Influence of Processing Method on Ileal Digestibility of Nutrients from Soybeans in Growing and Finishing Pigs

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ABSTRACT : Eight crossbred barrows (four growing and four finishing pigs with average initial BW of 40 and 82 kg, respectively) were fitted with T-cannulas at the distal ileum and used in a 36 d metabolism experiment (4×4 Latin squares) to determine the effects of roasting and extruding full-fat soybeans on nutrient utilization. Treatments were: 1) soybean meal; 2) roasted soybeans; 3) extruded soybeans; and 4) soybeans extruded with an extrusion enhancer (sodium sulfite). The control diet was corn starch-based with 0.90% lysine, 0.65% Ca and 0.55% P for the growing pigs and 0.75% lysine, 0.55% Ca and 0.45% P for the finishing pigs. For the growing pigs, apparent total tract digestibilities of DM ($p<0.04$) and GE ($p<0.008$) were greater for soybean meal than full-fat soy products. However, ileal digestibilities of DM, GE, N and most amino acids were, in general, greatest for extruded soybeans and lowest for roasted soybeans, with soybean meal intermediate. For finishing pigs, trends in digestibilities of nutrients were very similar to those for the growing pigs. Total tract digestibilities of DM ($p<0.03$) and GE ($p<0.001$) for soybean meal were greater than for the full-fat soy products and ileal digestibilities of DM, GE, N and most amino acids were greater for the extruded soybeans than for the roasted soybeans. In conclusion, nutrient digestibilities and availabilities of indispensable amino acids tended to be greatest in extruded soybeans, intermediate in soybean meal and lowest in roasted soybeans for growing and finishing pigs. (*Asian-Aus. J. Anim. Sci. 2000. Vol. 13, No. 2 : 192-199*)

Key Words : Pigs, Soybeans, Extrude, Roast, Sodium Sulfite, Ileum

INTRODUCTION

Ileal digestibility assays in pigs (Rudolph et al., 1983; Sauer and Ozimek, 1986; Knabe et al., 1989; Herkelman et al., 1992) are accepted procedures to determine digestibility of amino acids in feed ingredients. Just et al. (1985) and Moughan and Smith (1985) reported that digestible amino acids determined from ileal digesta had a higher correlations to carcass protein than digestible protein and amino acids determined from feces.

Raw or underheated soybean products have trypsin inhibitors and other antinutritional factors (Collins and Beaty, 1981; Rackis, 1981) that reduce N, GE and amino acid digestibilities (Rudolph et al., 1983; Vandergrift et al., 1983; Hansen et al., 1987). Fortunately, most of the antinutritional factors found in soybeans (at least those in biologically significant concentrations) are heat labile. As with roasted soybeans, care must be taken to prevent palatability problems and protein-carbohydrate complexing (i.e., maillard reaction) that occurs during overheating (Hancock et al., 1990a, b). Although some swine feeding experiments have suggested a decrease in pig growth performance compared to feeding soybean meal (Carlisle et al., 1973; Li et al., 1989), most researchers reported that pigs fed extruded soybeans had either equal or improved growth rate compared to pigs fed soybean meal (Faber and Zimmerman, 1973; Myer and Froseth, 1983; Kim et al., 1995, 1999a, b).

Sodium sulfite has been suggested as an extrusion aid. Sodium sulfite is believed to increase cross-linking of disulfide bonds in the linearized protein matrix formed during the extrusion process. Sodium sulfite is suggested to aid in the breaking of disulfide bonds that hold proteins in their biologically active configurations. If the sodium sulfite aids to disrupt those disulfide bonds, it should ensure very low activities for trypsin inhibitors and other antinutritional factors that limit the utilization of soybean proteins.

Thus, the objectives of these experiments were to determine if the greater nutritional value of extruded soybeans can be partially explained by greater nutrient availabilities (e.g., greater ileal digestibilities of amino acids). Also, we wished to evaluate differences of nutrient availability in pigs of different ages (i.e., growing vs. finishing). Finally, the experiment was to evaluate sodium sulfite as an extrusion aid for processing dry extruded whole soybeans.

MATERIALS AND METHODS

The soybean meal and full-fat soybeans used in these experiments were mill-run. For the roasting and extrusion treatments, processing conditions were a throughput of 454 kg/h and an average exit temperature of 127℃ in a Roast-A-Tron™ roaster vs. a throughput of 680 kg/h and an average barrel

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

	Growing pigs[a]		Finishing pigs[b]	
	Soybean meal	Soybeans	Soybean meal	Soybeans
Ingredient				
Corn starch	62.84	53.53	68.22	61.02
Soybean meal	29.08	-	24.11	-
Soybean	-	40.43	-	33.33
Soybean oil	1.00	-	1.00	-
Cellulose fiber	4.00	3.00	4.00	3.00
Dicalcium phosphate	1.97	1.64	1.54	1.28
Limestone	0.21	0.50	0.23	0.47
Salt	0.25	0.25	0.25	0.25
Vitamin/trace mineral premix[c]	0.40	0.40	0.40	0.40
Chromic oxide[d]	0.25	0.25	0.25	0.25
Total	100.00	100.00	100.00	100.00
Calculated analysis				
CP, %	13.81	14.55	11.45	12.00
Ether extract, %	0.3	7.6	1.2	6.3
DE, kcal/kg	3,572	3,675	3,723	3,812
ME, kcal/kg	3,484	3,508	3,646	3,674

[a] Grower diets were formulated to 0.90% lysine, 0.65% Ca and 0.55% P, and to meet or exceed concentrations for all other nutrients as suggested by NRC (1988).

[b] Finisher diets were formulated to 0.75% lysine, 0.55% Ca and 0.45% P, and to meet or exceed concentrations for all other nutrients as suggested by NRC (1988).

[c] Provided the following per kilogram of the complete diet: 11,025 IU of vitamin A; 1,103 IU of vitamin D_3; 44 IU of vitamin E; 4.4 mg of vitamin K (menadione bisulfate complex); 8.3 mg of riboflavin; 50 mg of niacin ; 29 mg of d-pantothenic; 166 mg of choline; 33 μg of vitamin B_{12}; 12 mg of Mn; 165 mg of Fe; 165 mg of Zn; 16 mg of Cu; 0.3 mg of I; and 0.3 mg of Se.

[d] Used as an indigestible marker.

temperature of 143℃ in an Insta-Pro™ dry-extruder. Treatments were: 1) soybean meal; 2) roasted soybeans; 3) extruded soybeans; and 4) soybeans extruded with an extrusion enhancer (sodium sulfite). The soybean meal and full-fat soybeans preparations were incorporated into corn starch-based diets formulated to 0.90% lysine, 0.65% Ca and 0.55% P for the growing pigs and 0.75% lysine, 0.55% Ca and 0.45% P for the finishing pigs (table 1). The diets were formulated to meet or exceed the nutrient concentrations recommended by NRC (1988) for 20 to 50 kg and 50 to 100 kg pigs. Chromic oxide (0.25%) was added to the diets as an indigestible marker.

Eight crossbred barrows (four growing and four finishing pigs with average initial BW of 40 and 82 kg, respectively) were surgically fitted with T-cannulas approximately 15 cm anterior to the ileo-cecal junction. The pigs were fasted for 16 to 20 h prior to surgery. Anesthesia was induced using 5% thiamyl sodium (Boehringer Ingelhelm Animal Health, St. Joseph, MO) and maintained with methoxyflurane (Pittman-Moore, Terr Haute, IN) and oxygen. After surgery, the pigs were individually housed in steel metabolism crate (1.5 m×0.5 m) in a temperature-controlled (22℃) room. The pigs were allowed 14 d to recuperate before initiation of the experiments. During the recovery period, the growing and finishing pigs were fed a standard 16% CP and 14% CP, respectively, corn-soybean meal-based diets with 110 mg of chlortetracycline, 110 mg of sulfathiazole and 55 mg of penicillin per kilogram of the complete diet.

The experimental designs were 4×4 Latin squares with pigs and periods as blocking criteria. Each period was 4 d of adjustment to the experimental diets, 3 d of total feces and urine collection and 2 d (12 h/d) of ileal digesta collection. The daily feed allowance was $0.05 \times BW^{0.9}$, as proposed by Armstrong and Mitchell (1955). The daily feed allotment was offered as two meals at 12 h intervals (7:00 a.m. and 7:00 p.m.). The feed was offered as a wetted mash and water was available for *ad libitum* consumption between feedings. Feces and urine were collected twice daily and frozen during the 3 d of collection. Total urine volumes were recorded and 5% was saved and frozen each day for later analyses. The urine was acidified during collection by 100 mL of 10% HCl in the collection vessel. At the end of the experiment, all feces were lyophilized and ground prior to analyses. Ileal digesta were collected during the 12 h period between the morning and evening feeding for the last 2 d of each collection period. Ileal digesta were collected into plastic bags attached to the cannulas. Every 20 min

the digesta were emptied into plastic containers and placed on ice. The collected digesta were pooled and frozen until being lyophilized and ground.

Feed, feces and ileal digesta were analyzed for DM, N and GE concentrations (AOAC, 1990). The urine was analyzed for N, and then mixed with cellulose (Solka-flock) for GE determinations. Chromium was determined by atomic absorption spectrophotometry (Model No. 1475, Varian Techtron, Springvale, Australia) as described by Williams et al. (1962) and apparent digestibilities of DM, N and GE were calculated using the indirect ratio method. Amino acid analyses were determined by ion exchange chromatography (Beckman model 126, Beckman Instruments, Palo Alto, CA) analyzer. For amino acid analysis, approximately 0.15 g of sample was weighed into screw-capped test tubes (20 mm × 125 mm) and mixed with 15 mL of 6 N HCl. The tubes were flushed with nitrogen and then heated in an oven at 110℃ for 24 h. The hydrolyzed samples were mixed with an internal standard (norleucine) and centrifuged at 29,000 × g for 20 min at room temperature.

The data were analyzed as Latin square designs using the GLM procedure of SAS (1988). The statistical model included the effects of experimental period, pig and treatment (soybean source). Treatment means were separated with the orthogonal comparisons: 1) soybean meal vs. other treatments; 2) roasted soybeans vs. extruded soybeans; and 3) extruded soybeans vs. soybeans extruded with sodium sulfite.

RESULTS AND DISCUSSION

1. Chemical composition

Chemical analyses were similar to those anticipated for soybean meal and full-fat soy products and as expected, with their greater fat content, the full-fat soy products had greater GE (table 2). Crude protein and, thus, amino acid concentrations were greater for soybean meal than the full-fat soy products. Trypsin inhibitor concentration of the soybean meal was slightly greater than that of the extruded soybeans (3.66 vs. 2.47 mg/g), however, Vandergrift et al. (1983) reported that amino acid digestibilities were similar to five sources of defatted soybean flakes heated from 25 to 105 min at 107℃ and having trypsin inhibitor activities that ranged from 1.4 to 6.2 mg/g.

2. Ileal digestibility assay in growing pigs

Digestibilities of DM ($p<0.04$) and GE ($p<0.008$) for the total tract were greater for soybean meal than the full-fat soy products, primarily because of the relatively low digestibilities for roasted soybeans (table 3). However, N digestibility differences among small intestine and total tract averaged 13.3% for soybean meal, 22.0% for roasted soybeans, 12.2% for extruded soybeans and 9.2% for soybeans extruded with sodium sulfite. In general, digestibilities of DM, N and GE were consistently higher measured over the total tract than at the end of the small intestine, indicating a loss of these nutrients in the large intestine. Higher digestibilities over the total tract than digestibilities at the terminal ileum have been reported for N and most amino acids for other protein sources (Tanksley et al., 1981; Sauer et al., 1982; Haydon et al., 1984). Nutrients disappearing in the large intestine would be used largely for microbial activity and are of little benefit to the host animal (Sauer and Ozimek, 1986). Digestibilities of DM ($p<0.08$), GE ($p<0.01$) and N ($p<0.001$) at the terminal ileum were greater for pigs fed extruded soybeans than for pigs fed roasted soybeans.

Table 2. Chemical composition of soybean meal, roasted soybeans, extruded soybeans, and soybeans extruded with sodium sulfite[a]

	Soybean meal	Soybeans		
		Roasted	Extruded	Sodium sulfite
DM, %[a]	89.5	95.2	94.6	94.3
CP, %[a]	43.3	36.0	37.0	35.5
Ether extract, %[a]	1.0	19.8	19.0	18.0
Crude fiber, %[a]	4.8	5.5	4.2	2.9
Gross energy, kcal/kg[a]	4,154	4,943	4,952	4,848
Indispensable amino acids, %[a]				
Arginine	3.2	2.6	2.8	2.5
Histine	1.2	1.0	1.0	1.0
Isoleucine	2.0	1.7	1.8	1.7
Leucine	3.5	2.8	3.0	2.8
Lysine	2.8	2.2	2.5	2.3
Methionine	0.6	0.5	0.6	0.5
Phenylalanine	2.3	1.9	2.0	1.8
Threonine	1.8	1.5	1.6	1.4
Tryptophan	0.6	0.5	0.5	0.5
Valine	2.2	1.8	1.9	1.8
Dispensable amino acids, %[a]				
Alanine	2.0	1.6	1.7	1.6
Aspartate	5.1	4.2	4.5	4.1
Cystine	0.7	0.6	0.6	0.6
Glutamate	7.8	6.4	6.9	6.4
Glycine	1.9	1.6	1.7	1.6
Proline	2.3	1.9	2.0	1.8
Serine	2.1	1.7	1.9	1.7
Tyrosine	1.6	1.4	1.4	1.3
Trypsin inhibitor, mg/g[b]	3.66	4.09	2.51	2.42

[a] AOAC (1990).
[b] With the method of Hammerstrand et al. (1981).

Table 3. Apparent nutrient digestibilities in growing pigs, %[a]

	Soybean meal	Soybeans			SE	Contrasts[b]		
		Roasted	Extruded	Sodium sulfite		1	2	3
DM digestibility								
Small intestine	75.7	71.5	75.6	80.1	2.7	NS[c]	0.08	NS
Total tract	92.7	88.9	91.3	92.7	0.6	0.04	0.002	NS
Difference	17.0	17.4	15.7	12.7	2.6	NS	NS	NS
GE digestibility								
Small intestine	76.5	70.1	78.1	81.2	2.7	NS	0.01	NS
Total tract	93.4	86.5	90.8	92.5	1.0	0.008	0.001	NS
Difference	16.9	16.3	12.7	11.3	2.6	NS	NS	NS
N digestibility								
Small intestine	76.3	62.2	77.6	81.5	1.9	NS	0.001	NS
Total tract	89.6	84.2	89.8	90.7	0.9	NS	0.001	NS
Difference	13.3	22.0	12.2	9.2	1.7	NS	0.001	NS

[a] Four barrows with an average initial BW of 40 kg.
[b] Probability for contrast: 1) soybean meal vs. others; 2) roasted vs. extruded and extruded with sodium sulfite; and 3) extruded vs. extruded with sodium sulfite.
[c] NS=not significant (p>0.10).

Table 4. Apparent nutrient utilization for growing pigs[a]

	Soybean meal	Soybeans			SE	Contrasts[b]		
		Roasted	Extruded	Sodium sulfite		1	2	3
Nutrient intake								
DM, g/d	1,455	1,459	1,427	1,480	41.1	NS[c]	NS	NS
N, g/d	32.2	38.4	40.3	36.7	0.9	0.001	NS	0.02
GE, kcal/d	6,004	6,717	6,613	6,853	175.2	0.004	NS	NS
N retention, %	71.1	69.8	75.7	79.5	2.9	NS	0.05	NS
N retention, g/d	23.1	26.8	30.5	29.2	1.4	0.003	0.09	NS
Biological value, %	79.4	82.8	84.3	87.6	3.1	NS	NS	NS
ME, %	73.8	77.5	76.3	77.6	3.2	NS	NS	NS
ME retention, kcal/d	4,410	5,222	5,049	5,356	192.5	0.004	NS	NS
ME of soy, kcal/kg	3,066	3,831	3,778	3,762	146.0	0.009	NS	NS

[a] Four barrows with an average initial BW of 40 kg.
[b] Probability for contrast: 1) soybean meal vs. others; 2) roasted vs. extruded and extruded with sodium sulfite; and 3) extruded vs. extruded with sodium sulfite.
[c] NS = not significant (p>0.10).

There were no differences in DM intake (p>0.38) among pigs fed the experimental diets (table 4). However, daily intake of N (p<0.001) and GE (p<0.004) were greater for pigs fed full-fat soy products than for pigs fed soybean meal. Nitrogen retention (p<0.003), expressed as gram/day differed in pigs fed full-fat soy products compared to pigs fed soybean meal. Also, pig fed the full-fat soy products had greater daily retention of ME (p<0.004). The full fat soy products had 724 kcal/kg more ME than soybean meal, which would be expected because of the fat content of the full-fat soy products.

Pigs fed extruded soybeans had greater daily N retention (p<0.09) than pigs fed roasted soybeans. This difference in N retention among extruded and roasted soybeans was caused by the greater (p<0.001) fecal N losses for roasted soybeans (i.e., lower N digestibility). Biological value was not different for extruded and roasted soybeans because of the greater urinary N losses for extruded soybeans. As for energy utilization, extruded soybeans were similar for percentage ME, ME retention and ME of the soys themselves.

However, our data suggested that extruded soybeans had the greatest feeding value compared to soybean meal and roasted soybeans. Our data agree with Rudolph et al. (1983) and Kim et al. (1999a), who indicated high gross energy digestibility, and greater metabolizable energy content of extruded soybean compared with soybean meal, thus, indicating good utilization of the oil in extruded soybeans. Hanke et al. (1972) and Seerley et al. (1974) reported that extruded soybeans had a feeding value equal to soybean meal in growing-finishing pigs.

Apparent digestibilities of amino acid at the terminal ileum followed the same patterns as N digestibility (table 5). Ileal digestibilities for nine indispensable amino acids measured at the terminal ileum averaged 80.3% for soybean meal, 62.6% for roasted soybeans, 81.7% for extruded soybeans and 84.8% for soybeans extruded with sodium sulfite. These differences suggested 30 to 35% improvements in digestibility of most essential amino acids when extrusion was selected as the thermal processing procedure. Ileal digestibilities of the dispensable amino acids followed the same pattern as indispensable amino acids. Previous research (Rudolph et al., 1983) indicated extruded soybeans had lower digestibilities of N and amino acids measured at the end of the small intestine than did soybean meal. Rodhouse et al. (1992) reported similar findings with ileal digestion of lysine that was not affected by extrusion soybean meal vs. soybean meal. However, our data indicated ileal digestibilities of N and amino acids were greater for extruded soybeans than soybean meal. Similarly, Marty and Chavez (1993) investigated the effects of extrusion, jet exploding, micronizing and roasting on nutrient digestibility of full-fat soybeans, and reported greater ileal digestibilities of amino acid. Extruded soybeans were the most digestible of the processed soybeans.

3. Ileal digestibility assay in finishing pigs

As for the assay with growing pigs, digestibilities of DM ($p<0.03$) and GE ($p<0.001$) for the total tract were greater for soybean meal than for the full-fat soy products, and these differences resulted primarily from the low digestibilities for roasted soybeans (table 6). Apparent digestibilities of DM, GE and N for the total tract were greater for the extruded soybeans than for the roasted soybeans ($p<0.001$). Also, ileal digestibilities for DM ($p<0.003$), GE ($p<0.001$) and N ($p<0.001$) were greater for the extruded soybeans than for the roasted soybeans.

Pigs fed the full-fat soy products had greater

Table 5. Apparent ileal amino acid digestibilities in growing pigs[a], %

	Soybean meal	Soybeans			SE	Contrast[b]		
		Roasted	Extruded	Sodium sulfite		1	2	3
Indispensable amino acids								
Arginine	87.6	72.7	88.7	90.3	1.6	0.06	0.001	NS[c]
Histidine	82.7	63.3	83.6	87.6	1.8	0.05	0.001	NS
Isoleucine	79.2	59.4	80.1	83.4	1.8	0.03	0.001	NS
Leucine	78.8	61.3	80.2	84.2	1.9	NS	0.001	NS
Lysine	82.6	67.1	86.2	88.5	1.7	NS	0.001	NS
Methionine	80.9	63.9	82.7	84.1	1.6	0.04	0.001	NS
Phenylalanine	80.9	62.2	83.4	86.1	1.8	NS	0.001	NS
Threonine	74.1	58.4	74.5	78.9	2.4	NS	0.001	NS
Valine	75.9	55.3	75.6	80.2	2.3	0.06	0.001	NS
Total indispensable amino acids	80.3	62.6	81.7	84.8	1.7	0.10	0.001	NS
Dispensable amino acids								
Alanine	75.0	57.5	76.8	80.9	2.1	NS	0.001	NS
Aspartate	79.6	60.2	82.4	84.8	2.3	NS	0.001	0.001
Glutamate	81.5	65.0	85.1	86.3	2.3	NS	0.001	NS
Glycine	70.8	54.5	75.9	79.9	2.9	NS	0.001	NS
Serine	78.2	61.0	79.9	83.5	2.1	NS	0.001	NS
Tyrosine	81.1	61.7	81.5	83.8	2.1	0.04	0.001	NS
Total dispensable amino acids	77.7	60.0	80.3	83.2	2.2	NS	0.001	NS

[a] Four barrows with an average initial BW of 40 kg.

[b] Probability for contrast: 1) soybean meal vs. others; 2) roasted vs. extruded and extruded with sodium sulfite; and 3) extruded vs. extruded with sodium sulfite.

[c] NS=not significant ($p>0.10$).

($p<0.02$) daily N retention (table 7). The full-fat soy products had 558 kcal/kg more ME than soybean meal ($p<0.001$), and pigs fed the extruded soybeans had greater daily N retention, biological value, percentage ME, ME retention and ME of the soybeans than pigs fed the roasted soybeans. The extruded soybeans had 351 kcal/kg more ME than roasted soybeans. Rodhouse et al. (1992) reported improved DE and ME utilization for pig fed extruded soybeans vs. soybean meal, but no effect on ileal or fecal digestibilities of CP or amino acids was observed. Other research (Noland et al., 1976; Skoch et al., 1983), however, indicated that extrusion improved energy digestibility from soybeans and grains.

Apparent amino acid digestibilities measured at the terminal small intestine are given in table 8. The digestibilities of the individual indispensable amino acids at the terminal ileum were greater ($p<0.001$) in extruded soybeans than in the roasted soybeans. For example, the availability of lysine was the greatest in soybeans extruded with sodium sulfite (88.9%) and lowest in roasted soybeans (71.2%) with soybean meal intermediate (83.3%). Overall, availabilities for nine indispensable amino acids measured at the terminal ileum averaged 83.4% for soybean meal, 72.2% for roasted soybeans, 84.1% for extruded soybeans and

Table 6. Apparent nutrient digestibilities in finishing pigs[a], %

	Soybean meal	Soybeans			SE	Contrast[b]		
		Roasted	Extruded	Sodium sulfite		1	2	3
DM digestibility								
Small intestine	85.4	80.4	84.6	85.7	1.0	NS[c]	0.003	NS
Total tract	92.6	87.9	92.7	93.0	0.5	0.03	0.001	NS
Difference	7.2	7.6	8.1	7.4	1.1	NS	NS	NS
GE digestibility								
Small intestine	86.2	78.4	85.6	86.6	1.1	0.06	0.001	NS
Total tract	93.2	84.9	92.7	93.0	0.5	0.001	0.001	NS
Difference	6.9	6.5	7.1	6.4	1.2	NS	0.001	NS
N digestibility								
Small intestine	80.7	69.2	83.9	85.6	2.6	NS	0.001	NS
Total tract	87.6	79.6	89.7	89.0	1.5	NS	0.001	NS
Difference	6.7	10.4	5.8	3.4	2.6	NS	0.10	NS

[a] Four barrows with an average initial BW of 82 kg.
[b] Probability for contrast: 1) soybean meal vs. others; 2) roasted vs. extruded and extruded with sodium sulfite; and 3) extruded vs. extruded with sodium sulfite.
[c] NS=not significant ($p>0.10$).

Table 7. Apparent nutrient utilization for finishing pigs[a]

	Soybean meal	Soybeans			SE	Contrast[b]		
		Roasted	Extruded	Sodium sulfite		1	2	3
Nutrient intake								
DM, g/d	2,402	2,368	2,356	2,430	66.3	NS[c]	NS	NS
N, g/d	44.2	50.7	53.7	53.2	1.4	0.001	NS	NS
GE, kcal/d	9,836	10,399	10,520	10,730	291.3	0.06	NS	NS
N retention, %	62.0	54.5	69.3	68.0	3.2	NS	0.004	NS
N retention, g/d	27.7	27.8	37.3	36.2	2.0	0.02	0.003	NS
Biological value, %	70.7	68.4	77.3	76.5	3.7	NS	0.086	NS
ME, %	91.2	83.2	90.7	91.5	0.7	0.007	0.001	NS
ME retention, kcal/d	8,986	8,668	9,538	9,827	265.2	NS	0.009	NS
ME, kcal/kg	3,789	4,113	4,492	4,436	31.5	0.001	0.001	NS

[a] Four barrows with an average initial BW of 82 kg.
[b] Probability for contrast: 1) soybean meal vs. others; 2) roasted vs. extruded and extruded with sodium sulfite; and 3) extruded vs.. extruded with sodium sulfite.
[c] NS=not significant ($p>0.10$).

87.8% for soybeans extruded with sodium sulfite. Likewise, the average digestibility of dispensable amino acids was still greater in extruded soybeans than in roasted soybeans ($p<0.001$).

Our data indicated that pigs fed soybeans extruded with sodium sulfite tended to have greater amino acid digestibilities measured at the terminal small intestine compared to pigs fed soybean meal, roasted soybeans or extruded soybeans. Sulfite ions have been shown to cleave disulfide bonds in thiols and s-sulfonic acid derivatives (Cecil and McPhee, 1955). Herkelman et al. (1991) reported that the performance of chicks fed soybeans heated for 10 or 20 min was improved with the addition of 2% sodium metabisulfite.

IMPLICATIONS

Digestibilities of nutrients were lower at the terminal ileum than in the feces with much of the treatment differences lost with total tract determinations. Thus, results based on the fecal analysis methods may provide erroneous interpretations of heat treatment effects on full-fat soybeans. Ileal digestibilities of DM, GE, N and various amino acids tended to be greatest in soybeans extruded with sodium sulfite and lowest for roasted soybeans. These trends were true for both growing and finishing pigs. Finally, our results indicated that future NRC values should indicate the type of processing used to generate full-fat soybean products to avoid overestimation of amino acid availability in roasted products and underestimation of amino acid availability for extruded products.

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Table 8. Apparent ileal amino acid digestibilities in finishing pigs[a], %

	Soybean meal	Soybeans			SE	Contrast[b]		
		Roasted	Extruded	Sodium sulfite		1	2	3
Indispensable amino acids								
Arginine	88.2	76.7	88.5	91.6	2.1	NS[c]	0.001	NS
Histidine	84.3	72.7	85.3	88.7	2.3	NS	0.001	NS
Isoleucine	84.9	71.9	84.4	87.1	2.2	NS	0.001	NS
Leucine	84.4	71.7	84.4	87.3	2.4	NS	0.001	NS
Lysine	83.3	71.2	84.7	88.9	2.4	NS	0.001	NS
Methionine	83.9	75.5	85.2	89.4	2.1	NS	0.001	NS
Phenylalanine	85.2	72.0	85.0	88.8	2.4	NS	0.001	NS
Threonine	76.0	68.1	78.3	83.6	2.5	NS	0.001	NS
Valine	80.8	69.6	80.8	84.7	2.5	NS	0.001	NS
Total indispensable amino acids	83.4	72.2	84.1	87.8	2.3	NS	0.001	NS
Dispensable amino acids								
Alanine	77.8	67.4	80.7	84.3	2.6	NS	0.001	NS
Aspartate	82.8	71.2	70.7	88.6	2.7	0.07	0.020	0.001
Glutamate	83.7	73.6	87.7	90.5	2.8	NS	0.001	NS
Glycine	70.1	62.7	75.1	77.9	3.2	NS	0.003	NS
Serine	80.8	68.5	81.2	86.2	2.6	NS	0.001	NS
Tyrosine	76.4	70.4	83.8	86.9	2.9	NS	0.001	NS
Total dispensable amino acids	78.6	69.0	79.9	85.7	2.7	NS	0.001	NS

[a] Four barrows with an average initial BW of 82 kg.

[b] Probability for contrast: 1) soybean meal vs. others; 2) roasted vs. extruded and extruded with sodium sulfite; and 3) extruded vs. extruded with sodium sulfite.

[c] NS=not significant ($p>0.10$).

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