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ABSTRACT: A study was conducted using the ileal digestibility technique with grower-finisher pigs to evaluate the effects of particle size reduction of soybean meal (SBM) on amino acid and energy digestibility. Soybean meal was processed through a hammer mill to achieve average particle sizes of 900, 600, 300, and 150 μm. The treatments included the use of two soybean meal sources and soy protein concentrate. One source of SBM was ground to four different particle sizes (i.e., 949, 600, 389, 185); a second source was a common SBM source used in other trials (i.e., 800 μm). The soy protein concentrate had an average particle size of 385 μm. A low-protein (5% casein) diet was fed to determine endogenous amino acid losses. This experiment was conducted in a 7 × 7 Latin Square design in two replicates using 14 crossbred barrows ([Landrace × Yorkshire] × Duroc) that averaged 28 kg BW and 60 d of age. Animals were surgically fitted with a T-cannula at the distal ileum. Treatment diets were fed in meal form, initially at 0.09 kg $BW^{0.75}$ and at graded increases at each subsequent period. Pigs within replicate were fed a constant quantity of their treatment diet for a 5-d adjustment period followed by a 2-d collection of ileal digesta samples. Apparent and true digestibility of amino acids was calculated by use of chromic oxide (0.5%) as an indigestible marker. Apparent digestibility of isoleucine, methionine, phenylalanine, and valine increased linearly ($P < 0.05$) as particle size decreased. True digestibility of isoleucine, methionine, phenylalanine, and valine increased linearly ($P < 0.05$) as particle size decreased. When the essential amino acids were averaged, apparent digestibility increased ($P < 0.10$) from 83.5% to 84.9% as particle size decreased, whereas, nonessential amino acid digestibility increased only slightly ($P > 0.15$). Essential amino acid true digestibility increased numerically from 91.0% to 92.4% as particle size decreased. Energy digestibility was not affected by particle size ($P > 0.15$). These results suggest that a reduction in particle size of soybean meal resulted in a small increase in the digestibility of its amino acids with the essential amino acids being affected more than the nonessential amino acids. The largest improvement in digestibility, however, was obtained when the particle size was reduced to 600 μm.

Key Words: Amino Acids, Digestibility, Ileum, Particle Size, Pigs, Soybeans

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Introduction

Dietary particle size affects the digestibility of feed nutrients (Wondra et al., 1995a,b,c,d). Smaller particles have an increased surface area thus allowing the digestive enzymes to more effectively release the nutrients. This generally results in higher digestibility coefficients and improved feed efficiency responses (Owsley et al., 1981). Average particle sizes between 600 to 700 μm are generally recommended for most swine diets (Wondra et al., 1995a). A preliminary survey of several soybean meal (**SBM**) samples demonstrated a particle size between 800 to 900 μm, suggesting that the digestibility of commercial SBM might be improved with a smaller particle size.

Although N digestibility measurements have previously used total fecal and urinary collections, colonic and large intestine microbial populations metabolize the N fractions, resulting in an amino acid profile that differs from that which exits the ileum. This indicates that terminal tract amino acid compositions and the resulting digestibility values do not accurately reflect

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amino acid digestibilities in the pig. The ileal digestibility technique has subsequently been used to reduce the confounding effects of the microbial populations (Low and Zebrowska, 1989).

Amino acids present in the ileal digesta are, however, not completely of dietary origin. The endogenous fraction of the upper digestive tract also contains microbial protein, sloughed cells, muco-proteins, and digestive enzymes (Moughan and Schuttert, 1991). The quantity and composition of this endogenous fraction is influenced by dietary protein, fiber, and dry matter intake. Adjusting for this fraction in the digesta gives a more accurate assessment of the true dietary amino acid digestibility.

Because the effect of differing particle sizes of SBM on amino acid digestibility is currently unknown, we therefore examined the amino acid and energy digestibilities using the ileal digestibility technique in grower-finisher pigs.

Materials and Methods

The experiment evaluated the ileal digestibility coefficients of commercial SBM processed to four different particle sizes and to compare the results to an unground SBM from another processor and to a soy protein concentrate source.

One source of SBM (48% CP) had an average particle size 949 μm and served as one treatment group. This meal was then processed through a 60 horsepower hammer mill (model 1040; Schutte, Buffalo, NY) to attain three other mean particle sizes of approximately 600, 300, and 150 μm; the final four products having average sizes of 949, 600, 329, and 185 μm, respectively. Another 48% CP SBM (i.e., 800 μm) and a soy protein concentrate (i.e., 383 μm) source both from a different processor than the initial SBM source was also evaluated. The soy protein concentrate was evaluated to determine the effects of its lower antinutritional factor content on amino acid digestibility. A low-protein (5% casein) diet served as a seventh treatment group to determine the endogenous amino acid secretions within each study period. We assumed that the casein was completely digestible thus reducing the animals' need to catabolize body protein reserves during the period of inadequate protein intake (Low, 1980). The amino acids in the digesta from this low-protein casein diet were considered to be of endogenous origin.

Fourteen crossbred barrows ([Yorkshire × Landrace] × Duroc) averaging 28 kg BW and 60 d of age were surgically fitted with a simple T-cannula at the distal ileum after a 24-h fast. Four additional animals were cannulated to replace animals if complications required their removal from the experiment. These pigs were fed the same quantity of a control corn SBM diet and were similarly managed in the digestion crates as experimental animals. During an approximate 10-d recovery period, all pigs were fed a corn-SBM grower diet formulated to 1.00% lysine (total).

The experiment was conducted in a 7 × 7 factorial arrangement of treatments in a Latin-square design. Pigs within each of two replicates were allotted to treatment diet sequences before the experiment began, such that each animal received the seven treatment diets in a different order and at different times. Each study period consisted of a 5-d adjustment to the treatment diet followed by a 2-d collection. The quantity of feed provided daily during the initial collection period was calculated to the average animals' metabolic body weight (0.09 $BW^{0.75}$) within each replicate. The amount of treatment diet fed during each subsequent period was increased by approximately 175 g/d or to a level where all pigs consumed the same quantity of diet during that collection period. Diets were provided in meal form twice daily in equal amounts at 12-h intervals (i.e., 0700 and 1900) with an approximate water to diet ratio of 1.5:1. Fresh water was provided to appetite during the 24-h period. During wk 5 of the second replicate, the animals experienced a slight diarrhea, whereupon they were removed from their treatment diets, fed a 1.00% lysine corn-SBM diet, and injected with an antibiotic. They were returned to the experiment within a 7-d period and resumed their diet sequence.

With the exception of the low-protein casein diet, all diets were formulated to 17% crude protein (Table 1). Chromium oxide was added to the diets at 0.50% as an indigestible marker. All diets met or exceeded vitamin and mineral nutrient requirements for growing pigs (NRC, 1998).

Pigs were housed in individual 0.6- × 1.2-m stainless steel adjustable metabolism crates (Rohn Agri Products, Peoria, IL). Room temperatures were maintained at 26 ± 2°C with fluorescent lighting provided from 0700 to 1930. The surgical site around the cannula was cleaned daily with an antibacterial soap (Palmolive Antibacterial; Colgate-Palmolive, NY, NY) followed by applying a thin layer of zinc oxide cream (Desitin, Pfizer, NY, NY).

Digesta was collected for two 12-h (0700 to 1900) periods on d 6 and 7 after the 5-d adjustment period. Plastic collapsible tubes (50-mm inside diameter) were attached to the cannula with digesta collected at 20- to 30-min intervals for the 12-h period. Care was taken to ensure that digesta flow into the tube was unobstructed during collection. Samples collected were placed in a freezer (–20°C), pooled by pig for the 2-d period, mixed, freeze-dried, and analyzed for their amino acid and Cr contents.

Analyses. Particle size distributions of the SBM samples were determined by the method outlined by the American Society of Agricultural Engineers (ASAE, 1995) using a Ro-tap style shaker (W. S. Tyler, Mentor, OH). Nine sieves used for particle size determination ranged from 2,000 to 105 μm. The geometric

Table 1. Composition of experimental diets (%, as fed basis)

	Treatment number			
	1[a]	2 to 5[b]	6	7
Ingredient	SBM[c]	SBM	SPC[d]	Low protein
Cornstarch	38.10	29.55	46.00	61.80
Dextrose	—	10.00	—	—
Sucrose	20.00	20.00	20.00	20.00
Soybean meal (common source), 48% CP	35.25	—	—	—
Soybean meal (treatment), 48% CP	—	33.80	—	—
Soy protein concentrate	—	—	27.00	—
Cellulose[e]	—	—	—	5.00
Casein, food grade	—	—	—	5.00
Corn oil	2.00	2.00	2.00	2.00
Salt	0.35	0.35	0.35	0.35
Dicalcium phosphate	3.00	3.00	3.00	3.00
Limestone	0.45	0.45	0.45	0.45
Trace mineral mix[f]	0.05	0.05	0.05	0.05
Chromium oxide	0.50	0.50	0.50	0.50
Potassium carbonate (55% K)	—	—	0.35	1.40
Magnesium oxide (58% mg)	—	—	—	0.15
Vitamin mix[g]	0.30	0.30	0.30	0.30
Analysis, calculated %				
Crude protein	17.00	17.00	17.00	4.10
Lysine	1.05	1.00	1.10	0.37
Lysine, analyzed %[h]	2.97	3.04	4.08	—

[a]Common source of soybean meal.
[b]Soybean meal particle sizes averaged 949, 600, 329, and 185 μm, respectively.
[c]SBM = soybean meal.
[d]SPC = soy protein concentrate.
[e]Solka floc (International Fiber Corp., New York, NY).
[f]Provided per kilogram diet: 90 mg Fe (ferrous 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).
[g]Provided per kilogram diet: 2,000 IU vitamin A; 300 IU vitamin D; 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 0.60 mg choline.
[h]Analyzed content of the soy protein source.

mean diameter of the samples was calculated according to ASAE (1995).

Soybean meal samples of each treatment group and the soy protein concentrate were analyzed for their CP content using a Perkin-Elmer 2410 Series II N analyzer (Perkin-Elmer, Norwalk, CT). Digesta samples were freeze-dried and analyzed for their N, amino acid, and Cr contents. Amino acids of the digesta and the soybean protein sources were determined using a Beckman 6300 (Beckman Coulter, Inc., Fullerton, CA) amino acid analyzer by the method outlined by AOAC (1995). The analytical amino acid values for the soybean protein sources were used to calculate the dietary contribution for digestibility determination. Chromium was determined by atomic absorption after wet ashing in HCl acid. Gross energy was analyzed on the freeze-dried treatment diets and digesta using a Parr (Moline, IL) model 1241 adiabatic oxygen bomb calorimeter.

Apparent digestibility (**AD**) values were calculated using the Cr concentration in the feed and digesta by the equation: $AD = 100 - [(N_D/N_F) \times (Cr_F/Cr_D) \times 100]$. In this equation, N_D is the nutrient concentration present in the ileal digesta, N_F is the nutrient concentration in the feed, Cr_F is the Cr concentration in the feed, and Cr_D is the Cr concentration in the ileal digesta. Endogenous amino acid losses (**EAL**) were calculated according to the equation reported by Moughan et al. (1992): $EAL = [N_D \times (Cr_F/Cr_D)]$. True digestibility (TD) values were calculated using the equation: $TD = AD + (EAL/N_F) \times 100$.

The data were statistically analyzed using the General Linear Model procedure of SAS (SAS Inst. Inc., Cary, NC). A Latin Square design was followed according to the method of Steel and Torrie (1980) using the individual pig as the experimental unit. The low-protein treatment diet was not used in statistical evaluation because its value would skew the variation and was used only for adjusting for TD within that study period. The statistical model included replicate, period, treatment, and pig nested within replicate. Linear regression analysis evaluated the effect of particle size of the four ground soybean meals. The common source soybean meal and the soy protein concentrate treatment groups were each contrasted to the 900-μm soybean meal treatment group.

Table 2. Particle size distribution of soy protein ingredients

	Common SBM		Treatment SBM[a] 900		600		300		150		SPC[b]	
Sieve size (μm)	Actual, %	Cum,[c] %	Actual, %	Cum, %	Actual, %	Cum, %	Actual, %	Cum, %	Actual, %	Cum, %	Actual %	Cum, %
2,000	2.4	2.4	4.8	4.8	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0
1,410	14.3	16.7	21.6	26.4	4.6	5.0	0.2	0.2	0.0	0.0	0.0	0.0
1,180	13.4	30.1	15.7	42.1	7.1	12.0	0.7	0.9	0.0	0.0	0.0	0.0
991	11.4	41.5	11.9	54.0	8.3	20.4	1.7	2.6	0.0	0.1	0.0	0.0
710	24.0	65.5	22.8	76.8	27.0	47.3	12.1	14.7	1.5	1.6	13.3	13.3
590	6.0	71.5	5.2	82.0	8.6	55.9	7.1	21.8	1.9	3.5	15.3	28.6
500	7.1	78.6	5.4	87.4	10.8	66.7	11.7	33.4	5.7	9.2	18.8	47.4
350	7.1	85.7	5.4	92.7	13.4	80.1	21.2	54.6	19.6	28.8	22.4	69.8
105	11.8	97.5	5.6	98.3	16.2	96.3	32.4	87.0	49.8	78.6	20.5	90.3
Residue	2.5	100.0	1.7	100.0	3.7	100.0	13.0	100.0	21.4	100.0	9.7	100.0
Average, μm		800.5		948.8		600.1		328.8		184.5		383.4
SD		2.44		2.11		2.45		2.63		2.25		2.45

[a]SBM = soybean meal.
[b]SPC = soy protein concentrate.
[c]Cum = cumulative.

Results

The analyzed lysine contents of the various soy protein sources and the subsequent calculated dietary lysine levels are presented in Table 1. Soy protein concentrate had a higher lysine content than the two soybean meal samples, consistent with NRC (1998) published values.

Individual and cumulative percentages of particle size weights in each sieve of the various soy protein source samples are presented in Table 2. Figure 1 presents the relative distribution of particles when the unground SBM sample (949 μm) was compared with the SBM processed to an average 600 μm. The greatest change in particle size seemed to be due to a reduction in the larger sized particles.

As average particle size decreased, the AD of isoleucine, methionine, phenylalanine, and valine increased ($P < 0.05$, Table 3). There was a trend for leucine to have a higher apparent digestibility coefficient as particle size decreased, but the response was not significant ($P < 0.10$).

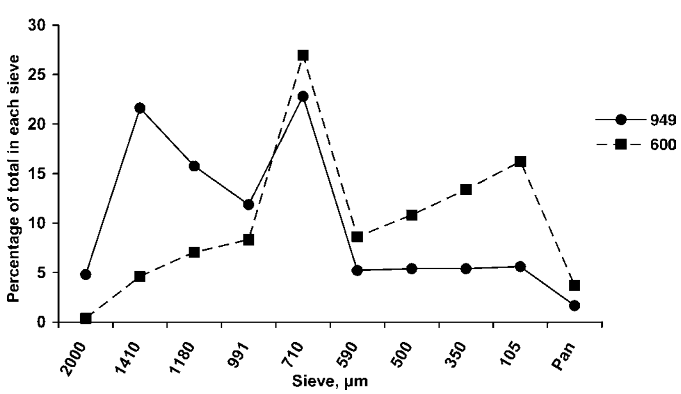

Figure 1. Particle size distribution in soybean meal treatment sizes.

Apparent digestibility coefficients of the essential amino acids had an average increase ($P < 0.10$) of 1.4% (i.e., 83.5 to 84.9%) as particle size decreased to 185 μm, whereas the nonessential amino acids increased only slightly (80.1 to 80.5%; $P > 0.15$).

Soy protein concentrate had a higher ($P < 0.05$) AD coefficient of several essential amino acids (i.e., isoleucine, leucine, lysine, phenylalanine, threonine, and tyrosine) and the entire group of essential amino acids ($P < 0.10$) than did either SBM source. Soy protein concentrate would be expected to have a higher amino acid digestibility due to its lower antinutritional content and lower oligosaccharide fraction, but it also had a particle size smaller than commercial SBM. Whether the improved digestibility coefficient response was due to the smaller particle size or the reduction in the level of antinutritional factors cannot be determined from our results.

The digestible energy content of SBM decreased numerically by 1.0% as particle size decreased, but the difference was not statistically significant ($P > 0.15$; Table 3). Both the unground SBM source used for the particle size study and soy protein concentrate, however, had higher digestible energy contents than the common source SBM, implying that differences may exist in the carbohydrate contents of the two SBM sources. Carbohydrates, such as stachyose and raffinose, present in the soluble fraction of SBM, have been shown to resist digestion in the small intestine but seem to be better utilized by microorganisms in the large intestine (Clarke and Wiseman, 1998).

Endogenous amino acid losses (milligrams per kilogram feed) determined from the low-protein 5% casein diet fed during each collection period are presented in Table 4. There was no significant difference in any of

Table 3. Apparent ileal amino acid and energy digestibility of soybean protein sources fed to grower-finisher pigs[a]

	Source						
	SBM[b]	Treatment SBM[c]				SPC[d]	
Particle size, μm:	800	900	600	300	150	383	
Amino acid / Trt. no.:	1[e]	2	3	4	5	6	SEM
EAA[f]							
Arg	86.7	85.3	86.1	86.1	86.6	88.3	1.79
His	86.6	86.0	86.7	86.9	87.2	88.2	0.65
Iso	83.6	82.5	83.9	84.0	84.6	86.5	0.69[vw]
Leu	83.8	82.8	83.3	84.2	84.0	86.6	0.67[vz]
Lys	85.3	84.6	85.4	85.6	85.9	88.2	0.84[v]
Met	87.1	85.9	87.5	88.0	87.8	88.3	0.73[w]
Phe	85.6	84.7	85.3	86.0	86.1	88.6	0.62[vw]
Trp	86.2	88.1	88.2	89.0	88.7	88.3	0.98
Thr	75.9	74.9	75.5	76.8	75.5	79.6	1.08[v]
Val	82.1	80.4	81.8	81.9	82.6	84.4	0.86[w]
Avg.	84.3	83.5	84.4	84.9	84.9	86.7	0.89[yz]
NEAA[g]							
Ala	81.1	78.2	79.5	80.4	79.8	82.4	0.97[x]
Asp	82.4	81.2	81.5	82.4	82.7	82.2	0.86[z]
Cys	78.0	76.4	76.4	77.7	77.3	79.6	1.40
Glu	86.6	85.7	83.8	83.3	84.2	86.4	1.17
Gly	75.8	72.7	72.6	72.2	72.6	74.1	1.60
Pro	83.7	81.0	81.3	80.9	80.2	83.7	1.13[x]
Ser	83.8	80.3	80.8	82.6	80.5	85.7	0.92[x]
Tyr	86.1	85.5	85.8	86.8	86.3	89.1	0.73[v]
Avg.	82.4	80.1	80.2	80.8	80.5	82.9	1.10
Energy	81.9	84.2	84.2	83.2	83.2	85.9	0.56[vx]

[a]14 observations per mean.
[b]SBM = soybean meal.
[c]Soybean meal particle sizes averaged 949, 600, 329, and 185 μm, respectively.
[d]SPC = soy protein concentrate.
[e]Common source of soybean meal.
[f]EAA = dietary essential amino acids.
[g]NEAA = dietary nonessential amino acids.
[v]Treatment 1 vs 6 ($P < 0.05$).
[w]Treatments 2 to 5 linear effect of particle size ($P < 0.05$).
[x]Treatment 1 vs 2 ($P < 0.05$).
[y]Treatment 1 vs 6 ($P < 0.10$).
[z]Treatments 2 to 5 linear effect of particle size ($P < 0.10$).

the specific amino acids, nor was there a difference in the total essential or nonessential amino acid content of the digesta between each period or between replicates ($P > 0.15$).

After adjusting AD for endogenous losses, the true digestibility coefficients of isoleucine, methionine, phenylalanine, and valine, increased linearly ($P < 0.05$) as soybean meal particle size decreased (Table 5). The TD of the other essential amino acids also showed a numerical increase in digestibility as particle size decreased, but the differences with these latter amino acids were not significant ($P > 0.10$).

The average essential amino acids from the TD calculations again resulted in a greater increase in their digestion coefficients than the nonessential amino acids, a response similar to that when the AD coefficients were determined. Average essential amino acid digestibility (Table 5) increased ($P < 0.10$) from 91.0% to 92.3% as particle size decreased, whereas the nonessential amino acids showed a smaller numerical increase (90.5 to 91.0; $P > 0.10$).

The common source SBM had higher ($P < 0.05$) TD coefficients of methionine, valine, and alanine than the unground soybean meal used for the particle size study. This was largely attributed to its smaller particle size (800 μm) compared with the larger (949 μm) particle size of the unground treatment SBM.

Discussion

The reduction in particle size resulted in somewhat different responses on specific amino acids, but there was a general improvement in ileal digestibility coefficients of many essential amino acids, whether expressed either on an AD or TD basis. The largest increase in amino acid digestibility seemed to occur, however, when the particle size was reduced from 949 to 600 μm. Figure 1 and the distribution of the particle

Table 4. Effect of experimental period on endogenous amino acid losses in growing pigs fed the casein diet[ab]

Amino acid	Period (wk)							SEM
	1	2	3	4	5	6	7	
EAA[c]								
Arg	298	256	259	219	236	220	285	31
His	166	139	158	150	141	136	142	11
Iso	497	374	460	403	460	346	394	54
Leu	574	438	460	461	448	420	504	52
Lys	387	320	359	334	354	294	372	32
Met	110	85	86	92	106	73	99	13
Phe	287	214	216	230	200	210	252	16
Trp	99	107	115	92	83	73	88	30
Thr	607	491	518	472	448	504	537	71
Val	497	406	460	438	460	399	427	14
Avg.	320	257	281	263	267	243	282	
NEAA[d]								
Ala	486	384	417	392	401	336	405	52
Asp	729	566	633	599	613	556	646	34
Cys	177	139	158	138	130	136	142	45
Glu	1,248	982	1,323	1,141	1,344	997	1,128	58
Gly	596	641	690	622	648	525	526	146
Pro	563	1036	863	403	519	504	876	63
Ser	696	534	676	542	648	504	580	240
Tyr	387	246	288	230	236	210	372	76
Avg.	542	503	561	452	504	419	519	

[a]Two observations per mean.
[b]Each amino acid is expressed on a mg/kg dry feed basis.
[c]EAA = dietary essential amino acid.
[d]NEAA = dietary nonessential amino acid.

sizes on different sieves in Table 2 largely indicate that the reduction in the larger particles in SBM may explain the increase in digestibility coefficients. The difference between essential or nonessential amino acid digestibilities may be due to a greater number of amino acid transporters specific for the absorption of the essential amino acids in the small intestine (Mailliard et al., 1995).

Wondra et al., (1995a,b,c,d) demonstrated that reducing the particle size of corn from 1200 to 400 μm in finishing and lactation diets also improved the digestibility of dry matter, N, and energy. Owsley et al. (1981) reported that reducing the particle size of sorghum in grower-finisher diets resulted in a 7.6% increase in apparent amino acid digestibility. Although commercial SBM is not normally processed further once received from the processor, our study suggests that an improvement in amino acid digestibility may occur if the particle size of SBM component of a diet is less than 600 μm. An increased digestibility could result in a decrease in amino acids excreted in the feces.

The apparent and true amino acid digestibility values achieved by reducing particle size of the SBM used in this study are similar to those reported by the NRC (1998) and Grala et al. (1998), although the particle size in these reports were not reported. Our values are, however, somewhat higher than those reported by Sohn et al. (1994) and Caine et al. (1997) possibly due to the difference in SBM level in their diets, differences in production phase evaluated, and the possibility that the particle size of their SBM source was higher. Both Sohn et al. (1994) and Caine et al. (1997) evaluated dietary levels >40%, whereas our study incorporated a level of 35%. They also conducted their studies with weanling pigs and provided higher dietary amino acid levels.

The common source SBM generally had higher numerical apparent and TD coefficients for most of the essential amino acids compared to the other source of SBM that we used, but the differences were not significant ($P > 0.15$). The slightly smaller average particle size (i.e., 800 μm) of the common source SBM than the unground (949 μm) SBM used in our particle size study suggests that the larger particle sizes in both samples had the same digestibility.

The soy protein concentrate that we evaluated, however, had a lower digestibility of amino acids than reported by NRC (1998), but it generally had similar true amino acid digestibility coefficients compared to the two soybean protein sources evaluated, except for glycine, which had a higher digestibility ($P < 0.05$). The NRC (1998) reports that soy protein concentrate digestibility coefficients of most essential amino acids are approximately 5.6% higher than SBM.

Endogenous amino acid excretion was not affected by replicate or period. Our values, expressed as milligrams per kilogram dry feed intake, are similar to

Table 5. True digestibility of amino acids adjusted by a low-protein casein diet in grower-finisher pigs fed soybean meals of various particle sizes[a]

	Source						
	SBM[b]	Treatment SBM[c]				SPC[d]	
Particle size, μm:	800	900	600	300	150	383	
Amino acid Trt. no.:	1[e]	2	3	4	5	6	SEM
EAA[f]							
Arg	93.3	92.0	92.7	93.0	93.4	93.5	1.00
His	92.4	91.6	92.3	92.5	92.7	92.4	0.63
Iso	93.5	92.0	93.3	93.8	93.9	93.7	0.59[w]
Leu	90.4	89.1	89.7	90.6	90.3	91.5	0.67[x]
Lys	91.2	90.4	91.1	91.3	91.5	92.5	0.80
Met	94.3	92.9	94.3	94.8	94.7	93.4	0.58[wy]
Phe	90.4	89.4	90.0	90.6	90.7	92.2	0.66[w]
Trp	93.9	94.0	94.7	95.1	94.8	93.9	0.98
Thr	90.2	88.6	89.4	90.4	89.2	89.7	1.28
Val	91.9	90.0	91.2	91.6	91.8	91.5	0.73[wy]
Avg.	92.2	91.0	91.9	92.4	92.3	92.4	0.79[x]
NEAA[g]							
Ala	90.3	87.8	89.1	89.9	89.3	89.6	0.97[y]
Asp	87.9	87.0	87.3	88.2	88.4	86.6	0.81[x]
Cys	87.6	85.8	85.7	87.0	86.6	86.4	1.45
Glu	93.0	92.4	90.4	89.9	90.7	91.4	1.05
Gly	90.2	87.6	87.6	87.3	87.4	85.5	1.48[z]
Pro	96.7	95.4	95.8	95.5	94.5	94.1	2.54
Ser	96.0	94.3	95.0	96.1	94.9	95.2	0.84
Tyr	94.5	93.6	93.9	95.0	94.4	95.5	1.11
Avg.	92.2	90.5	90.9	91.4	91.0	90.4	0.86

[a]14 observations per mean.
[b]SBM= soybean meal.
[c]Soybean meal particle sizes averaged 949, 600, 329, and 185 μm, respectively.
[d]SPC = soy protein concentrate.
[e]Common source of soybean meal.
[f]EAA = dietary essential amino acids.
[g]NEAA = dietary nonessential amino acids.
[w]Treatments 2 to 5 linear effect of particle size ($P < 0.05$).
[x]Treatments 2 to 5 linear effect of particle size ($P < 0.10$).
[y]Treatment 1 vs 2 ($P < 0.05$).
[z]Treatment 1 vs 6 ($P < 0.05$).

those reported by Traylor et al. (2001) and Hodgkinson et al. (2000) but higher than Hess and Seve (1999). The latter workers used a protein-free diet that resulted in lower EAL. The low-protein casein diet that we used would, however, be expected to have higher EAL than if a protein-free diet had been fed. Hodgkinson et al. (2000) demonstrated that proteins and peptides present in low-protein diets stimulates the secretion of endogenous amino acids in a dose dependent manner that would increase the amount of endogenous secretions. This would seem to better simulate the endogenous secretion when a diet containing protein is fed.

Implications

Particle size reduction increased the digestibility of some amino acids in the grower pig, particularly the essential amino acids isoleucine, leucine, methionine, phenylalanine, and valine. Overall, average essential amino acid digestibility increased by 1.4% for apparent and increased by 1.3% for true digestibility as particle size decreased to 185 μm. The largest increase in digestibility was evident when the particle size was reduced to 600 μm.

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