Received: 1 July 2019 | Revised: 9 October 2019 | Accepted: 2 December 2019

DOI: 10.1111/jpn.13289

ORIGINAL ARTICLE

Journal of Animal Physiology and Animal Nutrition | WILEY

The effects of diets varying in fibre sources on nutrient utilization, stool quality and hairball management in cats

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Funding information
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Abstract

Pet food companies use fibrous ingredients in cat foods to aid weight and hairball management. Miscanthus grass could be an alternative novel fibre source for cat foods. The objectives of this work were to determine the effects of Miscanthus grass as a fibre source on nutrient utilization, stool quality and hairball management in cats. Dry extruded cat foods (average chemical composition; digestibility trial: 94.54% dry matter—DM, 34.47% crude protein—CP, 11.67% crude fat, 7.06% ash and 13.04% total dietary fibre—TDF; and hairball trial: 94.88% DM, 34.60% CP, 11.30% crude fat, 7.02% ash and 9.77% TDF) were fed to 12 cats for a 9-day (digestibility trial) or 16-day (hairball trial) adaptation period followed by a 5-day total faecal collection period. Digestibility trial was performed as a replicated Latin square design, and the hairball trial was performed as a switchback design. In general, the cats fed the beet pulp diet (BPD) had higher DM, organic matter, gross energy and TDF digestibility than cats fed Miscanthus grass (MGD) or cellulose (CED) diet ($p < .05$). However, CP digestibility was lower for cats fed BPD (82.1 vs. 84.7 and 85.1%, respectively, for BPD, MGD and CED). These differences could be due to the differences in dietary fibre content and(or) composition. Faecal scores were lower for cats fed BPD (2.84) compared with MGD (3.32) and CED (3.21; $p < .05$). No effects due to fibre were reported on the faecal hairball variables, with the exception of less total hair weight and hair clumps per gram of dry faeces for cats fed Miscanthus grass (MGH) compared with control diet (COH; $p < .05$). In conclusion, Miscanthus grass could be used as an alternative ingredient to cellulose in cat diets.

KEYWORDS

beet pulp, cellulose, digestibility, faecal consistency, hairball, Miscanthus grass

1 | INTRODUCTION

Obesity among the pet population is growing. This issue is more prominent in cats than dogs with 33.5% of the US cat population obese versus 19.6% of the US dog population (Association of Pet Obesity Prevention – APOP, 2018). To address this problem, pet food companies have produced diets with reduced caloric content (Fahey et al., 1990a). This reduction is often achieved by a higher

inclusion of fibre. Traditionally, cellulose from the paper and pulp industry, and beet pulp from the sugar industry are used as standard fibre sources. The ingredient "cellulose" is a purified material, made after the digestion of wood chips and purification of the plant (tree) cell wall, which is bleached to produce a white powder (Dahl, 1884; Ververis, Georghiou, Christodoulakis, Santas, & Santas, 2004). Beet pulp is the leftover fibrous material from the extraction of sugar from beets. Despite the nutritional benefits of both fibre sources (Fahey et al., 1990b, 1990a; Sunvold, Fahey, Merchen, & Reinhart, 1995; Sunvold, Hussein, Fahey, Merchen, & Reinhart, 1995), many pet food companies are searching for novel ingredients to use as an alternative to these traditional ingredients.

In addition to the higher percentage of obese cats when compared to dogs, cats are also known to suffer from hairball regurgitation. While some people may think this is a normal condition, it can create other complications, such as hiatal hernias (Owen, Morris, & Bateman, 2005), intestinal blockages (Barrs et al., 1999), or fresh blood in the faeces and colonic mucosa inflammation (Cannon, 2013). Some authors have tested different fibre sources, either included in the diet or supplemented in the meal, to aid the passage of hairballs from the stomach to the intestine. The methodologies, fibre sources and results have varied greatly (Armbrust, Hoskinson, Lora-Michiels, & Milliken, 2003; Dann, Adler, Duffy, & Giffard, 2004; Loureiro et al., 2017; Weber, Sams, Feugier, Michel, & Biourge, 2015). Work reported by Lewis and Heaton (1999) showed that supplementation of plastic flakes could increase passage rate in human subjects; perhaps in a similar manner, the addition of an insoluble fibre to foods might also provide the stimulus necessary to move hairballs through to the intestine.

Miscanthus grass is a fibrous ingredient produced from the dried canes of *Miscanthus giganteus*. Different than cellulose and beet pulp, the fibrous portion of *M. giganteus* is the main product of this crop; thus, a fibrous ingredient produced from this grass would not be perceived as a by-product by consumers and might provide an alternative to traditional fibre sources. Other uses for Miscanthus have been explored such as cellulosic ethanol production (Adams, Winters, Hodgson, & Gallagher, 2018), construction materials, paper pulping and as an absorbent (Visser & Pignatelli, 2001). However, this ingredient has not previously been tested in cat foods. Therefore, the objectives of this study were to determine the effects of Miscanthus grass addition in cat foods on nutrient digestibility and stool quality, and effects on hairball management when compared to cellulose- and beet pulp-containing diets.

2 | MATERIALS AND METHODS

2.1 | Ingredients and dietary treatments

For the digestibility experiment diets containing three different fibre sources [cellulose (Fairview Mills, Seneca, KS), beet pulp (Fairview Mills, Seneca, KS) and Miscanthus grass (Renew Biomass, Springfield, MO)] were formulated to simulate a commercial weight management diet and contain equal amounts of the fibre sources (Table 1). Three batches of each diet were mixed separately in a paddle mixer (140 kg capacity). For the production of the diets, a single screw extruder (model E525, Extru-Tech, Seneca, KS) was used. Extrusion took place over three different days wherein one batch of each experimental diet was processed in each production day. After extrusion, kibbles were dried in a convection oven at 115.5°C until the moisture was less than 10%. Fibre sources were analysed for their fibre content by standard methods (moisture, AOAC 930.15; crude fibre, AOAC 962.09; acid detergent fibre and acid detergent lignin, van Soest, 1963; neutral detergent fibre, Van Soest & Wine, 1967; total dietary fibre, Prosky et al., 1985; insoluble and soluble fibre, Prosky, Asp, Schweizer, DeVries, & Furda, 1988). Additionally, particle size of the fibre sources was analysed using the standard procedure by the American Society of Agriculture and Biological Engineers (ASABE, 2008; method S319.4). Cat foods were analysed for dry matter, crude protein, crude fat, ash, crude fibre, total dietary fibre and gross energy following the same analytical methods.

TABLE 1 Ingredient composition of experimental diets

Ingredient	Percentage
Fibre source	10.00
Ration	84.34
Chicken by-product meal low ash	35.22
Brewers rice	14.07
Corn	14.07
Wheat	14.07
Corn gluten meal (75% CP)	5.00
Salt	0.40
Potassium chloride	0.26
Choline chloride (60%)	0.20
Calcium carbonate	0.20
Vitamin premix[a]	0.20
Trace mineral premix[b]	0.20
Fish Oil	0.10
Taurine	0.10
Natural antioxidant	0.10
Titanium oxide	0.40
Chromium sesquioxide	0.25
Chicken fat[c]	4.01
Flavour enhancer[c]	1.00

[a]Vitamin E supplement (79,887 IU/kg), niacin supplement (64,736 mg/kg), calcium pantothenate (12,186 mg/kg), vitamin A supplement (17,162,998 IU/kg), thiamin mononitrate (14,252 mg/kg), pyridoxine hydrochloride (5,537 mg/kg), riboflavin supplement (4,719 mg/kg), vitamin D3 supplement (920,000 IU/kg), biotin (70 mg/kg), vitamin B12 supplement (22 mg/kg) and folic acid (720 mg/kg).

[b]Zinc sulphate (88,000 mg/kg), ferrous sulphate (38,910 mg/kg), copper sulphate (11,234 mg/kg), manganous oxide (5,842 mg/kg), sodium selenite (310 mg/kg) and calcium iodate (1,584 mg/kg).

[c]Included as coating after diet were dried to <10% moisture.

For the hairball experiment, two dietary treatments were produced: control (COH) and Miscanthus grass (MGH). The inclusion level of Miscanthus grass was 10% and it was replaced by rice flour in the control diet at the same concentration (Table 6). The inclusion of Miscanthus grass and rice flour was chosen to produce two cat foods with high and low dietary fibre content respectively. Extrusion and drying conditions were similar to the diets for the digestibility study. Flavour enhancer was added at 1.5% to ensure better palatability and avoid food refusals.

2.2 | Digestibility study

The experimental procedure for the digestibility trial was approved by the Kansas State University Institutional Animal Care and Use Committee (IACUC protocol number 3669). For this study, 12 American shorthair cats were used (eight males and four females, average weight 4.59 kg ± 0.42 kg, average body condition score 5.04, average 2.26 ± 1.30 years old). Cats were kept in a room with controlled temperature (22°C ± 1°C), with a 12 hr light cycle (7:00 a.m. to 7:00 p.m.) and evaluated for weight and body condition score (Laflamme, 1997) at the beginning and end of each collection period. Food allowance was controlled for the cats to maintain body weight throughout the duration of the experiment. Each collection period was composed of 9 days of adaptation, wherein the cats were group housed but fed individually. During the adaptation phase, cats were fed at 8:00 and 16:30 with access to food for 1 hr. During the adaptation periods, some of the cats refused to eat the experimental diets. In those cases, an additional 0.5% of flavour enhancer was added topically to the food and was sufficient to stimulate food consumption. After the 9 days of adaptation, the cats were housed individually in stainless steel cages for 5 days of total faecal collection (TFC). During the collection phase, food was provided at 8:00 and 16:30 with 1 hr access to food and faeces were collected daily before and after the feeding. Orts were collected and weighed to compute food intake. After collected, faecal samples were scored on a 1–5 scale in 0.5 increments (1—liquid diarrhoea to 5—dry hard pellets; Carciofi et al., 2008) and stored in a plastic bag in a freezer until further processed.

At the end of each collection period, wet faecal samples were weighed and placed in an aluminum pan to thaw. Once thawed, samples were placed in a convection oven at 55°C until dry to touch, and sample weight was recorded. Next, the samples were ground to pass a 1-mm screen using a laboratory scale grinder (Retsch ZM200, Germany). Nutrient utilization was estimated by TFC using the following equation:

$$\mathrm{TFC} = \left(\left(\%\mathrm{ND} * \mathrm{FI}\right) - \left(\%\mathrm{NF} * \mathrm{FO}\right)\right) / \left(\left(\%\mathrm{ND} * \mathrm{FI}\right)\right).$$

wherein %ND is the per cent nutrient in the diet, FI is the food intake in g, %NF is the per cent nutrient in the faeces, and FO is the faecal output in g. For the digestibility estimation, faecal and food samples were analysed for moisture (AOAC 930.15), ash (AOAC 942.05), gross energy (bomb calorimetry, model 1351, Parr Instrument Company, Moline, IL), crude protein (AOAC 990.03), crude fat by acid hydrolysis (AOAC 954.02), crude fibre (diets only; AOAC 962.09) and total dietary fibre (Prosky et al., 1985). All sample analysis were done in duplicates, with the exception of the TDF analysis, which was done in triplicates. If the variation between duplicates or triplicates was higher than 5%, the sample analysis was repeated.

2.3 | Hairball study

The experimental procedure for the hairball trial was approved by the Kansas State University Institutional Animal Care and Use Committee (IACUC protocol number 3785). Twelve American shorthair cats (eight males and four females, average weight 4.98 kg ± 0.38 kg, average body condition score 5.04, average 2.26 ± 1.10 years old) were fed experimental diets for 16 days adaptation. During this period, the cats were group housed, but individually fed in metabolic cages at 8:00 and 16:30, with food available for 1 hr. The room where the cats were kept had controlled temperature (22°C ± 1°C) and light cycle (12 hr light, from 7:00 a.m. until 7:00 p.m.). The following 5 days the animals were individually housed in stainless steel cages, fed and faeces were collected. Faecal samples were stored in plastic bags and frozen until processed. During this evaluation, one of the cats refused to eat even with the addition of additional flavour enhancer and was removed from the trial.

The cats were brushed with 100 strokes of a brush designed for short hair cats (Furminator®, Blacksburg, VA) before the start of the experiment and at the end of each experimental period. Before sample processing, faeces were weighed. A sub-sample of faeces was collected and analysed for moisture (AOAC 930.15). The remainder of faeces were placed into an aluminum pan and soaked overnight in water to soften the material and facilitate the separation of the hair mass without disrupting the entangled hair clumps. Next, the water was drained by pouring the sample and water into a wire mesh strainer. The remaining faecal material was removed with water using a squirt bottle. After the hair clumps were separated from the faeces, they were measured for length and diameter using a digital caliper. Once measured, each mass was placed in a pre-weighed aluminum pan for determination of dry hair weight by oven drying at 105°C overnight. The remaining hair in the strainer was placed in an aluminum pan, dried and weighed as previously described for the hair clumps. This weight was considered the amount of hair that was mixed with the faeces rather than in a hair clump. Faecal hair clumps were classified according to their size as follows: extra small (<10.0 mm × < 5.0 mm; length × diameter), small (10.0–20.0 mm × 3.5–6.5 mm), medium (20.0–30.0 mm × 4.0–7.0 mm), large (30.0–40.0 mm × 4.5–8.5 mm) and extra-large (>40.0 mm × > 5.0 mm). Just one hairball was regurgitated by one cat; thus, no statistical analysis was performed for hairball incidents; this cat was on the control diet. In addition to the hair clumps characterization, diets were analysed for total dietary fibre (Prosky et al., 1985) and insoluble fibre (Prosky et al., 1988). Soluble fibre content was estimated by subtracting the insoluble

fibre content from the total dietary fibre (Fahey, Novotny, Layton, & Mertens, 2018).

2.4 | Experimental design and statistical analysis

The digestibility experiment was performed as a replicated 3x3 Latin Square design, wherein the row factor was the dietary treatments, the column factor was the periods, and cat was the experimental unit. Within each period, the 12 cats were randomly assigned to each dietary treatment. No cat ate the same food twice. Data were analysed using statistical software via the general linear model procedure for mixed models (GLMMIX procedure in SAS; v. 9.4). The square, period and cat nested within square were considered as random factors. In addition, a *t* test (TTEST procedure, SAS, v. 9.4) was used to test whether the treatment means for faecal scores were similar to the ideal score of 3.5. Treatment means were considered different when alpha was smaller than 5% and trends were considered significant when *p*-value varied from 0.05 to 0.10.

The hairball feeding trial was performed as a replicated switchback design. Within each period, the 12 cats were randomly assigned to each dietary treatment. No cat ate the same food twice. The cat was the experimental unit and considered as random factors for the statistical analysis. Data were analysed using the general linear model procedure for the mixed models (GLMMIX procedure in SAS; v. 9.4). Treatment means were considered different when alpha was smaller than 5% and trends were considered significant when *p*-value varied from 0.05 to 0.10.

3 | RESULTS AND DISCUSSION

3.1 | Digestibility study

Nutrient compositions of diets were similar and small differences in concentration of crude protein, crude fat, gross energy and ash were related to differences in the composition of the test fibre sources (Tables 1 and 2). Crude fibre content was included in the report because of its requirement by the American Association of Feed Control Officials (AAFCO, 2015) as part of the guaranteed analysis on pet food labels. Despite this requirement, crude fibre analysis only accounts for a portion of the insoluble fibre of the diet, since all the soluble components and some of the insoluble components of the dietary fibre are solubilized and removed from the sample by the acid and alkaline digestions (AOCS Ba 6a-05; de Oliveira et al., 2012). In addition to the crude fibre content, total dietary fibre was reported. In this case, the diets containing CED and MGD had higher total dietary fibre content than BPD. These results were expected, as the total fibre content of CED and MGD were higher than for BPD (102.62%, 90.00% and 62.36% total dietary fibre, respectively, for CED, MGD and BPD; Table 3). While it may seem odd that the TDF content of CED was above 100%, this was due to the variability of the TDF procedure as explained by Fahey et al. (2018). The relevance of this number is that CED is a purified ingredient and thus made exclusively of fibre.

TABLE 2 Nutrient composition of experimental diets expressed on a dry matter basis

Composition	MGD	CED	BPD
Dry matter, %	94.53	94.48	94.60
Crude protein, %	35.40	34.20	33.80
Crude fat, %	11.40	12.00	11.60
Ash, %	7.16	7.01	7.00
Crude fibre, %	5.56	8.90	2.95
Total dietary fibre, %	13.76	14.48	10.88
Gross energy[a], kcal/kg	4,839	4,823	4,839

Abbreviations: Dietary treatments; BPD, beet pulp; CED, cellulose; MGD, Miscanthus grass.

[a]Analysed by calorimetry (model 1351, Parr Instrument Company, Moline, IL).

The fibre profile of these experimental ingredients can be divided into two main categories: insoluble (like CED and MGD) and moderately soluble (like BPD) fibre sources. The high concentrations of insoluble fibres in CED and MGD are directly related to the composition of the raw materials used for the production of these two ingredients. Cellulose is derived from the paper and pulp industry. During production, wood chips are digested and all the cellular content from the trees are removed with the exception of the cellulose (Dahl, 1884). Conversely, the raw materials for the production of Miscanthus grass only go through a grinding step. Thus, since no purification step occurs, the concentration of other plant components is much higher in Miscanthus grass than in cellulose. This results in higher concentrations of lignin (13.68% vs. 0.73%, respectively, for Miscanthus grass and cellulose). Finally, beet pulp is the material remaining after sugar extraction from sugar beets. In this case, the soluble fibre content of beet pulp is about 3.5 times higher than Miscanthus grass and 10 times higher than cellulose.

Cats maintained weight and body condition score throughout the duration of the digestibility experiment. Food intake was similar among treatments (average 76.1 g per day per cat; Table 4). While defecation frequency was similar among dietary treatments (average 1.19 defecations per day per cat), a difference in faecal consistency was observed. Cats fed BPD had softer stools than cats fed MGD diet, maybe due to the differences in soluble fibre content as it will be latter detailed. Additionally, the faecal score for BP was lower than the ideal score of 3.5. Despite the similar wet faecal output among the dietary fibre sources, cats fed BPD had an increased faecal moisture when compared to the cats fed MGD and CED diets. This increase in faecal moisture may account for the increase in stool softness. Similarly, Fahey et al. (1990a) reported a quadratic decrease in faecal dry matter when the beet pulp concentration in dog foods increased, although the authors did not report faecal scores in their study. While these results are not completely understood, the fibre source could be the main cause of this increased

TABLE 3 Chemical and physical characterization of experimental fibre sources used to produce cat foods for the digestibility and hairball feeding trials

Fibre source	Miscanthus grass	Cellulose	Beet pulp
Chemical[a], %			
Dry matter	95.00	95.30	92.53
Crude fibre	47.58	76.29	20.21
Acid detergent Fibre	56.53	84.58	26.26
Neutral detergent Fibre	77.68	92.76	34.15
Acid detergent lignin	13.68	0.73	6.38
Total dietary fibre	90.00	102.62	62.36
Insoluble fibre	82.74	100.00	35.99
Soluble fibre	7.26	2.62	26.37
Physical			
DGW ± S_{gw}[b], μm	103.46 ± 76.39	77.33 ± 44.47	193.78 ± 194.83

[a]Expressed in dry matter basis.

[b]DGW: geometric mean diameter, S_{gw}: standard deviation, ASABE, 2008.

TABLE 4 Food intake, defecation frequency, faecal score, wet faecal output and faecal dry matter of cats fed diets with different fibre sources (N = 12)

Diet	MGD	CED	BPD	*SEM*	*p*-Value
Body Weight, kg	4.59	4.60	4.61	0.42	.9157
Body Condition Score	5.00	5.04	5.08	0.44	.8695
Food Intake, g/d/cat	74.9	78.9	74.7	4.71	.6353
Defecation Frequency, no/d/cat	1.25	1.25	1.07	0.098	.1393
Faecal Score[a]	3.32[a]	3.21[ab]	2.84[b]	0.15	.0439
Wet Faecal Output, g/d/cat	49.0	56.8	51.3	5.27	.3050
Faecal Dry Matter, %	34.23[a]	33.62[a]	26.98[b]	1.23	.0002

Abbreviations: Dietary treatments; BPD, beet pulp; CED, cellulose; MGD, Miscanthus grass; *SEM*, standard error of the mean.

[ab]Means with unlike superscripts differ (p < .05).

[a]Faecal score: 1—liquid diarrhoea, 5—dry hard pellets, 3.5—ideal.

TABLE 5 Apparent total tract digestibility estimated by total faecal collection (TFC) of experimental diets enriched with fibre and fed to cats

Digestibility, %	MGD	CED	BPD	*SEM*	*p*-Value
TFC					
Dry matter	76.2[b]	75.5[b]	81.1[a]	0.89	<.0001
Organic matter	80.5[b]	79.4[b]	85.9[a]	0.74	<.0001
Crude protein	85.8[ab]	86.1[a]	84.2[b]	0.88	.0567
Crude fat	85.0[b]	89.6[a]	89.2[a]	0.73	<.0001
Gross energy	81.7[b]	80.9[b]	85.6[a]	0.72	<.0001
Total dietary Fibre	20.8[b]	12.2[c]	39.7[a]	3.03	<.0001

[abc]Means with unlike superscripts differ (p < .05).

Abbreviations: Dietary treatments; BPD, beet pulp; CED, cellulose; MGD, Miscanthus grass; *SEM*, Standard error of the mean.

faecal moisture. As noted here, and in other studies (Diez, Hornick, Baldwin, Van Eenaeme, & Istasse, 1998; Fahey et al., 1990b; Lewis et al., 1994) the addition of insoluble fibres to the diet did not increase faecal moisture. Thus, one may suggest that the soluble component of the fibre was the main cause of the increased water excretion. In this case, since none of the animals had diarrhoea, it is expected that the fermentation was not the cause of the increased water content of the faeces. Rather, the soluble fibres present in beet pulp were likely not completely fermented and retained some water increasing the faecal moisture. This could be also related to a higher water holding capacity of beet pulp when compared to the other to test fibres. Similarly, Beagle dogs fed diets with increasing levels of beet pulp had a quadratic decrease in faecal DM (Fahey et al., 1990a).

Apparent nutrient digestibility was estimated using TFC. Cats fed BPD had a higher dry matter, organic matter, gross energy and total dietary fibre digestibility than cats fed other dietary treatments (p < .05; Table 5). In contrast, cats fed CED had a higher crude protein digestibility than cats fed BPD (86.1% vs. 84.2% respectively) or MGD (85.8%; p = .0567). Crude fat digestibility was lower for cats fed MGD than cats fed the other two treatments (p < .05, Table 5). The total dietary fibre digestibility of CED was the lowest of all dietary treatments, which is a good indication of the low utilization of this fibre source by the colonic micro-organisms. Sunvold, Fahey, et al. (1995), Sunvold, Hussein, et al. (1995) evaluated cellulose as a fibre source in an in vitro fermentation model using different faecal inoculums (dog, cat, horse, human, pigs and ruminal fluid) and incubation times (0, 6, 12, 24 and 48 hr) and in all cases, cellulose

TABLE 6 Ingredient composition of hairball experimental diets expressed on an as is basis

Ingredient, %	MGH	COH
Chicken by-product meal, low ash	35.22	35.22
Rice flour	14.07	24.07
Corn	14.07	14.07
Wheat	14.07	14.07
Miscanthus grass	10.00	—
Corn gluten meal (75% CP)	5.00	5.00
Salt	0.40	0.40
Potassium chloride	0.26	0.26
Choline chloride (60% dry)	0.20	0.20
Dicalcium phosphate	0.20	0.20
Calcium carbonate	0.20	0.20
Vitamin premix[a]	0.20	0.20
Trace mineral premix[b]	0.15	0.15
Fish oil	0.10	0.10
Taurine	0.10	0.10
Chicken fat[c]	4.00	4.00
Flavour enhancer[c]	1.50	1.50

Abbreviations: Dietary treatments; MGH: Miscanthus grass, COH: control.

[a]Vitamin E supplement (79,887 IU/kg), niacin supplement (64,736 mg/kg), calcium pantothenate (12,186 mg/kg), vitamin A supplement (17,162,998 IU/kg), thiamin mononitrate (14,252 mg/kg), pyridoxine hydrochloride (5,537 mg/kg), riboflavin supplement (4,719 mg/kg), vitamin D3 supplement (920,000 IU/kg), biotin (70 mg/kg), vitamin B12 supplement (22 mg/kg) and folic acid (720 mg/kg).

[b]Zinc sulphate (88,000 mg/kg), ferrous sulphate (38,910 mg/kg), copper sulphate (11,234 mg/kg), manganous oxide (5,842 mg/kg), sodium selenite (310 mg/kg) and calcium iodate (1,584 mg/kg).

[c]Included as coating after diet were dried to less than 10% moisture.

TABLE 7 Hairball dietary treatments nutrient composition expressed on a dry matter basis

Composition, %	MGH	COH
Dry matter	94.55	95.21
Crude protein	34.40	34.80
Crude fat	11.30	11.30
Ash	6.73	7.31
Crude fibre	5.51	0.43
Total dietary fibre	14.11	5.43
Metabolizable energy[a], kcal/kg	3,446	3,626

Abbreviations: Dietary treatments: MGH: Miscanthus grass, COH: Control.

[a]Metabolizable energy estimated using Atwater values (crude protein = 3.5, nitrogen-free extract = 3.5, crude fat = 8.5).

was poorly fermented and generated very small amounts of fermentation end products compared with other more fermentable fibre sources.

The higher dry matter, organic matter, gross energy and total dietary fibre digestibility of BPD can be attributed to its fibre composition, because the soluble fibre is better utilized by the bacteria in the colon and fermented to various end products (lactate, acetate, propionate, butyrate, valerate, H_2, CO_2 and methane). This is similar to the relationship reported by Sunvold, Fahey, et al., 1995; Sunvold, Hussein, et al., 1995; and Cutrignelli et al., 2009. In these cases, the undigested and unabsorbed digesta enter the colon and are fermented, the organic matter is transformed into fermentation end products and microbial mass. As a result, less material is excreted by the cat and an increase in digestibility is observed. Additionally, microbial protein and fats are eliminated through the faeces, thereby resulting in a decrease in crude protein and crude fat digestibility. In this study, crude protein digestibility was lower for cats fed BPD. However, the crude fat digestibility was not affected by dietary beet pulp. Similar to this work, Muir, Murray, Fahey, Merchen, and Reinhart (1996) did not report a fibre effect due to the addition of cellulose or beet pulp in crude fat digestibility by dogs. In addition to the differences in dietary fibre composition (insoluble vs. soluble) and how these fibres are utilized by the colonic bacteria, BPD had a lower TDF content and crude fibre than the other two dietary treatments (Table 2); therefore, BPD diet likely had more digestible components than the other dietary treatments. Possibly a combination of fibre content and fibre utilization by colonic bacteria was what promoted the higher DM and lower CP digestibility of BPD compared with CED and MGD diets. The different fibre content of these diets could be interpreted as a shortcoming of this study. Since the lower total dietary fibre content of BPD could have influenced the digestibility results. Finally, the lower crude fat digestibility of MGD could be related to the higher lignin content of Miscanthus grass compared with the other two fibre sources (Table 3). Lignin can bind bile acids which in turn become unavailable to aid in fat digestion. This has been previously reported in the literature (Dongowski & Ehwald, 1999; Pandolf & Clydesdale, 1992). However, to the authors' knowledge, Miscanthus grass bile acid-binding properties were never tested.

3.2 | Hairball study

Ingredient composition of experimental diets was similar to the diets from the digestibility experiment, with the exception of a higher inclusion of flavour enhancer, and the use of rice flour as a replacement for Miscanthus grass in the control diet (Table 6). In this case, flavour enhancer was added at a higher level to avoid food refusals; however, one cat had to be removed from the experiment since it would not eat the food. Cats are known to be finicky, and this was the first experience this colony of cats had with foods other than standard commercial diets. Nutrient compositions of both diets were similar except for the crude fibre, and total dietary fibre contents of MGH were higher than the COH (Table 7).

Cat body weight was maintained throughout the duration of the experiment and food intake, defecation frequency and faecal DM were similar between dietary treatments (Table 8). However, cats

TABLE 8 Average body weight, food intake, defecation frequency, faecal score, wet faecal output, and faecal dry matter (mean ± standard error of the mean) of cats fed diets with different fibre content

Response variable	MGH	COH	*p*-Value
Body weight, kg	4.97 ± 0.38	4.99 ± 0.38	.5835
Food intake, g/d/cat	88.35 ± 3.18	83.66 ± 3.08	.2191
Defecation frequency, no/day/cat	1.30 ± 0.12	1.22 ± 0.12	.5521
Faecal score[a]	3.99[a] ± 0.27	3.36[b] ± 0.26	.0065
Wet faecal output, g/day/cat	47.0[a] ± 3.03	28.8[b] ± 2.96	<.0001
Faecal dry matter, %	48.9 ± 3.24	47.3 ± 3.15	.6192
Hair clump count, no	13.19 ± 2.77	11.58 ± 2.74	.3050
Hair clump count per day, no/day	2.64 ± 0.55	2.32 ± 0.55	.3050
Hair clump size[b]	1.79 ± 0.23	2.22 ± 0.22	.1437
Hair clump weight, mg	36.8 ± 8.91	32.6 ± 8.73	.6110
Total hair clump weight, mg	674 ± 213	420 ± 209	.1167
Hair retained in strainer, mg	310 ± 81	248 ± 80	.0884
Total hair weight, mg	1641 ± 214	1,362 ± 210	.0790
Total hair weight per dry faecal weight, mg/g	14.59[b] ± 2.92	21.04[a] ± 2.90	.0004
Hair clumps per dry faecal weight, no/g	0.12[b] ± 0.039	0.19[a] ± 0.039	.0013

Abbreviations: Dietary treatments; MGH, Miscanthus grass (n = 11), COH, control (n = 12).

[ab]Means with unlike superscripts differ (p < .05).

[a]Faecal score: 1—liquid diarrhoea, 5—dry hard pellets, 3.5—ideal.

[b]Hair mass size: extra small (<10.0 mm × < 5.0 mm; length × diameter), small (10.0–20.0 mm × 3.5–6.5 mm), medium (20.0–30.0 mm × 4.0–7.0 mm), large (30.0–40.0 mm × 4.5–8.5 mm) and extra-large (>40.0 mm × > 5.0 mm).

fed MGH had harder stools than cats fed COH (p < .05). When comparing the faecal scores with the ideal score (3.5), cats fed COH had faecal consistency similar to the ideal score (p = .6616), but cats fed MGH had harder faeces than the ideal (3.99 vs. 3.5, p < .05). Wet faecal output was higher for cats fed MGH than cats for fed COH (p < .05), despite no changes in faecal dry matter. The greater faecal was a result of the higher fibre content of MGH (Table 7).

It is important to understand how hairballs are formed in cats. Hairball formation is common among other animals other than cats (dogs—Cannon, 2013, rabbits—Gillett, Brooks, & Tillman, 1983, horses—Turner, 1986, beef calves—Abutarbush & Radostits, 2004, lemur—Janssen, Robinson, & Meier, 1979; Canadian lynx—Kottwitz & Munsterman, 2013; and cougar – Langohr, Ramos-Vara, Wu, & Froderman, 2006). Despite reports of occurrence in other species, it is most concerning in domestic cats. In addition, long-haired cats were twice as likely to vomit a hairball than short-haired cats (Cannon, 2013). However, these results are based on cat owner surveys; therefore, they lack the necessary scientific evidence to support this observation.

The formation of hairballs in the stomach has been thought to be a combination of three factors: behaviour, anatomy and physiology. According to Panaman (1981), the cat spends about 25% of their awake time grooming themselves or other cats. This considerable amount of time contributes to hair ingestion by the animal. In addition, the cat's filiform papillae have several hook-like barbs facing the back of the oral cavity (Cannon, 2013). As a result, the conformation of the papillae facilitates hair ingestion. Lastly, cats have a different fasting gastrointestinal contraction type than most other mammals called the migrating spike complex (De Vos, 1993). These fasting contraction patterns are considered important to move any type of undigested material in the upper portions of the gastrointestinal tract to the large intestine. The migrating spike complex starts at the duodenum and moves to the ileum (Bebchuk, 2002). Because there are no fasting contractions in the stomach (De Vos, 1993), the hair accumulates. In most cases, these hairballs are small and pass to the duodenum; however, in some cases, they can be regurgitated or cause blockages in the gastrointestinal tract (Barrs et al., 1999).

In an attempt to increase the passage rate and stimulate gastric contraction, fibres have been added to cat foods to aid in hairball passage to the duodenum (Dann et al., 2004; Davenport, Sunvold, Reinhart, & Hayek, 2008, Patent no. 7,425,343 B2; Loureiro et al., 2017). For example, Dann et al. (2004) reported a decrease in clinical signs (vomiting, retching and coughing) of hairballs when cats with a history of hairballs were supplemented with a 2 g gelatin capsule containing a blend of Psyllium husk and slippery elm (b.i.d) when compared to the control treatment with no added fibre. Conversely, Loureiro et al. (2017) reported no effects due to the beet pulp content (8% vs. 16%) of extruded cat foods in number of hairballs excreted on the faeces, although there was a tendency for total number of hairballs relative to mass of fresh faeces to increase.

In addition, it is important to highlight that Loureiro et al. (2017) did not specify if the cats in this experiment were prone to hairballs (short-haired cats). Finally, Armbrust et al. (2003) reported no effect of fibre content in extruded cat food on transit time; however, the authors found that round kibbles increased passage rate compared with triangular kibbles. Despite the variability on the results, there could be a potential benefit of increasing gastrointestinal motility by increasing dietary fibre content. Lewis and Heaton (1999) reported that the supplementation of (human) foods with plastic flakes increased passage rate by 24% compared with no supplementation.

The cats used in this trial were shorthaired without a history of hairball incidents. That creates a greater hurdle to evaluate the diet effects. As a result, the responses evaluated were the hair clumps in the faeces. Hair clump count, hair clump count per cat per day, hair clump size and total hair clump weight were similar between treatments ($p > .05$; Table 8). These results corroborate with the initial observation that hair turnover was similar between the two experimental periods and treatments.

Despite the lack of differences in faecal hair clump traits, hair retained in the strainer tended to be higher for cats fed MGH compared with COH. This result, in addition to the similar hair turnover between treatments, may be an indication that the addition of insoluble fibres to the diet improves motility and may aid in breaking down or prevent formation of the hair clumps. Total faecal hair weight tended to be lower for cats fed COH. When considering the amount of hair in the faeces in relation to the faecal output, cats fed MGH had a lower total hair weight per gram dry faecal weight and less hair clumps per gram of dry faecal weight ($p < .05$; Table 8). While this result was unexpected, it may be an indication that more digesta passing through the gastrointestinal tract could aid in more regular movement of the hairballs to the duodenum.

Differently than the results here reported, Loureiro et al. (2014) reported that there was a linear decrease in small and medium size trichobezoars when cats were fed increasing levels of sugarcane fibre supplemented diets. Additionally, these authors reported that there was a decrease in trichobezoar mass excretion when cats were fed diets with sugarcane fibre. However, no effects were reported when the animals were fed the cellulose-containing diet. The Miscanthus grass diet used in the present study had the same inclusion level (10%) and similar particle size (103 µm) than the cellulose used by Loureiro and co-workers (10% inclusion, 112 µm). The larger particle size of sugarcane fibre (188 µm) could be what promoted the different results. Therefore, a future study should evaluate the particle size effects on the hairball elimination.

4 | CONCLUSION

The addition of insoluble fibre sources to cat foods may decrease digestibility. However, there may be an increase in faecal output as a result. Miscanthus grass had similar digestibility coefficients to cellulose, indicating that Miscanthus grass could be a viable alternative to cellulose in cat foods. Furthermore, the addition of Miscanthus grass to cat foods with the purpose of hairball management may be beneficial, but further investigation is needed. This provides a rationale for additional work to determine whether greater particle size for Miscanthus grass in long-hair cats prone to hairballs may provide benefits.

ACKNOWLEDGEMENTS

The authors would like to express their appreciation to Renew Biomass for the financial support of the projects.

CONFLICT OF INTEREST

Charles Gregory Aldrich has previously provided consulting services for the sponsor of the project (Renew Biomass).

AUTHORS CONTRIBUTIONS

Renan Antunes Donadelli was involved in experiment conduction, data and sample collection, sample analysis, statistical analysis, data interpretation and manuscript preparation; Charles Gregory Aldrich involved in experiment design, data interpretation and manuscript revision.

ANIMAL WELFARE STATEMENT

The authors confirm that the ethical policies of the journal, as noted on the journal's author guidelines page, have been adhered to and the appropriate ethical review committee approval has been received. The authors confirm that they have followed USA standards for the protection of animals used for scientific purposes. The Institutional Animal Cara and Use Committee numbers for both trials were 3669 (digestibility trial) and 3785 (hairball trial).

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How to cite this article: Donadelli RA, Aldrich CG. The effects of diets varying in fibre sources on nutrient utilization, stool quality and hairball management in cats.
J Anim Physiol Anim Nutr. 2020;104:715–724. https://doi.org/10.1111/jpn.13289