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Potato fiber as a dietary fiber source in dog foods

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ABSTRACT: Potato fiber (PF), a coproduct of potato starch manufacture, was evaluated as a potential novel fiber source in dog food. Potato fiber contained 55% total dietary fiber, 29% starch, 4% crude protein, and 2% acid-hydrolyzed fat. The PF substrate was evaluated for chemical composition, in vitro digestion and fermentation characteristics, and in vivo responses. For the in vitro hydrolytic-enzymatic digestion and fermentation experiment, raw and cooked PF substrates were first subjected to hydrolytic-enzymatic digestion to determine OM disappearance and then fermented using dog fecal inoculum. Fermentation characteristics were then measured at 0, 3, 6, 9, and 12 h. For the in vivo experiment, 10 female mixed-breed dogs (6.13 ± 0.17 yr; 22 ± 2.1 kg) were provided 5 diets with graded concentrations (0%, 1.5%, 3%, 4.5%, or 6%) of PF in a replicated 5 × 5 Latin square design. Dogs were acclimated to the test diet for 10 d, followed by 4 d of total fecal collection. Fresh fecal samples were collected to measure fecal pH and fermentation end products. In vitro digestion revealed that raw and cooked PF were 32.3% and 27.9% digested enzymatically, whereas in vitro fermentation showed that PF was fermentable through 9 h. Raw PF had greater ($P < 0.05$) acetate, propionate, and total short-chain fatty acid (SCFA) concentrations at the 12-h time point compared with cooked PF. The in vivo experiment showed no differences in apparent total tract DM, OM, CP, acid-hydrolyzed fat, or energy digestibility of diets containing graded concentrations of PF. However, total dietary fiber digestibility exhibited a linear increase ($P < 0.01$) with increasing PF concentrations in the diet. Overall, linear increases ($P < 0.01$) were observed for all individual and total SCFA, with a concomitant linear decrease ($P < 0.01$) in fecal pH with increasing dietary PF. Fecal protein catabolite concentrations were low or undetectable, with the exception of spermidine, which exhibited a linear increase with increasing concentrations of PF. These findings indicated that inclusion of PF elicited favorable fermentation characteristics without negatively affecting nutrient digestibility or stool characteristics, indicating that PF could be a functional dietary fiber source in dog foods.

Key words: canine, fermentative end products, in vitro fermentation, nutrient digestibility, potato fiber

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INTRODUCTION

The inclusion of dietary fibers in pet foods has become increasingly popular because of their positive effects on gut function and health, such as improved stool characteristics, laxation, and modulating intestinal microbiota populations (Gallaher, 2000; Flickinger et al., 2003; Propst et al., 2003). It is important to define an acceptable dietary fiber concentration range for each fiber source included because their physicochemical properties will impact digestive physiological outcomes and fecal characteristics uniquely.

Pet foods often include sources of moderately fermentable fibers because they tend to increase production of short-chain fatty acid (**SCFA**) that are beneficial to intestinal health, without decreasing nutrient digestibility (Silvio et al., 2000). Research using common dietary fiber sources, such as beet pulp and oat fiber, determined that an inclusion rate of 7.5% maximizes hindgut fermentation without sacrificing nutrient digestibility (Fahey et al., 1992). Overall, a fiber source that has minimal negative effects on nu-

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trient digestibility and is fermented throughout the entire distal gastrointestinal tract would be considered a high quality fermentable fiber.

Potato fiber (**PF**) is a coproduct of potato starch manufacture and has potential to be a fiber source for the dog, although most PF is used in cattle feed (Meyer et al., 2009). The chemical composition of PF includes fiber components, such as hemicelluloses, cellulose, and pectin, and nonfiber components, such as starch, oligopeptides, and free AA (Mayer, 1998). Potato fiber could ostensibly serve as a dietary fiber source in pet foods because of its favorable chemical composition of having high total dietary fiber (**TDF**) and moderate starch content, with low acid-hydrolyzed fat and CP concentrations. Therefore, the objective of this study was to characterize PF for its nutrient composition, in vitro digestion, and fermentability characteristics, and in vivo responses after extrusion.

MATERIALS AND METHODS

The Institutional Animal Care and Use Committee at the University of Illinois reviewed and approved the protocol used in the present experiment.

Chemical Analyses

A 500-g subsample of PF was suspended in 6 L of distilled water and autoclaved at 121°C for 1 h with a pressure of 82 kg/cm^2 to simulate processing conditions. Nonautoclaved PF (i.e., raw PF) and autoclaved PF (i.e., cooked PF), experimental diets, and fecal samples were analyzed for DM, OM, and ash (Methods 934.01 and 942.05; AOAC, 2006). Crude protein was calculated from total N values (FP2000 and TruMac; LECO Corp., St. Joseph, MI) according to AOAC (2006; Method 992.15). Total starch concentration of raw and cooked PF was determined according to AOAC (2006; Method 979.10). Free glucose and digestible starch concentrations were determined according to Muir and O'Dea (1993). Resistant starch (**RS**) was determined by subtracting digestible starch and free glucose from total starch concentration. Total lipid content was determined by acid hydrolysis, followed by ether extraction according to AACC (1983) and Budde (1952). Gross energy was measured using an oxygen bomb calorimeter (Model 1261, Parr Instruments, Moline, IL). Free monosaccharide concentrations were determined according to Smiricky et al. (2002). Total dietary fiber, insoluble dietary fiber, and soluble dietary fiber concentrations were determined according to Prosky et al. (1992).

Fecal SCFA and branched-chain fatty acid (**BCFA**) concentrations were determined by gas chromatography, according to Erwin et al. (1961), using a gas chromatograph (Hewlett-Packard 5890A Series II, Palo Alto, CA) and a glass column (180 cm × 4 mm i.d.), packed with 10% SP-1200/1% H_3PO_4 on 80/100 + mesh Chomosorb WAW (Supelco Inc., Bellefonte, PA). Nitrogen was the carrier gas with a flow rate of 75 mL/min. Oven, detector, and injector temperatures were 125, 175, and 180°C, respectively. Fecal ammonia concentrations were determined according to the method of Chaney and Marbach (1962). Fecal phenol and indole concentrations were determined, using gas chromatography, according to the methods described by Flickinger et al. (2003). Biogenic amines concentrations were quantified using HPLC according to methods described by Flickinger et al. (2003).

In vitro Hydrolytic Digestion/Fermentation Study

Approximately 500 mg of raw and cooked PF were weighed in triplicate and incubated with 12.5 mL phosphate buffer and 5 mL of a pepsin/hydrochloric acid solution at 39°C to simulate gastric digestion. After 6 h, the pH was adjusted to 6.8 and 5 mL of pancreatin solution (Sigma-Aldrich Co., St. Louis, MO), was added to each tube. Incubation continued at 39°C for 18 h to simulate small intestinal digestion (Boisen and Eggum, 1991). One set of samples was prepared for each end point, 1 set for enzymatic digestion, and 5 sets for each fermentation pull time (0, 3, 6, 9, and 12 h).

After incubation, a subset of samples was used to analyze digestible material. The PF samples were precipitated by the addition of 4 volumes of 95% ethanol. These samples were allowed to stand for 1 h before filtering though Whatman 541 filter paper. Residues were dried to a constant weight and ashed to determine OM disappearance. All remaining samples were freeze dried (Tray Dryer; FTS Systems Inc., Stone Ridge, NY) in preparation for the fermentation portion of the in vitro experiment.

In vitro fermentation was performed using a modification of the method of Bourquin et al. (1993). Samples were hydrated overnight in 26 mL of anaerobic media. Canine fecal samples from 3 dogs were collected within 10 min of defecation for making an inoculum. Fecal samples were maintained at 39°C until an inoculum was prepared by blending 10 g of each fecal sample with 90 mL anaerobic diluting solution for 15 s in a Waring (Fisher Scientific Inc., Pittsburgh, PA) blender under a stream of CO_2. Dogs were receiving a standard maintenance diet (Iams, Mason, OH) to control weight for 1 mo that contained dried beet pulp as a fiber source before fecal samples were collected. The resulting solution was filtered through 4 layers of cheesecloth and sealed in 125-mL serum bottles.

Samples, blanks, and standards were inoculated with 4 mL of diluted feces. Solka-Floc (International

Fiber Corp., North Tonawanda, NY) and pectin high-methoxyl (TIC Gums Inc., Belcamp, MD) were used as negative and positive fermentation controls, respectively. Tubes were incubated at 39°C with periodic mixing. A subset of tubes was removed from the incubator at 0, 3, 6, 9, and 12 h postinoculation, and processed immediately for analyses. A 2-mL subsample of the fluid was removed and acidified for SCFA and BCFA analysis. Concentrations of SCFA were determined by chromatography as described previously.

In vivo Digestibility Study

Animals and Diets. Ten mixed breed female dogs (6.13 ± 0.17 yr; 22 ± 2 kg) were used. Dogs were housed in individual kennels (2.4 × 1.2 m) in 2 temperature-controlled rooms, with a 16-h light:8-h dark cycle. A replicated 5 × 5 Latin square design experiment with 5 diets and 10 dogs in 2 different rooms for five 14-d periods was conducted. The first 10 d of each period served as an adaptation phase, followed by 4 d of total fecal collection. Five diets containing PF were formulated to contain ~32% CP and 18% crude fat (DM basis). Each diet contained graded concentrations of PF [0%, 1.5%, 3%, 4.5%, or 6% (as-fed basis)] that replaced cellulose (Solka-Floc; International Fiber Corp.) in the diet. Low-ash poultry by-product meal, poultry fat, brewer's rice, ground corn, and vitamin and mineral premixes made up the remainder of the dry, extruded, kibble diets. All diets were formulated to exceed NRC-(2006) recommended allowances for an adult dog. Because PF contains ~4% CP, brewer's rice was substituted to maintain isonitrogenous diets. Diets were mixed and extruded at the Kansas State University Bioprocessing and Industrial Value-Added Program Facility (Manhattan, KS), under the supervision of a commercial company (Pet Food and Ingredient Technology, Inc.; Topeka, KS). Dogs were offered 155 g of the diet twice daily (0800 and 1700 h) to meet the required energy needs, based on the estimated ME content of the diet. Food refusals were recorded daily and fresh water was provided to the dogs ad libitum.

Sample Handling and Processing

Total feces excreted during the collection phase of each period were taken from the pen floor, weighed, and frozen at –20°C, until analysis. All fecal samples during the collection period were subjected to a consistency score according to the following scale: 1 = hard, dry pellets, small hard mass; 2 = hard, formed, dry stool; remains firm and soft; 3 = soft, formed, and moist stool, retains shape; 4 = soft, unformed stool, assumes shape of container; and 5 = watery, liquid that can be poured.

Fecal samples were dried at 55°C in a forced-air oven and ground in a Wiley mill (Model 4, Thomas Scientific, Swedesboro, NJ) through a 2-mm screen. On d 11 of each period, fresh fecal samples were collected within 15 min of defecation. Aliquots for analysis of phenols, indoles, and biogenic amines were frozen at –20°C, immediately after collection. One aliquot of ~2 g was collected and placed in ~2 mL of 2N hydrochloric acid for ammonia and SCFA analyses. Additional aliquots were used for pH measurement and fresh fecal DM determination.

Statistical Analysis

Data were analyzed as a completely randomized design, using the MIXED Procedure of SAS (SAS Inst. Inc., Cary, NC). The UNIVARIATE procedure was used to ensure equal variance, normal distribution, and identify outliers. Any observation that was >3 SD away from the mean was considered an outlier, but no outliers were identified. Data were transformed by log or square root if the normality assumption was not met. Diet was considered a fixed effect, whereas random effects included animal and period. Linear and quadratic effects were tested, using orthogonal polynomial contrasts. For the in vitro experiment, mean seperation with a Tukey's adjustment was used to determine differences between substrates. A probability of $P < 0.05$ was accepted as being statistically significant.

RESULTS

Substrate Chemical Analysis

Table 1 presents the chemical composition of cooked and raw PF. Both substrates were similar in DM, OM, GE, CP, and acid-hydrolyzed fat concentrations. Total dietary fiber for both substrates was 55% (32% insoluble and 23% soluble fiber). Cooked PF contained 4.6% RS and 24.1% digestible starch, whereas raw PF contained 6.2% RS and 22.4% digestible starch. After autoclaving, the amount of free sugars increased for cooked PF but, overall, very little free sugar were detected for either substrate.

In vitro Hydrolytic Digestion/Fermentation

Figure 1 presents in vitro pH and SCFA concentration data over time for raw and cooked PF and pectin. Cellulose data were collected, but SCFA concentrations were negligible. Thus, data are not reported. During the in vitro hydrolytic-enzymatic digestion phase, 32% of raw PF and 28% of cooked PF were digested (data not shown). Both raw and cooked PF had consistent decreases in pH through 9 h of fermentation. Raw PF had a continued numerical decrease in pH from the 9 to 12 h time points, whereas cooked PF had a slight numeri-

Table 1. Chemical composition of raw and cooked potato fiber

Item	Raw potato fiber	Cooked potato fiber[1]
DM, %	88.4	90.2
Content, DM basis		
OM, %	97.1	97.2
CP, %	4.4	4.8
Acid-hydrolyzed fat, %	2.1	2.1
Total dietary fiber, %	55.2	55.0
Insoluble dietary fiber	31.9	32.7
Soluble dietary fiber	23.3	22.3
Starch, %		
Free glucose	0.0	0.1
Digestible starch	22.4	24.1
Resistant starch	6.2	4.6
Total starch	28.7	29.3
Free sugars, µg/g		
Arabinose	18.6	29.3
Galactose	19.5	29.5
Glucose	176	2,090
Sucrose	873	629
Mannose	0.0	0.0
Fructose	3.6	45.8
Total	1,091	2,823
GE, kcal/g	4.1	4.2

[1]Potato fiber (500 g) was suspended in distilled water (6 L) and autoclaved at 121°C for 1 h.

Table 2. Ingredient and chemical composition of experimental diets fed to dogs

	Potato fiber, %[1]				
Item	0	1.5	3.0	4.5	6.0
Ingredient, % (as-fed)					
Brewer's rice	46.55	45.90	45.25	44.60	43.95
Poultry by-product meal, low ash	25.50	25.50	25.50	25.50	25.50
Corn, ground	12.00	12.00	12.00	12.00	12.00
Poultry fat	8.00	8.00	8.00	8.00	8.00
Potato fiber[2]	0.00	1.50	3.00	4.50	6.00
Cellulose[3]	6.00	5.15	4.30	3.45	2.60
Salt	0.70	0.70	0.70	0.70	0.70
Potassium chloride	0.56	0.56	0.56	0.56	0.56
Chromic oxide	0.20	0.20	0.20	0.20	0.20
Mineral mix[4]	0.18	0.18	0.18	0.18	0.18
Vitamin mix[5]	0.18	0.18	0.18	0.18	0.18
Choline chloride, 50%	0.13	0.13	0.13	0.13	0.13
Chemical composition					
DM, %	95.8	95.7	95.5	95.5	95.3
Content (DM basis)					
OM, %	94.2	94.4	94.2	94.1	94.2
CP, %	25.1	24.8	24.9	25.2	25.1
Acid-hydrolyzed fat, %	13.5	14.5	14.5	14.2	13.1
Total dietary fiber, %	10.8	11.2	11.4	11.2	11.4
GE, kcal · g^{-1}	4.97	5.01	5.00	5.01	4.94

[1]Diet formulations contained raw potato fiber at the specified concentrations, but diets were ultimately extruded to produce the food provided to dogs.

[2]Roquette Frères (Lestrem, France).

[3]Solka-Floc (International Fiber Corp., North Tonawanda, NY).

[4]Provided per kilogram of diet: Mn (as $MnSO_4$), 66 mg; Fe (as $FeSO_4$), 120 mg; Cu (as $CuSO_4$), 18 mg; Co (as $CoSO_4$), 1.2 mg; Zn (as $ZnSO_4$), 240 mg; I (as KI), 1.8 mg; and Se (as Na_2SeO_3), 0.24 mg.

[5]Provided per kilogram of diet: vitamin A, 5.28 mg; vitamin D_3, 0.04 mg; vitamin E, 120 mg; vitamin K, 0.88 mg; thiamine, 4.40 mg; riboflavin, 5.72 mg; pantothenic acid, 22.0 mg; niacin, 39.6 mg; pyridoxine, 3.52 mg; biotin, 0.13 mg; folic acid, 0.44 mg; and vitamin B_{12}, 0.11 mg.

cal increase in pH at 12 h. Acetate, propionate, butyrate, and total SCFA concentrations increased over time for raw PF. Cooked PF had increased ($P < 0.05$) acetate, propionate, butyrate, and total SCFA concentrations through 9 h of fermentation, then exhibited a decrease ($P < 0.05$) in acetate and total SCFA concentrations at the 12-h time point. Raw PF had greater ($P < 0.05$) acetate, propionate, and total SCFA concentrations at 12 h than did cooked PF. Pectin had greater ($P < 0.05$) acetate, propionate, butyrate, and total SCFA concentrations than either raw or cooked PF at all time points.

In vivo Experiment

Table 2 presents the ingredient and chemical composition of each experimental diet. Raw PF was added at a concentration of up to 6% to the control diet in an even exchange with cellulose and inert fiber ingredient. Major carbohydrate ingredients included rice and corn, whereas low ash poultry by-product meal was the major protein source. Chromic oxide was added as a digestion marker but was not needed because of excellent stool quality and ease of fecal collection from the floor of pens. All diets had similar DM, OM, CP, acid-hydrolyzed fat, TDF, and GE concentrations. Food intake was similar among treatments and dogs ate all of their food with only minor food refusals in 1 period (Table 3).

Fecal output, expressed on an as-is basis, exhibited a linear increase ($P < 0.01$) with increasing PF additions to the diets. However, when fecal output was expressed on a DM basis, a linear decrease was noted with increasing dietary PF addition. Fecal DM was greatest for the control treatment and decreased ($P < 0.01$) linearly with increasing PF inclusion in diets. Fecal scores were nearly ideal, averaging 2.7 across treatments, with no differences noted among treatments. Apparent total tract nutrient digestibilities were similar across treatment. However, TDF digestibility showed a linear increase ($P < 0.01$) with increasing PF concentrations in the diet.

Fecal pH, SCFA, BCFA, and ammonia concentrations are presented in Table 4. Linear increases ($P < 0.01$) were observed for all individual and total SCFA, with a concomitant linear decrease ($P < 0.01$) in fecal pH with increasing dietary PF concentrations. Fecal BCFA and ammonia concentrations were low and showed few differences. Fecal valerate concentrations exhibited a

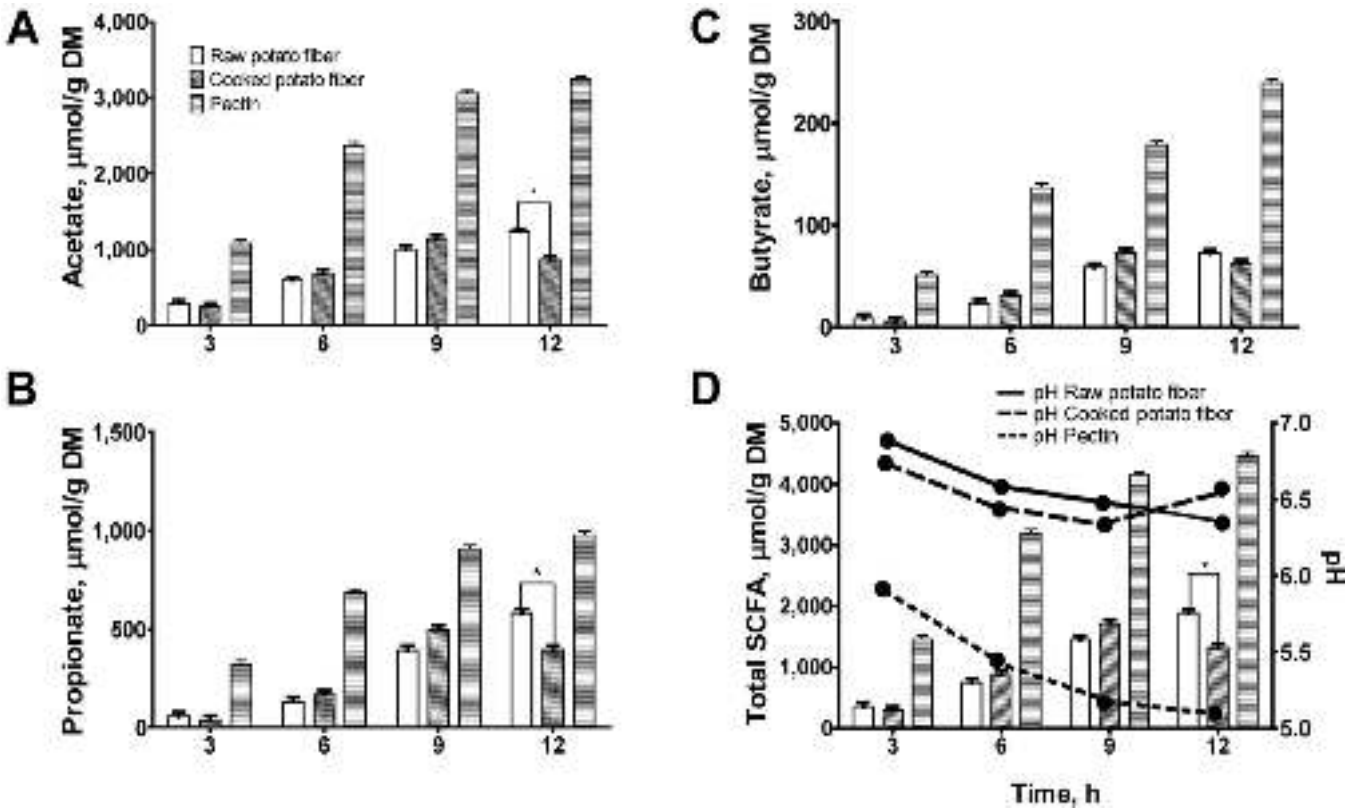

Figure 1. Concentrations of acetate (A), propionate (B), and butyrate (C), and pH and total short-chain fatty acid (SCFA) concentrations (D) during a 12-h in vitro fermentation of raw and cooked potato fiber and pectin. *Difference between raw and cooked potato fiber, $P < 0.05$.

linear increase ($P < 0.05$) in fecal valerate concentrations with increased PF concentrations in the diet.

Table 5 presents fecal biogenic amine, phenol, and indole concentration data. Few differences were observed among treatments. Fecal spermidine exhibited a linear increase ($P < 0.05$) when dogs were fed increased concentrations of PF.

DISCUSSION

A wide variety of dietary fibers are used in pet foods, ranging from those of low fermentability (e.g., cellulose and peanut hulls) to moderate fermentability (e.g., beet pulp and soybean hulls; Bosch et al., 2008). Many dietary fiber sources in pet foods are by-products or co-products of the human food industry. Briefly, potato starch processing involves rupturing starch granules and subsequent gelatinization. The rupturing process disrupts cells to free the starch granule (Nigam and Singh, 1995). This mash then is diluted and placed into a centrisieve to separate the skin and other cell contents from the starch. The skin and cell fragments are referred to as the fiber fraction or PF (Klingspohn et al., 1993).

Most moderately fermentable fibers have a medium to high TDF content and have varying amounts of insoluble and soluble fibers, with a preponderance of insoluble fibers. Beet pulp is one of the most commonly used moderately fermentable fibers, and, in one study (Sunvold et al., 1995), it had a TDF content of 68.4%, although values can range from 57 to 77%. Furthermore, beet pulp contained 55.1% insoluble fiber and 13.3% soluble fiber in the study by Sunvold et al. (1995). Because beet pulp contains considerable amounts of both insoluble and soluble fiber, this property has translated into favorable results in terms of stool quality, nutrient digestibility, and fermentability in vivo (Fahey et al., 1990). Other moderately fermentable fiber sources, such as oat fiber and soybean hulls, also have a high TDF value and an adequate ratio of insoluble to soluble fiber (Fahey et al., 1992; Burkhalter et al., 2001), but they have been tested to a lesser extent than beet pulp.

In our study, PF contained 55% TDF with 32% insoluble fiber and 23% soluble fiber. Compared with the beet pulp used by Sunvold et al. (1995), PF has a lower TDF but a greater portion of soluble fiber. Previous research indicated that diets with an insoluble to soluble fiber ratio of <2 had little to no negative effects on nutrient digestibility, with a TDF concentration at 8% of the diet (Burkhalter et al., 2001). Potato fiber has an insoluble to soluble ratio of 1.4, which is within those limits. Potato fiber also elicited no negative effects on nutrient digestibility and resulted in increased fecal SCFA concentrations with increasing dietary PF. These data are in agreement with those collected on beet pulp where decreased nutrient digestibility was observed only at dietary additions >7.5% (Fahey et al., 1990; Diez et al., 1997).

Table 3. Nutrient digestibility and fecal scores from dogs fed diets containing graded levels of potato fiber[1]

	Potato fiber, %[2]						*P*-value		
Item	0	1.5	3.0	4.5	6.0	SEM	*P*-value	Linear	Quadratic
Feed intake, g/d (DM basis)	296.8	296.5	296.1	295.9	295.4				
Fecal output, g/d									
As-is basis	146.0	150.2	158.5	160.4	173.5	7.2	0.04	0.01	0.67
DM basis	55.5	53.9	53.3	50.0	51.2	1.9	0.31	0.05	0.68
Fecal DM, %	38.0	36.0	33.7	31.5	29.7	0.6	0.01	0.01	0.78
Apparent total tract digestibility, %									
DM	81.3	81.8	81.9	82.3	82.7	0.6	0.51	0.12	0.98
OM	84.1	84.1	84.7	85.1	85.5	0.6	0.58	0.10	0.85
CP	81.7	81.3	80.7	80.2	80.2	0.8	0.31	0.22	0.76
Acid-hydrolyzed fat	94.1	94.6	94.6	94.4	94.1	0.3	0.31	0.96	0.05
Total dietary fiber	16.3	23.2	27.4	32.0	37.1	2.5	0.01	0.01	0.73
Energy	84.9	85.3	85.5	85.6	85.7	0.5	0.79	0.26	0.66
Digestible energy intake, kcal · d^{-1}	1,251	1,267	1,266	1,218	1251	24.9	0.63	0.54	0.88
Fecal score[3]	2.6	2.6	2.7	2.8	2.7	0.1	0.23	0.15	0.90

[1]Values expressed on a DM basis.

[2]Diet formulations contained raw potato fiber at the specified concentrations, but diets were ultimately extruded to produce the food provided to dogs.

[3]Based on a 5-point scale: 1 = hard, dry pellets, small hard mass; 5 = watery, liquid that can be poured.

Along with having relatively high amounts of TDF, PF also contained digestible starch and RS, along with low amounts of CP and acid-hydrolyzed fat. Digestible starch assisted in the maintenance of high in vivo nutrient digestibility coefficients, whereas RS behaved as a moderately to highly fermentable dietary fiber. Because PF is a novel ingredient, where limited data exist regarding inclusion in dog diets and because this ingredient would be included in the food matrix, from which a kibble is prepared by the process of extrusion, it was of interest to simulate the effects of extrusion of PF and determine their effect on chemical composition, particularly PF's starch and sugar components. Tran et al. (2011) showed that extrusion results in chemical and physical changes in ingredients can alter their nutrient composition. To simulate extrusion, PF was autoclaved for 1 h at 121°C and 82 kg/cm^2. This is more time but less pressure than exists in the actual process of extrusion. Autoclaving increased the digestible starch fraction of PF by 1.7% units and reduced the RS fraction from 6.2 to 4.6%. This is in agreement with the research of Murray et al. (2001), who showed increases in the digestible starch fraction of select substrates as a result of extrusion. Total starch concentration varied by only 0.6% units between PF substrates. Total dietary fiber was virtually unchanged by processing, but the insoluble dietary fiber fraction increased by 2.7% and soluble dietary fiber decreased by 4.5%, as a result of the autoclaving process. Whether similar responses would occur for PF that is a part of a diet matrix, then conditioned, extruded, and cooled, remains unknown.

An in vitro hydrolytic digestion/fermentation assay was used to simulate the in vivo digestion process. Substrates were first exposed to an acidic environment with pepsin to simulate gastric digestion, then a reaction with pancreatin at neutral pH to simulate the small intestinal environment. After undergoing these steps, raw and cooked PF had 32% and 28% OM disappearance, respectively. This indicates that nutrients in PF in the raw and cooked forms should be partially digested by the host. It was expected that there would be an increase in enzymatic digestion for the cooked PF because the starch portion would be more digestible after gelatinization (Topping et al., 2001). Indeed, the compositional analysis showed some increase in free sugars and digestible starch after autoclaving. However, a decrease in enzymatic digestion was observed for the cooked PF, which may be partly explained by the interaction of amylose with protein and fat constituents in PF. Starches containing large amounts of amylose form complexes with protein and fat, making them indigestible (Holm et al., 1983; Thorne et al., 1983). Complex formation could explain the decrease in enzymatic digestion of cooked PF (Holm et al., 1983; Thorne et al., 1983). Raw and cooked PF were enzymatically digested, in part, due to their digestible starch content.

Following digestion, SCFA production during fermentation was consistent with the pH decline over the 12-h fermentation period for both raw and cooked PF. Raw PF resulted in an increased SCFA production throughout the entire 12-h fermentation, whereas cooked PF resulted in an increase in SCFA through 9 h, followed by a decrease in SCFA production at 12 h. This finding indicates that cooked PF is depleted of fermentable components by 9 h of fermentation, whereas raw PF remains fermentable at 12 h. Furthermore, these data indicate that raw and cooked PF are moderately fermentable and are likely fermented throughout

Table 4. Fecal short-chain fatty acid (SCFA), branched-chain fatty acid (BCFA), and ammonia concentrations, and pH values for dogs fed potato fiber

	Potato fiber,%[1]							*P*-value	
Item	0	1.5	3.0	4.5	6.0	SEM	*P*-value	Linear	Quadratic
pH	6.71	6.45	6.27	6.13	6.00	0.13	0.01	0.01	0.54
SCFA, µmol/g DM									
Acetate	322.4	317.8	410.9	448.9	547.7	29.4	0.01	0.01	0.51
Propionate	102.2	117.0	145.6	160.9	178.6	10.1	0.01	0.01	0.85
Butyrate	55.5	52.2	64.2	79.8	81.6	7.9	0.01	0.01	0.97
Total SCFA	480.1	487.0	620.7	689.5	807.9	41.5	0.01	0.01	0.53
BCFA, µmol/g DM									
Isobutyrate	8.73	7.64	8.02	7.91	7.90	0.82	0.75	0.47	0.60
Isovalerate	13.60	11.72	12.14	12.06	11.29	1.45	0.54	0.22	0.77
Valerate	1.13	1.01	1.28	1.66	1.62	0.19	0.02	0.03	0.95
Total BCFA	23.43	20.37	21.43	21.63	20.81	2.31	0.68	0.39	0.69
Ammonia, µmol/g DM	98.63	105.14	100.15	106.26	111.41	14.04	0.78	0.50	0.53

[1]Diet formulations contained raw potato fiber at the specified concentrations, but diets were ultimately extruded to produce the food provided to dogs.

the hindgut. Bosch et al. (2008) found that sugar beet fiber had 1,990, 560, 330, and 2,880 µmol of acetate, propionate, butyrate, and total SCFA, respectively, per gram DM after 8 h of fermentation. These concentrations are comparable to what was observed for cooked and raw PF in the current study.

The differences observed between raw and cooked PF could be attributed to the effect of processing. Research has shown that processing affects the composition and fermentability of fibrous substrates (Guillon and Champ, 2000). For example, RS may be depleted after extrusion (Murray et al., 2001). Our compositional analysis revealed that RS decreased from 6.2 to 4.6%, which may explain why the fermentability of cooked PF deceased after 9 h. Most of the fermentation of PF is due to both its soluble dietary fiber fraction as well as its RS content. Potato fiber is high in cellulose and hemicelluloses, which represent insoluble fibers that are poorly to moderately fermented; and pectin, which is soluble and more highly fermentable (Mayer, 1998). Research indicates that soluble fiber increases and insoluble hemicellulose decreases as extrusion conditions increased in temperature (120 to 130°C) and pressure (145 to 613 KJ/kg; Dust et al., 2004). Cooked PF may have a more available soluble fiber fraction, making it more fermentable earlier in the 12-h fermentation period. Having more fermentable substrate available earlier in fermentation also may help explain why cooked PF was fermentable through 9 h.

The type of RS present in PF substrates is important in regard to fermentability. There are 4 types of RS: 1) RS1, physically inaccessible to be degraded by hydrolytic-enzymatic digestion (e.g., partially milled grains and seeds), 2) RS2, resistant granules (e.g., raw potato and green banana), 3) RS3, retrograded starch (e.g., cooked and cooled potato), and 4) RS4, chemically modified starch (i.e., cross-bonded starches found in processed foods; Topping and Clifton, 2001). Martin et al. (1998) reported that 87% of RS2 and 57% of RS3 from potato starch were fermented. Furthermore, RS2 potato starch yielded substantially more butyrate (25% of total SCFA) than from RS3 (14% of total SCFA;

Table 5. Fecal biogenic amine, phenol, and indole concentrations in dogs fed diets containing graded levels of potato fiber

	Potato fiber,%[1]							*P*-value	
Item	0	1.5	3.0	4.5	6.0	SEM	*P*-value	Linear	Quadratic
Biogenic amines, µmol/g DM									
Tryptamine	0.77	0.69	0.59	0.35	0.40	0.18	0.19	0.14	0.86
Putrescine	3.66	4.36	5.24	4.90	4.66	0.52	0.10	0.18	0.11
Cadaverine	1.60	1.63	1.64	1.84	1.73	0.18	0.88	0.62	0.91
Spermidine	1.55	1.63	1.43	1.58	2.10	0.19	0.02	0.04	0.09
Spermine	0.34	0.55	0.59	0.76	0.68	0.19	0.14	0.19	0.50
Total biogenic amines	7.92	9.28	9.54	9.46	9.92	0.73	0.17	0.06	0.43
Phenols and indoles, µmol/g DM									
Phenol	1.90	2.20	0.83	1.26	0.86	0.68	0.26	0.25	0.86
Indole	2.22	2.29	2.16	2.40	2.17	0.21	0.95	0.86	0.82
Total phenols and indoles	4.13	4.49	3.00	3.63	3.03	0.78	0.31	0.28	0.93

[1]Diet formulations contained raw potato fiber at the specified concentrations, but diets were ultimately extruded to produce the food provided to dogs.

Martin et al., 1998; Topping and Clifton, 2001). Raw PF, with all of its RS content as RS2 and with less available fermentable fiber early in fermentation, could ferment longer than cooked PF. Cooked PF contains less fermentable RS3 and more available soluble fiber for microbes to ferment, because it was autoclaved.

In regard to the in vivo experiment, increasing dietary fiber will typically decrease nutrient digestibility by nonruminant species (Fahey et al., 1990). However, in the present experiment, only TDF digestibility was modified by graded additions of PF to the diet. Total dietary fiber digestibility increased as dietary PF concentration increased, commensurate with an increase in fecal SCFA concentrations. This occurred because PF replaced cellulose as PF dietary concentrations increased in the iso-TDF diets. Cellulose is essentially 0% fermentable, whereas PF is moderately fermentable (Sunvold et al., 1995).

Commensurate with TDF digestibility results, fecal SCFA concentrations increased, whereas fecal pH decreased. Surprisingly, fecal consistency did not change with treatment. It is common that highly fermentable soluble fibers negatively affect fecal consistency (Wakshlag et al., 2011). Despite major compositional differences, PF behaves very similar to beet pulp (Fahey et al., 1990) in terms of physiological responses.

Fermentation of PF is largely affected by its soluble fiber fraction, which is mostly composed of pectin (Lesiecki et al., 2012). The pectin portion of PF would have a strong effect on all fermentative and physiological responses. Although RS was present in both the raw and cooked forms of PF, its presence is unlikely to have a marked effect on responses due to the low concentration provided. Indeed, Murray et al. (2001) determined that RS was not recovered after low and high temperature extrusion of potato.

Other physiological outcomes measured in the in vivo experiment (fecal BCFA, ammonia, biogenic amine, phenol, and indole concentrations) were mostly unaffected by graded dietary PF concentrations. One exception was spermidine and its concentration was increased with graded concentrations of PF. Spermidine is considered a beneficial biogenic amine as it aids in cell DNA, RNA, and protein turnover (Linsalata and Russo, 2008). Previous research that analyzed fecal spermidine in dogs was similar to the present finding (Propst et al., 2003). Fecal characteristics were near ideal, largely due to the way the diets were formulated (fiber substitution method) and inherent properties of PF.

Overall, PF demonstrated favorable fermentative characteristics in vitro and favorable physiological effects in vivo. The chemical composition and in vitro assays both showed that PF was abundant in fermentable TDF, with a favorable proportion of insoluble to soluble fiber. Potato fiber appears to exhibit fermentation characteristics, including increased fecal SCFA concentrations and excellent stool consistency, without eliciting negative effects on nutrient digestibility or increasing concentrations of unfavorable protein catabolites. In conclusion, this study indicates that PF has the potential to be a high-quality fiber source in dog foods and may compare favorably or better than most dietary fibers found in commercial foods.

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