Evaluating processing temperature and feeding value of extruded-expelled soybean meal on nursery and finishing pig growth performance[1,2]

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ABSTRACT: We conducted two experiments comparing the use of extruded-expelled soybean meal (EESoy) to solvent-extracted soybean meal (SBM) in swine diets. In Exp. 1, the objective was to determine the optimal processing temperature of EESoy for nursery pig growth performance. Pigs (n = 330, 13.2 ± 2.3 kg of BW) were fed a control diet containing SBM with added fat or one of five diets containing EESoy extruded at 143.3, 148.9, 154.4, 160.0, or 165.6°C. All diets were formulated on an equal apparent digestible lysine:ME ratio. From d 0 to 20, no differences were observed ($P > 0.32$) in ADG or ADFI (average of 544 and 924 g/d, respectively). However, gain:feed ratio (G/F) improved (quadratic, $P < 0.01$, range of 0.56 to 0.60) with increasing processing temperature, with the greatest improvement at 148.9°C. In Exp. 2, the objective was to determine the feeding value of EESoy relative to SBM with or without added fat for growing-finishing pigs in a commercial production facility. A total of 1,200 gilts (initially 24.5 ± 5.1 kg of BW) was used, with 25 pigs per pen and eight replications per treatment. Dietary treatments were arranged in a 2 × 3 factorial, with two sources of soybean meal (SBM or EESoy) and three levels of added fat. Pigs were phase-fed four diets over the experimental period and added fat (choice white grease) levels were 0, 3.4, and 7% initially, with the added fat levels decreasing in the next three dietary phases. Energy levels were based such that the higher energy in EESoy (with or without added fat) was calculated to be equal to that provided by SBM with added fat. From 24.5 to 61.2 kg, pigs fed EESoy had greater ($P < 0.07$) G/F than those fed SBM. Increasing added fat in either EESoy- or SBM-based diets increased G/F (linear, $P < 0.0003$). From 61.2 to 122.5 kg, ADG and G/F were unaffected in pigs fed EESoy and/or increasing added fat ($P > 0.10$). For the overall growing-finishing period, ADG was unaffected ($P > 0.61$) by increasing energy density of the diet; however, ADFI decreased ($P < 0.05$) and G/F increased ($P < 0.02$, range of 0.37 to 0.40) as energy density increased with either EESoy or added fat. Carcass leanness was not affected by dietary treatment. These results indicate that EESoy should be extruded at 148.9 to 154.4°C, and that increasing dietary energy density by using EESoy and/or added fat improves feed efficiency in finishing pigs reared in a commercial environment.

Key Words: Fat, Finishing Pigs, Piglets, Processing, Soybean Oilmeal

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Introduction

Dry extrusion aids in the mechanical extraction of oil from soybeans (Nelson et al., 1987). This technology has been adopted as an alternative means of producing soybean meal and other oilseed meal and oils for human consumption and/or the livestock industry. This dry extrusion-expelling technique (Insta-Pro Express extruder/press system, Des Moines, IA) results in meal with a greater fat content than conventionally processed solvent-extracted soybean meal **(SBM)** (Nelson et al., 1987). The ileal amino acid digestibility and ME of extruded-expelled soybean meal **(EESoy)** has been recently determined (Woodworth et al., 2001). In that study, EEsoy had a higher ME content than SBM, as well as greater digestibility of some essential amino acids. However, the effect of processing temperature on protein quality has not been determined with EESoy.

De la Llata et al. (2001) observed improved gain:feed ratio **(G/F)** with increasing dietary fat in the growing

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and finishing phases of pigs reared in a commercial facility. During the grower phase, when pigs were in an energy-dependent growth phase, increasing added dietary fat increased growth rate. However, during the late finisher phase, added fat had no effect on ADG. The linear improvements in pig performance suggest that when economical, the highest level of added dietary fat should be fed. However, added dietary fat in corn- and SBM-based diets is usually limited to 4 to 6% for feed manufacturing and handling reasons (Pettigrew and Moser, 1991). Thus, EESoy may provide an opportunity to increase energy density above the limit imposed by feed-handling problems of a SBM-based diet with 6% added fat.

The objectives of these studies were to determine the optimal processing temperature of EESoy and to verify the feeding value of EESoy in a growth trial conducted under commercial conditions. Additional goals were to determine and define some key analytical procedures to verify protein quality that would be helpful in developing quality assurance programs for EESoy.

Materials and Methods

All experimental procedures used in these studies were approved by the Kansas State University Institutional Animal Care and Use Committee.

In Exp. 1, a total of 360 nursery pigs (C22 × 326, PIC, Franklin, KY), initially 13.2 kg, was allotted to one of six dietary treatments in two similar trials. Pigs were housed in an environmentally controlled nursery. Each pen contained a stainless steel self-feeder and one nipple waterer to allow ad libitum access to feed and water. In the first trial, there were six pigs per pen (1.22 × 1.52 m) and five pens per treatment. In the second trial, there were five pigs per pen (1.2 × 1.2 m) and six pens per treatment.

The six dietary treatments consisted of a corn-SBM plus soy oil control diet and five EESoy-based diets. The SBM was purchased locally and the soybeans from which it was made would have been different from those used in producing the EESoy. The EESoy was processed at five different temperatures (143.3, 148.9, 154.4, 160.0, and 165.6°C) using an Insta-Pro Express extruder/press system that utilized a model 2500 (single screw) Insta-Pro dry extruder and model 1500 continuous horizontal press (Insta-Pro International). Temperatures were recorded in the last chamber of the extruder barrel. Retention time in the last chamber was approximately 5 s, with an overall retention time of approximately 20 s. To increase the extruder temperatures, the nose cone opening was decreased. In Exp. 2, the EEsoy was produced by a commercial facility using similar equipment (two model 2000, single-screw, Insta-Pro dry extruders and three model 1500 continuous horizontal presses) and a processing temperature of 160°C. The control diet contained added fat to equal the energy content provided by the EESoy. This treatment structure compared the effects of processing temperature of EESoy on growth performance of pigs to those fed a control diet. Diets were formulated (Table 1) using amino acid values for EESoy from Woodworth et al. (2001), but ME values were adjusted based on the higher fat content of the EESoy used in this study. This was done by calculating a caloric contribution from the oil content using the NRC (1998) value for soybean oil and adjusting it for the difference in oil content of the EEsoy evaluated by Woodworth et al. (2001) and the EEsoy used in our study. We used NRC (1998) values for corn and soybean meal to formulate diets with equal digestible lysine and ME concentrations.

Table 1. Diet composition of Experiment 1 on an as-fed basis

Ingredient, %	Control	Extruded-expelled soybean meal
Corn	58.22	64.12
Soybean meal, (46.5% CP)	33.00	—
Soy oil	4.90	—
Extruded-expelled soybean meal[a]	—	32.00
Monocalcium phosphate, 21% P	1.60	1.60
Limestone	1.00	1.00
Salt	0.35	0.35
Vitamin premix[b]	0.25	0.25
Trace mineral premix[c]	0.15	0.15
Antibiotic[d]	0.50	0.50
DL-Methionine	0.03	0.03
Calculated analyses		
Apparent digestible lysine, %	0.95	0.95
Total lysine, %	1.15	1.10
Protein, %	20.3	19.7
ME, Mcal/kg	3.49	3.48
Grams of Lys/Mcal of ME	3.57	3.58
Ca, %	0.80	0.80
P, %	0.72	0.73
Available P, %	0.40	0.40

[a]Values used in diet formulation were: 2.69% apparent digestible lysine and 4,009 Kcal/kg of ME based on the values of Woodworth et al. (2001).

[b]Provided the following per kilogram of complete diet: vitamin A, 11,023 IU; vitamin D_3, 1,653 IU; vitamin E, 44 IU; menadione (menadione bisulfate complex), 4.4 mg; vitamin B_{12}, 0.04 mg; riboflavin, 9.9 mg; pantothenic acid, 33 mg; and niacin, 55 mg.

[c]Provided the following per kilogram of complete diet: Mn, 40 mg (Mn oxide); Fe, 165 mg (Fe sulfate), Zn, 165 mg (Zn oxide), Cu, 17 mg (Cu slufate), I, 0.3 mg (Ca iodate); and Se, 0.3 mg (Na selenite).

[d]Provided 55 mg of carbadox per kilogram of complete diet.

Pigs were weighed and feed disappearance was recorded on d 0, 11, and 20 to determine ADG, ADFI, and G/F. Also, various assays were used to evaluate the protein quality of the five EESoy samples. All samples were analyzed in duplicate (Table 2). The analyses included protein dispersibility index (**PDI;** AOCS, 1980), nitrogen solubility index (**NSI;** AOCS, 1989), potassium hydroxide solubility (**KOH;** Araba and Dale, 1990), urease index (AOCS, 1973), and trypsin inhibitor (**TI**) assay (Hammerstand, 1981). Also, each EESoy sample was analyzed for DM (AOAC, 1995, Method 4.1.06), CP (AOAC, 1995, Method 990.03), crude fat (AOAC, 1995, Method 4.5.01), and one sample was analyzed for AA profile (AOAC, 1995; University of Missouri Experiment Station Lab, Columbia, MO).

Table 2. Effects of processing temperature on extruded-expelled soybean meal characteristics from Experiment 1 on an as-fed basis

	Extrusion temperatures, °C				
Assay[a]	143.3	148.9	154.4	160.0	165.6
Dry matter, %	92.7	93.1	93.3	93.2	94.1
Crude protein, %	44.0	43.8	43.9	43.9	45.1
Ether extract, %	7.68	7.71	7.41	7.05	7.04
Protein dispersibility index, %	19.7	13.1	12.9	13.1	12.2
Nitrogen solubility index, %	22.8	19.7	15.2	12.7	9.0
Potassium hydroxide solubility, %	80.5	81.8	76.4	73.4	71.7
Trypsin, mg of TI/g	2.98	2.25	1.56	1.00	0.81
Urease, change in pH	0.38	0.12	0.01	0.01	0.00
Amino acids, %[b]					
Arginine	—	—	3.07	—	—
Histidine	—	—	1.16	—	—
Isoleucine	—	—	2.00	—	—
Leucine	—	—	3.30	—	—
Lysine	—	—	2.74	—	—
Methionine	—	—	0.61	—	—
Phenylalanine	—	—	2.17	—	—
Threonine	—	—	1.65	—	—
Tryptophan	—	—	0.66	—	—
Valine	—	—	2.14	—	—

[a]Each assay performed in duplicate.
[b]Amino acid analysis was only performed on the extruded expelled soybean meal processed at 154.4°C.

In Exp. 2, a total of 1,200 gilts (C22 × 337, PIC), initially 24.5 kg, was allotted to one of the six dietary treatments. There were 25 pigs per pen in a commercial research finishing barn. The barn was a 48-pen, curtain-sided, totally slatted, deep-pit finishing barn with pen dimensions of 3.05 × 5.50 m to provide 0.67 m^2 per pig. Pens were equipped with one 4-hole self-feeder (Staco Inc., Schaeferstown, PA) and one cup waterer. Feed was delivered to each individual feeder using an auger cart equipped with a scale.

Treatments were arranged in a 2 × 3 factorial with soybean source and increasing energy density as main effects. There were eight observations (pens) per treatment. The control diet was corn- and SBM-based and contained no added fat. In the next dietary treatment, the SBM was replaced by EESoy and fat was added (1.5 to 3.4% based on phase) to the SBM-based control diet to equal the energy content of the EESoy diet. This amount of added fat was then added to the EESoy-based diet, and a SBM diet with added fat (3.1 to 7%) was formulated to equal the energy content of the EESoy diet with added fat. The last dietary treatment consisted of EESoy with 3.1 to 7% added fat, the same amount added to the SBM diet. So, the diet containing SBM with the medium levels of added fat was formulated to equal the ME level of the EESoy with no added fat. In addition, the diet containing SBM with the high levels of added fat was formulated to equal the ME level of the EESoy with the medium levels of fat. Both SBM and EESoy were purchased locally and would have originated from different sources of raw soybeans.

All pigs were phase fed four diets from 24.5 to 122.5 kg. Diets were formulated to the same digestible lysine:energy ratio within each phase. Because the lysine content of each diet decreased as the pigs became heavier, the amount of EESoy was also decreased. In turn, this decreased the amount of extra ME EESoy provided relative to diets containing SBM. Therefore, the amount of fat added to equalize energy density between SBM and EESoy decreased in each successive phase. Each phase was fed between 28 and 32 d (Tables 3 through 6). All diets were formulated using NRC (1998) nutrient values for SBM. Metabolizable energy and digestible amino acid values estimated by Woodworth et al. (2001) were used for the EESoy.

In Exp. 2, pigs were weighed and feed disappearance was determined every 14 to 18 d. Average daily gain, ADFI, and G/F were determined. At market, pigs were tattooed by pen for treatment identification and sent to the Swift processing plant (Worthington, MN), where standard carcass criteria (loin and fat depth, hot carcass weight, dressing percentage, lean percentage, and fat-free lean index) were measured.

Statistical Analyses

In Exp. 1, ANOVA was used to analyze the data as a randomized complete block design. The GLM procedure of SAS (SAS Inst., Inc., Cary, NC) was used for the contrasts between SBM and EESoy treatments. Also, linear, quadratic, and cubic polynomial contrasts were used to determine the effects of EESoy processing temperature on pig growth performance. Pen was the experimental unit for all calculations. In Exp. 2, ANOVA was used to analyze the data as a completely randomized design in a 2 × 3 factorial arrangement using GLM

Table 3. Diet composition (24.5 to 40.8 kg) of Experiment 2 on an as-fed basis

Fat level:	Low		Medium		High	
Source:	SBM[a]	EESoy[b]	SBM	EESoy	SBM	EESoy
Ingredients, % ME level:	3.31	3.46	3.46	3.62	3.62	3.79
Corn	69.17	69.99	63.59	64.59	57.77	58.78
Soybean meal, (46.5% CP)	28.05	—	30.16	—	32.30	—
EESoy[b]	—	26.92	—	28.85	—	30.94
Choice white grease	—	—	3.40	3.40	7.00	7.00
Monocalcium P, 21% P	1.05	1.33	1.10	1.39	1.16	1.48
Limestone	1.00	1.00	1.00	1.00	1.00	1.00
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[c]	0.08	0.08	0.08	0.08	0.08	0.08
Trace mineral premix[d]	0.15	0.15	0.15	0.15	0.15	0.15
Lysine HCl	0.15	0.15	0.15	0.15	0.15	0.15
DL-Methionine	—	0.03	0.02	0.04	0.04	0.07
Calculated analyses[e]						
Apparent digestible lysine, %	0.96	1.00	1.00	1.05	1.05	1.10
Protein, %	18.9	19.5	19.4	20.1	19.9	20.6
ME, Mcal/kg	3.31	3.46	3.46	3.62	3.62	3.79
Grams of Lysine/Mcal of ME	2.89	2.89	2.89	2.89	2.89	2.89
Ca, %	0.69	0.69	0.69	0.69	0.69	0.69
P, %	0.61	0.66	0.62	0.67	0.63	0.69
Available P, %	0.31	0.31	0.31	0.31	0.31	0.31

[a]Solvent-extracted soybean meal.
[b]Extruded-expelled soybean meal without hulls.
[c]Provided the following per kilogram of complete diet: vitamin A, 8,818 IU; vitamin D_3, 1,323 IU; vitamin E, 35.3 IU; menadione (menadione sodium bisulfate complex), 3.5 mg; vitamin B_{12}, 0.04 mg; riboflavin, 7.9 mg; pantothenic acid, 26.5 mg; and niacin, 44.1 mg.
[d]Provided the following per kilogram of complete diet: Mn, 40 mg (Mn oxide); Fe, 165 mg (Fe sulfate), Zn, 165 mg (Zn oxide), Cu, 17 mg (Cu sulfate), I, 0.3 mg (Ca iodate); and Se, 0.3 mg (Na selenite).
[e]Calculated values from NRC (1998) and Woodworth et al. (2001) were used in diet formulation.

Table 4. Diet composition (40.8 to 61.2 kg) of Experiment 2 on an as-fed basis

Fat level:	Low		Medium		High	
Source:	SBM[a]	EESoy[b]	SBM	EESoy	SBM	EESoy
Ingredients, % ME level:	3.31	3.44	3.44	3.58	3.58	3.73
Corn	72.48	73.84	67.98	69.41	63.14	64.84
Soybean meal, (46.5% CP)	24.89	—	26.49	—	28.23	—
EESoy[b]	—	23.35	—	24.83	—	26.28
Choice white grease	—	—	2.90	2.90	6.00	6.00
Monocalcium P, 21% P	1.00	1.18	1.00	1.23	1.00	1.25
Limestone	0.90	0.90	0.90	0.90	0.90	0.90
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[c]	0.08	0.08	0.08	0.08	0.08	0.08
Trace mineral premix[d]	0.15	0.15	0.15	0.15	0.15	0.15
Lysine HCl	0.15	0.15	0.15	0.15	0.15	0.15
DL-Methionine	—	—	—	0.01	—	0.03
Calculated analyses[e]						
Apparent digestible lysine, %	0.88	0.91	0.91	0.94	0.94	0.97
Protein, %	17.7	18.1	18.1	18.4	18.5	18.8
ME, Mcal/kg	3.31	3.44	3.44	3.58	3.58	3.73
Grams of Lysine/Mcal of ME	2.65	2.63	2.65	2.62	2.65	2.61
Ca, %	0.68	0.68	0.68	0.68	0.68	0.68
P, %	0.58	0.61	0.58	0.62	0.58	0.63
Available P, %	0.28	0.28	0.28	0.28	0.28	0.28

[a]Solvent-extracted soybean meal.
[b]Extruded-expelled soybean meal without hulls.
[c]Provided the following per kilogram of complete diet: vitamin A, 8,818 IU; vitamin D_3, 1,323 IU; vitamin E, 35.3 IU; menadione (menadione sodium bisulfate complex), 3.5 mg; vitamin B_{12}, 0.04 mg; riboflavin, 7.9 mg; pantothenic acid, 26.5 mg; and niacin, 44.1 mg. [d]Provided the following per kilogram of complete diet: Mn, 40 mg (Mn oxide); Fe, 165 mg (Fe sulfate), Zn, 165 mg (Zn oxide), Cu, 17 mg (Cu sulfate), I, 0.3 mg (Ca iodate); and Se, 0.3 mg (Na selenite).
[e]Calculated values from NRC (1998) and Woodworth (2001) were used in diet formulation.

Table 5. Diet composition (61.2 to 86.2 kg) of Experiment 2 on an as-fed basis

	Fat level:	Low		Medium		High	
	Source:	SBM[a]	EESoy[b]	SBM	EESoy	SBM	EESoy
Ingredients, %	ME level:	3.33	3.42	3.42	3.51	3.51	3.61
Corn		80.54	81.64	77.67	78.88	74.66	76.01
Soybean meal, (46.5% CP)		17.15	—	18.02	—	18.93	—
EESoy[b]		—	15.92	—	16.66	—	17.43
Choice white grease		—	—	2.00	2.00	4.10	4.10
Monocalcium P, 21% P		0.75	0.88	0.75	0.90	0.75	0.90
Limestone		0.90	0.90	0.90	0.90	0.90	0.90
Salt		0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[c]		0.06	0.06	0.06	0.06	0.06	0.06
Trace mineral premix[d]		0.10	0.10	0.10	0.10	0.10	0.10
Lysine HCl		0.15	0.15	0.15	0.15	0.15	0.15
Calculated analyses[e]							
Apparent digestible lysine, %		0.70	0.71	0.71	0.73	0.73	0.74
Protein, %		14.8	15.0	15.0	15.1	15.1	15.3
ME, Mcal/kg		3.33	3.42	3.42	3.51	3.51	3.61
Grams of Lysine/Mcal of ME		2.09	2.09	2.09	2.09	2.09	2.09
Ca, %		0.59	0.59	0.59	0.59	0.59	0.59
P, %		0.50	0.52	0.50	0.52	0.50	0.52
Available P, %		0.22	0.22	0.22	0.22	0.22	0.22

[a]Solvent-extracted soybean meal.
[b]Extruded-expelled soybean meal without hulls.
[c]Provided the following per kilogram of complete diet: vitamin A, 6,614 IU; vitamin D_3, 992 IU; vitamin E, 26.5 IU; menadione (menadione sodium bisulfate complex), 2.6 mg; vitamin B_{12}, 0.03 mg; riboflavin, 6.0 mg; pantothenic acid, 19.8 mg; and niacin, 33.1 mg.
[d]Provided the following per kilogram of complete diet: Mn, 27 mg (Mn oxide); Fe, 110 mg (Fe sulfate); Zn, 110 mg (Zn oxide); Cu, 11 mg (Cu sulfate); I, 0.2 mg (Ca iodate); Se, 0.2 mg (Na selenite).
[e]Calculated values from NRC (1998) and Woodworth et al. (2001) were used in diet formulation.

Table 6. Diet composition (86.2 to 122.5 kg) of Experiment 2 on an as-fed basis

	Fat level:	Low		Medium		High	
	Source:	SBM[a]	EESoy[b]	SBM	EESoy	SBM	EESoy
Ingredients, %	ME level:	3.33	3.40	3.40	3.47	3.47	3.54
Corn		84.82	85.74	82.76	83.79	80.62	81.66
Soybean meal, (46.5% CP)		12.97	—	13.53	—	14.07	—
EESoy[b]		—	11.97	—	12.42	—	12.93
Choice white grease		—	—	1.50	1.50	3.10	3.10
Monocalcium P, 21% P		0.70	0.78	0.70	0.78	0.70	0.80
Limestone		0.85	0.85	0.85	0.85	0.85	0.85
Salt		0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[c]		0.06	0.06	0.06	0.06	0.06	0.06
Trace mineral premix[d]		0.10	0.10	0.10	0.10	0.10	0.10
Lysine HCl		0.15	0.15	0.15	0.15	0.15	0.15
Calculated analyses[e]							
Apparent digestible lysine, %		0.60	0.61	0.61	0.62	0.62	0.63
Protein, %		13.2	13.3	13.3	13.4	13.4	13.5
ME, Mcal/kg		3.33	3.40	3.40	3.47	3.47	3.54
Grams of Lysine/Mcal of ME		1.79	1.79	1.79	1.79	1.79	1.79
Ca, %		0.52	0.52	0.52	0.52	0.52	0.52
P, %		0.47	0.49	0.47	0.48	0.47	0.49
Available P, %		0.20	0.20	0.20	0.20	0.20	0.20

[a]Solvent-extracted soybean meal.
[b]Extruded-expelled soybean meal without hulls.
[c]Provided the following per kilogram of complete diet: vitamin A, 6,614 IU; vitamin D, 992 IU; vitamin E, 26.5 IU; menadione (menadione sodium bisulfate complex), 2.6 mg; vitamin B_{12}, 0.03 mg; riboflavin, 6.0 mg; pantothenic acid, 19.8 mg; and niacin, 33.1 mg.
[d]Provided the following per kilogram of complete diet: Mn, 27 mg (Mn oxide); Fe, 110 mg (Fe sulfate); Zn, 110 mg (Zn oxide); Cu, 11 mg (Cu sulfate); I, 0.2 mg (Ca iodate); Se, 0.2 mg (Na selenite).
[e]Calculated values from NRC (1998) and Woodworth et al. (2001) were used in diet formulation.

Table 7. Effects of extruded-expelled soybean meal (EESoy) processing temperature on nursery pig performance, Experiment 1[a]

		Extrusion temperature, °C						Probability values, $P <$		
Item	Control	143.3	148.9	154.4	160.0	165.6	SEM	Linear	Quadratic	Control vs. EESoy
Day 0 to 11										
ADG, g	494	449	438	469	486	480	14.8	0.08	0.36	0.06
ADFI, g[b]	813	828	771	806	843	820	25.2	0.55	0.09	0.98
Gain/feed	0.61	0.54	0.57	0.58	0.58	0.59	0.01	0.07	0.22	0.002
Day 11 to 20										
ADG, g	665	618	639	657	595	637	20.6	0.75	0.07	0.10
ADFI, g[b]	1,067	1,053	1,056	1,064	1,047	1,073	36.6	0.98	0.75	0.82
Gain/feed	0.62	0.58	0.60	0.62	0.57	0.59	0.01	0.49	0.001	0.001
Overall										
ADG, g	570	525	528	553	535	551	15.5	0.47	0.51	0.05
ADFI, g[b]	926	929	898	922	935	934	29.1	0.76	0.51	0.93
Gain/feed	0.61	0.56	0.59	0.60	0.57	0.59	0.01	0.39	0.01	0.001

[a]A total of 360 pigs (initially 13.2 kg) allotted to six or five pigs per pen and five or six pens per treatment was used in two similar experiments. No treatment × trial interactions were observed ($P < 0.10$).
[b]As-fed basis.

procedures of SAS. The statistical model included the main and interactive effects of soybean meal source and fat. Linear and quadratic polynomial contrasts were used to determine the effects of increasing dietary energy by either adding dietary fat or by using EESoy. In addition, linear and quadratic polynomial contrasts were used to determine the effects of dietary ME concentration on pig performance. Carcass weight was used as a covariate to analyze the carcass composition data. Pen was the experimental unit for all calculations.

Results and Discussion

In Exp. 1, from d 0 to 11, pigs fed EESoy tended to have greater ADG and G/F as processing temperature of the soybeans increased (linear, $P < 0.08$ and $P < 0.07$, respectively) (Table 7). Also, control pigs tended to have greater ADG ($P < 0.06$) and G/F ($P < 0.002$) than the mean of pigs fed EESoy. There were no differences in ADFI between treatments.

In the last 10 d, pigs fed EESoy tended to have greater (quadratic, $P < 0.07$) ADG and improved (quadratic, $P < 0.001$) G/F as processing temperature increased, with the best G/F observed at a processing temperature of 154.4°C. This is likely because of the denaturazation of soy antinutritional factors, such as trypsin inhibitor. Furthermore, control pigs had greater G/F ($P < 0.001$) than the mean of pigs fed EESoy.

For the overall period, there were no differences ($P < 0.32$) in ADG and ADFI among pigs fed EESoy processed at different temperatures. However, among pigs fed EESoy, there was an improvement (quadratic, $P < 0.01$) in G/F as the processing temperature increased. The greatest improvement in G/F was observed at 148.9°C. In addition, control pigs had greater ADG ($P < 0.05$) and G/F ($P < 0.001$) than the mean of pigs fed EESoy. Control pigs had better growth performance than pigs fed EESoy because of the varying processing temperatures used for EESoy treatments. For example, pigs fed EESoy processed at 154.4°C had a performance ($P > 0.16$) similar to the controls. These results would agree with research conducted by Woodworth et al. (2001), who showed that pigs fed properly processed EESoy will perform similarly to pigs fed SBM with added fat.

The PDI percentage (Table 2) ranged from 19.7 to 12.2 for EESoy extruded at 143.3 to 165.6°C, respectively. According to Batal et al. (2000), SBM containing a PDI of 45% or lower is adequately heat processed. The NSI percentage ranged from 22.8 to 9.0 as processing temperature increased. This response is similar to the PDI levels when processing temperature increased. The KOH percentage ranged from 80.5 to 72.1 for EESoy extruded from 143.3 to 165.6°C, respectively. According to Araba and Dale (1990) and Parsons et al. (1991), KOH protein solubilities below 70% are indicative of overprocessed soybean meal. The optimum for KOH solubility would be approximately 75%. The content of trypsin inhibitors ranged from 2.98 to 0.81 mg/g of soybean meal sample for temperatures of 143.3 to 165.6°C. Batal et al. (2000) showed that chicks fed soyflakes with trypsin inhibitor content as high as 3.4 mg/g of sample had adequate growth performance. According to Araba and Dale (1990), urease index has been used to indicate the presence of trypsin inhibitors. This assay has been useful only in detecting undercooking of SBM since the urease activity drops sharply to zero as the SBM is heated (Parsons et al., 1991). For the urease assay, the change in pH ranged from 0.38 to 0.00 in EESoy extruded at 143.3 to 165.6°C. According to Parsons (1998), optimal pH increase in the urease assay is 0.20 to 0.05. However, the author states that urease levels below 0.05 mean only that the SBM may be overprocessed and many SBM samples have zero urease values but high amino acid digestibilities.

Table 8. Effects of increasing energy from added fat and/or extruded-expelled soybean meal (EESoy) on finishing pig growth performance in a commercial swine production facility, Experiment 2[a]

	Treatments							Probability values, $P <$						
Fat level:	Low		Medium		High						Fat		ME	
Source:	SBM	EESoy	SBM	EESoy	SBM	EESoy								
Item / ME level:[b]	3.31	3.46	3.46	3.62	3.62	3.79	SEM	Source	Fat	Source × fat	Linear	Quadratic	Linear	Quadratic
Phase 1 & 2 (24.5 to 61.2 kg)														
ADG, kg	0.71	0.69	0.71	0.77	0.74	0.76	0.01	0.06	0.001	0.02	0.001	0.23	0.001	0.63
ADFI, kg[c]	1.54	1.49	1.47	1.51	1.46	1.44	0.03	0.75	0.10	0.26	0.03	0.81	0.03	0.80
Gain/feed	0.46	0.47	0.48	0.51	0.51	0.53	0.01	0.07	0.001	0.60	0.001	0.44	0.001	0.91
Phase 3 & 4 (61.2 to 122.5 kg)														
ADG, kg	0.78	0.78	0.78	0.73	0.75	0.75	0.01	0.18	0.25	0.14	0.12	0.53	0.11	0.81
ADFI, kg[c]	2.41	2.29	2.36	2.19	2.22	2.24	0.05	0.03	0.04	0.11	0.01	0.74	0.004	0.17
Gain/feed	0.32	0.34	0.33	0.34	0.34	0.34	0.01	0.28	0.37	0.25	0.18	0.71	0.09	0.22
Overall (24.5 to 122.5 kg)														
ADG, kg	0.75	0.74	0.75	0.75	0.75	0.76	0.01	0.81	0.61	0.80	0.32	0.94	0.46	0.66
ADFI, kg[c]	2.02	1.94	1.97	1.90	1.89	1.89	0.03	0.05	0.02	0.44	0.01	0.91	0.002	0.28
Gain/feed	0.37	0.38	0.38	0.39	0.40	0.40	0.01	0.02	0.001	0.52	0.001	0.91	0.001	0.32
Final weight, kg	122.5	122.3	123.4	122.7	123.0	124.1	1.22	0.55	0.47	0.31	0.36	0.42	0.50	0.40

[a]A total of 1,200 PIC (Franklin, KY) gilts with an average initial weight of 24.5 kg was used in the experiment. The values represent the mean of eight pens per treatment and 25 pigs per pen.

[b]Values represent ME in Phase 1 diets. These values decrease in each subsequent dietary phase.

[c]As-fed basis.

Table 9. Effects of increasing energy from added fat and/or extruded-expelled soybean meal (EESoy) on finishing pig carcass characteristics, Experiment 2[a]

	Treatments							Probability values, $P <$						
Fat level:	Low		Medium		High						Fat		ME	
Source	SBM	EESoy	SBM	EESoy	SBM	EESoy								
Carcass characteristics / ME level:[b]	3.31	3.46	3.46	3.62	3.62	3.79	SEM	Source	Fat	Source × Fat	Linear	Quadratic	Linear	Quadratic
Without hot carcass weight (HCW) as a covariate														
HCW, kg	93.2	91.8	94.2	91.4	93.6	94.6	0.84	0.13	0.15	0.09	0.07	0.47	0.38	0.16
Yield, %	75.9	75.5	76.0	75.6	76.0	75.6	0.003	0.14	0.95	0.99	0.77	0.87	0.56	0.99
Back fat, mm	16.9	17.1	17.8	16.8	17.4	17.7	0.36	0.75	0.36	0.14	0.15	0.94	0.19	0.91
Loin depth, mm	59.8	57.5	58.3	57.9	57.3	58.6	0.91	0.52	0.70	0.15	0.42	0.78	0.31	0.07
Lean, %	55.8	55.3	55.0	55.5	55.1	55.1	0.254	0.98	0.25	0.20	0.10	0.87	0.10	0.49
Fat-free lean, %	50.6	50.4	50.2	50.5	50.4	50.2	0.162	0.75	0.60	0.37	0.34	0.71	0.23	0.60
With hot carcass weight as a covariate														
Yield, %	75.9	75.5	76.0	75.6	76.0	75.6	0.003	0.17	0.96	0.99	0.83	0.86	0.48	0.85
Back fat, mm	16.9	17.4	17.6	17.2	17.3	17.5	0.35	0.71	0.73	0.38	0.51	0.67	0.32	0.51
Loin depth, mm	59.9	58.3	57.7	59.0	57.0	57.8	0.80	0.82	0.14	0.20	0.05	0.89	0.11	0.21
Lean, %	55.8	55.3	55.1	55.4	55.2	55.1	0.263	0.78	0.41	0.27	0.20	0.78	0.15	0.31
Fat-free lean, %	50.6	50.3	50.3	50.4	50.4	50.3	0.169	0.66	0.69	0.45	0.46	0.67	0.28	0.49

[a]A total of 1,200 PIC (Franklin, KY) gilts with an average initial weight of 24.5 kg was used in the experiment. The values represent the mean of eight pens per treatment and 25 pigs per pen.
[b]Values represent ME in Phase 1 diets. These values decrease in each subsequent dietary phase.

In this experiment, the EESoy treatments were processed in a narrower range of temperatures than in other studies. This is evident by the results from the protein quality tests. According to the studies cited earlier, each test has a threshold, or range of values, that is considered to be indicative of adequate thermal processing. Our results may suggest that for EESoy, we may be able to further refine the ideal range of analytical test results used to evaluate soybean meals. This is based on the changes in growth performance, suggesting a processing range of 148.9 to 154.4°C for EESoy, and the change in corresponding protein quality test results. In this experiment, we can further refine the PDI and trypsin inhibitor content recommendations to less than 19% and 2.00 mg of TI/g of sample, respectively. The KOH assay results were consistent with previous findings, suggesting a value of approximately 75%, indicating optimal soybean meal processing. The urease index is an excellent measurement of underprocessed soybean meal. Both the KOH and urease assays would be simple, quick, and relatively inexpensive for commercial application.

In Exp. 2, from d 0 to 54 (24.5 to 61.2 kg), a source × fat interaction ($P < 0.02$) was observed for ADG (Table 8). In the diets without added fat, pigs fed SBM had greater ADG than those fed EESoy. However, when medium and high levels of fat were added, pigs fed EESoy had greater ADG than those fed SBM. Replacing SBM with EESoy had no affect on ADFI but tended ($P < 0.07$) to increase G/F. Increasing added fat decreased (linear, $P < 0.03$) ADFI and increased (linear, $P < 0.0003$) G/F. Also, as the ME increased, ADG and G/F improved (linear, $P < 0.001$). This response to increasing the energy density of the diet by adding fat agrees with previous research conducted by Stahly et al. (1981) and De la Llata et al. (2001). However, Tribble et al. (1979) and Smith et al. (1999) found no differences in growth performance by increasing the energy density of the diet in the grower stage. During this grower period, pigs are in an energy-dependent stage of growth and would be expected to increase in growth as energy intake increases (Campbell and Taverner, 1988). One of the possible reasons for differences between the results of different studies could come from the difference in feed intakes. Pigs in commercial facilities generally have lower ADFI compared with those observed in university research environments (De la Llata et al., 2001) and can potentially respond to the added energy intake.

From d 54 to 126 (61.2 to 122.5 kg), ADG was not affected ($P > 0.12$) by either EESoy or added fat. However, ADFI decreased with the addition of EESoy ($P < 0.02$) or increasing added fat (linear, $P < 0.01$). Feed efficiency was not affected ($P > 0.18$) by dietary treatment. As ME increased, ADFI decreased ($P < 0.004$). This response to increasing energy density of the diet is similar to the response found by Tribble et al. (1979) and De la Llata et al. (2001). However, Tribble et al. (1979) reported an improvement in G/F. Smith et al.

(1999), on the other hand, observed a decreasing effect on ADG as the energy density of the diet increased.

For the overall experiment, ADG was not affected ($P > 0.32$) by either EESoy or added fat. However, increasing dietary energy content by either replacing SBM with EESoy and/or increasing added fat decreased ADFI ($P < 0.06$, and linear, $P < 0.03$, respectively) and improved G/F ($P < 0.02$, and linear $P < 0.01$, respectively). Furthermore, as ME increased, ADFI decreased ($P < 0.002$) and G/F improved ($P < 0.0001$). The response to increasing energy density of the diet agrees with Azain et al. (1991) and De la Llata et al. (2001).

No differences were observed in the carcass data among the dietary treatments with or without the use of hot carcass weight as a covariate (Table 9). These results are supported by data from Seerly et al. (1978a), Tribble et al. (1979), and Azain et al. (1991). These studies all maintained a constant calorie:lysine ratio. Also, De la Llata et al. (2001) found no differences in carcass traits as the energy density of the diet increased. However, in that study, there were differences in backfat thickness despite the constant calorie:lysine ratio, but it was correlated with the heavier market weights of pigs fed added-fat diets. Thus, when hot carcass weight was used as a covariate, no differences were observed. We anticipated the possibility that pigs fed the high-ME diet might grow faster and be heavier at the conclusion of the study, thus justifying using hot carcass weight as a covariate. However, a large impact of added fat would not be expected in our experiment because low levels of fat were added during the late finishing phase.

There have been some studies (Tribble et al., 1979; Smith et al., 2001) that disagree with the ADG response to increasing energy density of the diet observed in this experiment. This could be due to the differences in feed intake levels between research and commercial facilities. Because feed intakes may be lower in a commercial facility compared with a university research environment, a greater benefit will be demonstrated in a commercial facility as the energy density of the diet is increased.

Implications

Extruded-expelled soybean meal should be processed at approximately 154.4°C. The procedures to evaluate adequately processed extruded-expelled soybean meal would be a combination of assays. Potassium hydroxide solubility and urease index could provide a measure of properly processed extruded-expelled soybean meal. Both procedures could be implemented at the feed mill or production plant as a relatively inexpensive measure of quality. Also, results indicate that extruded-expelled soybean meal and solvent-extracted soybean meal affect average daily gain, average daily feed intake, and feed efficiency similarly when formulated to the same energy level.

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