618
Blackberry	1	2	0.588
Blueberry	13	15	0.344
Broccoli	4	3	1.000
Carrot	16	16	0.643
Cauliflower	0	2	0.230
Celery	2	5	0.235
Chickpea	0	6	0.007
Chicory	9	8	1.000
Corn	12	0	0.000
Cranberry	20	18	0.821
Flax	24	15	0.256
Green beans	0	2	0.203
Kelp	9	4	0.361
Lentil	1	6	0.042
Lettuce	2	4	0.402
Millet	5	0	0.059
Oat	19	0	0.000
Pea	14	32	0.000
Pomegranate	1	1	1.000
Potato	8	17	0.008
Pumpkin	5	5	1.000
Raspberry	1	2	0.588
Rice	34	0	0.000
Sorghum/milo	3	0	0.246
Soy	8	0	0.007
Spinach	9	9	0.788
Sweet potato	7	15	0.021
Tapioca/cassava	0	12	0.000
Tomato	11	7	0.596
Watercress	2	4	0.402
Wheat	7	0	0.014
Yucca	1	1	1.000

Discussion

The mean manufacturer-reported carbohydrate content of the grain-free diets was 25% lower than the reported carbohydrate content of the grain-containing diets, which did not support our hypothesis. However, there was considerable overlap between the two groups, and within each group, individual diets varied widely in carbohydrate content.

The physiological and clinical relevance of this 25% difference is unclear since, while cats do have some metabolic differences related to carbohydrate metabolism compared with many other species, they are able to digest and metabolize carbohydrates. Cats have low hepatic glucokinase activity, which is the primary enzyme used by most animals to phosphorylate glucose inside hepatic cells as the first step in glycolysis when blood glucose levels are high, such as after meals containing carbohydrates.[8] Adult cats, as well as many other mammals, have no dietary requirement for carbohydrate.[9] In one study, cats preferred to consume a diet containing about 8 g carbohydrate daily, and were reluctant to consume more than 20 g of carbohydrate daily. These amounts would be provided by a diet containing 40 g and 100 g of carbohydrate/1000 kcal, respectively, for a cat consuming 200 kcal.[10] However, these results may be related to the specific diets used in the study, and may not be generalizable to all cats. Safe upper limits have been described for some specific types of carbohydrates (including glucose, sucrose and lactose) in cat diets, but not for overall carbohydrate, assuming protein

and fat needs are met.[11] Under the known limits, the data show that cats can efficiently digest and metabolize carbohydrates,[12] utilizing enzymes such as hexokinase to metabolize carbohydrates through the traditional pathways of glycolysis through oxidative phosphorylation. In addition cats can obtain not only energy but other nutrients, such as fiber, protein, vitamins and minerals from plant (carbohydrate) ingredients, in their diets. While differences in postprandial glucose and insulin in healthy cats fed diets of differing carbohydrate concentrations have been reported,[13,14] clear clinical consequences to these differences in healthy cats remain undocumented. Therefore, any clinical implications of the mean 25% lower carbohydrate content found in the current study will require additional research.

The current study only looked at the total amount of carbohydrate, and not the source or type of carbohydrate, which also is important as not all carbohydrate ingredients in pet foods have equivalent nutritional profiles or physiologic effects. In addition, dietary carbohydrate is not in isolation – processing and interaction with other diet ingredients can also alter physiologic effects. Whole grains often contain more protein and less sugar and simple carbohydrates than common non-grain carbohydrate sources used in cat diets such as tapioca and potatoes. These ingredients may have differing effects on insulin release, gut function and other metabolic activities that cannot be predicted based solely on the total reported carbohydrate content. Evaluation of these additional factors is warranted in future studies.

Regardless of any potential clinical importance, evaluating carbohydrate content in pet diets is a challenge for not only the pet food consumer, but also for veterinary medical professionals who want to have the most accurate information available in order to compare and contrast different pet diets. In comparing the different tests offered by three different commercial laboratories that specialize in food/feed nutrient analysis for this study (Midwest Laboratories, Eurofins Scientific, Covance), there were no standard analytes that could be compared across the board; each laboratory had different inclusions for tests deemed as 'carbohydrate analyses'. For example, one laboratory offered 23 different assays in the category of carbohydrate testing with almost no overlap of what specific compounds were being measured, and another manufacturer only offered NFE. This discrepancy is likely because there are many types of carbohydrates and it can be difficult and expensive to distinguish the individual components. However, the type of monosaccharides and the bonds that connect them are important as the metabolism of the different carbohydrates depends on them. There is little regulatory guidance in this regard currently, although the AAFCO has organized a carbohydrate working group to address the matter of carbohydrates in pet food. A standard method of measuring and reporting carbohydrate content would be ideal, but owing to the nature of carbohydrates, condensing this information down into one single value for assessing and reporting accurate carbohydrate content may not be possible.

Currently, the most commonly reported value relating to carbohydrate content is NFE. As an estimate of carbohydrate content, NFE has a number of limitations. Owing to the nature of the NFE equation, any errors in analyses of other nutrients will result in alterations in the NFE. One example is that the NFE equation uses crude fiber, which typically underestimates the amount of total fiber that is present in pet diets and can result in higher calculated NFE.[15] In addition to inaccuracies from the equation itself, using guaranteed analysis values (minimums and maximums) rather than average or typical analyses to estimate NFE will lead to even greater inaccuracies.

Because NFE is the most common way of representing carbohydrates in pet food currently, it is likely that many manufacturers were providing NFE when asked for diet carbohydrate content for this study, but this is not known for sure. The differences seen between manufacturer-reported carbohydrate content and calculated NFE in this study could thus be due to use of different carbohydrate assays (NFE vs other measurements), variation in assays for crude protein, moisture, ash, crude fiber and crude fat from the laboratories used by the manufacturers to calculate NFE vs the laboratory used for this study, or to variations in the actual nutrient concentrations between batches of diet as only one bag of each diet was analyzed in this study.

The final objective of this study was to compare ingredients and investigate potential allergens in grain-containing vs grain-free diets. Although, anecdotally, many cat owners appear to believe that grains are a common cause of allergies in cats, studies of food sensitivities and allergies do not bear this belief out. In one study of 55 cats with chronic idiopathic gastrointestinal problems, only 29% were diagnosed as having food sensitivities.[4] Another study of 128 cats with pruritus or gastrointestinal signs confirmed only 17% as food allergic.[16] The rate in the general cat population would be assumed to be dramatically lower than in these two very selected populations. The most commonly reported allergens in cat diets are animal protein sources such as beef, dairy, fish, chicken and lamb, with plant sources such as barley and wheat less common and other plant-sourced ingredients even rarer.[3] Multiple sensitivities are even more infrequent, making claims of allergy to 'all grains' an unlikely scenario for cats.[2]

In the current study, besides all of the grains (which was expected), poultry and soy were the only ingredients that were significantly less common in the grain-free diets than the grain-containing diets. Chicken has been reported to be one of the more common causes of food allergies in cats, but other ingredients such as beef and dairy products that are also reported to be causes of

food allergies in cats were just as common in grain-free diets. The greater inclusion of poultry and soy in the grain-containing vs grain-free diets may reflect current marketing trends to include more exotic ingredients than chicken. Several exotic ingredients such as venison, rabbit and bison were seen in this study only in grain-free foods. There also seems to be a trend for companies to specifically advertise that their foods contain no soy. As such, these differences may reflect the philosophy of the manufacturer or the desires of the customer base rather than having any relation to whether the diet does or does not contain grains.

There are a number of limitations to this study. The total number of dry cat diets on the market is hard to define and will vary based on how manufacturers are selected. This study used online searches of retailers and it is likely that some manufacturers were excluded because they are not sold by these online retailers. Therefore, the population of diets used in this study may not accurately reflect the total population of dry cat diets available for sale in the USA. This is particularly likely in the case of comparing products from pet specialty stores to those from mass-market channels. Pet foods sold on the mass market are less likely to be also available online, which is how the foods in this study were chosen, so the mass market diets that were included in this study may not be representative of overall mass market diets. The study may also not be appropriately powered for detailed ingredient comparisons between the diets as this was a secondary aim rather than the primary one. Only one sample of each diet was analyzed for financial reasons and while a product with good-quality control should have a similar analysis from batch-to-batch, inter-batch variability is certainly possible, especially among brands with less reliable quality-control measures. A major, but unavoidable, limitation was the use of the NFE as a surrogate of the carbohydrate content value and the assumption that the manufacturers were providing NFE when asked for the carbohydrate content. Future studies could attempt to investigate the specific methods used by each manufacturer to determine carbohydrate content or investigate both carbohydrate type and amounts.

Conclusions

The grain-free dry cat diets included in this study had lower carbohydrate values than the grain-containing diets, but individual diets varied widely in both type and amount of carbohydrate ingredients and all of the diets contained measurable carbohydrates. Although many pet owners that select grain-free diets may worry about food allergies, many common allergens were just as frequently found in the grain-free diets. Selecting a grain-free diet is thus no guarantee that lower carbohydrate content or fewer common food allergens are being fed.

Conflict of interest The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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References

1 American Pet Products Association (APPA). APPA national pet owners survey. Greenwich, CT: APPA, 2016, pp 178–277.
2 Guilford WG, Jones BR, Markwell PJ, et al. **Food sensitivity in cats with chronic idiopathic gastrointestinal problems**. *J Vet Intern Med* 2001; 15: 7–13.
3 Verlinden A, Hesta M, Millet S, et al. **Food allergy in dogs and cats: a review**. *Crit Rev Food Sci Nutr* 2006; 46: 259–273.
4 Mueller RS, Olivry T and Prelaud P. **Critically appraised topic on adverse food reactions of companion animals (2): common food allergen sources in dogs and cats**. *BMC Vet Res* 2016; 12: 9.
5 Association of American Feed Control Officials (AAFCO). Regulation PF7. Nutritional adequacy. Oxford, IN: AAFCO, 2016, pp 142–144.
6 United States Department of Agriculture. **All about the grains group.** http://www.choosemyplate.gov/grains (accessed November 4, 2016).
7 Association of American Feed Control Officials (AAFCO). Regulation PF9. Statements of calorie content. Oxford, IN: AAFCO, 2017, p 144.
8 Tanaka A, Inoue A, Takeguchi A, et al. **Comparison of expression of glucokinase gene and activities of enzymes related to glucose metabolism in livers between dog and cat**. *Vet Res Commun* 2005; 29: 477–485.
9 MacDonald M, Rogers Q and Morris J. **Nutrition of the domestic cat, a mammalian carnivore**. *Annu Rev Nutr* 1984; 4: 521–562.
10 Hewson-Hughes AK, Hewson-Hughes VL, Miller AT, et al. **Geometric analysis of macronutrient selection in the adult domestic cat, *Felis catus*.** *J Exp Biol* 2011; 214: 1039–1051.
11 National Research Council. **Carbohydrates and fiber**. Nutrient requirements of dogs and cats. Washington, DC: The National Academies Press, 2006, pp 49–80.
12 Morris JG, Trudell J and Pencovic T. **Carbohydrate digestion by the domestic cat (*Felis catus*)**. *Br J Nutr* 1977; 37: 365–373.
13 Farrow HA, Rand JS, Morton JM, et al. **Effect of dietary carbohydrate, fat, and protein on postprandial glycemia and energy intake in cats**. *J Vet Intern Med* 2013; 27: 1121–1135.
14 Coradini M, Rand JS, Morton JM, et al. **Effects of two commercially available feline diets on glucose and insulin concentrations, insulin sensitivity and energetic efficiency of weight gain**. *Br J Nutr* 2011; 106 Suppl 1: S64–S77.
15 Owens TJ, Larsen JA, Farcas AK, et al. **Total dietary fiber composition of diets used for management of obesity and diabetes mellitus in cats**. *J Am Vet Med Assoc* 2014; 245: 99–105.
16 Guilford WG, Markwell PJ, Jones BR, et al. **Prevalence and causes of food sensitivity in cats with chronic pruritus, vomiting or diarrhea**. *J Nutr* 1998; 128 Suppl 12: 2790s-1s.