Roasting and Extruding Affect Nutrient Utilization from Soybeans in 5 and 10 kg Nursery Pigs

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ABSTRACT : Ninety nursery pigs were used in two metabolism experiments to determine the effects of roasting and extruding on the nutritional value of Williams 82 soybeans with (+K) and without (-K) gene expression for the Kunitz trypsin inhibitor. Treatments for both experiments were: 1) soybean meal; 2) +K roasted; 3) +K extruded; 4) -K roasted; and 5) -K extruded. Diets were the soybean preparations (96.5% of the diet) with only vitamins and minerals added as needed to meet or exceed NRC recommendations. Daily feed allowance was 5% of initial BW given as three equal meals. In Exp. 1, 50 weanling pigs (4.7 kg average BW and 21 d average age) were used. Apparent values for N digestibility ($p<0.001$), biological value ($p<0.09$), percentage N retention ($p<0.05$), GE digestibility ($p<0.001$) and percentage ME ($p<0.001$) were greater for pigs fed extruded soybeans than pigs fed roasted soybeans. Also, N digestibility ($p<0.05$), biological value ($p<0.03$) and percentage N retention ($p<0.04$) were greater for pigs fed -K soybeans than those fed +K soybeans. In Exp. 2, 40 pigs (9.7 kg average BW and 35 d average age) were allowed to adjust to the nursery environment before use in the experiment. In general, the pigs in Exp. 2 (i.e., the older pigs) had greater utilization of nutrients from all of the soybean products than the younger pigs used in Exp. 1. Digestibilities of DM, N and GE were greater ($p<0.001$) for pigs fed -K soybeans than those fed +K soybeans and extruded soybeans had greater digestibilities of DM, N and GE than roasted soybeans ($p<0.001$). Also, percentage N retention ($p<0.01$) and percentage ME ($p<0.001$) for pigs fed extruded soybeans were greater than for pigs fed roasted soybeans. In conclusion, extruded and -K soybeans were greater nutritional value than roasted and +K soybeans for 4.7 and 9.7 kg nursery pigs. (*Asian-Aus. J. Anim. Sci. 2000. Vol. 13, No. 2 : 200-206*)

Key Words : Pigs, Soybeans, Roast, Extrude, Nitrogen Retention, Immunology

INTRODUCTION

The major constituent that limits the nutritional value of raw soybeans is a group of small proteins collectively called trypsin inhibitors. The Kunitz trypsin inhibitor was isolated and characterized during the 1940s (Kunitz, 1945). Raw soybeans have been shown to inhibit growth performance of growing (Yen et al., 1974; Cook et al., 1988; Giesemann et al., 1989; Hancock et al., 1989) and finishing (Pontif et al., 1987; Southern et al., 1990) pigs. A genetic line of soybeans recently has been developed that is low in the Kunitz trypsin inhibitor. Low trypsin inhibitor soybeans were a superior protein source to conventional soybeans for chicks (Burnham, 1995), nursery pigs (Kim et al., 1999b) and growing-finishing pigs (Cook et al., 1988; Hancock et al., 1991), yet some heat processing is still required to maximize their nutrient value (Giesemann et al., 1989). More recently, Kim et al. (1999a) suggested equal or greater nutrient digestibility when soybean meal was replaced with dry extruded whole soybeans in growing and finishing pigs. Also, Kim et al. (1995) reported pigs fed dry extruded whole soybeans had greater ADG and gain/feed than pigs fed the soybean meal. Data about the effects of heat processing of soybeans on nutrient utilization by nursery pigs (e.g., 5 and 10 kg) are limited.

Therefore, the objective of experiment reported herein was to determine the effects of roasting vs extruding on the nutritional value of Williams 82 soybeans with (+K) and without (-K) gene expression for the Kunitz trypsin inhibitor.

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Received January 29, 1999; Accepted March 17, 1999

MATERIALS AND METHODS

1. Experiment 1

Williams 82 soybeans with (+K) and without (-K) gene expression for the Kunitz trypsin inhibitor were either roasted or extruded soybeans-based diets (table 1). The roasting and extrusion treatments were accomplished at a throughput of 454 kg/h and an average exit temperature of 132℃ in a Roast-A-Tron™ (Blount, IN) roaster vs a throughput of 680 kg/h and an average barrel temperature of 163℃ in an Insta-Pro™ (Triple F, IA) dry-extruder. The screw assembly consisted of four single-flight screws and seven double-flight screws (screw diameter of 13.3 cm). Treatments were: 1) soybean meal; 2) +K roasted; 3) +K extruded; 4) -K roasted; and 5) -K extruded. The diets were fed in meal form and were the soybean preparations with only vitamins and minerals added as needed to meet NRC (1988) requirements for the 1 to 5 kg pig. Chromic oxide was added at 0.25% to the diets as an indigestible marker.

Table 1. Composition of diets (Exp. 1 and 2, as-fed basis), %

	Soybean meal	+ K Roasted	- K Roasted
Ingredient			
Soybean meal (48% CP)	96.49	-	-
Whole soybeans[a]	-	96.49	96.49
Monocalcium phosphate (21% P)	0.86	0.86	0.86
Limestone	1.40	1.40	1.40
Salt	0.30	0.30	0.30
Vitamin/trace mineal premix[b]	0.45	0.45	0.45
Antibiotic[c]	0.50	0.50	0.50
Total	100.00	100.00	100.00

[a] Roasted and extruded +K and -K soybeans were added in place of soybean meal.

[b] Provided the following per kilogram of complete diet: 5,512 IU of vitamin A; 551 IU of vitamin D3; 22 IU of vitamin E; 2.2 mg of vitamin K (as menadione bisulfite complex); 5.5 mg of riboflavin; 30.3 mg of niacin; 13.8 mg of pantothenic acid (as d-calcium pantothenate); 27.6 μg of vitamin B12; and 551 mg of choline; 100 mg of Mn; 100 mg of Fe; 100 mg of Zn; 40 mg of Ca; 264 mg of Cu; 1.0 mg of Co; and 3.0 mg of I; and 0.30 mg of Se.

[c] Provided the following per kilogram of complete diet: 110 mg of chlortetracycline; 110 mg of sulfathiazole; and 55 mg of penicillin.

Fifty weanling pigs (4.7 kg average BW and 21 d average age) were used in a 10 d metabolism experiment. The pigs were housed in individual cages (46 cm$\times$46 cm) equipped with woven-wire flooring. Room temperature was maintained at 28℃. The pigs were fed powdered milk for 3 d of adjustment to cages and then the experimental diets for 3 d before any collections were made. Daily food allowance was 5% of BW divided into three equal feedings (given at 7:00 am, 1:00 pm and 7:00 pm) throughout the experiment. Water was available for ad libitum consumption between feedings. Feces and urine samples were collected for 4 d and feces were lyophized and pooled. Urine samples were collected in containers with 100 mL of 10% HCl. Total urine volumes were recorded each day and 5% was frozen for analysis of GE and N concentration. Orts were collected twice daily and frozen. Concentrations of Cr (Williams et al., 1962), DM, N and GE (AOAC, 1990) in the feces and diets were determined to allow calculation of apparent digestibilities of DM, N and GE using the indirect ratio method. Intakes of digestible DM, N and GE were calculated by multiplying nutrient intakes by their respective apparent digestibilities. The portion of nutrient intake not digested was reported as fecal excretion. Also, concentrations of N and GE in the urine were determined to allow calculation of daily excretion of N and GE, apparent biological value, apparent N retention and ME.

Serum samples were collected from every pig on d 11 for determination of antibody titers specific to the combination of glycinin and β-conglycinin. Samples were analyzed by the procedure described by Li et al. (1990). Briefly, 96-well microtiter plates were coated with 100 μL/well of a solution consisting of a 40 g/mL protein concentrate (glycinin and β-conglycinin) in 1$\times$citrate buffer (0.05 μL, pH 9.6). Plates were sealed and incubated at 4℃ for 18 h. After incubation, the plates were washed three times with ELISA phosphate buffer solution, coated with 200 μL/well of 1% egg albumin solution and allowed to incubate for 1 h at 37℃. Serum samples were serially diluted twofold in ELISA phosphate buffer solution plus Tween-20. Sample dilutions were added after a second washing of the microtiter plate (three times with EPBS+Tween-20) and incubated for 1 h to allow an antibody-antigen complex to form. The plates were washed for a third time (three times with EPBS+Tween-20), and anti-pig goat serum conjugate (1:2,000 dilution in EPBS+Tween-20) was added as a secondary binder to the antigen-antibody complex. After a 1 h incubation period, the plate was washed (four times) with EPBS+Tween-20. Substrate was added to the plate and allowed to incubate at room temperature for 20 min, allowing the color reaction to take place. The extent of the reaction was determined in an EIA reader (Model EL 309, Bio-Tek Instruments, Winooski, VT). Anti-body titers were expressed as reciprocals of higher dilutions indicating a positive reaction. The ELISA measurements were expressed of a $\log_2$ basis.

Procedures developed by Reddy (personal communication) were used to determine the concentrations of glycinin and β-conglycinin in the soybean preparations. Briefly, 3 g of soybeans preparations was extracted by stirring in phosphate buffer solution for 1 h. The samples were centrifuged at 2,000$\times$g for 20 min, and the supernatant was decanted from the substrate. These purified protein samples were analyzed by the same procedure used to determine serum antibody titers (Li et al., 1990). Trypsin inhibitor concentrations were determined by the procedure of Hammerstrand et al. (1981).

All data were analyzed using the GLM procedure of SAS (1988). The experiment was a randomized complete block with initial BW as the blocking term. Response criteria were chemical composition of the

Table 2. Chemical composition of experimental ingredients (Exp. 1 and 2)

	Soybean meal	+ K		- K	
		Roasted	Extruded	Roasted	Extruded
DM, %[a]	88.6	93.0	93.5	92.2	93.1
CP, %[a]	44.4	37.0	37.5	37.4	37.0
Ether extract, %[a]	1.0	19.5	18.0	19.1	15.5
Crude fiber, %[a]	2.4	10.5	7.8	9.2	4.5
GE, kcal/kg[a]	3,902	5,011	4,892	4,927	4,890
Indispensable amino acid, %[a]					
Arginine	3.3	2.6	2.6	2.7	2.6
Histidine	1.2	1.0	0.9	1.0	1.0
Isoleucine	2.1	1.6	1.6	1.6	1.7
Leucine	3.6	2.8	2.8	2.8	2.9
Lysine	2.9	2.2	2.2	2.2	2.2
Methionine	0.7	0.5	0.5	0.5	0.5
Phenylalanine	2.4	1.8	1.8	1.9	1.9
Threonine	1.8	1.4	1.4	1.4	1.4
Tryptophan	0.7	0.5	0.5	0.4	0.5
Valine	2.2	1.8	1.8	1.8	1.8
Dispensable amino acid, %[a]					
Alanine	2.0	1.6	1.6	1.6	1.6
Aspartate	5.3	4.1	4.1	4.2	4.1
Cystine	0.8	0.6	0.6	0.6	0.6
Glutamate	8.3	6.2	6.1	6.4	6.4
Glycine	1.9	1.5	1.5	1.6	1.5
Proline	2.5	2.0	2.0	2.0	2.0
Serine	2.3	1.7	1.7	1.8	1.7
Tyrosine	1.7	1.3	1.2	1.3	1.3
Trypsin inhibitor, mg/g[b]	0.9	3.2	2.6	1.3	1.3
Urease activity, pH rise	0.02	0.12	0.01	0.07	0.01
Glycinin activity, log_2[c]	6	5	4	2	2
β-conglycinin activity, log_2[c]	4	4	2	1	1

[a] AOAC (1990); [b] Hammerstrand et al. (1981); [c] P. G. Reddy, personal communication.

ingredients (i.e., proximate analysis, amino acids, trypsin inhibitor, urease activity and glycinin and β-conglycinin activity), apparent nutrient digestibilities and immune response (villus height, crypt depth and anti-soy titers). Treatment means were separated with the orthogonal comparisons: 1) soybean meal vs extruded and roasted soybeans; 2) -K vs +K soybeans; 3) extruded vs roasted soybeans; and 4) -K vs +K × extruded vs roasted soybeans.

2. Experiment 2

For the second experiment, forty weanling pigs (9.3 kg average BW and 35 d average age) were used in a 10 d metabolism experiment. The experiment used in older pigs to allow the pigs time to adjust to nursery diet for 14 d. The same soybean treatments that were used in Exp. 1 were used in Exp. 2. Actual roasting and extrusion conditions were the same as in Exp. 1. The pigs were allowed to adjust to the nursery environment before use in the experiment. All analyses for diets, feces and urine samples were as described for Exp. 1. All statistical analyses and contrasts were the same as in Exp. 1.

RESULTS AND DISCUSSION

1. Chemical composition

Chemical composition of the soybean preparations used in Exp. 1 and 2 is given in table 2. Dry matter content was similar among all soybean preparation. The protein and amino acid concentrations of the soybean products were similar to those expected (NRC, 1988), with higher values for soybean meal (i.e., the defatted product). Urease activities were similar among all soybean preparation, but trypsin inhibitor activities were lower for the -K than for the +K soybeans. Rackis (1966) reported heat treatment of soybeans resulted in the destruction of the trypsin

Table 3. Apparent nutrient digestibilities in weanling pigs (4.7 kg average body weight) fed conventional (+K) or low-trypsin-inhibitor (-K) soybeans either roasted or extruded (Exp. 1)[a]

Item	Soybean meal	+ K		- K		SE	Contrasts[b]			
		Roasted	Extruded	Roasted	Extruded		1	2	3	4
ADG, g	194	145	175	190	203	28	NS[c]	NS	NS	NS
Apparent digestibility, %										
DM	82.3	75.4	80.8	76.3	84.3	1.8	NS	NS	0.001	NS
N	82.6	75.0	81.3	78.5	86.1	1.9	NS	0.05	0.001	NS
GE	78.3	70.8	82.8	71.4	83.7	2.2	NS	NS	0.001	NS
Biological value, %	63.1	53.8	65.4	67.7	69.9	4.1	NS	0.03	0.09	NS
N retention, %	47.4	44.6	53.2	53.6	60.4	3.9	NS	0.04	0.05	NS
N retention, g/d	3.7	3.3	5.4	4.4	5.3	0.5	NS	NS	0.002	NS
ME, %	71.0	63.0	78.3	68.1	79.3	2.2	NS	NS	0.001	NS
ME retention, kcal/d	269.4	347.3	533.3	418.2	548.6	42.7	0.09	NS	0.001	NS
ME of soys, kcal/kg	2,770	3,157	3,830	3,355	3,878	156	0.02	NS	0.001	0.03

[a] A total of 50 baby pigs (one pig/pen and ten pens/treatment) were fed from an average initial BW of 4.7 kg.

[b] Contrast: 1) soybean meal vs. other treatments; 2) -K soybeans vs. +K soybeans; 3) roasted soybeans vs. extruded soybeans; and 4) -K vs. +K × roasted vs. extruded soybeans.

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

inhibitors and other antinutritional factors. Grant (1989) also reported that heat processing is an effective method for decreasing the activity of anti-nutritional factors in soybeans. Denaturation of trypsin inhibitor and removal or destruction of other antinutritional factors in alcohol extracted soybean meal was demonstrated by Hancock et al. (1990a, b). The authors measured intestinal morphology of pigs fed soybean flakes subjected to various levels of heat treatment and with or without alcohol extraction. The degree of heat treatment in soybean meal is often estimated by determining urease activity, because urease and trypsin inhibitors are destroyed by heat at a similar rate (Albrecht et al., 1966) and it is easier and less costly to determine urease activity than to measure trypsin inhibitor activity (Wright, 1981; Waldroup et al., 1985). Research by Vandergrift et al. (1983) suggested that heating the raw soyflakes for 25 min, which produced a drop in trypsin inhibitor content from 31.1 to 6.2 mg/g, markedly improved nitrogen and amino acid digestibilities. Herkelman et al. (1991) reported that the trypsin inhibitor content of the soybeans fed to chicks was a good predictor of efficiency of feed utilization (r^2=0.95) and weight gain (r^2=0.92). Urease activity of soybeans was less accurate than trypsin inhibitor in predicting feed efficiency (r^2=0.63) or weight gain (r^2=0.74) of chicks. Soybean antigenic potential (i.e., glycinin and β-conglycinin activity) was less for the heat-treated soybeans than soybean meal. These data are in agreement with those of Kim et al. (1999b), who indicated a decreased concentration of glycinin and β-conglycinin when pigs were fed extruded soybeans compared to roasted soybeans and soybean meal.

2. Experiment 1

Digestibilities of DM, N and GE (table 3) were not different (p>0.11) for soybean meal compared to the other treatments. However, the full-fat soy products supported greater daily retention of ME (p<0.09) and had 785 kcal/kg more ME than soybean meal (p<0.02). This higher ME would be expected because of the fat content of the full-fat soybean preparations. The -K soybeans had greater digestibility of N than the +K soybeans (p<0.05). Also, biological value and percentage N retention were greater (p<0.04) for -K than +K soybeans. However, daily retention of ME and ME of the soy products themselves was not different for -K soybeans compared to +K soybeans. Our data of this experiment agree with Herkelman et al. (1992), who reported that the digestibility of N was greater in the raw, low trypsin-inhibitor soybeans than in the raw, conventional soybeans. Improved performance of animals fed raw -K soybeans compared to raw +K soybeans has been suggested by several researchers. Yen et al. (1972) and Cook et al. (1988) reported that, when unheated, low trypsin inhibitor soybeans supported greater ADG and gain/feed compared to conventional soybeans in growing and finishing pigs. Improvements in ADG and gain/feed in broiler chicks was reported by Yen et al. (1973) and Bajjalieh et al. (1980) when low trypsin inhibitor soybeans were compared to raw conventional soybeans. However, in these experiments, heat-processed soybean meal was superior to the unheated conventional and low trypsin inhibitor varieties. Thus, it seems that some heat treatment would be required for maximum nutritional value of all soybean varieties evaluated to data.

Table 4. Gut morphology and serum antibody immunoglobulin G titers of nursery pigs fed conventional (+K) or low-trypsin-inhibitor (-K) soybeans either roasted or extruded (Exp. 1)[a]

Item	Soybean meal	+ K		- K		SE	Contrasts[b]			
		Roast	Extrude	Roast	Extrude		1	2	3	4
Villus height, μm	376	354	403	376	413	21	NS[c]	NS	0.05	NS
Crypt depth, μm	372	356	351	345	336	21	NS	NS	NS	NS
Anti-soy, $\log_2$	7.0	6.7	6.6	6.5	6.2	0.4	NS	NS	NS	NS

[a] A total of 50 baby pigs (one pig/pen and ten pens/treatment) were fed from an average initial BW of 4.7 kg.
[b] Contrast: 1) soybean meal vs. other treatments; 2) -K soybeans vs. +K soybeans; 3) roasted soybeans vs. extruded soybeans; and 4) -K vs. +K×roasted vs. extruded soybeans.
[c] NS=Not significant (p>0.10).

Extrusion resulted in an improvement in the digestibilities of DM, N and GE (p<0.001) compared to roasting. Also, extrusion improved nearly all of the other response criteria, with 40% greater daily N retention and 598 kcal/kg more ME in the soy products with extrusion processing compared to roasting. In various feeding experiments, these low-inhibitor soybeans were superior protein source to conventional soybeans for chicks (Burnham, 1995), nursery pigs (Hancock et al., 1989; Kim et al., 1999b), and growing-finishing pigs (Hancock et al., 1991). Faber and Zimmerman (1973) reported that digestibility of energy and protein from infrared-roasted soybeans was lower than from soybean meal plus soybean oil or extruded-processed soybeans. Noland et al. (1976) reported that the cooked soybeans and soybean meal diets had almost the same ME, but diets with extruded soybeans had approximately 140 kcal/kg more ME than soybean meal or cooked soybeans.

Pigs fed extruded soybeans had longer villi (p<0.05) than pigs fed roasted soybeans, but no differences occurred in crypt depth or antisoy titers among pigs fed the various soy products (table 4). The greater villi height for pigs in our experiment fed extruded soybeans would tend to increase absorptive surface area and possibly indicates improved functional status of the small intestine for those pigs compared to pigs fed roasted soybeans. Research by Kilshaw and Sissons (1979a, b) indicated that the major storage protein soybeans (glycinin and β-conglycinin) are dietary antigens to the early-weaned pigs. The concentration of glycinin and β-conglycinin was decreased in extruded soybeans (Kim et al., 1999b). These data suggested denaturalization of the protein matrix allowed improved N utilization. Li et al. (1991) reported that pigs fed soybean meal had shorter villi than pigs fed either milk protein, extruded soy protein concentrate or soy protein isolate. Similarly, Friesen et al. (1993) reported that pigs fed moist-extruded soy flakes had a marked reduction in antisoy serum titers compared to pigs fed nonextruded soy flakes.

3. Experiment 2

In the experiment with older pigs, digestibilities of DM, N and GE were greater (p<0.05) for soybean meal compared to the full-fat soybean preparations (table 5). However, these differences were because of the relatively low digestibilities for the roasted soybeans and the full-fat soy products still had 588 kcal/kg more ME than the defatted soybean meal (p<0.001). Digestibilities of DM, N and GE were greater for pigs fed -K soybeans vs +K soybeans (p<0.001). Also, the -K soybeans supported greater percentage N retention (p<0.03) and percentage ME (p<0.002) than +K soybeans. According to Cook et al. (1988), N digestibility and retention were higher for pigs fed the soybean meal diet than for those fed the low-Kunitz trypsin inhibitor diet than for those fed the high-Kunitz trypsin inhibitor diet. Digestible and metabolizable energy values also were greater for pigs fed soybean meal than for pigs fed low and high-Kunitz trypsin inhibitor diets.

Extrusion improved apparent digestibilities of DM, N and GE by 11, 8 and 18% compared to roasting (p<0.001). Responses for other measurements of nutritional value (i.e., N utilization and ME) were similar to those for digestibility, with consistently greater utilization of nutrients from extruded soybeans than roasted soybeans. The extruded soybeans had 588 kcal/kg more ME than roasted soybeans. Noland et al. (1976) reported no advantage (fecal digestibility, N retention or performance) for extruded soybeans compared to that of soybean meal for nursery pigs. Contrary to these findings, Faber and Zimmerman (1973) reported increased ADG and gain/feed for weanling pigs fed extruded soybeans compared to roasted soybeans or a soybean meal-soybean oil control. Hanke et al. (1972) and Myer and Froseth (1983) reported that dry extrusion supported increased ADG compared to wet extrusion and both extrusion processes improved feed efficiency compared to soybean meal for nursery pigs. Also, Marty and Chavez (1993) reported that extruded soybeans had

Table 5. Apparent nutrient digestibilities in weanling pigs (9.3 kg average body weight) fed conventional (+K) or low-trypsin-inhibitor (-K) soybeans either roasted or extruded (Exp. 2)[a]

	Soybean meal	+ K		- K		SE	Contrasts[b]			
		Roasted	Extruded	Roasted	Extruded		1	2	3	4
ADG, g	359	223	338	281	382	38	NS[c]	NS	0.007	NS
Apparent digestibility, %										
DM	83.2	71.6	81.0	78.1	84.7	1.3	0.008	0.001	0.001	NS
N	86.8	75.6	85.3	84.1	86.4	1.3	0.02	0.001	0.001	0.006
GE	83.6	68.1	82.8	75.5	86.6	1.5	0.006	0.001	0.001	NS
Biological value, %	73.7	73.5	74.1	75.3	80.9	2.8	NS	NS	NS	NS
N retention, %	63.9	56.0	64.1	63.2	69.0	2.6	NS	0.03	0.01	NS
N retention, g/d	16.5	12.4	13.4	13.5	15.0	1.0	0.01	NS	NS	NS
ME, %	81.5	66.2	81.4	73.7	84.7	1.6	0.01	0.002	0.001	NS
ME retention, kcal/d	1,261	1,290	1,478	1,325	1,547	81	NS	NS	0.01	NS
ME of soys, kcal/kg	3,180	3,317	3,982	3,631	4,142	85	0.001	NS	0.001	0.005

[a] A total of 40 baby pigs (one pig/pen and eight pens/treatment) were fed from an average initial BW of 9.3 kg.
[b] Contrast: 1) soybean meal vs. other treatments; 2) -K soybeans vs. +K soybeans; 3) roasted soybeans vs. extruded soybeans; and 4) -K vs. +K×roasted vs. extruded soybeans.
[c] NS=Not significant (p>0.10).

superior digestibility of CP than jet sploded, micronized, roasted soybeans and soybean meal. Kim et al. (1999a) reported that ileal digestibilities of DM, GE, N and amino acids were greater for the extruded soybeans than for roasted soybeans and soybean meal.

IMPLICATIONS

The roasted and extruded soybean preparations were well utilized by pigs in our experiments. However, as in previous growth assays completed here at Kansas State University, -K soybeans tended to be of greater nutritional value than +K soybeans and extrusion processing resulted in marked improvements in nutritional value compared to roasting. Finally, our results indicate that the NRC value of 3,624 kcal/kg for full-fat soy products should be revised to indicate the type of processing used. Using our data for conventional (+K) and low-inhibitor (-K) soybeans, NRC overestimates ME of roasted products by 368 kcal/kg in 5 kg pigs and by 150 kcal/kg in 10 kg pigs. In contrast, the ME value of extruded soybeans is underestimated by 230 kcal/kg in 5 kg pigs and 438 kcal/kg in 10 kg pigs.

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