Extruded feline diets formulated with high inclusion of soybean hulls: effects on apparent total tract macronutrient digestibility, and fecal quality and metabolites

Katelyn B. Detweiler,* Fei He,* Heather F. Mangian,* Gary M. Davenport,[†] and Maria R. C. de Godoy^{*,1}

*Department of Animal Sciences, University of Illinois, Urbana, IL 61801; and [†]Archer Daniels Midland Company, Decatur, IL 62526

ABSTRACT: Dietary fibers have gained renewed interest in companion animal nutrition as a means to manage pet obesity and improve gut and host health. Soybean hulls (SBH), a coproduct of the soybean oil extraction process, is an accessible and economical fiber source. However, limited research is available on the use of SBH in feline nutrition. Thus, the aim of this study was to determine the effects of a high SBH inclusion level on daily food intake, apparent total tract (ATT) macronutrient digestibility, fecal quality, and fecal fermentative end products in diets of adult cats. Four diets were formulated with either SBH, beet pulp (BP), or cellulose (CL) as the main source of dietary fiber, with the control diet formulated with no added fiber (NF). The fiber treatments were formulated to achieve approximately 15% total dietary fiber (TDF). Eight adult male cats (mean age = 10.5 yr $\pm$ 0.1; mean BW = 6.1 $\pm$ 0.8 kg) were used in a replicated 4 $\times$ 4 Latin square design. Each period consisted of 14 d, with 10 d of diet adaptation followed by 4 d of total fecal and urine collections. Food was offered twice daily and cats were fed to maintain BW. Food intake on a DM basis (DMB) was lower ($P < 0.05$) in cats fed BP (55.2 g/d) when

compared with SBH (70.8 g/d). As-is fecal output did not differ in cats fed BP or SBH, and when expressed on a DMB, fecal output did not differ among fiber treatments. The ATT digestibility of DM, OM, and GE was greater ($P < 0.05$) in cats fed NF when compared with those fed BP, CL, or SBH. Cats fed CL had the greatest ($P < 0.05$) ATT CP digestibility (88.5%), followed by cats fed NF (84.9) and SBH (81.7%) with the lowest values (77%) noted for cats fed BP. Acid-hydrolyzed fat (AHF) digestibility was greater for cats fed CL (92.9%) than for cats fed BP (86.9%) and SBH (88.6%). The TDF ATT digestibility was lowest for cats fed NF and CL (8.5% and 15.1%, respectively), followed by SBH (18.0%), with BP having the highest digestibility (33.7%). Total short-chain fatty acid concentration was greatest ($P < 0.05$) in cats fed BP (699.7 μ mole/g) when compared with the other 3 treatments, whereas phenol and indole concentrations did not differ among treatments. In conclusion, a high inclusion level (15% TDF) of SBH appears acceptable in diets for adult cats, resulting in no negative effects on daily food intake, fecal scores, and similar ATT digestibility for most macronutrients when compared with BP and CL.

Key words: cats, dietary fiber, fecal score, food intake, gut health, nutrient digestion

© The Author(s) 2019. Published by Oxford University Press on behalf of the American Society of Animal Science. All rights reserved. For permissions, please e-mail: journals.permissions@oup.com.

J. Anim. Sci. 2019.97:1042–1051

doi: 10.1093/jas/skz014

INTRODUCTION

Dietary fiber is not nutritionally required by the adult cat [National Research Council (NRC), 2006]. As an obligate carnivore, the nutritional

¹Corresponding author: mgodoy2@illinois.edu

Received October 11, 2018.

Accepted January 8, 2019.

relevance of dietary fiber for the domestic cat has been overlooked until recently. However, dietary fibers can provide a multitude of health benefits such as eliciting satiety and aiding in weight loss, blunting the postprandial glycemic response, improving gut health and fecal quality, and increasing fecal short-chain fatty acid (SCFA) concentrations (Banta et al., 1979; Fahey et al., 1992; Massimino et al., 1998; Swanson et al., 2002; German, 2006; den Besten et al., 2013).

Soybean hulls (SBH) are a fiber-rich coproduct of the soybean oil extraction process. In the United States, soybean production is increasing, and it is followed by a steady decrease in yearly costs [United States Department of Agriculture (USDA), 2017]. According to the USDA's National Agricultural Statistics Services (NASS), soybean production in 2017 was forecast at approximately 4.4 billion bushels, from which it can be estimated about 220 million bushels of SBH (NASS/USDA, 2017). Historically, SBH have been partially reintroduced into soybean meal. However, increasing demand for soybean meal with greater protein content has resulted in SBH to be readily available for ruminant and monogastric nutrition (Extension, 2008). Previous research evaluating SBH has been performed in canines; however, there is a lack of research evaluating SBH in feline diets. Therefore, the objective of this study was to evaluate the effects of SBH on fecal fermentative end products and apparent total tract (ATT) macronutrient digestibility of cats compared with a no fiber diet (control) and 2 added dietary fiber diets, beet pulp, and cellulose. It was hypothesized that cats fed a SBH diet would exhibit intermediate macronutrient ATT digestibility and fecal fermentative end product concentrations when contrasted with beet pulp and cellulose.

MATERIALS AND METHODS

Animals and Diets

This study used 8 adult neutered male domestic shorthair cats (mean age = 10.5 ± 0.1 yr; mean BW = 6.1 ± 0.8 kg). The cats were housed in a temperature-controlled room at the Edward R. Madigan Laboratory at the University of Illinois at Urbana-Champaign, under a 14:10 (L:D) h schedule. All cats were group housed with the exception of 2 h, twice daily, for feeding (0800 to 1000 and 1500 to 1700) and during 4 d of fecal and urine collection in each experimental period. All cats were given free access to water at all times.

All animal care procedures were approved by the University of Illinois Institutional Animal Care and Use Committee prior to animal experimentation.

Four experimental diets were formulated to contain no additional fiber (NF), beet pulp (BP), cellulose (CL), or SBH as the main sources of dietary fiber (Table 1). Each source of dietary fiber was added at the expense of chicken by-product meal and brewer's rice to achieve diets with similar nutrient profile (Table 2) and targeting approximately 30% CP, 15% acid-hydrolyzed fat (AHF), and 15% total dietary fiber (TDF), except for the NF diet that was formulated to have 5% TDF. The diets were formulated to be complete and balanced according to AAFCO (2016) for adult cats at maintenance. The diets were extruded at the Kansas State University Bioprocessing and Industrial Value-Added Program facility (Manhattan, KS). Food intake was individualized based on metabolic body size and cats were fed to maintain BW based on previous food intake records.

Experimental Design

A replicated 4×4 balanced Latin square design was used. Each experimental period consisted of 14 d; 10 d of diet adaptation, followed by 4 d of total fecal and urine collection. Food intake and refusals were recorded after each meal. During the collection phase, all feces were collected, scored (1 = dry, hard feces to 5 = diarrhea; a score of 2 to 3 considered ideal), and stored in a -20°C freezer until analysis to determine ATT macronutrient digestibility. In addition, during the collection period, one fresh fecal sample was collected from each cat within 15 min of defecation. The fresh sample was scored, weighed, and analyzed for pH using pH meter (AP10; Denver Instrument, Bohemia, NY). The sample then was aliquoted out to be measured for fermentative end product concentrations, including SCFA, branched-chain fatty acids (BCFA), phenols, indoles, and ammonia. One aliquot was placed in 2 N hydrochloric acid and frozen at -20°C until analysis of SCFA, BCFA, and ammonia concentrations. Two aliquots were collected for measurement of phenols and indoles and frozen at -20°C until analysis. Finally, 2 aliquots were collected to determine DM. Total urine output was collected from days 11 to 14 and the volume and weight recorded. Urine samples were collected in containers containing 5 mL of 2 N hydrochloric acid for immediate acidification on urination. Acidified urine samples were subsampled (25% of each sample retained) and stored at -20°C until analysis. In addition, at the end of each period, one fasted blood sample (6 mL)

Table 1. Ingredient composition of experimental diets containing select fiber sources

Item, % DM basis	Treatments			
	No fiber	Beet pulp	Cellulose	Soybean hulls
Chicken by-product meal	29.1	29.6	31.1	28.7
Corn gluten meal	7.7	7.7	7.7	7.7
Brewer's rice	43.0	26.9	31.3	29.4
Corn, whole, ground	3.7	3.7	3.7	3.7
Choice white grease	8.0	8.0	8.0	8.0
Coating—palatant ¹	2.0	2.0	2.0	2.0
Coating—choice white grease	4.0	4.0	4.0	4.0
Beet pulp ²	—	15.5	—	—
Cellulose ²	—	—	9.6	—
Soybean hulls ²	—	—	—	14.0
Salt	0.5	0.5	0.5	0.5
Potassium chloride	0.45	0.45	0.45	0.45
Taurine	0.2	0.2	0.2	0.2
Mineral premix ³	0.18	0.18	0.18	0.18
Vitamin premix ⁴	0.18	0.18	0.18	0.18
Choline chloride	0.13	0.13	0.13	0.13

¹AFB BioFlavor F25003, St. Charles, MO.

²Lortscher Animal Nutrition Inc., Bern, KS.

³Provided per kg diet: 17.4 mg manganese (MnSO₄), 284.3 mg iron (FeSO₄), 17.2 mg copper (CuSO₄), 2.2 mg cobalt (CoSO₄), 166.3 mg zinc (ZnSO₄), 7.5 mg iodine (KI), and 0.2 mg selenium (Na₂SeO₃).

⁴Provided per kg diet: 11,000 IU vitamin A acetate; 900 IU vitamin D₃; 57.5 IU vitamin E acetate; 0.6 mg vitamin K; 7.6 mg thiamin HCl; 11.9 mg riboflavin; 18.5 mg pantothenic acid, calcium; 93.2 mg niacin; 6.6 mg pyridoxine HCl; 12.4 mg biotin; 1,142.1 µg folic acid; 164.9 µg vitamin B12, 0.1% mannitol.

Table 2. Analyzed chemical composition and energy content of experimental diets containing select fiber sources

Item	Treatments			
	No fiber	Beet pulp	Cellulose	Soybean hulls
DM, %	92.2	93.9	95.4	94.8
		%, DM basis		
OM, %	92.4	92.4	92.3	92.1
CP, %	30.8	30.2	31.9	30.7
Acid-hydrolyzed fat, %	13.7	14.5	16.4	15.2
TDF, ¹ %	4.5	17.1	15.1	16.6
Insoluble, %	2.7	11.2	13.6	15.6
Soluble, %	1.8	5.9	1.5	1.0
GE, kcal/g; measured	5.2	5.2	5.3	5.2
ME, ² kcal/g; calculated	3.8	3.4	3.5	3.4

¹TDF = total dietary fiber.

²ME = 8.5 kcal ME/g fat + 3.5 kcal ME/g CP + 3.5 kcal ME/g nitrogen-free extract.

from each cat was collected to evaluate serum chemistry profiles and complete blood count. Blood was collected in BD Vacutainer serum separator tubes and EDTA tubes (Becton, Dickinson and Company, Franklin Lakes, NJ), respectively. Blood and serum samples were analyzed by the University of Illinois Veterinary School Diagnostics Laboratory using a Hitachi 911 clinical chemistry analyzer (Roche Diagnostics, Indianapolis, IN).

Sample Preparation and Chemical Analyses

Food and fecal samples were dried at 55 °C in a forced-air oven. Diet and fecal samples were then ground in a Wiley mill (model 4, Thomas Scientific, Swedesboro, NJ) through a 2-mm screen and then analyzed for DM, OM, and ash according to [Association of Official Analytical Chemists \(AOAC, 2006; methods 934.01 and 942.05\)](#). Crude protein

content of diets and feces was calculated from Leco (TruMac N, Leco Corporation, St. Joseph, MI) total nitrogen values according to [AOAC \(2006; method 992.15\)](#). Lipid content was determined according to the methods of the [American Association of Cereal Chemists \(1983\)](#) and [Budde \(1952\)](#). Diet, feces, and urine were analyzed for GE, measured by bomb calorimetry (Model 6200, Parr Instruments Co., Moline, IL). Urine GE values were used to calculate ME. Fecal and diet TDF were measured according to [Prosky et al. \(1992\)](#).

Fecal ammonia concentrations were measured according to the method by [Chaney and Marbach \(1962\)](#). Fecal phenol and indole concentrations were determined using gas chromatography according to the method by [Flickinger et al. \(2003\)](#). Fecal SCFA and BCFA concentrations were determined using gas chromatography according to [Erwin et al. \(1961\)](#).

Statistical Analyses

All data were analyzed using the mixed model procedure of SAS. Fecal score was analyzed using the GLIMMIX procedure of SAS. PROC UNIVARIATE was used to analyze for data normality (SAS Institute Inc., version 9.4, Cary, NC). The model contained the fixed effect of diet and the random effect of cat. Differences among treatments were determined using a Fisher-protected least significant difference test with a Tukey adjustment to control for type-1 experiment-wise error. Reported pooled SEM were determined according to the mixed model procedure of SAS. A probability of $P \leq 0.05$ was accepted as statistically significant.

RESULTS AND DISCUSSION

Diet, Food Intake, and Fecal Characteristics

All 4 experimental diets were similar in chemical composition ([Table 2](#)). Dry matter content ranged from 92.2% to 95.4%. On a DM basis (DMB), all diets contained approximately 92% OM and an average of 30.9% CP. Fat content varied slightly among treatments with CL having the highest AHF content (16.4%), SBH and BP having intermediate AHF content (15.2% and 14.5%, respectively), and NF having the lowest AHF content (13.7%). These values are reflected in the GE content of the diets. The variation observed in the AHF content of these diets was due to deviations in the amount of fat dispersed on the kibbles during the fat coating step that could not be further controlled in the pilot

plant. In addition, due to low diet acceptance by the cats prior to the start of the study, the diets were coated with additional white choice grease and palatant (AFB BioFlavor F25003, St. Charles, MO) at 4% and 2% inclusion rates, respectively. The additional coating did not completely adhere to all of the diets, resulting in the slightly varying concentrations of AHF content. However, this should have a negligible effect on the findings of this research, as there was an AHF difference of less than 3 percentage units among the dietary treatments. The 3 fiber treatments were formulated to have approximately 15% TDF and the NF treatment to have 5% TDF. The SBH and BP treatments had slightly higher TDF contents (16.6% and 17.1%, respectively), but this is not surprising as TDF content of these dietary fibers can vary depending on the source ([Fahey et al., 1990](#); [Sunvold et al., 1995b](#); [Cole et al., 1999](#)). Also, as expected, the insoluble and soluble fractions differed among fiber treatments. The BP diet contained the highest amount of soluble fiber (5.9%) compared with the CL (1.5%) and SBH (1.0%) diets.

Food intake (g/d, DMB) differed ($P < 0.05$) among treatments ([Table 3](#)). Cats fed SBH had higher ($P < 0.05$) food intake (70.8 g/d) compared with those fed BP (55.2 g/d). This was due to greater food refusals by the cats fed BP. Decrease in food palatability was expected with greater TDF content of the diets. However, based on our findings, it appears that cats did not tolerate the high levels of TDF only in the BP diet compared with other treatments. Previous research evaluating up to 12.5% BP and 10% CL in diets of adult cats has not observed negative effects on food intake ([Sunvold et al., 1995a](#)). Despite the lower food intake by cats fed the BP diet, no significant differences in BW was observed among dietary treatments. This was likely due to the short experimental period (14 d). However, this finding must be considered when developing commercial pet foods at this high level of TDF content, as they can lead to suboptimal intake of essential nutrients and potential nutrient deficiencies over time.

Fecal score did not differ among fiber treatments (mean = 2.2) and remained within the acceptable fecal score range using a 5-point scale. Cats fed the NF treatment had a higher ($P < 0.05$) fecal score (2.8) than those fed the fiber treatments. Similar fecal scores were previously observed in cats (2.3) fed a diet containing 12.5% BP corresponding to 10.6% TDF ([Sunvold et al., 1995a](#)). However, in that same study, a lower fecal score (1.8) was reported for cats fed a diet with 8.1% CL and 11.2%

Table 3. Food intake and fecal characteristics of cats fed diets containing selected fiber sources

Item	Treatments				SEM	P-value
	No fiber	Beet pulp	Cellulose	Soybean hulls		
Food intake						
g/d, DM basis	69.7 ^{ab}	55.2 ^b	70.6 ^{ab}	70.8 ^a	5.43	0.0320
Fecal characteristics/output						
Fecal score ¹	2.8 ^a	2.3 ^b	2.0 ^b	2.2 ^b	0.09	0.0001
Fecal output, as-is (g/d)	28.1 ^c	50.5 ^a	33.5 ^{bc}	45.6 ^{ab}	4.15	0.0024
Fecal output, DM basis (g/d)	9.8 ^b	12.8 ^{ab}	16.0 ^{ab}	17.9 ^a	1.73	0.0118
Fecal DM (%)	35.0 ^{bc}	30.6 ^c	47.8 ^a	38.9 ^b	1.30	0.0001

^{a-c}Means in the same row without common superscript letters denote a significant difference ($P < 0.05$).

¹Fecal score: 1 = hard, dry pellets; small hard mass; 2 = hard formed, remains firm and soft; 3 = soft, formed and moist stool, retains shape;

4 = soft, unformed stool; assumes shape of container; 5 = watery, liquid that can be poured.

Table 4. Total tract apparent macronutrient and energy digestibilities of cats fed diets containing selected fiber sources

Item	Treatments				SEM	P-value
	No fiber	Beet pulp	Cellulose	Soybean hulls		
Nutrient and energy digestibilities, %						
DM	85.5 ^a	74.5 ^b	78.4 ^b	75.4 ^b	1.55	0.0001
			%, DM basis			
OM	88.8 ^a	77.9 ^b	81.1 ^b	78.5 ^b	1.37	0.0001
CP	84.9 ^{ab}	77.2 ^c	88.5 ^a	81.7 ^b	1.13	0.0001
Acid-hydrolyzed fat	89.9 ^{ab}	86.9 ^b	92.9 ^a	88.6 ^b	1.63	0.0001
TDF ¹	8.5 ^b	33.7 ^a	15.1 ^b	18.0 ^{ab}	4.88	0.0113
DE	88.6 ^a	78.6 ^b	83.7 ^b	79.9 ^b	1.31	0.0001
ME	82.3 ^a	70.9 ^c	78.2 ^{ab}	73.6 ^{bc}	1.52	0.0001

^{a-c}Means in the same row without common superscript letters denote a significant difference ($P < 0.05$).

¹TDF = total dietary fiber.

TDF. As-is fecal output (g/d) was greater ($P < 0.05$) for cats fed BP (50.5 g/d) in comparison with cats fed CL (33.5 g/d) and NF (28.1 g/d), whereas SBH (45.6 g/d) did not differ from the other fiber treatments. When daily fecal output was converted to DMB, fecal output (g/d) did not differ among fiber treatments. This indicates that BP had a greater water holding capacity due to its higher concentration of soluble fibers. Previous research in canines and sows fed diets containing BP have also reported this water holding capacity (Burkhalter et al., 2001; Serena et al., 2008).

Apparent Total Tract Macronutrient and Energy Digestibilities

Apparent total tract digestibilities by cats fed the experimental diets are listed in Table 4. Cats fed the BP, CL, and SBH treatments had lower ($P < 0.05$) ATT digestibilities of DM (74.5%, 78.4%, and 75.4%, respectively) and OM (77.9%, 81.1%, and 78.5%, respectively) when compared with the NF diet (DM: 85.5% and OM: 88.8%). Lower DM

(70.9%) and OM (74.7%) digestibility values were reported by Fischer et al. (2012) when overweight cats were fed a diet containing 15.5% BP and 25.6% TDF. In contrast, Sunvold et al. (1995a) reported greater coefficients of DM and OM digestibility in cats fed diets containing 12.5% BP (DM: 80.4% and OM: 83.8%) and 8.1% CL (DM: 81.0% and OM: 83.5%). Dietary fiber has been reported to reduce OM digestibility in cats (Kienzle et al., 1991). In the present study, TDF content of the fiber-supplemented diets was high compared with previously reported data.

Cats fed the BP diet had lower ($P < 0.05$) ATT CP digestibility (77.2%) among all experimental treatments. Cats fed the NF treatment did not differ in CP digestibility (84.9%) when compared with cats fed CL or SBH; however, CL had greater ($P < 0.05$) CP digestibility than SBH (88.5% and 81.7%, respectively). Even though cats fed BP had lower CP digestibility, BP is higher in soluble, fermentable fibers compared with other fiber treatments. This fermentable property of BP fiber might have caused an increase microbial N due to fermentative

process in the hindgut, which were then partially excreted in the feces thus causing a false perception of undigested protein and decreased ATT CP digestibility (Sunvold et al., 1995b; Rossoni Serão and Fahey, 2013). Similar rationale can be applied for the reduced CP digestibility observed in cats fed the SBH diet.

Cats fed NF, BP, and SBH treatments had no differences ($P > 0.05$) in ATT AHF digestibility (89.9%, 86.9%, and 88.6%, respectively). Cats fed CL had the highest AHF digestibility (92.9%) that could be due to the higher AHF concentration in the CL diet. Previous studies have reported slightly higher AHF digestibility in adult cats. Barry et al. (2010) observed higher AHF digestibility (95.8%) in a diet containing 4.0% CL and 7.9% TDF. In addition, Sunvold et al. (1995a) fed NF, BP, and CL diets to cats that contained 1.7%, 10.6%, and 11.2% TDF and higher AHF digestibility was observed (93.9%, 91.5%, and 95.0%, respectively). However, the previous research examined diets containing lower TDF values. As TDF increases, ATT nutrient digestibility tends to decrease. Furthermore, the present study used choice white grease vs. more common fat sources, such as chicken fat or vegetable oil. Choice white grease contains greater concentrations of saturated fatty acids compared with other fat sources. For comparison, choice white grease has an unsaturated:saturated ratio of 0.31, compared with beef tallow (0.08), poultry fat (0.71), and soybean oil (4.07; NRC, 2006). Diets containing higher amounts of unsaturated fats (i.e., soybean oil) have been demonstrated to have higher fat digestibility by dogs (Marx et al., 2015), which may have influenced the coefficients of AHF digestibility observed in the present study.

Cats fed BP had the greatest ($P < 0.05$) ATT TDF digestibility (33.7%), followed by SBH (18.0%) and CL (15.1%). Cats fed the NF treatments had the lowest TDF digestibility (8.5%). These are expected results as the NF diet was formulated without additional dietary fiber source, except from intrinsic fiber fractions present on ingredients used, predominantly from corn and corn gluten meal, and because CL and SBH had a higher ratio of insoluble to soluble fiber (13.6:1.5 and 15.6:1.0) in contrast with BP (11.2:5.9). Similar BP digestibility coefficients were reported when cats were fed a diet containing 15.5% BP (Fischer et al., 2012). Sunvold et al. (1995a) reported TDF digestibility values that were approximately half of what we found (8.9%) to cats fed a diet containing 8.1% CL. However, they reported similar TDF digestibility in cats fed diets containing BP and NF, 38.2% and

5.3%, respectively. Insoluble fibers are less fermentable in the large intestine of monogastric animals, especially in cats where the large intestine is very short. This resulted in most of the insoluble fiber not being fermented by the microbiota and excreted in the feces.

Similar to DM and OM digestibilities, DE was similar for cats fed the 3 fiber treatments and lower ($P < 0.05$) than cats fed the NF treatment. Slightly lower DE (75.7%) was previously reported in cats fed a BP diet containing 15.5% BP (Fischer et al., 2012). The ME values were the lowest ($P < 0.05$) for cats fed BP, followed by SBH and CL, with NF having the highest ME. These results are expected as higher fiber diets have been observed to interfere with digestibility of energy (Earle et al., 1998; Fahey et al., 2004). Moreover, the lower DE and ME values are not a negative attribute to the fibrous diets. Fischer et al. (2012) and Weber et al. (2007) suggest that higher TDF levels could lead to improved satiety and have weight loss and management applications due to its lower DE and ME.

Fecal Fermentative End Products and Serum Chemistry

It is assumed that the higher amounts of fermentative end products measured in the feces are a reflection of the colonic fermentative process in the large intestine in the cat. There were no differences among treatments in regards to fecal ammonia (mean = 119.2 $\mu\text{mole/g}$, DMB) or total phenol and indole concentrations (mean = 1.8 $\mu\text{mole/g}$, DMB; Table 5). This contrasts with previous research that observed higher 4-methylphenol and indole concentrations in cats fed a CL diet that contained 7.9% TDF (Fischer et al., 2012). In addition, cats fed BP, SBH, and NF diets had a similar fecal pH, ranging from 5.5 to 5.7, whereas a greater fecal pH (6.0) was observed in cats fed the CL diet. Lower fecal pH (5.9) has been reported to reduce the resorption of ammonia in dogs, causing a faulty greater fecal ammonia concentration (Matsuoka et al., 1990). This is in agreement with our data as BP, SBH, and NF diets had an observed lower pH and numerically higher fecal ammonia concentrations when compared with cats fed CL.

Cats fed BP had greater ($P < 0.05$) total fecal SCFA concentration (699.7 $\mu\text{mole/g}$, DMB) than the other 3 treatments, suggesting an increase in saccharolytic fermentation. Cats fed NF and SBH had intermediate total SCFA concentrations (456.0 and 422.7 $\mu\text{mole/g}$ DMB, respectively), followed by CL-fed cats (231.6 $\mu\text{mole/g}$, DMB). The authors

Table 5. Fecal fermentative end products of cats fed diets containing select fiber sources

Item ($\mu\text{mole/g}$, DM basis)	Treatments				SEM	P-value
	No fiber	Beet pulp	Cellulose	Soybean hulls		
Fecal pH	5.5 ^b	5.7 ^{ab}	6.0 ^a	5.7 ^{ab}	0.11	0.0059
Ammonia	125.5	126.0	94.9	130.5	17.24	0.2608
Phenols and indoles						
Total phenols/indoles	1.7	2.6	1.1	1.9	0.89	0.6773
4-Methylphenol	0.5	1.2	0.4	0.5	0.52	0.9714
Indole	1.2	1.4	0.7	1.4	0.42	0.3638
SCFA ¹						
Total SCFA	456.0 ^b	699.7 ^a	231.6 ^c	422.7 ^{bc}	58.41	0.0001
Acetate	238.1 ^b	459.2 ^a	146.4 ^b	274.3 ^b	42.09	0.0001
Propionate	62.7 ^b	139.0 ^a	47.2 ^b	76.2 ^b	13.22	0.0002
Butyrate	155.2 ^a	101.5 ^b	38.0 ^c	72.1 ^{bc}	16.70	0.0001
BCFA ¹						
Total BCFA	24.6 ^a	24.6 ^a	11.9 ^b	26.8 ^a	4.81	0.0029
Isobutyrate	6.6 ^a	6.0 ^{ab}	3.0 ^b	7.6 ^a	1.48	0.0075
Isovalerate	11.5 ^a	10.1 ^{ab}	5.0 ^b	13.4 ^a	2.65	0.0017
Valerate	6.6	8.5	4.0	5.8	2.72	0.3202

^{a-c}Means in the same row without common superscript letters denote a significant difference ($P < 0.05$).

¹SCFA = short-chain fatty acids; BCFA = branched-chain fatty acids.

hypothesize that the lower SCFA concentration in fecal samples of cats fed the CL diet in contrast with NF diet was most likely due to lower fermentable dietary fiber concentration in this diet, in combination with a dilution of SCFA concentration based on the larger fecal output. Similar total fecal SCFA concentrations were observed in cats fed CL (Barry et al., 2010) and in cats fed BP (Fischer et al., 2012). When total SCFA concentrations were divided into individual SCFA (i.e., acetate, propionate, and butyrate), cats fed BP had the greatest ($P < 0.05$) acetate and propionate concentration compared with the other 3 experimental diets, which was also observed by Fischer et al. (2012). In in vitro studies completed using cat fecal inoculum, BP was also observed to have higher acetate, propionate, and total SCFA production (Sunnold et al., 1995a,b). Cats fed the NF diet had the greatest ($P < 0.05$) amount of butyrate concentration (155.2 $\mu\text{mole/g}$, DMB), followed by BP (101.5 $\mu\text{mole/g}$, DMB) and SBH (72.1 $\mu\text{mole/g}$, DMB), while cats fed CL had the lowest butyrate concentration (38.0 $\mu\text{mole/g}$, DMB). Although cats fed SBH appear to be producing less butyrate numerically when compared with BP, proportionally it is producing more (17.1%) when compared with BP (14.5%) and CL (16.4%). Butyrate is a key energy source for colonocytes and preferentially taken up and used compared with acetate and propionate (Slavin, 2013). In addition, butyrate has been observed in humans to have potential protective qualities against diseases (Christl et al., 1996).

Cats fed CL had lower ($P < 0.05$) fecal BCFA concentrations (11.9 $\mu\text{mole/g}$, DMB) in contrast with cats fed the NF, BP, or SBH treatments (average = 25.3 $\mu\text{mole/g}$, DMB). Low BCFA concentrations indicate that there was less protein fermentation; therefore, more dietary protein was being digested by the animal. These data contrast with previous research, as Fischer et al. (2012) reported BCFA concentrations in cats fed CL to reach 63.3 $\mu\text{mole/g}$, DMB. However, it agrees with our ATT CP digestibility data, which was greatest for the CL diet compared with BP and SBH diets, and not different from NF diet. Phenols, indoles, ammonia, and BCFA are putrefactive compounds that result from bacterial fermentation in the hindgut and cause undesirable fecal characteristics, including foul-smelling feces. This can be an unappealing quality from a pet owner's standpoint (Miner and Hazen, 1969; O'Neill and Phillips, 1992). Branched-chain fatty acids are produced when carbohydrates are limiting to the large intestinal microbes, resulting in branched-chain AA being fermented (Macfarlane et al., 1992). Previous research has reported that increasing the amount of rapidly fermentable fibers (i.e., short-chain fructooligosaccharides, galactooligosaccharides, and pectin) results in an increase in peptides and AA produced in the proximal colon, followed by microbes fermenting the products to generate the putrefactive compounds (Barry et al., 2010; Kanakupt et al., 2011). In the present study, there were no differences between BP, the fiber gold

Table 6. Serum metabolites of cats fed diets containing select fiber sources

Item	Reference range ¹	Treatments				SEM
		No fiber	Beet pulp	Cellulose	Soybean hulls	
Creatinine, mg/dL	0.4 to 1.6	1.6	1.8	1.7	1.7	0.09
BUN, mg/dL ²	18 to 38	23.3	21.4	22.3	23.5	1.03
Total protein, g/dL	5.8 to 8.0	6.6	6.5	6.5	6.7	0.20
Albumin, g/dL	2.8 to 4.1	3.1	3.1	3.1	3.2	0.08
Globulin, g/dL	2.6 to 5.1	3.5	3.3	3.4	3.5	0.14
Ca, mg/dL	8.8 to 10.2	9.3	9.2	9.2	9.3	0.14
P, mg/dL	3.2 to 5.3	4.1	3.8	4.1	3.8	0.17
Na, mmol/L	145 to 157	148.6	149.0	149.7	149.3	0.45
K, mmol/L	3.6 to 5.3	4.7	4.4	4.5	4.5	0.10
Na:K ratio	28 to 36	32.0	33.9	33.3	33.1	0.77
Cl, mmol/L	109 to 126	117.0	116.4	118.0	116.8	0.67
Glucose, mg/dL	60 to 122	83.3	77.1	83.8	78.9	3.69
Total bilirubin, mg/dL	0.0 to 0.3	0.1	0.1	0.1	0.1	0.02
Cholesterol, mg/dL	66 to 160	147.5	140.5	158.4	143.8	14.32
Triglycerides, mg/dL	21 to 166	33.5	34.0	41.3	35.1	3.82
Bicarbonate, mmol/L	12.0 to 21.0	17.5	18.3	16.7	16.9	0.56

¹University of Illinois Veterinary Diagnostic Laboratory Reference Ranges.

²BUN = blood urea nitrogen.

standard, and SBH, illustrating the benefit of SBH as a valuable dietary fiber source in pet food.

The serum chemistry profiles were analyzed for this study as a health check to ensure that the experimental diets were not detrimental to cat health (Table 6). There were no differences ($P > 0.05$) among treatments, and all values, aside from creatinine, were within the corresponding reference ranges provided by the University of Illinois Veterinary School Diagnostics Laboratory. The creatinine values above the reference range observed for BP, CL, and SBH treatments are reflective of the age of the cats (Ross et al., 2006). There was no effect of treatment on serum creatinine concentration. Due to the age of the cats (~10 yr) used in this study, a gradual increase in serum creatinine is expected. These cats were clinically healthy and with no signs of renal dysfunction or failure. Complete blood count results also were within reference ranges for all cats (data not shown).

CONCLUSIONS

Results of this study indicated that up to 14% inclusion of SBH in extruded diets was well accepted by adult cats, without negative effect on daily food intake. Cats fed SBH had similar ATT DM and OM digestibilities of BP and CL diets, with no detrimental effects on fecal quality or health status. As expected, the lack of additional dietary fiber on NF diet greater digestibility of DM, OM, and ME. Soybean hulls diet resulted in

intermediate fermentative profile when compared with CL and BP diets, producing similar concentration of total fecal SCFA, but similar proportions of SCFA of cats fed the BP diet. Fecal putrefactive compounds of cats fed the SBH diet were similar when compared with NF and BP treatments. Although the SBH diet had a higher insoluble:soluble fiber ratio than CL, fecal fermentative end product results suggest that the insoluble fraction of SBH might be more fermentable than CL. Based on the findings of this research, SBH appears to be a suitable dietary fiber source in feline diets even when fed at high concentrations. Overall, SBH can be used as an economical, readily available, and sustainable dietary fiber source in adult cat food formulations. It also can have further applications in weight maintenance diets for overweight cats, as the addition of palatable fibers can reduce dietary energy content while maintaining normal food intake (Fekete et al., 2001), and may also support gut health due to its moderate fermentative profile and beneficial shifts in SCFA concentrations observed in this study.

LITERATURE CITED

- American Association of Cereal Chemists (AACC). 1983. Approved methods. 8th ed. AACC, St. Paul, MN.
- Association of American Feed Control Officials (AAFCO). 2016. Official publication. Assoc. Am. Feed Cont. Off. Inc., Champaign, IL.
- Association of Official Analytical Chemists (AOAC). 2006. Official methods of analysis. 17th ed. AOAC, Arlington, VA.

- Banta, C. A., E. T. Clemens, M. M. Krinsky, and B. E. Sheffy. 1979. Sites of organic acid production and patterns of digesta movement in the gastrointestinal tract of dogs. *J. Nutr.* 109:1592–1600. doi:10.1093/jn/109.9.1592
- Barry, K. A., B. J. Wojcicki, I. S. Middelbos, B. M. Vester, K. S. Swanson, and G. C. Fahey, Jr. 2010. Dietary cellulose, fructooligosaccharides, and pectin modify fecal protein catabolites and microbial populations in adult cats. *J. Anim. Sci.* 88:2978–2987. doi:10.2527/jas.2009-2464
- Budde, E. F. 1952. The determination of fat in baked biscuit type of dog foods. *J. AOAC* 35:799–805.
- Burkhalter, T. M., N. R. Merchen, L. L. Bauer, S. M. Murray, A. R. Patil, J. L. Brent, Jr. and G. C. Fahey, Jr. 2001. The ratio of insoluble to soluble fiber components in soybean hulls affects ileal and total-tract nutrient digestibilities and fecal characteristics of dogs. *J. Nutr.* 131:1978–1985. doi:10.1093/jn/131.7.1978
- den Besten, G., K. van Eunen, A. K. Groen, K. Venema, D. J. Reijngoud, and B. M. Bakker. 2013. The role of short-chain fatty acids in the interplay between diet, gut microbiota, and host energy metabolism. *J. Lipid Res.* 54:2325–2340. doi:10.1194/jlr.R036012
- Chaney, A. L., and E. P. Marbach. 1962. Modified reagents for determination of urea and ammonia. *Clin. Chem.* 8:130–132.
- Christl, S. U., H. D. Eisner, G. Dusel, H. Kasper, and W. Scheppach. 1996. Antagonistic effects of sulfide and butyrate on proliferation of colonic mucosa: A potential role for these agents in the pathogenesis of ulcerative colitis. *Dig. Dis. Sci.* 41:2477–2481.
- Cole, J. T., G. C. Fahey, Jr, N. R. Merchen, A. R. Patil, S. M. Murray, H. S. Hussein, and J. L. Brent, Jr. 1999. Soybean hulls as a dietary fiber source for dogs. *J. Anim. Sci.* 77:917–924.
- Earle, K. E., E. Kienzle, B. Opitz, P. M. Smith, and I. E. Maskell. 1998. Fiber affects digestibility of organic matter and energy in pet foods. *J. Nutr.* 128(Suppl. 12):2798S–2800S. doi:10.1093/jn/128.12.2798S
- Erwin, E. S., G. J. Marco, and E. M. Emery. 1961. Volatile fatty acid analyses of blood and rumen fluid by gas chromatography. *J. Dairy Sci.* 44:1768–1771.
- Extension. 2008. What are soybean hulls?. Extension Foundation, Inc. www.eXtension.org (Accessed 29 December 2017.)
- Fahey, G. C., Jr., E. A. Flickinger, C. M. Grieshop, and K. S. Swanson. 2004. The role of dietary fibre in companion animal nutrition. In: J. W. Van Der Kamp, N.-G. Asp, J. Miller Jones, and G. Schaafsma, editors, *Dietary fibre: Bio-active carbohydrates for food and feed*. Wageningen Acad. Publ., Wageningen, The Netherlands. p. 295–328.
- Fahey, G. C., Jr, N. R. Merchen, J. E. Corbin, A. K. Hamilton, L. L. Bauer, E. C. Titgemeyer, and D. A. Hirakawa. 1992. Dietary fiber for dogs: III. Effects of beet pulp and oat fiber additions to dog diets on nutrient intake, digestibility, metabolizable energy, and digesta mean retention time. *J. Anim. Sci.* 70:1169–1174.
- Fahey, G. C., Jr, N. R. Merchen, J. E. Corbin, A. K. Hamilton, K. A. Serbe, S. M. Lewis, and D. A. Hirakawa. 1990. Dietary fiber for dogs: I. Effects of graded levels of dietary beet pulp on nutrient intake, digestibility, metabolizable energy and digesta mean retention time. *J. Anim. Sci.* 68:4221–4228.
- Fekete, S., I. Hullár, E. Andrásófszky, Z. Rigó, and T. Berkényi. 2001. Reduction of the energy density of cat foods by increasing their fibre content with a view to nutrients' digestibility. *J. Anim. Physiol. Anim. Nutr. (Berl.)* 85:200–204.
- Fischer, M. M., A. M. Kessler, L. R. de Sá, R. S. Vasconcellos, F. O. Filho, S. P. Nogueira, M. C. Oliveira, and A. C. Carciofi. 2012. Fiber fermentability effects on energy and macronutrient digestibility, fecal traits, postprandial metabolite responses, and colon histology of overweight cats. *J. Anim. Sci.* 90:2233–2245. doi:10.2527/jas.2011-4334
- Flickinger, E. A., E. M. Schreijen, A. R. Patil, H. S. Hussein, C. M. Grieshop, N. R. Merchen, and G. C. Fahey, Jr. 2003. Nutrient digestibilities, microbial populations, and protein catabolites as affected by fructan supplementation of dog diets. *J. Anim. Sci.* 81:2008–2018. doi:10.2527/2003.8182008x
- German, A. J. 2006. The growing problem of obesity in dogs and cats. *J. Nutr.* 136:1940S–1946S.
- Kanakupt, K., B. M. Vester Boler, B. R. Dunsford, and G. C. Fahey, Jr. 2011. Effects of short-chain fructooligosaccharides and galactooligosaccharides, individually and in combination, on nutrient digestibility, fecal fermentative metabolite concentrations, and large bowel microbial ecology of healthy adult cats. *J. Anim. Sci.* 89:1376–1384. doi:10.2527/jas.2010-3201
- Kienzle, E., H. Meyer, and R. Schneider. 1991. Investigations on palatability, digestibility and tolerance of low digestible food components in cats. *J. Nutr.* 121(Suppl. 11):S56–S57. doi:10.1093/jn/121.suppl_11.S56
- Macfarlane, G. T., G. R. Gibson, E. Beatty, and J. H. Cummings. 1992. Estimation of short-chain fatty acid production from protein by human intestinal bacteria based on branched-chain fatty acid measurements. *FEMS Microbiol. Ecol.* 101:81–88.
- Marx, F. R., L. Trevizan, Ø. Ahlstrøm, and A. D. E. M. Kessler. 2015. Soybean oil and beef tallow in dry extruded diets for adult dogs. *Arch. Anim. Nutr.* 69:297–309. doi:10.1080/1745039X.2015.1058619
- Massimino, S. P., M. I. McBurney, C. J. Field, A. B. Thomson, M. Keelan, M. G. Hayek, and G. D. Sunvold. 1998. Fermentable dietary fiber increases GLP-1 secretion and improves glucose homeostasis despite increased intestinal glucose transport capacity in healthy dogs. *J. Nutr.* 128:1786–1793. doi:10.1093/jn/128.10.1786
- Matsuoka, Y., T. Uruno, M. Yamada, A. Mizukami, Y. Kanetake, N. Sunagane, and K. Kubota. 1990. Effects of lactulose on blood ammonia levels in beagles with end to-side portacaval shunt. *Nihon Yakurigaku Zasshi* 96:97–101.
- Miner, J. R., and T. E. Hazen. 1969. Ammonia and amines: Components of swine building odor. *Trans. ASAE* 12:772–774.
- National Agricultural Statistics Services (NASS). 2017. USDA forecasts record-high soybean production in 2017. https://www.nass.usda.gov/Newsroom/2017/08_10_2017.php (Accessed 29 December 2017.)
- National Research Council (NRC). 2006. *Nutrient requirements of dogs and cats*. 2nd ed. Natl. Acad. Press, Washington, DC.
- O'Neill, D. H., and V. R. Phillips. 1992. A review of the control of odour nuisance from livestock buildings: Part 3. Properties of the odorous substances which have been

- identified in livestock wastes or in the air around them. *J. Agric. Eng. Res.* 53:23–50.
- Prosky, L., N. G. Asp, T. F. Schweizer, J. W. De Vries, and I. Furda. 1992. Determination of insoluble and soluble dietary fiber in foods and food products: Collaborative study. *J. Assoc. Off. Anal. Chem.* 75:360–367.
- Ross, S. J., C. A. Osborne, C. A. Kirk, S. R. Lowry, L. A. Koehler, and D. J. Polzin. 2006. Clinical evaluation of dietary modification for treatment of spontaneous chronic kidney disease in cats. *J. Am. Vet. Med. Assoc.* 229:949–957. doi:10.2460/javma.229.6.949
- Rossoni Serão, M. C., and G. C. Fahey, Jr. 2013. Companion animal nutrition as affected by dietary fibre inclusion. In: J. Delcour and K. Poutanen, editors, *Fibre-rich and wholegrain foods*. Woodhead Publ., Swaston, Cambridge, UK. p. 407–420.
- Serena, A., H. Jørgensen, and K. E. Bach Knudsen. 2008. Digestion of carbohydrates and utilization of energy in sows fed diets with contrasting levels and physicochemical properties of dietary fiber. *J. Anim. Sci.* 86:2208–2216. doi:10.2527/jas.2006-060
- Slavin, J. 2013. Fiber and prebiotics: Mechanisms and health benefits. *Nutrients* 5:1417–1435. doi:10.3390/nu5041417
- Sunvold, G. D., G. C. Fahey, Jr, N. R. Merchen, L. D. Bourquin, E. C. Titgemeyer, L. L. Bauer, and G. A. Reinhart. 1995a. Dietary fiber for cats: In vitro fermentation of selected fiber sources by cat fecal inoculum and in vivo utilization of diets containing selected fiber sources and their blends. *J. Anim. Sci.* 73:2329–2339.
- Sunvold, G. D., H. S. Hussein, G. C. Fahey, Jr, N. R. Merchen, and G. A. Reinhart. 1995b. In vitro fermentation of cellulose, beet pulp, citrus pulp, and citrus pectin using fecal inoculum from cats, dogs, horses, humans, and pigs and ruminal fluid from cattle. *J. Anim. Sci.* 73:3639–3648.
- Swanson, K. S., C. M. Grieshop, E. A. Flickinger, L. L. Bauer, H. P. Healy, K. A. Dawson, N. R. Merchen, and G. C. Fahey, Jr. 2002. Supplemental fructooligosaccharides and mannanoligosaccharides influence immune function, ileal and total tract nutrient digestibilities, microbial populations and concentrations of protein catabolites in the large bowel of dogs. *J. Nutr.* 132:980–989. doi:10.1093/jn/132.5.980
- United States Department of Agriculture (USDA). 2017. Related data and statistics. www.ers.usda.gov/topics/crops/soybeans-oil-crops/related-data-statistics/ (Accessed 20 November 2017.)
- Weber, M., T. Bissot, E. Servet, R. Sergheraert, V. Biourge, and A. J. German. 2007. A high-protein, high-fiber diet designed for weight loss improves satiety in dogs. *J. Vet. Intern. Med.* 21:1203–1208.