The effects of fiber source on extrusion processing parameters and kibble characteristics of dry cat foods

Renan Antunes Donadelli, Hulya Dogan, and Charles Gregory Aldrich[1]

Department of Grain Science and Industry, Kansas State University, 1301 Mid Campus Drive, Manhattan, KS 66506

ABSTRACT: Cellulose and beet pulp have been commonly used in the pet food industry to increase the dietary fiber content of cat foods. However, pet food companies seek alternatives to these so-called byproducts. Miscanthus grass is grown for its fiber content and may serve as an alternative to traditional fibrous ingredients. The objectives of this study were to determine the effects of fiber sources on extrusion processing and kibble structure of cat foods. Three replicate batches of a complete and balanced foods for adult cats at maintenance each containing 10% of Miscanthus grass, cellulose, or beet pulp was mixed and kibbles were produced on a single-screw extruder. Feed rate, preconditioner water and steam, extruder screw speed, extruder water and steam addition, and knife speed were adjusted to achieve a wet bulk density of 330 g/L. After extrusion, kibbles were dried at 115.5 ºC to less than 10% moisture. Dried kibbles were coated with chicken fat and flavor enhancer. No effects due to fiber source were reported for extrusion parameters or kibble measurements ($P > 0.05$) with the exception of compression energy, wherein kibbles produced with cellulose required more energy to compress than those containing beet pulp (6,917 N mm vs. 3,591 N mm, respectively). In conclusion, tested fiber sources had no impact on extrusion parameters and most kibble characteristics. Kibbles containing cellulose required more energy to compress than kibbles containing beet pulp. Miscanthus grass could be used as an alternative to traditional fiber sources used to produce cat foods.

Key words: beet pulp, cellulose, compression energy, extrusion, Miscanthus grass

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INTRODUCTION

Obesity is an issue in the dog and cat population in the United States. This disease is more common in cats than dogs, wherein 33.5% of cats are considered obese compared to 19.6% of dogs (APOP, 2020). Historically, pet food companies have produced diets with lower caloric contents to aid this pet population to reduce energy intake and lose weight. The dietary energy dilution, in most cases, has been accomplished by the reduction of fat and the addition of fiber. Since most fat is topically applied to extruded pet foods, its reduction is straightforward with no direct impact on the process. In addition to weight maintenance, dietary fiber is thought to aid in hairball management in cats (Davenport et al., 2008; Loureiro et al., 2017). Despite its benefits to the animals, dietary fiber can have deleterious effects on extrusion parameters and kibble characteristics (Monti

[1]Corresponding author: aldrich4@ksu.edu
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et al., 2016; Wang et al., 2017; Alvarenga et al., 2018).

One of the most prominent fiber sources added to pet food is cellulose from the paper pulping industry (Burrows et al., 1982; Koppel et al., 2015). However, this ingredient is costly compared to other dietary components. Beet pulp is another common fiber source studied in dog and cat foods for its effects on nutrient utilization (Fahey et al., 1990a, 1990b) and fermentation dynamics in vitro (Sunvold et al., 1995a, 1995b). Although cellulose and beet pulp were extensively studied and commonly used, pet food manufacturers have been in search of novel ingredients to differentiate their products from competitors and supply alternative foods to consumers.

Unlike commonly used fiber sources, Miscanthus grass is a novel ingredient made from *Miscanthus giganteus*, a perennial C4 grass. Unlike cellulose and beet pulp, Miscanthus grass is purposefully grown for its fiber content. As a result, this ingredient could be used by companies that claim to produce food without the addition of byproducts. Miscanthus grass has been previously tested by other industries (cellulosic ethanol—Adams et al., 2018; construction, paper pulping, and absorbent—Visser and Pignatelli, 2001). However, little was known about its effects on companion animal nutrition until recently (Donadelli and Aldrich, 2019, 2020; Donadelli et al., 2019). Therefore, the hypothesis of this study was that Miscanthus grass would be a viable alternative fiber source to cellulose. Fiber is known to affect the process and structure of extruded pet foods, which can ultimately impact diet palatability and utilization. Thus, the objective of this work was to determine the effects of Miscanthus grass on the extrusion processing parameters and kibble characteristics of cat foods.

MATERIALS AND METHODS

For easier identification, the fiber sources used to produce the cat foods will be identified by their full name, for example, Miscanthus grass, cellulose, and beet pulp. The cat foods produced from such fiber sources will be referred as MG, CE, and BP, for Miscanthus grass, cellulose, and beet pulp, respectively.

Ingredient Sourcing and Mixing

Experimental ingredients, except the fiber sources, digestibility markers, chicken fat, and flavor enhancer were purchased as a blend from a commercial feed mill (Fairview Mills, Seneca, KS; Table 1). Cellulose and beet pulp were purchased from the same feed mill. Miscanthus grass was provided by the study sponsor (Renew Biomass, Springfield, MO). Experimental cat foods were formulated to meet the requirements for adult cats at maintenance according to the Association of American Feed Control Officials (AAFCO, 2015). Three individual batches of each cat food were blended to provide replication for each dietary treatment. Basal dietary blend (121.1 kg), fiber source (14.36 kg), chromic oxide (0.36 kg), and titanium dioxide (0.57 kg) were mixed in a paddle mixer (140 kg capacity) for 5 min prior to extrusion. Fiber source addition in the diet was fixed at 10% for all treatment. At a similar inclusion among the different cat foods, the results presented here were an outcome of the fiber ingredient inclusion rather than a variable inclusion, which would have affected the starch and protein levels (in the case of formulating the diet to a similar fiber content). All ingredients were ground to pass a number 16 screen (1.18 mm opening) before being mixed and extruded.

Extrusion

Extrusion of the diets was performed on three separate days (one batch of each dietary treatment per day). The order that the diets were extruded was MG, CE, and BP on the first day; BP, CE, and MG on the second day; and BP, MG, and CE on the last extrusion day. A single-screw pilot-scale extruder (model E525, Extru-Tech, Seneca, KS) was used to produce the dietary treatments. The length to diameter ratio of the extruder was 13.1:1 with an internal barrel diameter of 133.35 mm. Screw and barrel configurations were divided into seven sections (Fig. 1). The feeding zone had a barrel without grooves and a screw with a forward single flight. For segments 1–4, the screw was similar to the feeding zone; however, the barrel had a spiral groove to increase the retention time. For section 5, the barrel had a spiral groove and the screw was a 1.5 forward flight. For the last segment, a conical spiral groove barrel and conical double-cut flight screw were used (Fig. 1). Additionally, shear locks were used between segments 4 and 5 and 5 and 6. The die plate was mounted at the end of the extruder barrel with three inserts containing three circular holes of 3.3 mm of diameter each.

A wet bulk density of 330 g/L was targeted, and all extrusion parameters were adjusted to meet

Table 1. Ingredient and nutrient composition of experimental cat foods

Diet	MG	CE	BP
Ingredient composition, %			
Chicken byproduct meal low ash	35.22	35.22	35.22
Brewers rice	14.07	14.07	14.07
Corn	14.07	14.07	14.07
Wheat	14.07	14.07	14.07
Miscanthus grass	10.00	–	–
Cellulose	–	10.00	–
Beet pulp	–	–	10.00
Corn gluten meal (75% crude protein)	5.00	5.00	5.00
Salt	0.40	0.40	0.40
Potassium chloride	0.26	0.26	0.26
Choline chloride (60%)	0.20	0.20	0.20
Vitamin premix[a]	0.20	0.20	0.20
Calcium carbonate	0.20	0.20	0.20
Trace mineral premix[b]	0.20	0.20	0.20
Fish oil	0.10	0.10	0.10
Taurine	0.10	0.10	0.10
Natural antioxidant	0.10	0.10	0.10
Titanium oxide	0.40	0.40	0.40
Chromium sesquioxide	0.25	0.25	0.25
Chicken fat[c]	4.01	4.01	4.01
Flavor enhancer[c]	1.00	1.00	1.00
Nutrient concentration on a dry matter basis			
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 fiber, %	5.56	8.90	2.95
TDF, %	13.76	14.48	10.88
Nitrogen-free extract[d], %	26.81	26.79	31.32
Gross energy, kcal/kg	4839	4823	4839

[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), as is basis.

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

[c]Added after the diets were dried to less than 10% moisture as a coating step.

[d]Nitrogen-free extract = dry matter − crude protein − crude fat − ash − TDF.

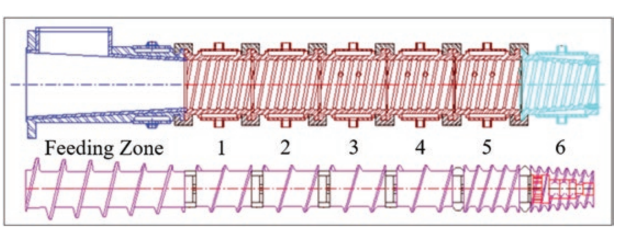

Figure 1. Screw and barrel profile of E525 extruder. Inlet on the left side, outlet on the right.

the desired wet bulk density. After steady state was achieved, feed rate, water and steam addition in the preconditioner, discharge temperature, extruder screw speed, water and steam addition in the extruder barrel, die temperature, die pressure, knife speed, specific mechanical energy (SME, equation bellow), total mass flow, and wet bulk density were recorded every 20 min.

$$\mathrm{SME} = \frac{\frac{\tau - \tau_0}{100} \times \frac{N}{N_r} \times P_r}{m}$$

wherein SME is the specific mechanical energy in kilojoules per kilogram, τ is the motor torque in newton meter, τ_0 is the no-load motor torque in newton meter, N is the motor speed in revolutions per minute, N_r is the rated motor speed in revolutions per minute, P_r is the motor power in watts, and m is the produced mass in kilograms. After extrusion, diets were dried in a convection oven at 115.5 °C until moisture was less than 10%. Chicken fat and flavor enhancer were applied as a coating after the diets were dried at 4% and 1% of the weight, respectively. After kibbles were coated, they were stored in paper bags with a plastic lining.

Kibble Characteristics

In addition to the extrusion parameters, during each 20 min interval, 10 kibbles were collected after the extruder and were measured for their length and diameter (twice). Similarly, 10 kibbles out of the dryer were measured for length and diameter (twice) and weighed for calculation of piece volume, density, and sectional expansion ratio index (SEI) as follows:

$$V = \frac{\pi \times h \times D_k^2}{4}$$

$$d = \frac{m_k}{V}$$

$$\mathrm{SEI} = \frac{D_k^2}{D_d^2}$$

wherein V is the volume in milliliters, h is the kibble length in millimeters, D_k is the average of the two measurements of the kibble diameter in millimeters, d is the kibble density in grams per liter, m_k is the kibble mass in grams, SEI is the sectional expansion ratio index, and D_d is the die hole diameter in millimeters.

Texture analysis was performed using a texture analyzer (model TA-XT2, Texture Technology Corp., Scarsdake, NJ) equipped with a 30-kg load cell. A cylindrical probe (25 mm diameter) was used to compress 30 kibbles from each collection point for each batch (total 90 kibbles per diet per day of extrusion). Kibbles from each time point and collection point were conditioned in a convection oven at 45 ºC for 48 h and then moved into a desiccator for 24 h at room temperature to allow for moisture to be equilibrated among treatments. The pretest speed was 2 mm/s, test speed was 1 mm/s, and a posttest speed was 10 mm/s (adapted from Dogan and Kokini, 2007). Strain level was set at 90%. Kibble hardness (N) was the peak force of the first major kibble breakage; the energy to compress (N mm) the kibbles to 90% was the computed area under the curve for each compressed kibble. Negative values were rounded to 0 for the calculation of energy to compress. The average values of 90 kibbles for hardness and compression energy were used as an experimental unit for statistical analysis.

Chemical and Physical Analyses

Test fibers were analyzed for their bulk density according to Donadelli et al. (2020). Fiber particle size was analyzed according to the ASABE (2008; method S319.4). In addition to the physical characterization of the fiber sources, they were analyzed for moisture (AOAC 930.15) (AOAC, 1990), crude fiber (AOCS Ba 6a-05 method) (AOCS, 2017), acid detergent fiber (Ankom Technology method), neutral detergent fiber (Ankom Technology method using α-amylase), acid detergent lignin (Ankom Technology method), total dietary fiber (TDF), and insoluble fiber (Sigma Aldrich TDF kit, catalog number TDF 100A). The soluble fiber content was estimated by subtracting the insoluble fiber content from the TDF (Table 4).

Moreover, diets were analyzed for their moisture (AOAC 930.15), crude protein (AOAC 990.03), crude fat (AOCS Ba 3–38 method), ash (AOAC 942.05), TDF (Prosky et al., 1985; Prosky et al., 1988), and gross energy content by bomb calorimetry (model 1351, Parr Instrument Company, Moline, IL). Nitrogen-free extract was calculated by subtracting crude protein, crude fat, ash, and TDF from the dry matter.

Experimental Design and Statistical Analysis

A complete block design was used as the experimental design. Day was considered a random blocking factor and batch was considered as the experimental unit. The GLIMMIX procedure from SAS (v. 9.4, SAS Institute, Inc., Cary, NC) was used to analyze the data. Treatment means were considered different at an alpha of 5% by Fisher least square difference. Additionally, each treatment wet bulk density mean was compared to the targeted wet bulk density (330 g/L) using a t-test. Treatments were considered different from target if P was smaller than alpha ($\alpha < 0.05$) and tendencies were considered when P varied from 0.05 to 0.10.

RESULTS

To reiterate, when referring to the fiber sources, the full names will be used and, when referring to the experimental diets, the abbreviations will be used. Ingredient compositions of the diets were the same except for the source of fiber (Table 1). The common basal diet composition was intended to provide a baseline to evaluate the changes required for processing conditions resulting from the fiber addition in order to produce a cat food with a target wet bulk density of 330 g/L. The nutrient composition of the diets varied slightly and in accordance with the type of fiber added. Total dietary fiber was higher for CE, intermediate for MG, and lowest for BP. In addition to the dietary fiber variation, crude protein of MG was higher than BP. Crude fat, ash, and gross energy content were similar among diets (Table 1).

None of the extrusion parameters were affected by the fiber source (Table 2) and no water was added into the extruder barrel. Likewise, kibble characteristics were similar among treatments, except for wet bulk density and compression energy (Table 3). The BP diet tended to have a lower wet bulk density compared to the targeted 330 g/L value ($P = 0.0833$). Compression energy was higher for CE kibbles than BP kibbles (6,917 vs. 3,591 N mm, respectively), with MG kibbles similar to the other treatments (Table 3). It is important to highlight that the cellulose used in this study had some clumps, likely due to issues during the grinding of the cellulose pellets to a powder. This could be due to the screen used in the grinder, which was discovered after processing to have a hole that led to the improper separation of particles by target size. As a result, a higher variation in kibble size was observed for CE diet compared to the other treatments. As an attempt to account for some of this variation in the kibble parameters, 30 kibbles from each one of the three collection points were measured, totaling 90 kibble measurements per replication to account for this higher size variation. For future studies, it would be recommended to analyze the grind size before mixing the different batches when the fiber sources were procured as pellets, as well as confirming the grinder screen integrity beforehand.

DISCUSSION

As mentioned previously, dietary fiber in cat foods can have benefits for the animals (Davenport et al., 2008; Roudebush, et al., 2008; Owens et al., 2014; Linder and Parker, 2016; Loureiro et al., 2017); however, it is known to impact extrusion processing. The impacts are well described for breakfast cereals and other snacks for humans (Mendonça et al., 2000; Brennan et al., 2008; Karkle et al., 2012a, 2012b; Kallu et al., 2017; Wang et al., 2017). While this information from the human food literature can be useful, caution is suggested when making direct comparisons because pet foods have a greater proportion of proteins, fats, and ash when compared to human foods, and these ingredients can also impact the final product characteristics, thus the reason for why we chose to include the same quantity of each ingredient in the formula rather than creating iso-fibrous diets.

Despite the differences in measured dietary fiber composition, none of the extrusion parameters were affected by the fiber source (Table 2). In contrast, Monti et al. (2016) reported that, when sugarcane fiber was added to dog foods, there was a decrease in specific mechanical energy compared to wheat bran. In that study, sugarcane fiber and wheat bran had a similar composition to Miscanthus grass and beet pulp, respectively. However, the crude protein and ash of the diets reported here were higher than those from Monti et al. (2016), which could account for some of

Table 2. Extrusion processing conditions of cat foods with different fiber sources

Parameter	MG	CE	BP	SEM	*P*-value
Feed rate, kg/h	239	250	239	6.56	0.444
Preconditioner					
Water, kg/h	41.3	37.6	38.0	2.04	0.450
Steam, kg/h	29.4	29.6	27.7	1.42	0.344
Temperature, °C	67.7	67.0	65.4	3.00	0.505
Extruder					
Screw speed, rpm	369	336	350	18.14	0.405
Water, kg/h	0.00	0.00	0.00		
Steam, kg/h	17.3	22.5	16.6	5.66	0.447
Die					
Temperature, °C	145.1	144.6	145.3	1.62	0.952
Pressure, psi	350	350	350		
Knife speed, rpm	1,650	1,694	1,827	226	0.646
Other					
Specific mechanical energy, J/kg	141.3	143.2	152.0	6.54	0.364
Total mass flow, kg/h	289	298	286	7.83	0.401

Table 3. Kibble characteristics out of the extruder and drier, shrinkage, and macrostructure of dry cat foods with varying fiber sources

Kibble parameter	MG	CE	BP	SEM	*P*-value
Out of the extruder					
Wet bulk density, g/L	306	313	314	9.40	0.723
Bulk density = 330 g/L, *P*-value	0.1994	0.1970	0.0833		
Length, mm	7.57	8.04	6.20	0.49	0.107
Diameter, mm	7.87	8.32	7.67	0.40	0.412
Out of the drier					
Length, mm	6.77	7.49	5.73	0.51	0.162
Diameter, mm	6.75	7.10	7.12	0.43	0.733
SEI, mm^2/mm^2	3.58	3.92	3.95	0.45	0.750
Weight, g	0.126	0.118	0.131	0.0067	0.458
Volume, cm^3	0.254	0.297	0.235	0.047	0.616
Density, g/cm^3	0.593	0.400	0.597	0.109	0.371
Kibble texture analysis					
Hardness, N	6.18	5.87	7.55	0.55	0.138
Compression energy, N mm	5145[ab]	6917[a]	3591[b]	693.78	0.029

[ab]Means with unlike superscripts differ, $P < 0.05$.

Table 4. Chemical composition, bulk density, and particle size of tested fiber sources

Composition	Miscanthus grass	Cellulose	Beet pulp
Dry matter, %	95.00	95.30	92.53
Crude fiber, %	47.58	76.29	20.21
Acid detergent fiber, %	56.53	84.58	26.26
Neutral detergent fiber, %	77.68	92.76	34.15
Acid detergent lignin, %	13.68	0.73	6.38
TDF, %	90.00	102.62	62.36
Insoluble fiber, %	82.74	100.00	35.99
Soluble fiber[a], %	7.26	2.62	26.37
Bulk density, g/mL	0.31	0.19	0.73
GMD ± STD, µm	103.46 ± 76.39	77.33 ± 44.47	193.78 ± 194.83

GMD, geometric mean diameter; STD, standard deviation.

[a]Soluble fiber calculated by the difference between TDF and insoluble fiber.

the differences between these studies. Similar to Monti et al. (2016), the use of different fractions from sorghum (e.g., sorghum millfeed vs. sorghum flour) in pet foods also impacted extrusion processing parameters (Alvarenga et al., 2018). Probably, these differences were a result of the fiber content of the different fractions.

As more dietary fiber and (or) protein is added to the formula, less starch will be present. Starch is the major dietary component responsible for the formation of the foam-like structure of the kibble (Rokey et al., 2010). If starch is diluted by other dietary components, expansion and kibble characteristics are affected. For example, the addition of graded levels of cherry pomace to corn starch resulted in decreased piece expansion and higher piece density (Wang et al., 2017). In the present experiment, kibble measurements were not impacted by fiber sources, except for compression energy and a tendency for BP diet to be lower than the targeted bulk density. Conversely, dog food produced with the addition of higher fiber sorghum fractions resulted in decreased kibble diameter, volume, and sectional expansion ratio index and increased kibble length and density (Alvarenga et al., 2018). Moreover, adding sugarcane fiber (rich in insoluble fibers) to dog food increased the cutting force compared to the addition of wheat bran (with moderate content of soluble fibers; Monti et al., 2016). It is likely in the present study that the combination of the diet composition and small changes in extrusion settings were insignificant enough that fiber sources did not affect the processing parameters and most kibble measurements.

In contrast, when processing conditions were maintained equivalent across treatments (feed rate, preconditioner shaft speed, extruder screw speed, and knife speed), extrusion outcomes and kibble measurements for dog foods containing Miscanthus grass, cellulose, or beet pulp had an effect (Donadelli et al., 2020). The main difference between the present study and the Donadelli et al. (2020) work with dogs is that those diets contained more starch and less protein and fat. In the present study, brewers rice, corn, and wheat were added at 14.07% each; Donadelli et al. (2020) added brewers rice and corn at 17.12% and wheat at 14.55%, which accounted for the increased starch content and, therefore, the functionality of the formula. Additionally, the die dimension was different between these studies [3.3 vs. 5.5 mm diameter, respectively, for this study and Donadelli et al. (2020)]. Dimensions of the die can also impact the final product characteristics (Ganjyal and Hanna, 2004). In this case, in addition to diet ingredient composition differences with Donadelli et al. (2020), the die hole was smaller and may have contributed to some of the outcomes. A smaller die hole increases the pressure at the die [350 vs. 200 psi, respectively, for the present study and Donadelli et al. (2020)], which likely increased starch gelatinization (Diosady et al., 1985). Thus, under these circumstances, less effect of fiber sources would be expected. This difference in pressure could also be a response to the higher screw speed reported by Donadelli et al. (2020) compared to the present study (425 vs. 352 rpm average, respectively). For future studies, starch gelatinization should be evaluated to better understand the relationship among die pressure, screw speed, and kibble expansion.

CONCLUSION

All fiber sources produced a diet with similar wet bulk densities without affecting extrusion parameters. More compression energy was required for CE kibbles compared to BP kibbles, likely due to higher variation in CE kibble size and shape. Finally, Miscanthus grass could be used as an alternative fiber source in extruded cat foods without negatively affecting processing parameters and kibble characteristics.

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