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The influence of soy oligosaccharides on apparent and true ileal amino acid digestibilities and fecal consistency in growing pigs[1,2]

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ABSTRACT: Fourteen ileally cannulated pigs (BW = 35 ± 2 kg) were randomly allotted to a replicated 7 × 7 Latin square design experiment to evaluate the influence of the soybean oligosaccharides (OS), raffinose and stachyose, on ileal nutrient digestibility and fecal consistency. Semipurified diets containing soy protein concentrate (SPC) or soybean meal (SBM) as the sole protein sources were fed. Soy solubles (SS), a by-product of SBM processing containing 3.5% raffinose and 11.5% stachyose, were used to increase dietary raffinose and stachyose concentrations. The seven dietary treatments were SPC, SPC + 9% SS, SBM, SBM + 9% SS, SBM + 18% SS, SBM + 24,000 U α-galactosidase enzyme preparation/kg diet, and a low-protein casein (LPC) diet used to calculate true digestibility. Diets, with the exception of the LPC diet, were formulated to contain 17% CP. All diets contained 0.5% chromic oxide as a marker for ileal digestibility determination. The experimental periods were divided into a 5-d diet adaptation followed by 2-d of ileal digesta collection. Diets and digesta were analyzed for DM, N, Cr, amino acids (AA), raffinose, and stachyose. Fecal consistency was determined on d 6 and 7 of each experimental period. The apparent and true ileal AA digestibilities were not different ($P < 0.05$) for the SPC and SBM control diets. When SS was added to the SPC diet, apparent and true N and AA digestibilities were depressed ($P < 0.05$) with the exception of Trp and Pro. The apparent and true ileal N and AA digestibilities were not different ($P > 0.05$) between the SBM control and SBM + 9% SS diets with the exception of Glu. There was a linear decrease ($P < 0.05$) in apparent and true DM, Val, Gly, and Tyr digestibilities when increasing levels of SS were added to the SBM diet. The addition of α-galactosidase did not improve apparent or true ileal N or AA digestibilities except for apparent and true Val and Tyr. Ileal raffinose digestibility was improved ($P < 0.05$) by addition of α-galactosidase, but was not affected by any other dietary treatment. Ileal stachyose digestibility was not affected ($P > 0.58$) by treatment. Fecal consistency likewise was not affected ($P > 0.36$) by dietary treatment. In conclusion, soy OS reduced nutrient digestibilities, but the reductions were small, ranging from approximately 1.1 to 7.4 percentage units. This suggests that other factors may be negatively impacting SBM digestibility.

Key Words: Amino Acids, Digestibility, Oligosaccharides, Pigs

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Introduction

Among protein sources, soybean meal (**SBM**) has an excellent reputation for high amino acid (AA) quality, but there still remains large variations in the nutritive value of the SBM product. Performance responses resulting from feeding SBM are influenced by the concentration of antinutritional factors present after processing, such as the oligosaccharides (OS) (Liener, 1981; Anderson and Wolf, 1995). Soybean OS, raffinose and stachyose, are not eliminated by processing (Leske et al., 1993). They represent approximately 4 to 6% of DM and have been reported to increase the incidence of diarrhea in rats (Kuriyama and Mendel, 1917). The antinutritional effects of OS in SBM have been demonstrated in poultry; however, limited research has been conducted in swine. Removing the OS from SBM in poultry diets increased the true metabolizable energy value of the diet by 20% (Coon et al., 1990). Soy OS are likely responsible for increasing viscosity of digesta, which interferes with

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digestion of nutrients by decreasing their interaction with digestive enzymes in the intestine (Smits and Annison, 1996).

Hydrolytic digestion of OS in the small intestine is minor because mammals lack α-galactosidase necessary to hydrolyze the α 1,6 linkages present in OS (Slominski, 1994). Dietary supplementation with α-galactosidase enzyme may prove beneficial in reducing viscosity and improving nutrient digestion by swine. A small amount of OS fermentation can occur due to the action of small intestinal microflora (Rackis, 1975). However, the majority of digestion presumably occurs in the large intestine, where OS may function as selective growth factors for beneficial bacteria (Hayakawa et al., 1990).

A greater understanding of how soy OS affect the nutritional value of SBM could enhance the nutritive value of SBM for swine. Therefore, the objectives of the present study were to determine the effects of graded levels of soy OS on apparent and true ileal nutrient digestibilities and fecal consistency.

Materials and Methods

Animals and Diets

Fourteen crossbred pigs (BW = 35 ± 2 kg; PIC 326 sire line × C22 dams; PIC, Franklin, KY) were used in this experiment. The pigs had been surgically fitted with a simple-T cannula approximately 12 cm anterior to the ileocecal junction according to procedures adapted from Sauer et al. (1983). Adaptations included the cannula design and anesthetics. Nylon cannulas, with a smooth outer ring, plug, and screw cap were used. The cannula barrel diameter was widened to allow for collection of greater volumes of digesta. The flange was widened and smoothed to allow increased stability when the cannula was exteriorized between the last two ribs. Prior to use of halothane anesthesia, pigs were sedated with 1.5 mL of an i.m. mixture of tiletamine HCl, and zolazepan HCl (100 mg/mL telazol), ketamine HCl (50 mg/mL), and xylazine HCl (50 mg/mL) (Fort Dodge Animal Health, Fort Dodge, IA). The University of Illinois Institutional Animal Care Advisory Committee approved all experimental procedures prior to experiment initiation (protocol # 99277). Pigs were housed in individual metabolism crates in a temperature-controlled room.

After a 10-d recovery from surgery, pigs were fed one of seven experimental diets according to a replicated 7 × 7 Latin square design. Pigs were fed twice daily (0800 and 2000, equal portions at each meal). Initially, pigs were fed at a level of 9% of metabolic BW ($BW^{0.75}$). Feed intake was increased 150 g each subsequent period to account for BW increase over the duration of the experiment. Water was provided for ad libitum consumption from a low-pressure drinking nipple.

Six isonitrogenous diets and a low-protein casein (**LPC**) diet were used in this experiment (Table 1). Diets were formulated to meet or exceed the nutrient requirements of 25 to 50 kg pigs as outlined by NRC (1998) and to contain 17% CP (as-fed basis). The exception was the LPC diet, which was used to estimate endogenous losses of amino acids. The six other diets included: 1) soy protein concentrate (**SPC**); 2) SPC + 9% soy solubles (**SS**); 3) soybean meal; 4) SBM + 9% SS, 5) SBM +18% SS; and 6) SBM + α-galactosidase (Alpha-Gal 600 L, Novo Nordisk, Davis, CA, provided 600 α-galactosidase enzyme units/g of enzyme preparation). For diets 4 to 6, SBM from Central Soya Processing Plant (Gibson City, IL) was used. Diet 3 contained another source of SBM originating from Ohio. Diets 1 and 3 were part of a larger regional project and the results from these diets were compared with results from other universities. The SS served as the source of additional soy OS, providing 3.49% raffinose, 11.47% stachyose, and minor amounts of both indispensable and dispensable AA. The composition of SS was analyzed by the University of Illinois and the Quality Assurance Laboratory of Central Soya; results are presented in Table 2. Alpha-galactosidase is not produced by the intestinal tract of nonruminants and was added to the SBM diet to determine if this enzyme would degrade soy OS and improve nutrient digestibility. Chromic oxide was included (0.5%, as-fed) in all experimental diets and served as an inert marker for digestibility calculations. Following mixing, diets were screened through a 0.5-cm screen to improve the incorporation of corn oil and SS into the diets. This was done to minimize the occurrence of clumps in the diet due to the oil and (or) SS.

Each experimental period lasted 7 d and included a 5-d adaptation period and a 2-d collection period. Ileal digesta collection and fecal scoring occurred on d 6 and 7. Fecal scores were determined at 0800 and 2000 using the following fecal scoring system: 1 = hard, dry pellet; 2 = firm, formed stool; 3 = soft, moist stool that retains shape; 4 = soft, unformed stool that assumes shape of container; 5 = watery liquid that can be poured. Digesta were collected continuously from 0800 to 2000 into polyethylene tubing (5 cm × 25 cm; Rand Materials Handling Equipment Co., Inc., Pawtucket, RI) that was emptied every hour into plastic containers and stored at −10°C until the end of collection. After the 2 d of collection, digesta were thawed, pooled by pig, and a subsample was freeze-dried.

Chemical Analyses

Diets and freeze-dried digesta were ground in a coffee mill (Mr. Coffee, Bedford Heights, OH). Diets and digesta were analyzed for DM (AOAC, 1995) at the University of Illinois. The Experiment Station Chemical Laboratories (University of Missouri, Columbia) analyzed diets and digesta for N (method no. 999.03), chromium (Cr, method no. 975.03, sample preparation, and method no. 990.08, instrument analysis),

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Table 1. Ingredient and chemical composition of the experimental diets (as-fed)

Item	Treatment number and description						
	1 Soy protein concentrate (SPC)	2 SPC + 9% soy solubles (SS)	3 Soybean meal (SBM)	4 SBM + 9% SS	5 SBM + 18% SS	6 SBM + α-galactosidase	7 Low-protein casein (LPC)
Ingredient,%							
Cornstarch	46.00	37.00	38.10	29.10	20.10	34.10	61.60
Soybean meal (48%)[a]	—	—	35.25	35.25	35.25	35.25	—
Soy protein concentrate	27.00	27.00	—	—	—	—	—
Sucrose	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Corn oil	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Solka floc	—	—	—	—	—	—	5.00
Casein	—	—	—	—	—	—	5.00
Sodium chloride	0.35	0.35	0.35	0.35	0.35	0.35	0.40
Dicalcium phosphate	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Calcium carbonate	0.45	0.45	0.45	0.45	0.45	0.45	0.60
Trace mineral premix[b]	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Vitamin premix[c]	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Potassium carbonate (55% K)	0.35	0.35	—	—	—	—	1.40
Magnesium oxide (58% Mg)	—	—	—	—	—	—	0.15
Alpha-galactosidase[d]	—	—	—	—	—	4.00	—
Soy solubles[e]	—	9.00	—	9.00	18.00	—	—
Chromic oxide	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Analyzed composition, %							
Dry matter	85.9	87.5	89.1	86.6	83.5	84.6	89.9
Nitrogen	2.65	2.62	2.77	2.98	3.12	2.82	0.69
Lysine	1.09	1.07	1.13	1.26	1.23	1.04	0.38
Total soy oligosaccharides[f]	1.03	2.26	2.42	3.74	5.36	2.42	—

[a]Soybean meal for diet 3 originated from Ohio; SBM for diets 4 to 6 originated from Central Soya, Gibson City, IL.
[b]Provided per kg diet: 2,000 IU vitamin A; 300 IU vitamin D_3; 20 IU vitamin E; 1.0 mg vitamin K (menadione); 4 mg thiamine; 15 mg niacin; 4 mg riboflavin; 12 mg pantothenic acid; 15 μg vitamin B_{12}; 2 mg pyridoxine; 0.1 mg D-biotin; 0.5 mg folic acid; and 0.6 g choline.
[c]Provided per kg diet: 90 mg Fe (iron sulfate); 5 mg Mn (manganese oxide); 8 mg Cu (copper sulfate); 0.20 mg I (potassium iodate); 0.21 mg Se (sodium selenite); and 90 mg Zn (zinc sulfate).
[d]Provided per kg diet: 24,000 alpha-galactosidase enzyme units.
[e]Provided per kg SS: 34.9 g raffinose, 114.7 g stachyose, and 3.1 g verbascose.
[f]Total soy oligosacchairdes = % stachyose + % raffinose + % verbascose.

and AA (method no. 982.30) using AOAC (1995) methodology.

Raffinose and stachyose concentrations of diets and digesta were quantified by HPLC. Approximately 5 g of ground sample (as-is basis) were weighed and transferred into a homogenizer reservoir (Omni ES homogenizer, Omni, Warrenton, VA). One hundred milliliters of water were added to the reservoir. The mixture was homogenized at 8,500 × *g* for 10 min. The mixture then was rinsed into a plastic bottle with approximately 25 mL water. The bottle was sealed and placed in an 80°C water bath for 1 h. During incubation, the sample was mixed every 10 min. After incubation, the sample was allowed to cool to room temperature. The sample then was transferred to a 250-mL volumetric flask and brought up to volume with water. This mixture was filtered into a Büchner funnel containing a Whatman No. 541 filter paper supported in a 125-mL side-arm filter flask. Fifteen milliliters of filtrate was filtered centrifugally using a 10^4 Da cutoff filter (Centriprep 10, Amicon, Inc., Beverly, MA). After centrifugation, the filtrate was used for chromatographic analysis. Fifty microliters of sample were injected into a Dionex DX-300 HPLC (Dionex Corp., Sunnyvale, CA) fitted with a CarboPac PA-1 (4 × 250 mm) analytical column and a CarboPac PA-1 (4 × 50 mm) guard column (Dionex Corp., Sunnyvale, CA). The degassed mobile phase consisted of 120 m*M* NaOH initially, increasing linearly to 150 m*M* NaOH by 10 min. From 10 to 20 min, the concentration of NaOH increased linearly to 240 m*M*. At this time, the concentration of NaOH was changed to 300 m*M*, which was maintained for 10 min to clean the column. The column then was reequilibrated for 15 min with 120 m*M* of NaOH. All eluents were prepared with carbonate-free water and purged with helium. Flow rate was constant at 1.0 mL/min, and the elution was conducted at room temperature. Eluted OS and sucrose were detected using a Dionex pulsed electrochemical detector (**PED**) equipped with a gold-working electrode. The PED was operating in the integrated amperometry mode. Total run time per sample was 45 min. Appropriate dilutions of a solution containing sucrose (Sigma Chemicals, St. Louis, MO), raf-

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Table 2. Analyzed composition of soy solubles (as-fed basis)

Item	%[a]	%[b]
DM	54.73	58.40
N	1.06	1.17
Ash	5.71	4.20
Fat	—	4.10
Amino Acids	—	
Arg	0.30	
His	0.14	
Ile	0.14	
Leu	0.27	
Lys	0.21	
Met	0.07	
Phe	0.25	
Thr	0.17	
Trp	0.11	
Val	0.16	
IDAA[c]	1.82	
Ala	0.22	
Asp	0.62	
Cys	0.11	
Glu	1.02	
Gly	0.19	
Pro	0.22	
Ser	0.22	
Tyr	0.14	
DAA[d]	2.74	
Sucrose	18.79	23.30
Monosaccharides	—	2.60
Oligosaccharides		
Raffinose	3.49	2.90
Stachyose	11.47	11.40
Verbascose	0.31	—

[a]As analyzed at the University of Illinois prior to experiment initiation.
[b]As analyzed by the Quality Assurance Laboratory of Central Soya, Laboratory, Fort Wayne, IN.
[c]Sum of indispensible amino acids.
[d]Sum of dispensible amino acids.

finose, stachyose, and verbascose (Megazyme International, Bray, County Wicklow, Ireland) were used as calibration standards.

The Quality Assurance Laboratory of Central Soya analyzed SS for CP (method no. Bc 4-91), fat (method no. Bc 3-49), and fiber (method no. Ba 6-84) using AOCS (1994) methodology. Additionally, the sugars and oligosaccharides were quantified by the method described by Shukla (1987).

Calculations and Statistical Analyses

Apparent ileal digestibility coefficients were calculated according to the following formula:

$$\text{AID}\ (\%) = 100 - ((\text{Cr}_F/\text{Cr}_D)\ (\text{N}_D/\text{N}_F) \times 100)$$

where AID is the apparent ileal digestibility of N, an AA, stachyose, or raffinose, Cr_F is the concentration of chromium in the feed, Cr_D is the concentration of chromium in the digesta, N_D is the concentration of nutrient in digesta, and N_F is the concentration of nutrient in the feed. Endogenous nutrient losses (**ENL**) of N and AA were calculated in each experimental period using the pigs fed the LPC diet. The following formula (Moughan et al., 1992) was used to determine ENL:

$$\text{ENL} = \text{N}_D \times (\text{Cr}_F/\text{Cr}_D)$$

where ENL is endogenous losses on a g/kg DMI basis, Cr_F is the concentration of chromium in the feed, Cr_D is the concentration of chromium in the digesta, and N_D is the concentration of nutrient in digesta. True ileal digestibility of N and AA was calculated using the following formula:

$$\text{TID} = \text{AID} + [(\text{ENL}/\text{N}_D) * 100]$$

where TID is true ileal digestibility of N or an AA, AID is apparent ileal digestibility of N or AA, N_D is the concentration of nutrient in digesta, and ENL is endogenous losses of N or an amino acid for the same period. Endogenous losses were used for each period and not pooled over the entire experiment because endogenous losses change with body weight for pigs that weigh less than 60 kg (Stein et al., 1999).

The data were analyzed using the GLM procedures of SAS (SAS Inst. Inc., Cary, NC). Analysis of variance was performed according to a replicated Latin square design (Steele and Torrie, 1980). The model included the effects of period, square, pig (square), pig (diet), and diet × square interaction. Treatment effects on apparent and true ileal digestibility were evaluated using the following nonorthogonal contrasts: linear and quadratic effects of SS in the SBM diets (diets 3, 4, and 5), SPC vs SBM (diet 1 vs diet 3), effect of adding SS to SPC (diet 1 vs diet 2), effect of adding SS to SBM (diet 3 vs diet 4), and the effect of α-galactosidase addition to SBM diet (diet 3 vs diet 6). For all statistical analyses, an alpha level of 0.05 was used to determine statistical significance.

Results

In general, pigs remained healthy and consumed their meals throughout the experiment. Two pigs did not consume the LPC diet in two different periods of the experiment; thus, the ENL value for the second pig consuming the LPC diet was used for all pigs in the study in those two periods only. Otherwise, the ENL value from the pig consuming the LPC diet within square was used for the calculations for that specific square. At the conclusion of the trial, the pigs were euthanized. Examination of the cannulation site and gastrointestinal tract revealed no abnormalities.

Fecal consistency scores did not change ($P > 0.57$) as a result of dietary treatment. The average fecal consistency scores for the SPC diet, SPC + 9% SS diet, SBM diet, SBM + 9% SS diet, SBM + 18% SS diet, SBM + α-galactosidase diet, and LPC diet were 1.14, 1.07, 1.07, 1.14, 1.29, 1.14, and 1.01, respectively.

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Table 3. Apparent ileal digestibility coefficients (%) for dry matter, nitrogen, amino acids, and oligosaccharides[a]

	Treatment number and description						
Item	1 Soy protein concentrate (SPC)	2 SPC + 9% soy solubles (SS)	3 Soybean meal (SBM)	4 SBM + 9% SS	5 SBM + 18% SS	6 SBM + α-galactosidase	SEM[b]
Dry matter[cef]	84.3	81.9	80.5	80.3	75.7	82.5	0.7
Nitrogen[f]	81.4	75.9	81.5	79.8	79.7	82.2	1.3
Amino Acids							
Arg[f]	91.3	87.1	92.0	90.7	90.3	90.8	1.1
His[f]	85.9	80.8	87.3	85.9	84.6	85.5	1.2
Ile[f]	84.4	81.3	84.1	83.7	82.5	84.2	1.0
Leu[f]	85.2	81.7	85.0	83.5	83.2	84.0	1.1
Lys[f]	85.4	78.0	85.7	83.8	82.1	83.2	1.4
Met[f]	87.4	84.2	87.9	87.4	86.9	88.7	0.8
Phe[f]	86.8	83.4	86.4	84.8	83.9	85.0	1.0
Thr[f]	79.1	74.3	79.3	77.7	78.1	79.5	1.5
Trp	85.7	83.9	88.4	85.9	87.2	88.6	1.1
Val[cfh]	82.0	78.6	84.5	81.5	78.4	94.8	1.2
IDAA[fi]	85.5	81.3	86.1	84.4	83.6	88.0	1.1
Ala[f]	79.4	74.2	80.1	78.4	79.0	79.4	1.8
Asp[f]	83.0	78.1	84.0	82.5	82.9	84.7	1.5
Cys[f]	74.8	67.8	77.2	74.8	76.0	77.6	3.6
Glu[fg]	85.7	80.2	87.5	84.3	84.7	85.5	1.1
Gly[cf]	71.2	62.8	75.8	72.2	71.9	73.5	3.1
Pro	75.0	75.8	74.1	69.1	74.6	77.3	3.1
Ser[f]	85.2	82.4	84.7	83.1	84.2	84.6	1.1
Tyr[cfh]	84.9	81.8	87.0	86.1	80.7	96.2	1.1
DAA[fj]	82.3	77.2	84.3	81.9	82.0	85.7	1.3
TAA[fk]	83.8	79.0	85.1	83.0	82.7	86.8	1.2
Oligosaccharides							
Raffinose[h]	80.3	77.6	62.6	70.3	73.0	91.2	7.5
Stachyose	97.0	93.8	87.4	84.7	84.0	96.3	3.9

[a]Means based on 14 observations per treatment.
[b]Standard error of the means.
[c]Linear effect of SS addition to diets 3 to 5 ($P < 0.05$).
[d]Quadratic effect of SS addition to diets 3 to 5 ($P < 0.05$).
[e]Diet 1 vs diet 3 ($P < 0.05$).
[f]Diet 1 vs diet 2 ($P < 0.05$).
[g]Diet 3 vs diet 4 ($P < 0.05$).
[h]Diet 3 vs diet 6 ($P < 0.05$).
[i]Sum of indispensable amino acids.
[j]Sum of dispensable amino acids.
[k]Sum of total amino acids.

Apparent ileal digestibility coefficients are presented in Table 3. The apparent ileal digestibilities of AA were not different ($P > 0.05$) between the SPC and SBM control diets; however, apparent DM digestibility was lower ($P < 0.05$) for pigs consuming the SBM diet. The apparent ileal digestibilities of N and all AA except Trp and Pro were decreased ($P < 0.05$) for pigs consuming the SPC + 9% SS diet when compared to pigs consuming the SPC control diet. However, the apparent ileal digestibilities of N and all AA except Glu were not different ($P > 0.05$) for pigs consuming the SBM or the SBM + 9% SS diet. There was a linear decrease ($P < 0.05$) in apparent ileal DM, Val, Gly, and Tyr digestibilities when increasing concentrations of SS were added to the SBM diets. When the SBM control diet was compared to the SBM diet containing α-galactosidase enzyme, apparent ileal Val, Tyr, and raffinose digestibilities were improved ($P < 0.05$) by enzyme addition. The endogenous losses of N and AA are presented in Table 4.

True ileal digestibility data are presented in Table 5. Similar to apparent digestibilities, true ileal digestibilities of AA were not different ($P > 0.05$) between the SPC and SBM control diets. The true ileal digestibilities of N and all AA except Trp and Pro were decreased ($P < 0.05$) for pigs consuming the SPC + 9% SS diet when compared to pigs consuming the SPC control diet. The true ileal digestibilities for pigs consuming the SBM or the SBM + 9% SS diet followed the same pattern as for apparent ileal digestibilities. There was a linear decrease ($P < 0.05$) in true ileal Val, Gly, and Tyr digestibilities when increasing concentrations of SS were added to the SBM diets. True ileal Val and Tyr digestibilities were improved ($P < 0.05$) by enzyme addition to the SBM diet.

Discussion

The effects of supplemental OS in the diet have been investigated in pigs, dogs, and chickens. This study

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Table 4. Endogenous losses of nitrogen and amino acids in growing pigs fed a low protein casein diet

Item	Endogenous loss, g/kg DMI	Standard deviation
Nitrogen	0.862	0.136
Amino acids		
Arg	0.225	0.035
His	0.187	0.029
Ile	0.287	0.045
Leu	0.587	0.093
Lys	0.475	0.075
Met	0.162	0.025
Phe	0.300	0.047
Thr	0.250	0.031
Trp	0.087	0.013
Val	0.387	0.061
IDAA[a]	2.949	0.467
Ala	0.200	0.031
Asp	0.425	0.067
Cys	0.025	0.003
Glu	1.374	0.217
Gly	0.125	0.019
Pro	0.600	0.094
Ser	0.370	0.053
Tyr	0.262	0.041
DAA[b]	3.348	0.530
TAA[c]	6.297	0.997

[a]Sum of indispensable amino acids.
[b]Sum of dispensable amino acids.
[c]Sum of total amino acids.

evaluated the effects of supplemental soy OS, provided as SS and included at concentrations higher than in typical SBM-based diets, on apparent and true ileal AA digestibilities.

In the current study, addition of any level of soy OS did not adversely affect fecal consistency. Strickling et al. (2000) fed 0 or 0.5% added OS in a corn-SBM-poultry meal-based diet to dogs and reported no effect of treatment on fecal scores. Additionally, there was no effect of supplemental OS on apparent ileal DM or N digestibilities. The researchers concluded that the amount of OS added was not sufficient to affect digestive processes.

As expected, growing pigs digested the protein in SPC and SBM with equal efficiency. Most of the data reporting improvements in ileal AA digestibilities of SPC vs SBM-based diets was conducted using newly weaned pigs. For example, Sohn et al. (1994) reported a 14% increase in apparent ileal DM digestibility and an 11% increase in apparent ileal IDAA and DAA digestibilities for 25 to 53-d old pigs consuming a SPC-based diet compared to pigs consuming a SBM-based diet. Yet Grala et al. (1998) reported minimal improvements in apparent ileal nutrient digestibility by pigs fed SPC-based diet compared to a SBM-based diet. These researchers reported improvements ($P < 0.05$) only in apparent ileal DM, His, Ile, Leu, Trp, Gly, and Ser digestibilities. However, these pigs were 10 wk old when the first digesta collection occurred. Soy protein concentrate is typically utilized in diets fed to starter pigs due to the immaturity of the digestive capabilities of the young pig and, therefore, is not used in grower diets.

The apparent ileal AA digestibility coefficients for the SBM-based control diet were comparable to published values (Li et al., 1993). In this study most of the true ileal Pro digestibilities were over 100%. The use of a LPC diet to estimate endogenous losses may result in mobilization of glutamine from muscle, which can be metabolized into glutamate for use by the enterocytes to synthesize ammonia, citrulline, and Pro. This has been speculated to cause an overestimation of endogenous Pro and, thus, an overestimation of true ileal Pro digestibility (de Lange et al., 1989).

Interestingly, when soy OS were added back to SPC to result in equal concentrations found in SBM, ileal digestibility of all components measured decreased when compared to the SBM-based control diet. However, addition of 9% SS to the SBM control diet did not detrimentally affect nutrient digestion. This may be a result of an interaction between nutrients in SPC and SS, but at this time, the reason for this response is unknown.

There was no linear decrease in apparent or true ileal AA digestibilities of the SBM diets containing added soy OS, when compared to the SBM-based control diet, with the exception of Val, Gly, and Tyr. Many studies that have evaluated the effects of OS on apparent ileal digestibilities of DM, N, and AA involved supplementation of OS in forms other than those found in soy products. For example, Gabert et al. (1995) fed a diet containing wheat, barley, and SBM with added galactooligosaccharides, glucooligosaccharides, or lactitol to ileally cannulated pigs and reported no effect of dietary treatment on apparent ileal digestibilities of DM, CP, or most of the indispensable or dispensable AA measured. However, the levels fed in the current study were much higher (1 to 6% total soy OS) than those used in the Gabert study (0.2 to 1% OS).

Other OS have been fed to pigs. Houdijk et al. (1999) reported an increase in apparent ileal digestibility of DM by weanling pigs fed a semipurified diet containing 40 g/kg of either fructooligosaccharides or transgalactooligosaccharides. They reported no effect of dietary treatment on apparent ileal digestibility of CP. They also fed two levels of the same OS to growing pigs and reported no effect of level or source of OS on apparent ileal digestibilities of DM or CP.

Veldman et al. (1993) used pigs surgically modified with ileorectal anastomosis to study the effect of 15% velasse addition on ileal nutrient digestibility. Velasse is the residue left after evaporation of an ethanol/water extract of SBM that results in the production of SPC and contains 18% soy OS. Pigs were fed a SPC-cornstarch-based diet with and without added soy OS (0.7 or 2.8% soy OS) from velasse. They found a 25% decrease in both OM and CP digestibilities. The authors speculated that the decrease in digestibility was the result of an increase in gut osmolarity and dilution

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Table 5. True ileal digestibility coefficients (%) for nitrogen and amino acids[a]

	Treatment number and description						
Item	1 Soy protein concentrate (SPC)	2 SPC + 9% soy solubles (SS)	3 Soybean meal (SBM)	4 SBM + 9% SS	5 SBM + 18% SS	6 SBM + α-galactosidase	SEM[b]
Nitrogen[f]	89.4	84.1	89.1	87.0	86.1	89.6	1.1
Amino Acids							
Arg[f]	94.8	90.6	95.1	93.7	93.0	94.2	0.7
His[f]	90.1	85.0	91.2	89.4	88.1	89.7	1.1
Ile[f]	91.3	88.1	90.6	89.7	88.3	90.7	0.9
Leu[f]	89.6	86.1	89.0	87.4	86.8	88.4	1.0
Lys[f]	89.4	82.3	89.6	87.3	85.6	87.4	1.3
Met[f]	92.0	88.9	92.5	91.8	91.0	93.2	0.8
Phe[f]	90.3	86.9	89.5	87.8	86.7	88.4	0.9
Thr[f]	87.4	82.5	87.2	85.2	85.0	87.8	1.3
Trp	90.5	88.6	92.7	90.0	90.7	92.9	1.0
Val[cfh]	89.0	85.5	90.5	87.5	85.1	96.7	1.1
IDAA[f], I	90.5	86.3	90.7	88.8	87.8	91.9	1.0
Ala[f]	86.8	81.6	87.1	85.0	85.0	86.7	1.3
Asp[f]	87.3	82.4	88.0	86.3	86.4	88.8	1.1
Cys[f]	81.9	74.8	84.2	80.9	81.2	84.4	1.7
Glu[fg]	90.8	85.2	92.1	88.7	88.8	90.3	1.0
Gly [cf]	84.8	76.4	88.3	83.9	82.6	86.5	1.7
Pro	106.8	101.6	110.7	106.4	104.8	108.9	2.8
Ser[f]	94.6	91.6	93.7	91.5	91.7	93.8	1.0
Tyr[cfh]	90.5	87.4	91.6	90.5	86.1	97.5	1.0
DAA[f]	90.8	85.5	92.1	89.2	88.8	92.6	1.1
TAA[f]	90.6	85.9	91.5	89.0	88.3	92.3	1.0

[a]Means based on 14 observations per treatment.
[b]Standard error of the means.
[c]Linear effect of SS addition to diets 3 to 5 ($P < 0.05$).
[d]Quadratic effect of SS addition to diets 3–5 ($P < 0.05$).
[e]Diet 1 vs diet 3 ($P < 0.05$).
[f]Diet 1 vs diet 2 ($P < 0.05$).
[g]Diet 3 vs diet 4 ($P < 0.05$).
[h]Diet 3 vs diet 6 ($P < 0.05$).
[i]Sum of indispensable amino acids.
[j]Sum of dispensable amino acids.
[k]Sum of total amino acids.

of digestive enzyme activities and substrate concentrations. The concentrations of soy OS in the two experimental diets used by Veldman et al. (1993) are comparable to those in our SPC and SBM + 9% SS treatments. The apparent ileal digestibility of N was not different ($P > 0.25$) between the SPC and the SBM + 9% SS diets in our study. Veldman et al. (1993) reported that some of their pigs were ill and were exchanged when illness occurred. This could have introduced variation and biased the digestibility data.

Typically, oligosaccharides are considered indigestible in the small intestine. Nondigestible oligosaccharides (**NDO**) are best defined as "carbohydrates with a degree of polymerization of two or more, which are soluble in 80% ethanol and are not susceptible to digestion by pancreatic and brush-border enzymes" (Quigley et al., 1999). However, the nondigestibility of NDO is largely assumed and not always investigated. Most of the research concerning NDO is based on fecal analysis. However, bacterial numbers increase along the small intestine of humans and presumably nonruminant animals to a density of 10^6 to 10^8 bacteria/mL in the distal ileum (Bird et al., 2000). In the current study, apparent ileal digestibilities of raffinose and stachyose ranged from 62.2 to 91.2% and 84 to 97%, respectively. These data support the idea of bacterial colonization at the terminal ileum. Our data are supported by Veldman et al. (1993) who reported apparent ileal digestibilities of the α-galactosides in the range of 57 to 97% in pigs. Additionally, Houdijk et al. (1999) reported apparent ileal digestion of nonstarch neutral-detergent soluble carbohydrates (**NNSC**) of 77.6 to 89.1% in weanling pigs fed diets with and without NDO. Therefore, fermentation of these NDO may have occurred as a result of the action of the prececal bacteria populations.

The results of α-galactosidase enzyme addition to SBM-containing diets on nutrient digestibility are not conclusive. Addition of 0.5% α-galactosidase enzyme to a SPC-cornstarch-based diet fed to 9-wk-old pigs increased ($P < 0.05$) apparent ileal digestibility of the α-galactosides (raffinose, stachyose, and verbascose) (Veldman et al., 1993). However, Irish et al. (1995) found no effect of a 0.2% addition of α-galactosidase

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to a corn-SBM diet fed to broilers on ileal CP digestibility. Variation in results may be due to differences in source and relative activity of the α-galactosidase enzyme preparations. In Veldman et al. (1993), the enzyme preparation was reported to have an activity of 7,100 U/kg diet. However, in Irish et al. (1995), the source of α-galactosidase was a combination of two crude extracts with a total activity of 109 U/kg diet. In the current study, the α-galactosidase source had an activity of 24,000 U/kg diet. The concentration of the enzyme used in the study by Veldman et al. (1993) was lower than in this study, and improvements in digestion were observed. However, the enzyme source used in our study was different than in the study by Veldman et al. (1993), and thus may be the reason minimal effect of α-galactosidase addition to SBM was observed, with improvements being observed in apparent and true Val and Tyr digestibilities. Additionally, the minimal improvements may be due to the fact that the α-galactosidase enzyme has an optimal activity at pH 5 and approximately 60°C. These are not representative of the conditions in the gastrointestinal tract of the pig. Enzyme denaturation or inactivation may occur when the enzyme reaches the acidic stomach.

In conclusion, the addition of soy OS to SBM-based diets minimally affected the apparent or true ileal digestibilities of the components studied. The addition also did not result in loose stools or diarrhea, which has been a common problem with high dietary intakes of soy OS. The addition of soy OS to the SPC-based diet lowered both apparent and true ileal digestibilities of most nutrients studied. Digestibility of OS was not improved by the addition of α-galactosidase enzyme; therefore, this enzyme may not be a beneficial method for reducing the OS concentration of soy products. Therefore, soy OS present in the SBM-containing diets may not be as major a factor as previously believed when considering the antinutritional components of soy products.

Implications

The addition of soybean oligosaccharides to soybean meal-cornstarch semipurified diets only minimally affected apparent or true ileal dry matter, nitrogen, or amino acid digestibilities. Thus, antinutritional factors other than oligosaccharides may impact soybean meal protein utilization to a greater extent. The high concentrations of soy oligosaccharides used in this study did not increase the incidence of diarrhea in the pig. Additionally, the soy oligosaccharides were partially digested prior to the cecum, indicating ileal fermentative activity.

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