Evaluation of soy protein concentrates in nursery pig diets[1]

N. A. Lenehan, J. M. DeRouchey,[2] R. D. Goodband, M. D. Tokach, S. S. Dritz, J. L. Nelssen, C. N. Groesbeck, and K. R. Lawrence

Department of Animal Sciences and Industry, Kansas State University, Manhattan 66506-0201

ABSTRACT: Four experiments were conducted with 730 weanling pigs to determine the effects of soy protein concentrate (SPC) in diets for weanling pigs. Experimental diets were fed from d 0 to 14 postweaning and a common diet was fed from d 15 to 28 for Exp. 1, 2, and 3; experimental diets were fed from d 0 to 7 postweaning in Exp. 4. In Exp. 1, the 4 experimental diets included 1) a 0% soybean meal (SBM) diet containing animal protein sources; 2) a 40% SBM diet; or a 28.55% SPC (replacing the 40% SBM on a total Lys basis) diet from 3) source 1, or 4) source 2. Pigs fed diets containing either animal protein or 40% SBM had greater ADG and ADFI ($P < 0.05$) than pigs fed either SPC source. In Exp. 2, the 5 experimental treatments included diets 2, 3, and 4 from Exp. 1, along with 14.28% SPC from each SPC source used in Exp. 1 (replacing half of the total Lys from the 40% SBM diet). From d 0 to 14 and d 0 to 28, the SPC source × level interaction was significant for ADG ($P < 0.01$) and was a tendency for ADFI ($P < 0.07$). Replacing SBM with SPC from source 1 did not affect pig performance. However, replacing SBM with SPC from source 2 resulted in an improvement (quadratic, $P < 0.05$) in ADG for pigs fed the diet containing 14.3% SPC, but resulted in no benefit from replacing all the SBM with SPC. Replacing SBM with SPC from either source improved G:F (quadratic, $P < 0.01$), with the greatest G:F observed for pigs fed the diets with 14.3% SPC. Experiment 3 evaluated increasing levels of source 2 SPC, with treatments consisting of 1) 0% (40% SBM); 2) 7.14%; 3) 14.28%; 4) 21.42%; and 5) 28.55% SPC. There was a tendency for increased ADG (quadratic, $P < 0.06$) and increased ADFI (quadratic, $P < 0.04$) as inclusion of SPC in the diet increased. The gain-to-feed ratio improved (linear, $P < 0.01$) as the SPC level in the diet increased. Inclusion of approximately 14 to 21% SPC from source 2 maximized pig performance. In Exp. 4, pigs were offered a choice of consuming the diets containing 40% SBM or 28.6% SPC from source 2. Daily feed intake was greater ($P < 0.0001$) for the SBM diet (186 g/d) than for the SPC diet (5 g/d). Our results suggest that replacing a portion, but not all, of the high-SBM diet with SPC from source 2, but not from source 1, improves pig performance. The poor intake of pigs fed high levels of SPC may indicate a palatability problem, thus limiting its inclusion in nursery pig diets.

Key words: growth, ingredient, protein, soy protein concentrate, weanling pig

J. Anim. Sci. 2007. 85:3013–3021
doi:10.2527/jas.2007-0071

INTRODUCTION

Commercial diets for early-weaned pigs currently contain relatively little soybean meal (**SBM**). Newby et al. (1984) have suggested that the quantity of SBM in diets is limited by a transient hypersensitivity response of young pigs to large amounts of SBM. Li et al. (1990) further described the hypersensitivity response, reporting that villus height decreased and crypt depth increased because of a cell-mediated immune response in the intestine. If increased amounts of SBM could replace more expensive protein sources without affecting pig performance, this would be a large economic advantage for producers. A greater inclusion of soy proteins may be possible without negatively affecting pig performance resulting from different processing methods of SBM (Li et al., 1991a; Friesen et al., 1993b). Therefore, further processed soy proteins, such as soy protein concentrate (**SPC**) and extruded SPC, may be alternatives to animal-based protein sources. Soy protein concentrates are produced from defatted soy flakes from which soluble carbohydrates, primarily sucrose, raffinose, and stachyose, have been removed. The objective of the experiments was to determine the effects of diets containing different SPC sources compared with effects of a complex diet containing animal proteins, or a diet containing 40% SBM.

[1]Contribution no. 07-140-J of the Kansas Agric. Exp. Stn., Manhattan 66506-0210.

[2]Corresponding author: jderouch@ksu.edu

Received January 29, 2007.
Accepted July 23, 2007.

MATERIALS AND METHODS

General

The Kansas State University Institutional Animal Care and Use Committee approved all experimental protocols used in this study.

Pigs (Exp. 1, 2, and 3; Line 327 sire × C42 dams; PIC, Franklin, KY; Exp. 4, C42 gilts; PIC) were housed in environmentally controlled nurseries. Each pen (Exp. 1, 2, and 3 = 1.9 m^2) had slatted metal flooring and contained a stainless-steel self-feeder and 1 nipple waterer to allow ad libitum consumption of feed and water. In Exp. 4, each pen (3.0 m^2) had slatted metal flooring and contained 2 stainless-steel self-feeders and 2 nipple waterers to allow ad libitum consumption of feed and water.

In Exp. 1, 2, and 3, pigs were fed the experimental diets from d 0 to 14 postweaning and a common diet from d 15 to 28 postweaning. In Exp. 4, pigs were fed experimental diets from d 0 to 7 postweaning. In all experiments, pigs were weighed and allotted to their respective pens at weaning. For each experiment, diets were formulated to meet or exceed the nutrient requirements for pigs suggested by the NRC (1998). Because it was not an objective to determine AA availability among protein sources, Lys-deficient diets were not fed. All ingredient nutrient compositions used to formulate experimental diets were according to the NRC (1998) recommendations, except for the ME value of both SPC sources, for which 4,131 kcal/kg was used. Because of the anticipated similarity in nutrient profile of SPC sources and SBM with published values of the NRC (1998), they were used in formulation of diets. Analyzed values for AA (AOAC, 1995; method 985.30), CP (AOAC, 1995; method 990.03), and protein solubility index (Araba and Dale, 1990) were determined at the conclusion of the experiments for the SBM and both SPC sources (Table 1). Soy protein concentrate source 1 (Soycomil P, ADM, Des Moines, IA) was ethanol-extracted and heat-treated via a torus disc, with steam used as the heating medium. Soy protein concentrate source 2 (Profine E, Solae/Central Soya, Decatur, IL) was ethanol-extracted and moist-extruded. Pigs were weighed and feed disappearance was measured every 7 d during the experiments to determine ADG, ADFI, and G:F.

Exp. 1

A total of 216 barrows and gilts (initially 6.7 ± 2.2 kg of BW and 18 ± 2 d of age at weaning) were used to evaluate the effect of 2 SPC sources as replacements for either animal proteins or SBM in the diets for nursery pigs. All pigs were blocked by initial BW and allotted randomly to 1 of 4 dietary treatments. There were 6 pigs per pen, with 9 replications per treatment.

Pigs were fed experimental diets from d 0 to 14 postweaning (6.7 to 17.9 kg), which included 1) a positive control (animal protein-based) diet; a negative control diet containing 2) 40% SBM; 3) 28.6% SPC (source 1); or 4) 28.6% SPC (source 2). The diets containing SPC replaced all of the SBM in the negative control diet on an equal total Lys basis (Table 2). All pigs were fed a common diet from d 15 to 28 postweaning (Table 3).

Table 1. Analyzed AA, CP, and protein solubility of soybean meal and soy protein concentrate (SPC) sources (Exp. 1, 2, 3, and 4; as-fed basis)[1]

Item	Ingredient: Soybean meal	SPC source 1[2]	SPC source 2[3]
AA, g/100 g			
Arg	3.46	4.95	4.70
His	1.31	1.82	1.74
Ile	2.20	3.15	2.97
Leu	3.70	5.27	5.00
Lys	3.07	4.41	4.20
Met	0.69	0.93	0.90
Phe	2.44	3.51	3.32
Thr	1.82	2.59	2.47
Trp	0.79	1.14	1.10
Tyr	1.72	2.37	2.23
Val	2.37	3.39	3.20
CP, %	47.73	67.17	64.62
Protein solubility index, %	80.06	58.86	74.28

[1]Values represent the mean of 2 samples taken from the different soybean-derived sources.
[2]Source 1 SPC = Soycomil P (ADM, Des Moines, IA).
[3]Source 2 SPC = Profine E (Solae/Central Soya, Decatur, IL).

Exp. 2

A total of 210 barrows and gilts (initially 6.4 ± 2.6 kg of BW and 18 ± 2 d of age at weaning) were used to determine the effects of replacing half or all of the SBM with 2 SPC sources in the diets for nursery pigs. Pigs were blocked by initial BW and allotted randomly to 1 of 5 dietary treatments. The dietary treatments were arranged in a 2 × 2 factorial with a negative control that did not contain SPC. The main effects in the factorial were SPC source and level. There were 6 pigs per pen, with 7 replications per treatment.

Pigs were fed the experimental diets from d 0 to 14 postweaning (6.4 to 17.9 kg), which included a negative control diet containing 1) 40% SBM; 2) 14.3% SPC (source 1); 3) 28.6% SPC (source 1); 4) 14.3% SPC (source 2); or 5) 28.6% SPC (source 2). The diets containing 14.3% SPC replaced half of the SBM, whereas the diets containing 28.6% SPC replaced all of the SBM on an equal total Lys basis (Table 4). All pigs were fed a common diet from d 15 to 28 postweaning (Table 3).

Exp. 3

A total of 240 barrows and gilts (initially 5.9 ± 2.0 kg of BW and 18 ± 2 d of age at weaning) were used to determine the effects of increasing amounts of SPC in the diets for nursery pigs. Pigs were blocked by initial

Table 2. Diet composition (Exp. 1; as-fed basis) of treatments containing soybean meal (SBM) and soy protein concentrate (SPC)

Item	Control	40% SBM	SPC Source 1	SPC Source 2
Ingredient, %				
Corn	55.01	31.18	46.88	46.88
SBM, 46.5% CP	—	40.00	—	—
SPC[1]	—	—	28.55	28.55
Spray-dried whey	20.00	20.00	20.00	20.00
Spray-dried animal plasma	8.60	—	—	—
Select menhaden fish meal	7.50	—	—	—
Spray-dried blood meal	2.50	—	—	—
Soybean oil	2.85	4.30	—	—
Monocalcium phosphate, 21% P	0.55	1.40	1.45	1.45
Limestone	0.60	0.90	0.975	0.975
Salt	0.30	0.30	0.30	0.30
Vitamin premix[2]	0.25	0.25	0.25	0.25
Trace mineral premix[3]	0.15	0.15	0.15	0.15
Medication[4]	1.00	1.00	1.00	1.00
Zinc oxide	0.375	0.375	0.375	0.375
L-Lys·HCl	0.03	0.05	—	—
DL-Met	0.10	0.10	0.075	0.075
L-Ile	0.185	—	—	—
Total	100.0	100.0	100.0	100.0
Calculated analysis				
Total Lys, %	1.51	1.51	1.51	1.51
Ile:Lys ratio, %	60	71	77	77
Leu:Lys ratio, %	137	132	143	143
Met:Lys ratio, %	29	30	30	30
Met + Cys:Lys ratio, %	58	57	57	57
Thr:Lys ratio, %	64	65	70	70
Trp:Lys ratio, %	18	21	19	19
Val:Lys ratio, %	79	76	84	84
CP, %	20.8	23.7	25.0	25.0
ME, kcal/kg	3,426	3,426	3,426	3,426
Lys:calorie ratio, g/Mcal of ME	4.41	4.41	4.41	4.41
Ca, %	0.90	0.90	0.90	0.90
P, %	0.80	0.80	0.80	0.80
Determined analysis				
CP, %	21.0	23.9	24.8	25.5

[1]An energy value of 4,131 ME kcal/kg was used for both SPC sources. Source 1 SPC = Soycomil P (ADM, Des Moines, IA); source 2 SPC = Profine E (Solae/Central Soya, Decatur, IL).

[2]Contributed per kilogram of complete diet: vitamin A, 11,025 IU; vitamin D_3, 1,654 IU; vitamin E, 44.0 IU; vitamin K, 4.4 mg (as menadione sodium bisulfate); niacin, 55.1 mg; pantothenic acid, 33.1 mg (as D-calcium pantothenate); riboflavin, 9.9 mg; and B_{12}, 0.044 mg.

[3]Contributed per kilogram of complete diet: Zn (from zinc oxide), 165.0 mg; Fe (from ferrous sulfate), 165.4 mg; Mn (from manganese oxide), 39.7 mg; Cu (from copper sulfate), 16.5 mg; I (from calcium iodate), 0.30 mg; and Se (from sodium selenite), 0.30 mg.

[4]Provided 55 mg of Carbadox (Phibro Animal Health, Ridgefield Park, NJ)/kg of complete diet.

BW and allotted randomly to 1 of 5 dietary treatments to determine the optimal dietary inclusion level for SPC. There were 6 pigs per pen, with 8 replications per treatment.

Pigs were fed experimental diets from d 0 to 14 postweaning (5.9 to 19.0 kg), which included a control diet containing 40% SBM, or diets containing 7.14, 14.28, 21.42, or 28.55% SPC (source 2), respectively (Table 5). All pigs were fed a common diet from d 15 to 28 (Table 3).

Exp. 4

Sixty gilts (initially 6.1 ± 1.7 kg of BW and 18 ± 2 d of age at weaning) were used to determine nursery pig preference for consumption of diets containing either SBM or SPC. Pigs were blocked by initial BW and allotted randomly to a pen containing 2 feeders, to give a total of 10 pens (replications) with 6 pigs per pen.

Pigs were offered a choice of eating the diet containing 40% SBM or the diet containing 28.6% SPC from source 2 (Table 4) from d 0 to 7 postweaning (6.1 to 7.2 kg). The placement of feeders in each pen was alternated twice daily to enable a more accurate portrayal of preference by the pigs for these diets. Feeders were weighed on d 7 to calculate the response criterion of ADFI.

Statistical Analysis

Data from Exp. 1, 2, and 3 were analyzed as a randomized complete block design, with pen as the experi-

Table 3. Composition of common diet (Exp. 1, 2, and 3; as-fed basis)[1]

Item	Amount
Ingredient, %	
Corn	51.17
Soybean meal, 46.5% CP	27.30
Soybean oil	3.00
Select menhaden fish meal	4.50
Spray-dried whey	10.00
Monocalcium phosphate, 21% P	0.90
Limestone	0.60
Salt	0.30
Vitamin premix[2]	0.25
Trace mineral premix[3]	0.15
Medication[4]	1.00
Zinc oxide	0.25
L-Thr	0.13
L-Lys·HCl	0.30
DL-Met	0.15
Total	100.0
Calculated analysis	
Total Lys, %	1.50
Ile:Lys ratio, %	61
Leu:Lys ratio, %	121
Met:Lys ratio, %	34
Met + Cys:Lys ratio, %	58
Thr:Lys ratio, %	65
Trp:Lys ratio, %	17
Val:Lys ratio, %	68
CP, %	21.1
ME, kcal/kg	3,408
Lys:calorie ratio, g/Mcal of ME	4.40
Ca, %	0.81
P, %	0.73

[1]Fed from d 15 to 28 postweaning.
[2]Contributed per kilogram of complete diet: vitamin A, 11,025 IU; vitamin D_3, 1,654 IU; vitamin E, 44.0 IU; vitamin K, 4.4 mg (as menadione sodium bisulfate); niacin, 55.1 mg; pantothenic acid, 33.1 mg (as D-calcium pantothenate); riboflavin, 9.9 mg; and B_{12}, 0.044 mg.
[3]Contributed per kilogram of complete diet: Zn (from zinc oxide), 165.0 mg; Fe (from ferrous sulfate), 165.4 mg; Mn (from manganese oxide), 39.7 mg; Cu (from copper sulfate), 16.5 mg; I (from calcium iodate), 0.30 mg; and Se (from sodium selenite), 0.30 mg.
[4]Provided 55 mg Carbadox (Phibro Animal Health, Ridgefield Park, NJ)/kg of complete diet.

Table 4. Diet composition (Exp. 2 and 4; as-fed basis)[1] of treatments containing soybean meal (SBM) and soy protein concentrate (SPC)

	40%	SPC	
Item	SBM	14.3%	28.6%
Ingredient, %			
Corn	32.98	38.68	44.40
SBM, 46.5% CP	40.00	20.00	—
SPC	—	14.28	28.55
Spray-dried whey	20.00	20.00	20.00
Soybean oil	2.50	2.50	2.50
Monocalcium phosphate, 21% P	1.38	1.40	1.40
Limestone	0.925	0.95	0.975
Salt	0.30	0.30	0.30
Vitamin premix[2]	0.25	0.25	0.25
Trace mineral premix[3]	0.15	0.15	0.15
Medication[4]	1.00	1.00	1.00
Zinc oxide	0.375	0.375	0.375
L-Lys·HCl	0.05	0.03	0.01
DL-Met	0.10	0.09	0.09
Total	100.0	100.0	100.0
Calculated analysis			
Total Lys, %	1.51	1.51	1.51
Ile:Lys ratio, %	72	74	77
Leu:Lys ratio, %	133	137	142
Met:Lys ratio, %	30	30	30
Met + Cys:Lys ratio, %	57	57	57
Thr:Lys ratio, %	65	67	70
Trp:Lys ratio, %	21	20	19
Val:Lys ratio, %	77	80	83
CP, %	23.8	24.3	24.8
ME, kcal/kg	3,336	3,336	3,336
Lys:calorie ratio, g/Mcal ME	4.53	4.53	4.53
Ca, %	0.90	0.90	0.90
P, %	0.80	0.80	0.80

[1]In Exp. 2, 14.3 and 28.6% of both SPC sources (source 1 SPC = Soycomil P, ADM, Des Moines, IA; source 2 SPC = Profine E, Solae/Central Soya, Decatur, IL) were used. In Exp. 2, analyzed CP values were 25.9, 26.1, 27.3, 25.9, and 25.5% for the diets containing 40% SBM, 14.3 and 28.6% SPC source 1, and 14.3 and 28.6% SPC source 2, respectively. In Exp. 4, the diets containing 40% SBM and 28.6% SPC source 2 were used. Analyzed CP values were 24.46 and 23.65%, respectively.
[2]Contributed per kilogram of complete diet: vitamin A, 11,025 IU; vitamin D_3, 1,654 IU; vitamin E, 44.0 IU; vitamin K, 4.4 mg (as menadione sodium bisulfate); niacin, 55.1 mg; pantothenic acid, 33.1 mg (as D-calcium pantothenate); riboflavin, 9.9 mg; and B_{12}, 0.044 mg.
[3]Contributed per kilogram of complete diet: Zn (from zinc oxide), 165.0 mg; Fe (from ferrous sulfate), 165.4 mg; Mn (from manganese oxide), 39.7 mg; Cu (from copper sulfate), 16.5 mg; I (from calcium iodate), 0.30 mg; and Se (from sodium selenite), 0.30 mg.
[4]Provided 55 mg Carbadox (Phibro Animal Health, Ridgefield Park, NJ)/kg of complete diet.

mental unit. Experiment 4 was analyzed as a randomized complete block design, with feeder considered the experimental unit and pen of pigs considered the block. Pigs were blocked based on weaning weight, and ANOVA was performed by using the MIXED procedure (SAS Inst. Inc., Cary, NC). All means are reported are least squares means. In Exp. 1, means were compared by using least significant difference tests ($P < 0.05$) when the overall effect of treatment was significant ($P < 0.05$). In Exp. 2 and 3, preplanned contrasts were used to evaluate dietary treatment effects. Because of the related nature of the treatment doses, the comparisons in Exp. 2 and 3 were not protected with significant, dietary treatment *F*-tests ($P < 0.05$). The data in Exp. 2 were first examined by using a set of contrasts to evaluate the interaction and main effects of source and level. For those response criteria that had a significant or tended to have a significant interaction ($P < 0.10$), linear and quadratic contrasts were performed within each source by using the negative control as the 0% level of SPC. For those response criteria lacking evidence of an interaction, the data were pooled among SPC sources and level was evaluated by using linear and quadratic contrasts, with the negative control as the 0% level of SPC. Linear and quadratic polynomial contrasts were performed to determine the effects of increasing amounts of SPC level in Exp. 2 and 3. Because of the related nature of the treatment doses, the comparisons

Table 5. Diet composition (Exp. 3; as-fed basis) of treatments containing soybean meal (SBM) and soy protein concentrate (SPC)

Item	40% SBM	SPC, % 7.14	SPC, % 14.28	SPC, % 21.42	SPC, % 28.55
Ingredient, %					
Corn	32.96	35.92	38.91	41.87	44.34
SBM, 46.5% CP	40.00	29.90	19.75	9.65	—
Soybean oil	2.50	2.50	2.50	2.50	2.50
SPC	—	7.14	14.28	21.42	28.55
Spray-dried whey	20.00	20.00	20.00	20.00	20.00
Monocalcium phosphate, 21% P	1.38	1.39	1.40	1.41	1.45
Limestone	0.93	0.93	0.94	0.95	0.98
Salt	0.30	0.30	0.30	0.30	0.30
Vitamin premix[1]	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[2]	0.15	0.15	0.15	0.15	0.15
Medication[3]	1.00	1.00	1.00	1.00	1.00
Zinc oxide	0.38	0.38	0.38	0.38	0.38
L-Lys·HCl	0.05	0.04	0.04	0.03	0.01
DL-Met	0.10	0.10	0.10	0.09	0.09
Total	100.0	100.0	100.0	100.0	100.0
Calculated analysis					
Total Lys, %	1.51	1.51	1.51	1.51	1.51
Ile:Lys ratio, %	72	73	74	75	77
Leu:Lys ratio, %	133	135	137	139	142
Met:Lys ratio, %	30	30	30	30	30
Met + Cys:Lys ratio, %	57	57	57	58	57
Thr:Lys ratio, %	65	66	67	68	70
Trp:Lys ratio, %	21	20	20	19	19
Val:Lys ratio, %	77	78	80	81	83
CP, %	23.8	24.0	24.2	24.4	24.7
ME, kcal/kg	3,336	3,336	3,336	3,338	3,336
Lys:calorie ratio, g/Mcal ME	4.53	4.53	4.53	4.53	4.53
Ca, %	0.90	0.90	0.89	0.89	0.90
P, %	0.80	0.80	0.80	0.79	0.80

[1]Contributed per kilogram of complete diet: vitamin A, 11,025 IU; vitamin D_3, 1,654 IU; vitamin E, 44.0 IU; vitamin K, 4.4 mg (as menadione sodium bisulfate); niacin, 55.1 mg; pantothenic acid, 33.1 mg (as D-calcium pantothenate); riboflavin, 9.9 mg; B_{12}, 0.044 mg.

[2]Contributed per kilogram of complete diet: Zn (from zinc oxide), 165.0 mg; Fe (from ferrous sulfate), 165.4 mg; Mn (from manganese oxide), 39.7 mg; Cu (from copper sulfate), 16.5 mg; I (from calcium iodate), 0.30 mg; and Se (from sodium selenite), 0.30 mg.

[3]Provided 55 mg Carbadox (Phibro Animal Health, Ridgefield Park, NJ)/kg of complete diet.

in Exp. 2 and 3 were not protected with significant dietary treatment *F*-tests ($P < 0.05$).

RESULTS

Exp. 1

Protein solubility values of 80.06, 58.86, and 74.28% were obtained for SBM, SPC source 1, and SPC source 2, respectively (Table 1). During d 0 to 14 after weaning, pigs fed the animal protein diet and the diet containing 40% SBM had similar ADG, and both diets resulted in greater ADG ($P < 0.05$) than those from diets containing either SPC source (Table 6). The improved performance in pigs fed the control diet and the diet containing 40% SBM was a result of greater ADFI than in pigs fed either SPC source. Pigs fed SPC source 2 had improved ($P < 0.05$) G:F over pigs fed SPC source 1 or the control diet. From d 15 to 28, when all pigs were fed a common diet, pigs previously fed 40% SBM had greater ($P < 0.05$) ADFI than pigs previously fed source 2 SPC.

Overall (d 0 to 28), pigs fed the diet containing 40% SBM or the control diet from d 0 to 14 had greater ($P < 0.05$) ADG and ADFI than did pigs fed either SPC source. There were no differences in G:F among pigs fed the dietary treatments.

Exp. 2

From d 0 to 14 after weaning, there was a SPC source × level interaction for ADG ($P < 0.01$) and ADFI ($P < 0.02$; Table 7). Replacing SBM with SPC from source 1 did not affect pig performance (Table 7). Replacing SBM with SPC from source 2 resulted in an improvement (quadratic, $P < 0.05$) in ADG for pigs fed the diet containing 14.3% SPC, but there was no benefit from replacing all the SBM with SPC. Replacing SBM with SPC from either source improved G:F (quadratic, $P < 0.01$), with the best G:F observed for pigs fed the diets with 14.3% SPC from either source. From d 15 to 28, pigs previously fed SCP from source 1 had greater G:F ($P < 0.03$) then pigs previously fed SPC from source 2.

Table 6. Effect of soy protein concentrate (SPC) sources on growth performance of weanling pigs (Exp. 1)[1]

Item	Control	Soy protein source: 40% SBM[2]	SPC source 1	SPC source 2	SEM
d 0 to 14					
ADG, g	315[a]	315[a]	247[b]	255[b]	11.86
ADFI, g	392[a]	366[a]	305[b]	291[b]	16.16
G:F	0.82[a]	0.87[ab]	0.82[a]	0.88[b]	0.021
d 15 to 28[3]					
ADG, g	527	535	517	509	18.09
ADFI, g	723[ab]	741[a]	694[ab]	685[b]	18.89
G:F	0.73	0.73	0.75	0.75	0.011
d 0 to 28					
ADG, g	421[a]	425[a]	382[b]	382[b]	13.11
ADFI, g	558[a]	553[a]	499[b]	488[b]	15.33
G:F	0.77	0.80	0.78	0.81	0.012

[a,b]Means in the same row with different superscripts differ ($P < 0.05$).
[1]A total of 216 pigs (initially 6.7 ± 2.2 kg and 18 ± 2 d of age at weaning) with 6 pigs per pen and 9 pens per treatment, with experimental diets fed for 14 d.
[2]SBM = soybean meal.
[3]All pigs were fed a common diet from d 15 to 28.

From d 0 to 28, there was a SPC source × level interaction for ADG ($P < 0.01$) and a trend of the interaction for ADFI ($P < 0.07$). Pigs fed 14.3% SPC from source 2 had the greatest ADG, with no difference in ADG at any level of SPC from source 1. Average daily gain (quadratic, $P < 0.01$) and ADFI (quadratic, $P < 0.05$) increased as the percentage of SPC from source 2 increased to 14.3%, but decreased when SPC inclusion increased to 28.6%. Pigs fed SPC from source 2 had improved G:F compared with pigs fed SPC from source 1 ($P < 0.02$). There was an improvement (quadratic, $P < 0.01$) in G:F as the percentage of SPC in the diet increased to 14.3%, and G:F decreased as the percentage increased to 28.6%.

Exp. 3

During d 0 to 14 after weaning, there was a tendency for increased ADG (quadratic, $P < 0.06$) and increased ADFI (quadratic, $P < 0.04$) as inclusion of SPC source 2 in the diet increased to 21.4% (Table 8). Pigs fed increasing levels of SPC source 2 had improved (linear, $P < 0.01$) G:F. From d 15 to 28, when all pigs were fed a common diet, growth performance was not affected

Table 7. Effect of soy protein concentrate (SPC) sources and levels on growth performance of weanling pigs (Exp. 2)[1]

Item	Soy protein source: 40% SBM[2]	SPC source 1, %: 14.3	SPC source 1, %: 28.6	SPC source 2, %: 14.3	SPC source 2, %: 28.6	SE	P-value: SPC level	SPC source	Level × source
d 0 to 14									
ADG,[3] g	346	323	321	375	312	16.27	0.01	0.07	0.01
ADFI,[4] g	416	384	398	415	354	19.76	0.11	0.65	0.02
G:F[5]	0.86	0.87	0.83	0.95	0.92	0.015	0.03	0.01	0.49
d 15 to 28[6]									
ADG, g	489	511	506	518	484	16.27	0.09	0.53	0.20
ADFI, g	698	718	706	734	705	19.76	0.17	0.64	0.57
G:F	0.70	0.71	0.72	0.71	0.69	0.015	0.26	0.03	0.11
d 0 to 28									
ADG,[3] g	417	417	413	447	398	14.22	0.01	0.40	0.01
ADFI,[4] g	557	551	552	574	529	17.79	0.08	0.99	0.07
G:F[3]	0.78	0.79	0.78	0.83	0.80	0.012	0.02	0.02	0.50

[1]A total of 210 pigs (initially 6.4 ± 2.6 kg of BW and 18 ± 2 d of age at weaning), with 6 pigs per pen and 7 pens per treatment with experimental diets fed for 14 d.
[2]SBM = soybean meal.
[3]Quadratic effect of SPC source 2, $P < 0.05$.
[4]Linear effect of SPC source 2, $P < 0.05$.
[5]Quadratic effect of SPC level ($P < 0.01$).
[6]All pigs were fed a common diet from d 15 to 28.

Table 8. Effect of increasing soy protein concentrate (SPC) source 2 on growth performance of the weanling pig (Exp. 3)[1]

Item	Soy protein source					SEM	*P*-value (*P* <)	
	40% SBM[2]	SPC, %						
		7.1	14.3	21.4	28.6		Linear	Quadratic
d 0 to 14								
ADG, g	329	335	356	353	325	15.27	0.81	0.06
ADFI, g	362	378	378	385	332	23.04	0.33	0.04
G:F	0.92	0.90	0.96	0.93	1.00	0.02	0.01	0.28
d 15 to 28[3]								
ADG, g	631	617	611	617	633	15.27	0.93	0.15
ADFI, g	849	823	832	847	828	23.04	0.76	0.74
G:F	0.75	0.75	0.74	0.73	0.77	0.02	0.74	0.25
d 0 to 28								
ADG, g	480	476	483	485	479	12.74	0.83	0.77
ADFI, g	605	600	605	616	580	21.12	0.44	0.30
G:F	0.83	0.83	0.85	0.83	0.88	0.01	0.01	0.15

[1]A total of 240 pigs (initially 5.9 ± 2.0 kg BW and 18 ± 2 d of age at weaning), with 6 pigs per pen and 8 pens per treatment, with experimental diets fed for 14 d.
[2]SBM = soybean meal.
[3]All pigs were fed a common diet from d 15 to 28.

by protein source or percentage of SPC from source 2 fed from d 0 to 14. Overall (d 0 to 28), no differences were observed for ADG or ADFI. However, G:F improved (linear, $P < 0.01$) as the percentage of SPC in the diet increased to 28.6%.

Exp. 4

Preference by the pigs for the diet containing 40% SBM over the diet containing 28.6% SPC from source 2 quickly became clear during the 7-d trial. Average daily feed disappearance was 186 and 5 g for the 40% SBM and 28.6% SPC from source 2 diets, respectively ($P < 0.0001$; SE = 0.02).

DISCUSSION

Soybean meal, spray-dried animal plasma, fish meal, and spray-dried blood meal are among the protein sources commonly used in combination in starter diets to meet the AA requirements and to stimulate feed intake in nursery pigs. The amount of SBM in starter diets is currently limited because of adverse reactions of young pigs to large amounts in the diet. A decrease in ADG and G:F caused by a decrease in villus height and increased crypt depth was reported by Li et al. (1991a,b) from d 0 to 14 postweaning, owing to the delayed transient hypersensitivity response when SBM was fed. A study by Sohn et al. (1994b) suggested that the low digestibility of Lys, the first-limiting AA, may be a reason for the poorer performance of pigs fed a diet containing SBM. Friesen et al. (1993b) and Sohn et al. (1994a) showed that protein sources from further processing of soybeans improved the growth performance of early-weaned pigs. Hence, extensive effort has been invested in research on the use of SPC in an attempt to reduce the amount of SBM in the starter pig diet, and thus minimize adverse effects on pig performance.

Sohn et al. (1994a) reported a greater ADG and G:F for pigs fed SPC compared with pigs fed SBM from d 0 to 14 postweaning. This finding is in agreement with studies by Dietz et al. (1988) and Geurin et al. (1988) that recognized SPC as a potential source of protein for use in starter pig diets. The value of SPC relative to SBM was evaluated by Jones et al. (1990). A SBM diet was compared with a diet that had high nutrient density, and the high-nutrient-dense diet was compared with 50 and 100% replacement of dried skim milk with SPC. As inclusion of SPC increased, ADG ($P < 0.11$) and ADFI ($P < 0.09$) had a tendency to increase compared with pigs fed the SBM diet. A similar ADG was observed in pigs fed the diet with high nutrient density and in pigs fed SPC. In Exp. 1, pigs fed both sources of SPC had surprisingly poorer performance than did pigs fed the highly digestible animal protein diet or the diet containing 40% SBM. This finding was not expected, because previous research reported improved growth when pigs were fed SPC compared with SBM alone (Li et al., 1991a,b; Sohn et al., 1994a). In Exp. 1, greater ADFI was seen for pigs fed the animal protein-based diet and the diet containing 40% SBM compared with both SPC sources, whereas pigs fed SPC source 2 had greater G:F than those pigs fed the animal protein diet.

The nutrient-dense animal protein diet used in Exp. 1 contained spray-dried animal plasma, blood meal, and fish meal. Spray-dried porcine plasma and blood meal have been shown to be effective protein sources for the early-weaned pig (Hansen et al., 1993; Kats et al., 1994), whereas select menhaden fish meal was shown by Stoner et al. (1990) to be a suitable protein source for the weaned pig. In Exp. 1, however, there was no improvement in performance in those pigs fed an animal protein diet compared with pigs fed a diet containing 40% SBM. Friesen et al. (1993a) concluded that SBM at percentages up to 22.5% could be included in the diet of the weanling pig from d 0 to 14 postweaning while avoiding a decrease in ADG and G:F. Their experiment also suggested that the phase I starter diet must contain some amount of SBM to achieve optimal feed efficiency in phase II, because the pig needs to become acclimated to soy protein. In both Exp. 1 and 2, however, inclusion of 40% SBM in the diet did not have adverse effects on the performance of the weanling pig.

The method of processing can affect the nutritive value of SPC. Turlington et al. (1990) reported that pigs fed moist-extruded SPC had better performance than did pigs fed SBM. This finding is supported by Li et al. (1991a), who reported that pigs fed moist-extruded SPC had greater performance than did pigs fed SBM. Moist extrusion also has been suggested as a means of improving the nutritional value of SBM for use in starter pig diets (Li et al., 1991a,b; Friesen et al., 1993b). When Friesen et al. (1993b) compared dry and moist extrusion as a means of improving SBM quality, they reported that moist extrusion resulted in a superior product for inclusion in starter pig diets because of an increase in ADG and G:F. Moist extrusion, compared with dry extrusion, may result in an enhanced product because there is greater control in preventing overheating, which can result in lower product digestibility.

Soy protein concentrate source 1 was processed via a torus disc, which is an enclosed system with steam as the heating medium. The product moves through a tubular shaft with hollow concentric rings filled with steam. Agitator blades pick up the product and convey it through the system. The purpose of this system is to drive off any alcohol remaining as moisture, and to reduce or eliminate antinutritional factors. This drying procedure will generate some degree of heat, and the procedure possibly generates mechanical forces similar to those in extrusion processing. Soy protein concentrate source 2 is ethanol-extracted and moist-extruded. Processing method may account for the improvement in performance observed for pigs fed SPC source 2 relative to pigs fed SPC source 1 in Exp. 2. Trypsin inhibitor values are an indication of the adequacy of soybean processing. Trypsin inhibitor values of 4.0, 4.2, and 2.0 mg/g were reported by Hamerstrand et al. (1981) for SBM, SPC, and extruded SPC, respectively. No detectable level of trypsin inhibitor was detected in SPC sources used in the present studies, indicating that heat treatments were sufficient and adequate to reduce antinutritional factors to an acceptable level. In addition, no urease activity was detected in our samples. Urease levels are of interest because they are used as indicators of the presence of trypsin inhibitors (Araba and Dale, 1990). As a further indication of proper processing, protein solubility tests were conducted on the SBM and on SPC sources 1 and 2 used in Exp. 1. Protein solubility values of 80.06, 58.86, and 74.28% were obtained for SBM, SPC source 1, and SPC source 2, respectively. Protein solubility values below 70% are suggestive of overheating (Araba and Dale, 1990), thereby indicating that the decreased performance of pigs fed SPC source 1 may be due in part to overheating.

Palatability of the SPC diet was investigated in Exp. 4. A clear preference was shown by pigs for the diet containing 40% SBM compared with the diet containing 28.6% SPC source 2, which suggests that there may be a palatability issue when high amounts of SPC are included in the diet.

In summary, the results of our experiments suggest that the inclusion of SPC from source 2 leads to better performance in weanling pigs then does SPC from source 1. When given a choice between a diet containing 40% SBM or a diet containing 28.6% SPC from source 2, pigs prefer to eat the diet containing 40% SBM. It seems that SBM cannot be fully replaced by SPC while avoiding adverse effects on pig growth performance. Our results suggest that approximately 14 to 21% SPC from source 2 can be included in the diet for weanling pigs to optimize growth performance.

LITERATURE CITED

AOAC. 1995. Official Methods of Analysis. 16th ed. Assoc. Off. Anal. Chem., Arlington, VA.

Araba, M., and N. M. Dale. 1990. Evaluation of protein solubility as an indicator of overprocessing soybean meal. J. Poult. Sci. 69:76–83.

Dietz, G. N., C. V. Maxwell, and D. S. Buchanan. 1988. Effect of protein source on performance of early weaned pigs. J. Anim. Sci. 66 (Suppl.1):374. (Abstr.)

Friesen, K. G., R. D. Goodband, J. L. Nelssen, F. Blecha, D. N. Reddy, and L. J. Kats. 1993a. The effect of pre- and postweaning exposure to soybean meal on growth performance and on the immune response in the early-weaned pig. J. Anim. Sci. 71:2089–2098.

Friesen, K. G., J. L. Nelssen, R. D. Goodband, K. C. Behnke, and L. J. Kats. 1993b. The effect of moist extrusion of soy products on growth performance and nutrient utilization in the early-weaned pig. J. Anim. Sci. 71:2099–2109.

Geurin, H. B., G. A. Kesel, W. T. Black, T. Batteffield, and C. N. Caniels. 1988. Effect of isolated soy protein and whey on replacing dried skim milk in a prestarter diet for weaned baby pigs. J. Anim. Sci. 66 (Suppl.1):320. (Abstr.)

Hamerstrand, G. E., L. T. Black, and J. D. Glover. 1981. Trypsin inhibitors in soy products: Modification of the standard analytical procedure. Cereal Chem. 58:42–45.

Hansen, J. A., J. L. Nelssen, R. D. Goodband, and T. L. Weeden. 1993. Evaluation of animal protein supplements in diets of early-weaned pigs. J. Anim. Sci. 71:1853–1862.

Jones, D. B., J. D. Hancock, P. G. Reddy, R. D. Klemm, and F. Blecha. 1990. Effect of replacing dried skim milk with specially processed soy products on digestibility of nutrients and growth performance of nursery pigs. Pages 37–40 in Swine Day SRP 610. Kansas Agric. Exp. Sta., Manhattan, KS.

Kats, L. J., J. L. Nelssen, M. D. Tokach, R. D. Goodband, J. A. Hansen, and J. L. Laurin. 1994. The effect of spray-dried porcine plasma on growth performance in the early-weaned starter pig. J. Anim. Sci. 72:2075–2081.

Li, D. F., J. L. Nelssen, P. G. Reddy, F. Blecha, J. D. Hancock, G. L. Allee, R. D. Goodband, and R. D. Klemm. 1990. Transient hypersensitivity to soybean meal in the early-weaned pig. J. Anim. Sci. 68:1790–1799.

Li, D. F., J. L. Nelssen, P. G. Reddy, F. Blecha, R. D. Klemm, D. W. Giesting, J. D. Hancock, G. L. Allee, and R. D. Goodband. 1991a. Measuring suitability of soybean meal products for early-weaned pigs with immunological criteria. J. Anim. Sci. 69:3299–3307.

Li, D. F., J. L. Nelssen, P. G. Reddy, F. Blecha, R. Klemm, and R. D. Goodband. 1991b. Interrelationship between hypersensitivity to soybean proteins and growth performance in early-weaned pigs. J. Anim. Sci. 69:4062–4069.

Newby, T. J., B. Miller, C. R. Stokes, D. Hampson, and F. J. Bourne. 1984. Local hypersensitivity response to dietary antigens in early weaned pigs. Pages 49–59 in Recent Advances in Animal Nutrition. Butterworths, London, UK.

NRC. 1998. Nutrient Requirements of Swine. 10th ed. Natl. Acad. Press, Washington, DC.

Sohn, K. S., C. V. Maxwell, D. S. Buchanan, and L. L. Southern. 1994a. Improved soybean protein sources for early-weaned pigs: I. Effects on performance and total tract amino acid digestibility. J. Anim. Sci. 72:622–630.

Sohn, K. S., C. V. Maxwell, L. L. Southern, and D. S. Buchanan. 1994b. Improved soybean protein sources for early-weaned pigs: II. Effects on ileal amino acid digestibility. J. Anim. Sci. 72:631–637.

Stoner, G. R., G. L. Allee, J. L. Nelssen, M. E. Johnston, and R. D. Goodband. 1990. Effect of select menhaden fish meal in starter diets for pigs. J. Anim. Sci. 68:2729–2735.

Turlington, W. H., D. S. Pollmann, J. A. Coalson, and J. G. Enders. 1990. Nutritive value of soy protein concentrate in starter pig diets. J. Anim. Sci. 68 (Suppl.1):357. (Abstr.)