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Ileal and total tract nutrient digestibilities and fecal characteristics of dogs as affected by soybean protein inclusion in dry, extruded diets

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ABSTRACT: Plant-based protein sources are generally less variable in chemical composition than animal-based protein sources. However, relatively few data are available on the nutrient digestibilities of plant-based protein sources by companion animals. The effects of including selected soybean protein sources in dog diets on nutrient digestion at the ileum and in the total tract, as well as on fecal characteristics, were evaluated. Six protein sources were used: soybean meal (SBM), Soyafluff 200W (soy flour), Profine F (traditional aqueous-alcohol extracted soy protein concentrate [SPC 1]), Profine E (extruded SPC [SPC 2]), Soyarich I (modified molecular weight SPC [SPC 3]), and poultry meal (PM). All diets were extruded and kibbled. Test ingredients varied in CP and fat contents; however, diets were formulated to be isonitrogenous and isocaloric. Nutrient intakes were similar, except for total dietary fiber (TDF), which was lower ($P < 0.01$) for dogs fed the PM diet. Apparent ileal digestibilities of DM, OM, fat, and TDF were not different among treatments; however, CP digestibility at the terminal ileum was higher ($P < 0.01$) for diets containing soy protein sources than for PM. Total tract CP digestibility was greater ($P < 0.01$) for soy protein-containing diets than for PM. Apparent total tract digestibilities of DM, OM, fat, and TDF were not different among treatments. Apparent amino acid digestibilities at the terminal ileum, excluding methionine, threonine, alanine, and glycine, were higher ($P < 0.01$) for soy protein-containing diets than for PM. Dogs fed SPC diets had lower ($P < 0.01$) fecal outputs (g as-is feces/g DMI) than dogs fed the SF diet, and dogs fed SBM tended ($P < 0.11$) to have lower fecal outputs than dogs fed the SF diet. However, dogs fed the PM diet had lower ($P < 0.03$) fecal outputs than dogs fed SPC-containing diets. Fecal outputs and scores reflected the TDF and nonstructural carbohydrate contents of the soy protein fraction. Soy protein sources are well utilized by the dog prior to the terminal ileum, and SPC offers a viable alternative to PM as a protein source in dry, extruded canine diets.

Key Words: Diet, Digestibility, Dogs, Ileum, Soyabean

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Introduction

In 1998, the world market for pet food, pet accessories, veterinary care, and health care items totaled $39 billion, an increase of nearly 15% from 1994 (Irwin, 2000). Increased pet populations, increased spending per pet, and an increased use of prepared pet foods and treats in both developed and emerging nations drive this market. The two main categories of ingredients used by the pet food industry include 1) grains and milling by-products and 2) animal tissue by-products from the meat-packing, poultry-processing, and fish-canning industries (Morris and Rogers, 1994). To achieve adequate dietary concentrations of essential amino acids, several ingredients with high protein content are included in dry dog foods. Meat and bone meal (**MBM**), other animal by-products, and soybean meal (**SBM**) added in varying concentrations are the primary protein sources in dry commercial dog foods (Huber et al., 1994).

Nutrient composition and bioavailability of animal by-products is inconsistent. This is due partly to the fact that any number of animal tissues are included in the animal by-product sold to the petfood manufacturer (Fahey and Hussein, 1998). The variation in nutrient content of animal protein meals is much larger than that of protein of plant origin (Lowe, 1989). In 1998,

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27.7 million tons of SBM were used in the United States for animal feeds. Of this, only 3%, or 780,000 tons, was used in pet foods (United Soybean Board, 1999).

Relatively few published data are available on the quantitative ability of companion animals to digest materials from plant sources. Soy protein, when combined with other protein sources that contain complementary amino acids, can provide a high-quality protein source for the dog. The objective of this study was to quantify the effects of selected soybean protein fractions incorporated into extruded, kibbled diets on nutrient intake, digestion before the terminal ileum, total tract digestion, and fecal characteristics.

Materials and Methods

Five soy protein sources from Central Soya Company, Inc., Fort Wayne, IN, and one poultry meal (**PM**) from Tyson Foods, Rogers, AR, were obtained and analyzed for DM, OM, ash, and CP (AOAC, 1985). Total lipid content was determined by acid hydrolysis followed by ether extraction according to AACC (1983) and Budde (1952). Samples were analyzed for total dietary fiber (**TDF**) using the method of Prosky et al. (1984). Chemical composition of the various soy sources and PM is presented in Table 1.

Soy Protein Source Preparation

Soy flour and grits are produced from defatted flakes. Flours are differentiated from grits on the basis of particle size. The defatted flakes are dried and ground through a hammer mill such that 97% will pass through a 0.15-mm (No. 100 U.S. standard) screen. It is customary to do the grinding in two steps and to separate the coarse from the fine particles in an air classifier between grindings (Circle and Smith, 1972). Soy flours can be used without further treatment as an ingredient or as the raw material for several further refined or specially treated dietary ingredients. Defatted soy flakes and soy flours contain three major components that can be separated from each other: protein, fiber, and carbohydrates. The protein can be either concentrated or isolated from soy flour.

Soy protein fractions that contain a minimum of 70% protein are termed soy protein concentrates (**SPC**). Concentrates consist of the major proteins plus the polysaccharides. Soy protein concentrates are produced by selectively removing soluble carbohydrates from defatted soy flakes by water, aqueous alcohol, or isoelectric leaching. According to Russett (1998), there are three types of SPC of interest in animal feeding, traditional, texturized, and low antigen.

Traditional SPC is made by aqueous alcohol extraction (a 20 to 80% aqueous organic solvent, the concentration range being one in which the proteins are insoluble but that extracts the nonprotein solubles) of defatted soy flakes (**SPC 1**). Texturized SPC is produced using extrusion technology on traditional SPC (**SPC 2**). Modification of the aqueous alcohol mixture by increasing the temperature and time of processing can further reduce the antinutritional content of the SPC, producing a low-antigen product (**SPC 3**).

Diets

Each of the six diets tested contained one primary protein source: SBM, SF, SPC 1, SPC 2, SPC 3, or PM. Bleached tallow was the primary fat source, although flax seed also contributed to the overall fat percentage. Chicken bone residue, a by-product of the chicken deboning process, was used as a nutrient source at the level of 19 to 20% in the soy protein-containing diets. The ingredient composition of the diets is presented in Table 2.

All diets were extruded and kibbled. Diets were extruded using a Wenger extruder, model TX-52 (Sabetha, KS). Extruded diet was cut into 1.5-cm pieces to facilitate rapid drying. The pieces were dried on a Wenger belt dryer at 180°C for 30 min. Dried, extruded diet was stored at 4°C for 3 mo prior to the trial.

Animals

Six female, purpose-bred dogs with a functional ileal cannula, an average initial body weight of 25.5 ± 3.9 kg, and an average age of 3 yr (1 to 5 yr) were used in a 6 × 6 Latin square design. Ileal cannulation was conducted according to the procedure of Walker et al. (1994). The dogs were housed in 1.2- × 3.1-m solid-floor pens in the College of Agricultural, Consumer and Environmental Sciences Animal Care Facility. The room was temperature-controlled, with an average temperature of 22°C, and had an 8 h dark:16 h light cycle. Animal care procedures were conducted under a research protocol approved by the Campus Laboratory Animal Care Advisory Committee, University of Illinois, Urbana-Champaign.

Each dog was offered 250 g of diet (as-is basis) at 0800 and 2000, for a total of 500 g/d. Any feed refusals from the previous feeding were weighed, recorded, labeled, and stored. Water was available for ad libitum consumption.

A gelatin capsule containing 500 mg of chromic oxide, used as a digestion marker, was administered orally twice daily prior to feeding. Digestibilities at the ileum and in the total tract were determined by the marker ratio technique.

Each treatment period was 9 d long. A 6-d diet adaptation phase preceded a 3-d collection of ileal effluent and feces in each period. The effluent was collected every 3 h, rotating up 1 h each day, and each collection lasted 1 h. Consequently, an effluent sample from each hour between 0800 and 2000 was obtained. Ileal effluent was collected by attaching a Whirlpak bag (Pioneer Container Corp., Cedarburg, WI) to the cannula barrel and the cannula hose clamp with a rubber band. Prior to bag attachment, the cannulas were cleaned with a

Table 1. Chemical composition of protein sources fed to dogs

Item	Protein source[a]					
	SBM	SF	SPC 1	SPC 2	SPC 3	PM
DM, %	87.4	92.7	94.9	94.3	94.5	96.2
	% of DM					
OM	92.6	93.0	93.9	93.0	95.9	90.4
CP	56.6	55.3	72.2	70.4	70.5	74.5
Fat	2.5	2.8	1.1	0.8	3.2	15.0
TDF[b]	15.7	16.2	21.3	17.5	21.1	2.7
Essential amino acids						
Arginine	3.5	3.7	4.9	4.8	4.9	4.9
Histidine	1.3	1.3	1.7	1.8	1.7	1.8
Isoleucine	2.2	2.4	3.1	3.0	3.2	2.8
Leucine	3.8	4.2	5.4	5.3	5.6	5.2
Lysine	3.1	3.4	4.3	4.3	4.3	4.7
Methionine	0.4	0.4	0.6	0.4	0.4	0.8
Phenylalanine	2.5	2.7	3.4	3.4	3.5	2.8
Threonine	1.9	2.0	2.5	2.6	2.6	2.8
Valine	2.2	2.5	3.2	3.1	3.3	3.3
Nonessential amino acids						
Alanine	2.2	2.4	3.0	2.9	3.0	4.4
Aspartate	5.9	6.5	8.1	8.0	8.2	6.3
Cystine	1.0	0.9	0.9	1.3	0.9	1.0
Glutamate	9.2	10.0	13.0	12.6	13.0	9.7
Glycine	2.2	2.3	2.9	2.9	2.9	5.5
Proline	2.5	2.9	3.9	3.6	3.9	4.4
Serine	2.7	3.0	3.8	3.6	3.8	3.2
Tyrosine	1.6	1.7	2.2	2.3	2.3	2.1
TEAA[c]	20.9	22.6	29.1	28.7	29.5	29.1
TNEAA[d]	27.3	29.7	37.8	37.2	38.0	36.6
TAA[e]	48.2	52.3	66.9	65.9	67.5	65.7

[a]SBM = soybean meal; SF = Soyafluff 200W (soy flour); SPC 1 = Profine F (traditional aqueous alcohol-extracted SPC); SPC 2 = Profine E (extruded SPC); SPC 3 = Soyarich I (modified molecular weight SPC); PM = poultry meal.
[b]TDF = total dietary fiber.
[c]TEAA = total essential amino acids.
[d]TNEAA = total nonessential amino acids.
[e]TAA = total amino acids.

spatula and dried digesta were discarded. Generally, 15 to 30 mL of ileal effluent was collected during each sampling period. Dogs were encouraged to move about freely during ileal collections and were continually observed to ensure that they would not remove the bag from the cannula.

During the 3-d collection phase in each period, effluent samples were collected, frozen (–4°C), and composited. Feces excreted were collected from the pen floor, weighed, scored, frozen (–4°C), and composited. Fecal scores were estimated at each collection. Scoring was determined as follows: 1 = hard, dry pellets: small, hard mass; 2 = hard, formed, dry stool: remains firm and soft; 3 = soft, formed, moist; softer stool that retains shape; 4 = soft, unformed: stool assumes shape of container, pudding-like; 5 = watery: liquid that can be poured. Composited feces and ileal effluent were freeze-dried in a Tri-Philizer MP microprocessor-controlled lyophilizer, ground through a Wiley mill with a 2-mm screen, and stored for analyses.

Chemical Analyses

Diets, feces, and ileal effluent were analyzed in duplicate (< 5% variation accepted) for DM, OM, ash, and CP using AOAC (1985) methods. Total lipid content was determined by acid hydrolysis followed by ether extraction according to AACC (1983) and Budde (1952). Gross energy was determined by oxygen bomb calorimetry (Parr Instruments Co., Moline, IL). Total dietary fiber (TDF), soluble fiber, and insoluble fiber were determined as outlined by Prosky et al. (1984; 1992). Chromium was analyzed according to Fenton and Fenton (1979). Protein sources, diets, and ileal effluent were analyzed for amino acid content in singlet by hydrolyzing 150 mg of sample in 15 mL of 6 *N* HCl for 22 h at 110°C according to Spitz (1973). The amino acid concentrations were determined using ion-exchange chromatography (Spackman et al., 1958) following hydrolysis. Methionine and cystine were determined using the performic acid oxidation method described by Moore

(1963), except that excess performic acid was removed by freeze-drying in a Tri-Philizer MP microprocessor-controlled lyophilizer.

Dry matter flow (g/d) at the ileum and fecal DM output (g/d) were calculated by dividing the Cr intake (mg/d) by ileal or fecal Cr concentrations (mg Cr/g ileal or fecal DM), respectively. Ileal and fecal nutrient flows were calculated by multiplying the DM flow by the concentration of the nutrient in the ileal or fecal DM. Ileal and total tract nutrient digestibilities were calculated as nutrient intake (g/d) minus the ileal or fecal nutrient flow (output, g/d), divided by nutrient intake (g/d).

Data were analyzed as a 6 × 6 Latin square arrangement of treatments using the General Linear Models procedure of SAS (SAS Inst. Inc., Cary, NC). Model sums of squares were separated into treatment, period, and animal effects. Treatment mean comparisons were conducted by single degree of freedom contrasts. The contrasts included 1) PM diet vs all soy protein-containing diets, 2) SBM diet vs SF diet, 3) SBM diet vs all SPC-containing diets, 4) SF diet vs all SPC-containing diets, and 5) PM diet vs all SPC-containing diets.

Results and Discussion

Chemical Composition

The chemical composition of the protein sources used in the experimental diets is reported in Table 1. Dry matter concentrations ranged from 87.4% for SBM to 96.2% for PM, and OM ranged from 90.4% for PM to 95.9% for SPC 3. Crude protein concentrations were lowest for SBM and SF, 56.6 and 55.3%, respectively, and higher for all SPC sources and PM (average 71.9%). By definition, SPC must contain a minimum of 70% CP. The soy protein sources all had fat percentages of 3.2 or less, whereas PM was 15% fat. All soy protein sources were much higher in TDF than PM. Differences in CP and fat concentrations were accounted for when the diets were formulated such that all diets were isonitrogenous and isocaloric.

The quantity of the SBM and SF components (the sum of the ash, CP, fat, and TDF) reported in Table 1 total 82.2 and 81.3%, respectively, whereas that of SPC 1 totaled to 100.7%, SPC 2 to 95.7%, SPC 3 to 98.9%, and PM to 101.8%. Soybean meal and SF both contain carbohydrates not accounted for by the TDF fraction. In processing defatted soy flakes to SPC, the nonstructural carbohydrates are removed, leaving the protein and the fiber. Therefore, our analyses account for essentially all of the constituents of SPC. Poultry meal is nearly carbohydrate-free; therefore, protein, fat, TDF, and ash constitute all the nutrients present in this animal by-product.

Amino acid concentrations in the soy protein sources differed based on the processing method used to prepare the fraction. Concentrations of all amino acids excluding methionine and cystine were lower for the SBM and SF than for SPC. The SPC amino acid concentrations were comparable to those of PM. Poultry meal was higher in methionine, alanine, glycine, and proline than soy protein sources and lower in aspartate and glutamate. Total essential (**TEAA**), total nonessential (**TNEAA**), and total amino acid (**TAA**) concentrations for soy protein ranked as follows: SBM < SF < SPC 1 = SPC 2 = SPC 3. Soy protein concentrates and PM

Table 2. Ingredient composition of experimental diets fed to dogs (as-fed basis)

	Diet[a]					
Ingredient, %	SBM	SF	SPC 1	SPC 2	SPC 3	PM
Protein source	44.03	45.16	33.17	34.06	33.99	32.76
Potato starch	7.90	7.42	12.40	11.72	12.35	19.38
Brewer's rice	7.90	7.42	12.40	11.72	12.35	19.38
Chicken bone residue[b]	18.70	18.64	20.17	20.57	20.19	7.84
Beet pulp	4.12	4.11	4.12	4.12	4.11	4.00
Flax seed	2.05	2.06	2.06	2.06	2.05	2.00
Bleached tallow	14.10	13.96	14.47	14.52	13.56	13.44
Salt	0.67	0.67	0.67	0.67	0.77	0.65
Vitamin mix[c]	0.10	0.10	0.10	0.10	0.12	0.10
Mineral mix[d]	0.10	0.10	0.10	0.10	0.12	0.10
Choline chloride	0.12	0.12	0.12	0.13	0.14	0.12
Potassium sorbate	0.21	0.21	0.21	0.21	0.23	0.20
Ethoxyquin	0.02	0.02	0.02	0.02	0.02	0.02

[a]SBM = soybean meal; SF = Soyafluff 200W (soy flour); SPC 1 = Profine F (traditional aqueous alcohol-extracted SPC); SPC 2 = Profine E (extruded SPC); SPC 3 = Soyarich I (modified molecular weight SPC); PM = poultry meal.

[b]Chicken bone residue contains 41.3% DM, 65.5% OM, 40.8% CP, 17.1% fat, 19.9% Ca, and 6.1% P on an absolute DM basis.

[c]Provided per kilogram of diet: vitamin A, 10.95 kIU; vitamin D, 0.89 kIU; vitamin E, 57.49 IU; vitamin K, 0.55 mg; thiamin, 7.56 mg; riboflavin, 11.89 mg; pantothenic acid, 18.50 mg; niacin, 93.16 mg; pyridoxine, 6.60 mg; biotin, 12.42 mg; folic acid, 1,142.10 μg; vitamin B_{12}, 164.87 μg.

[d]Provided per kilogram of diet: Mn, 17.43 mg; Fe, 284.33 mg; Cu, 17.24 mg; Co, 2.20 mg; Zn, 166.28 mg; I, 7.52 mg; Se, 0.21 mg.

Table 3. Chemical composition of diets fed to dogs

	Diet[a]					
Item	SBM	SF	SPC 1	SPC 2	SPC 3	PM
DM, %	97.3	97.5	97.5	96.8	96.1	96.5
	% DM					
OM	92.5	93.0	93.5	93.1	94.1	94.1
CP	31.9	31.2	32.3	32.7	32.3	30.5
Fat	25.3	25.0	23.4	25.0	26.4	24.8
TDF[b]	11.3	12.2	12.2	10.7	12.0	6.0
Insoluble fiber	10.4	11.0	10.7	8.7	11.5	4.9
Soluble fiber	0.9	1.2	1.5	2.0	0.5	1.1
Essential amino acids						
Arginine	2.2	2.3	2.5	2.3	2.3	2.1
Histidine	0.8	0.8	0.9	0.8	0.8	0.8
Isoleucine	1.3	1.4	1.4	1.4	1.4	1.2
Leucine	2.4	2.4	2.6	2.5	2.5	2.3
Lysine	1.8	1.9	2.1	1.9	1.9	2.0
Methionine	0.3	0.3	0.2	0.3	0.2	0.3
Phenylalanine	1.4	1.5	1.7	1.5	1.6	1.3
Threonine	1.2	1.2	1.2	1.2	1.2	1.3
Valine	1.5	1.4	1.5	1.5	1.5	1.5
Nonessential amino acids						
Alanine	1.5	1.5	1.6	1.5	1.5	2.0
Aspartate	3.6	3.6	3.8	3.7	3.6	2.8
Cystine	0.6	0.6	0.5	0.6	0.5	0.4
Glutamate	5.6	5.7	6.2	5.9	5.9	4.4
Glycine	1.7	1.7	1.9	1.7	1.6	2.5
Proline	1.8	1.8	1.9	1.8	1.7	1.7
Serine	1.6	1.7	1.9	1.7	1.7	1.4
Tyrosine	1.0	1.0	1.1	1.0	1.1	0.9
TEAA[c]	12.9	13.2	14.1	13.4	13.4	12.8
TNEAA[d]	17.4	17.6	18.9	17.9	17.6	16.1
TAA[e]	30.3	30.8	33.0	31.3	31.0	28.9

[a]SBM = soybean meal; SF = Soyafluff 200W (soy flour); SPC 1 = Profine F (traditional aqueous alcohol-extracted SPC); SPC 2 = Profine E (extruded SPC); SPC 3 = Soyarich I (modified molecular weight SPC); PM = poultry meal.
[b]TDF = total dietary fiber.
[c]TEAA = total essential amino acids.
[d]TNEAA = total nonessential amino acids.
[e]TAA = total amino acids.

were similar in concentrations of TEAA, TNEAA, and TAA. Total amino acids accounted for an average of 92.4% of the CP for soy protein fractions and 88.2% for PM.

The chemical composition of the experimental diets is reported in Table 3. The six diets contained similar concentrations of DM, OM, CP, and fat. A lower TDF concentration was observed for the PM diet (6.0%) than for the soy protein-containing diets (average = 11.7%). Concentrations of insoluble and soluble fiber fractions varied modestly among the soy protein-containing diets. When insoluble:soluble fiber ratios (**I:S**) were calculated, a wide range of values was revealed, from 4.4 for SPC 2 to 23 for SPC 3. Nonstructural carbohydrates are removed from the defatted soy flakes to produce SPC. Soy protein concentrate 2 is an extruded form of traditional SPC (SPC 1), and SPC 3 has a modified molecular weight and a smaller particle size. The different processing methods used to produce the various SPC dramatically affected the I:S. Concentrations of essential and of most nonessential amino acids did not vary greatly among diets.

Nutrient Intakes

Nutrient intake and apparent digestibility data are reported in Table 4. Intakes of DM, OM, CP, fat, and GE were similar among diets. These data concur with information reported by Zuo et al. (1996), Murray et al. (1997), and Bednar et al. (2000). Due to differences in dietary TDF concentrations, dogs fed the PM diet had lower ($P < 0.01$) TDF intakes than those fed soy protein-containing diets. Dogs fed the PM diet had lower ($P < 0.01$) TDF intakes than those fed the SPC-containing diets. Also, TDF intakes tended to be higher ($P < 0.08$) for dogs fed the SF treatment than for those fed the SPC-containing diets.

Apparent Ileal Digestibilities

No differences were observed among treatments in apparent ileal digestibilities of DM, OM, fat, or GE.

These data are in agreement with results of Bednar et al. (2000), who compared SBM to beef and bone meal, poultry meal, and poultry by-product meal; Murray et al. (1997), who compared defatted soy flour to rendered beef meat and bone meal, fresh beef, poultry by-product meal, and fresh poultry; and Zuo et al. (1996), who compared two concentrations and two sources of SBM to PM. Crude protein digestibilities were similar among the soy protein-containing diets (average = 85.1%). However, greater digestibilities of CP were observed when soy protein-containing diets ($P < 0.01$) or the SPC-containing diets ($P < 0.01$) were compared to the PM diet. Zuo et al. (1996) reported a trend ($P < 0.06$) for greater apparent ileal digestibilities of CP in SBM treatments compared to a PM treatment (average = 73.6 and 65.1%, respectively). Neither Murray et al. (1997) nor Bednar et al. (2000) observed any significant differences between soy protein and animal by-product protein digestibility at the terminal ileum.

Apparent Total Tract Digestibilities

Dry matter, OM, and GE total tract apparent digestibilities were unaffected by treatment. Moore et al. (1980) found no differences in DM digestibility by dogs fed 30% SBM (81.1%) or 30% meat and bone meal (78.8%) diets. Data of Zuo et al. (1996) and Huber et al. (1994) support these results. No differences in total tract apparent DM digestibility were reported by Murray et al. (1997); however, they found an increase ($P < 0.01$) in OM digestibility when diets containing animal by-products (average = 91.7%) were compared to a diet containing defatted soy flour (90.2%). Bednar et al. (2000) reported similar DM apparent total tract digestibilities for diets containing SBM and beef and bone meal; however, these values were lower ($P < 0.05$) than for diets containing poultry protein sources. Organic matter digestibility was lower ($P < 0.05$) for the SBM treatment than for the animal protein treatments. Four soy protein sources were compared to wheat gluten by Wiernusz et al. (1995) and, as the soy protein sources were more completely processed, DM digestibility increased linearly ($P < 0.05$) (soy grits = 81.1%; soy flour = 82.7%; SPC = 84.7%, and SPI = 86.4%).

Fat digestibility values were lower ($P < 0.02$) for SBM (92.5%) than for SF (95.5%). Dogs consuming SF tended ($P < 0.10$) to have higher fat digestibilities (95.5%) than dogs consuming SPC-containing diets (average = 93.8%). No differences in fat digestibility were observed when comparing SBM (Zuo et al., 1996; Bednar et al., 2000) or defatted soy flour (Murray et al., 1997) to animal by-products. Wiernusz et al. (1995) reported similar fat digestibilities for soy grits and soy flour (94.9 and 95.0%, respectively) but a greater ($P < 0.05$) digestibility for SPC (96.2%).

Apparent total tract digestibilities of CP mirror apparent ileal digestibility results. Digestibilities were similar for the soy protein-containing diets (average =

Table 4. Nutrient intakes and apparent digestibilities by dogs

	Diet[a]							Contrast[b]				
Item	SBM	SF	SPC 1	SPC 2	SPC 3	PM	SEM	PM vs soy	SBM vs SF	SBM vs SPC	SF vs SPC	PM vs SPC
Intake, g/d												
DM	299	294	264	246	247	271	28.4	0.96	0.91	0.18	0.22	0.57
OM	276	273	247	229	232	255	26.6	0.90	0.94	0.21	0.24	0.54
CP	95	92	85	81	80	83	9.0	0.72	0.82	0.24	0.35	0.93
Fat	76	74	62	62	65	67	7.2	0.97	0.84	0.14	0.22	0.61
TDF[c]	34	36	32	26	30	16	3.0	0.01	0.63	0.22	0.08	0.01
Gross energy, kcal/d	1,641	1,645	1,478	1,380	1,382	1,547	159.5	0.81	0.99	0.23	0.22	0.48
Apparent ileal digestion, %												
DM	73.5	78.4	70.0	74.0	75.7	76.3	4.41	0.63	0.42	0.93	0.29	0.47
OM	77.5	80.9	75.1	78.4	79.9	81.4	3.67	0.42	0.51	0.95	0.46	0.35
CP	85.3	87.2	82.6	84.5	85.9	72.7	2.91	0.01	0.64	0.77	0.39	0.01
Fat	94.5	95.9	93.9	95.0	94.0	94.8	0.93	0.92	0.27	0.88	0.14	0.65
Gross energy	81.6	85.0	80.0	82.8	83.3	83.6	3.05	0.73	0.42	0.90	0.39	0.62
Apparent total tract digestion, %												
DM	81.8	79.6	79.8	82.2	80.9	81.9	2.57	0.68	0.54	0.78	0.63	0.73
OM	81.7	85.6	84.4	84.3	86.8	84.7	2.06	0.96	0.19	0.15	0.86	0.82
CP	83.9	87.3	86.5	84.7	89.3	76.9	1.93	0.01	0.21	0.19	0.84	0.01
Fat	92.5	95.5	93.3	93.7	94.5	92.9	0.87	0.23	0.02	0.20	0.10	0.29
Gross energy	83.8	87.8	86.2	86.0	88.5	84.9	1.86	0.41	0.14	0.15	0.67	0.31

[a]SBM = soybean meal; SF = Soyafluff 200W (soy flour); SPC 1 = Profine F (traditional aqueous alcohol-extracted SPC); SPC 2 = Profine E (extruded SPC); SPC 3 = Soyarich I (modified molecular weight SPC); PM = poultry meal.

[b]Preplanned contrasts with P-value for each comparison: PM vs soy = poultry meal diet vs all soy protein-containing diets; SBM vs SF = soybean meal diet vs Soyafluff 200W diet; SBM vs SPC = soybean meal diet vs all SPC-containing diets; SF vs SPC = Soyafluff 200W diet vs all SPC-containing diets; PM vs SPC = poultry meal diet vs all SPC-containing diets.

[c]Total dietary fiber.

Table 5. Amino acid intakes (g/d) by dogs

Item	Diet[a]						SEM	Contrast[b]				
	SBM	SF	SPC 1	SPC 2	SPC 3	PM		PM vs soy	SBM vs SF	SBM vs SPC	SF vs SPC	PM vs SPC
Essential amino acids												
Arginine	6.9	7.3	6.6	6.1	5.8	5.7	0.73	0.28	0.71	0.37	0.19	0.58
Histidine	2.5	2.6	2.4	2.2	2.1	2.3	0.26	0.75	0.72	0.34	0.17	0.83
Isoleucine	4.2	4.3	3.8	3.7	3.4	3.3	0.43	0.23	0.78	0.28	0.16	0.54
Leucine	7.3	7.8	6.9	6.6	6.2	6.4	0.78	0.47	0.70	0.37	0.18	0.85
Lysine	5.7	6.1	5.4	5.1	4.6	5.4	0.62	0.95	0.66	0.37	0.16	0.56
Methionine	0.8	0.9	0.6	0.8	0.5	0.8	0.09	0.26	0.62	0.08	0.02	0.06
Phenylalanine	4.4	4.8	4.4	4.1	4.0	3.4	0.48	0.07	0.61	0.62	0.26	0.15
Threonine	3.7	3.9	3.1	3.2	3.1	3.5	0.40	0.78	0.70	0.24	0.11	0.37
Valine	4.5	4.6	4.0	3.9	3.7	4.0	0.47	0.77	0.85	0.23	0.16	0.76
Nonessential amino acids												
Alanine	4.8	4.9	4.3	4.2	3.8	5.3	0.52	0.10	0.87	0.23	0.17	0.04
Aspartate	10.9	11.6	10.1	9.7	9.0	7.7	1.13	0.03	0.65	0.32	0.13	0.12
Cystine	1.7	1.8	1.2	1.5	1.2	1.0	0.17	0.01	0.49	0.06	0.01	0.11
Glutamate	17.2	18.2	16.3	15.3	14.4	12.1	1.80	0.03	0.67	0.38	0.17	0.09
Glycine	5.5	5.6	4.9	4.7	4.3	6.7	0.62	0.01	0.90	0.23	0.18	0.01
Proline	5.4	5.7	4.9	4.8	4.3	4.6	0.57	0.43	0.75	0.25	0.13	0.87
Serine	4.9	5.3	5.0	4.5	4.1	3.7	0.52	0.04	0.56	0.56	0.21	0.11
Tyrosine	3.1	3.3	2.9	2.8	2.6	2.5	0.33	0.23	0.58	0.40	0.14	0.52
TEAA[c]	40.0	42.2	37.2	35.5	33.3	34.9	4.25	0.51	0.71	0.34	0.17	0.92
TNEAA[d]	53.4	56.5	49.6	47.5	43.7	43.6	5.60	0.24	0.69	0.31	0.14	0.56
TAA[e]	93.4	98.7	86.8	83.0	77.0	78.4	9.86	0.34	0.70	0.33	0.15	0.71

[a]SBM = soybean meal; SF = Soyafluff 200W (soy flour); SPC 1 = Profine F (traditional aqueous alcohol-extracted SPC); SPC 2 = Profine E (extruded SPC); SPC 3 = Soyarich I (modified molecular weight SPC); PM = poultry meal.

[b]Preplanned contrasts with *P*-value for each comparison: PM vs soy = poultry meal diet vs all soy protein-containing diets; SBM vs SF = soybean meal diet vs Soyafluff 200W diet; SBM vs SPC = soybean meal diet vs all SPC-containing diets; SF vs SPC = Soyafluff 200W diet vs all SPC-containing diets; PM vs SPC = poultry meal diet vs all SPC-containing diets.

[c]TEAA = total essential amino acids.

[d]TNEAA = total nonessential amino acids.

[e]TAA = total amino acids.

86.3%). However, greater digestibilities were observed when soy protein-containing diets ($P < 0.01$) or the SPC-containing diets ($P < 0.01$) were compared to the PM diet (76.9%). By-products may contain varying amounts of tissues, organs, fat, feet, hair, or feathers, which influence the nutrient composition and availability of the batch mixture. Rendering of meals also influences protein quality (Murray et al., 1997). Wiernusz et al. (1995) found that processing soybeans to SPC and SPI increased CP digestibility (89.8 and 89.7%, respectively) compared to soy grits and soy flour (86.7 and 87.0%, respectively). Bednar et al. (2000) and Zuo et al. (1996) reported higher apparent total tract digestibilities for diets containing SBM than for those containing animal by-products. Crude protein digestibility tended ($P < 0.10$) to be lower for defatted soy flour (88.3%) than for several raw and rendered animal by-product proteins (89.3%) (Murray et al., 1997). Moore et al. (1980) and Huber et al. (1994) observed no differences in apparent total tract CP digestibilities in their experiments.

Amino Acid Intakes and Apparent Ileal Amino Acid Digestibilities

Amino acid intake data are presented in Table 5. Crude protein intakes were not significantly different; however, there were significant differences in amino acid intake. Essential amino acid intakes were similar except for methionine and phenylalanine. Methionine intake ranged from 0.5 g/d for SPC 3 to 0.9 g/d for SF. Intakes of methionine tended ($P < 0.08$ and $P < 0.06$, respectively) to be higher for SBM and PM than for all SPC-containing diets (average = 0.6 g/d) and were greater ($P < 0.05$) for SF than for SPC-containing diets. Phenylalanine intake tended ($P < 0.07$) to be lower for PM (3.4 g/d) than for soy-containing diets (average = 4.3 g/d), which is in agreement with data of Bednar et al. (2000).

Nonessential amino acid intakes were more variable than essential amino acid intakes. Dogs fed PM tended ($P < 0.10$) to consume more alanine (5.3 g/d) than dogs fed soy protein-containing diets (average = 4.4 g/d) and more alanine ($P < 0.05$) than dogs fed SPC-containing diets (average = 4.1 g/d). Glycine intakes were greater ($P < 0.01$ and $P < 0.01$, respectively) for PM (6.7 g/d) than for soy protein-containing diets (average = 5 g/d) and SPC-containing diets (4.6 g/d). These data are in agreement with Bednar et al. (2000) and Murray et al. (1997). Intakes of aspartate, cystine, glutamate, and serine were lower ($P < 0.05$ or less) for dogs fed PM than for dogs fed soy protein-containing diets. Cystine intakes were higher ($P < 0.06$ and $P < 0.01$, respectively) for SBM (1.7 g/d) and flour (1.8 g/d) compared to SPC-containing diets (average = 1.3 g/d). Dogs consuming PM tended ($P < 0.11$ and $P < 0.09$, respectively) to consume less cystine (1.0 g/d) and glutamate (12.1 g/d) than dogs consuming SPC-containing diets (average = 1.3 and 15.3 g/d, respectively). No differences in TEAA, TNEAA, or TAA intakes were detected.

Apparent ileal amino acid digestibility data are presented in Table 6. In the case of the essential amino acids, apparent ileal digestibilities of arginine, histidine, isoleucine, leucine, lysine, phenylalanine, and valine were higher ($P < 0.01$ and $P < 0.05$, respectively) for the soy protein-containing diets and the SPC-containing diets than for PM. Zuo et al. (1996) reported similar results; however, they did not find statistically significant differences between plant and animal protein sources for lysine, phenylalanine, or threonine digestibilities. Aspartate, cystine, glutamate, proline, serine, and tyrosine were more highly digestible ($P < 0.01$) in dogs fed the soy protein-containing diets and the SPC-containing diets than in dogs fed the PM treatment. Alanine and glycine digestibilities tended ($P < 0.07$ and $P < 0.07$, respectively) to be higher for soy protein-containing diets than for the PM diet. The Association of American Feed Control Officials (AAFCO, 2000) states that only those amounts of hair, feathers, hooves, horn, and so on, that are naturally occurring in raw animal materials may be present in processed animal by-products. Because many sorting methods exist, varying amounts of these contaminants may be added to the overall mixture; therefore, animal by-product proteins are variable in nutritive value (Murray et al., 1997). Murray et al. (1997) and Bednar et al. (2000) found no differences in apparent ileal amino acid digestibilities between soy proteins and animal by-product proteins. Total essential amino acid digestibilities were greater for soy protein-containing and SPC-containing diets than for PM ($P < 0.01$ and $P < 0.02$, respectively). Total nonessential and TAA digestibilities were greater for soy protein-containing and SPC-containing diets than for PM ($P < 0.01$ and $P < 0.01$, respectively). No differences in amino acid digestibilities were detected among soy protein sources.

Fecal Output and Scores

Fecal characteristics are outlined in Table 7. Fecal output on an as-is basis was lower ($P < 0.01$) for dogs consuming PM (30.0 g/100 g DMI) than for dogs fed the soy protein diets (average = 46.4 g/100 g DMI) and SPC-containing diets (41.5 g/100 g DMI). Dogs fed SPC treatments had lower ($P < 0.01$) fecal outputs than dogs

Table 6. Apparent amino acid digestibilities (%) at the terminal ileum of dogs

	Diet[a]							Contrast[b]				
Item	SBM	SF	SPC 1	SPC 2	SPC 3	PM	SEM	PM vs soy	SBM vs SF	SBM vs SPC	SF vs SPC	PM vs SPC
Essential amino acids												
Arginine	93.2	94.1	93.2	93.5	94.3	88.3	1.35	0.01	0.63	0.75	0.79	0.01
Histidine	87.3	88.7	86.7	86.0	88.5	75.9	2.64	0.01	0.70	0.94	0.59	0.01
Isoleucine	89.1	90.1	87.2	87.7	89.5	79.5	2.38	0.01	0.77	0.71	0.47	0.01
Leucine	88.0	89.1	86.2	86.9	88.6	80.3	2.48	0.02	0.74	0.78	0.50	0.01
Lysine	89.3	91.0	89.3	88.8	91.1	81.0	2.15	0.01	0.58	0.85	0.62	0.01
Methionine	85.7	88.2	79.4	87.1	82.3	79.4	3.72	0.17	0.63	0.53	0.23	0.35
Phenylalanine	83.9	85.9	81.0	83.6	84.2	71.6	3.53	0.01	0.68	0.80	0.45	0.01
Threonine	80.1	82.7	72.6	78.0	79.5	71.9	4.21	0.12	0.66	0.48	0.22	0.28
Valine	85.3	86.8	82.4	83.6	85.6	75.6	3.07	0.01	0.73	0.68	0.41	0.02
Nonessential amino acids												
Alanine	85.9	87.4	83.4	84.3	86.2	80.1	2.80	0.07	0.70	0.69	0.39	0.13
Aspartate	84.7	88.1	83.1	82.1	87.5	63.1	3.44	0.01	0.48	0.90	0.32	0.01
Cystine	70.8	78.6	65.3	73.0	68.4	38.5	7.92	0.01	0.48	0.83	0.29	0.01
Glutamate	90.4	91.9	90.6	90.5	92.5	80.3	2.03	0.01	0.60	0.73	0.76	0.01
Glycine	83.3	85.3	81.4	80.9	84.7	77.3	3.11	0.07	0.64	0.78	0.40	0.13
Proline	86.0	87.7	84.1	84.4	86.5	77.2	2.82	0.01	0.67	0.76	0.41	0.01
Serine	83.7	86.2	82.8	83.2	84.4	67.3	3.40	0.01	0.61	0.95	0.49	0.01
Tyrosine	86.0	88.0	83.6	85.2	85.7	74.8	2.79	0.01	0.60	0.72	0.32	0.01
TEAA[c]	86.9	88.5	84.2	86.1	87.1	78.2	2.79	0.01	0.68	0.74	0.40	0.02
TNEAA[d]	83.8	86.6	81.8	82.9	84.5	69.8	3.44	0.01	0.56	0.84	0.36	0.01
TAA[e]	85.5	87.6	83.1	84.6	85.9	74.2	3.09	0.01	0.61	0.79	0.38	0.01

[a]SBM = soybean meal; SF = Soyafluff 200W (soy flour); SPC 1 = Profine F (traditional aqueous alcohol-extracted SPC); SPC 2 = Profine E (extruded SPC); SPC 3 = Soyarich I (modified molecular weight SPC); PM = poultry meal.

[b]Preplanned contrasts with *P*-value for each comparison: PM vs soy = poultry meal diet vs all soy protein-containing diets; SBM vs SF = soybean meal diet vs Soyafluff 200W diet; SBM vs SPC = soybean meal diet vs all SPC-containing diets; SF vs SPC = Soyafluff 200W diet vs all SPC-containing diets; PM vs SPC = poultry meal diet vs all SPC-containing diets.

[c]TEAA = total essential amino acids.

[d]TNEAA = total nonessential amino acids.

[e]TAA = total amino acids.

Table 7. Fecal characteristics of dogs

Item	Diet[a]						SEM	Contrast[b]				
	SBM	SF	SPC 1	SPC 2	SPC 3	PM		PM vs soy	SBM vs SF	SBM vs SPC	SF vs SPC	PM vs SPC
Feces, g as-is/100 g DMI	48.2	59.3	39.2	42.3	43.2	30.0	4.73	0.01	0.11	0.23	0.01	0.03
Fecal score[c]	3.3	3.3	3.1	3.1	3.0	2.8	0.12	0.01	0.75	0.12	0.05	0.06

[a]SBM = soybean meal; SF = Soyafluff 200W (soy flour); SPC 1 = Profine F (traditional aqueous alcohol-extracted SPC); SPC 2 = Profine E (extruded SPC); SPC 3 = Soyarich I (modified molecular weight SPC); PM = poultry meal.

[b]Preplanned contrasts with P-value for each comparison: PM vs soy = poultry meal diet vs all soy protein-containing diets; SBM vs SF = soybean meal diet vs Soyafluff 200W diet; SBM vs SPC = soybean meal diet vs all SPC-containing diets; SF vs SPC = Soyafluff 200W diet vs all SPC-containing diets; PM vs SPC = poultry meal diet vs all SPC-containing diets.

[c]Scores based on the following scale: 1 = hard, dry pellets; 2 = hard, formed, dry stool that remains firm and soft; 3 = soft, formed, moist that retains shape; 4 = soft, unformed stool that assumes shape of container and is pudding-like; 5 = watery, liquid that can be poured.

fed the SF diet (59.3 g/100 g DMI). Bednar et al. (2000) found DM excretion by dogs fed SBM and beef and bone meal to be higher ($P < 0.05$) than that by dogs fed PM or poultry by-product meal. This was attributed, in part, to higher DM intakes by dogs fed the SBM and beef and bone meal diets. In the current study, dogs ingested numerically more of the SBM (299 g/d) and SF (294 g/d) diets and excreted more feces per gram of intake than dogs consuming the SPC-containing diets (average = 252 g/d) or the PM diet (271 g/d). Zuo et al. (1996) did not observe a decrease in wet fecal excretion when a low-oligosaccharide SBM was fed compared to a conventional SBM. In our experiment, removing the entire nonstructural carbohydrate fraction from the soy protein source, not just the oligosaccharides, numerically decreased wet fecal mass excreted by dogs compared to SBM and SF. Wiernusz et al. (1995) found that wet and dry fecal output decreased ($P < 0.05$) linearly as nonstructural carbohydrate consumption decreased. Therefore, processing soybeans beyond the meal or flour stages can decrease wet fecal volume excreted. This is a key point; one of the greatest disadvantages of including soy products in pet foods is the resultant fecal volume.

Fecal scores ranged from a low of 2.8 (PM) to a high of 3.3 (SBM and SF). Poultry meal resulted in a lower score ($P < 0.01$) compared to all soy protein-containing diets. However, SPC-containing diets tended ($P < 0.06$) to result in similar scores. Dogs fed SF also had higher fecal scores than dogs fed SPC-containing diets ($P < 0.05$), indicating a softer stool. Wiernusz et al. (1995) reported similar findings, and as the soybean protein fraction was more highly processed, the fecal score improved ($P < 0.05$).

Fecal output and score data reflect the TDF and nonstructural carbohydrate contents of the soy protein sources. The SBM and SF diets contain all normal structural and nonstructural carbohydrates associated with soy that lead to an increase in wet fecal volume. The soluble fiber component of the TDF fraction can result in an increase in water-holding capacity of digesta and the insoluble fiber component results in greater fecal bulk (Bednar et al., 2000). Nonstructural carbohydrates, too, affect the digestive physiology of the large bowel of the dog, but they have been studied to a much lesser degree than the structural carbohydrates. Complicating the matter is the fact that this fraction contains components such as oligosaccharides, resistant starches, and soluble hemicelluloses that must be fermented to be utilized. Thus, this carbohydrate fraction contains components that are hydrolytically digested and components that are fermentatively digested. Disregarding treatment effects, however, average fecal scores were close to 3, implying a desirable fecal consistency.

Implications

Soy protein, when combined with other protein sources that contain complementary amino acids, can provide an economical source of highly available and consistent-quality protein to the canine. Fecal bulk and flatulence are the greatest concerns in promoting the benefits of soy product inclusion to pet owners. Results of the current study and previous work in our laboratory agree that, at the terminal ileum, soy protein fractions are equal to or superior to animal protein by-products. When soybeans are processed beyond the meal and flour forms into soy protein concentrate and soy protein isolate, nutrient digestibility may be increased and the problem with fecal bulk lessened, resulting in fecal characteristics comparable to those of dogs consuming animal protein by-products. Soybean processing technologies offer an opportunity for increased soy protein fraction inclusion in companion animal diets.

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