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Influence of Protein Source on Growth Performance in Nursery Pigs

Ethan B. Stas, Mike D. Tokach, Robert D. Goodband, Jason C. Woodworth, Joel M. DeRouchey, and Jordan T. Gebhardt[1]

Summary

A total of 330 pigs (241 × 600, DNA; initially 10.7 lb) were used to determine the influence of dietary protein source on growth performance in nursery pigs. At weaning, pigs were randomly allotted to 1 of 6 dietary treatments with 4 or 5 pigs per pen and 12 replications per treatment. Dietary treatments were arranged in a one-way treatment structure with diets containing different protein sources; enzymatically treated soybean meal (HP 300; Hamlet Protein, Findlay, OH), spray-dried bovine plasma (APC Corp, Ankeny, IA), fermented soybean meal (ME-PRO; Prairie Aquatech, Brookings, SD) with or without fish solubles (TASA, Lima, Peru), fish meal (TASA Prime meal; TASA, Lima, Peru), and custom-made fish meal (TASA Swine; TASA, Lima, Peru). Because of a delay in arrival of the fish meal source, all pigs were placed on a common phase 1 diet for 3 d after weaning. On d 3, all feeders were weighed, dumped, and refilled with experimental diets. Pigs were fed experimental phase 1 diets for 9 d (d 3 to 12) followed by phase 2 diets for 15 d. Following phase 2, all pigs were fed a common diet for an additional 15 d. In all weigh periods and overall, there were no significant differences between treatments for BW, ADG, ADFI, and F/G. For economic analysis (d 0 to 40), pigs fed spray-dried bovine plasma had the greatest ($P \leq 0.001$) feed cost and feed cost per lb of gain compared to all other treatments. There were no differences in revenue or IOFC between treatments. In summary, utilizing alternative protein sources in phase 1 and 2 nursery pigs' diets had no effect on growth performance. However, there was a 5 to 7% improvement in ADG for pigs fed spray-dried bovine plasma and custom-made fish meal.

Introduction

Although soybean meal is the predominant protein source used in nursery pig diets, it contains antinutritional factors that limit its inclusion rate in diets immediately after weaning. Thus, other protein sources are used to meet the pig's amino acid requirements. These protein sources must be highly digestible and palatable to encourage feed intake. Ideally, the protein source will also provide other benefits, such as improving the omega 6:3 fatty acid ratio or providing other immunological benefits.

Fish meal traditionally has been known as a highly palatable and digestible ingredient for nursery pig diets. It is considered a good protein source due to its content of AA,

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vitamins, minerals, and omega 3 fatty acids.[2] Fish meal has been shown to increase nursery pig feed intake and body weight gain.[3] In recent years, fish meal has often been replaced with fermented or enzymatically hydrolyzed soybean products to reduce cost or because of variation in quality of fish meal sources. Fermented soybean meal has also been shown to improve feed efficiency and AA digestibility.[4] However, a high-quality fish meal or additives produced from whole fish rather than fish byproducts may impact feed intake and pig performance more than other protein sources. Therefore, the objective of this study was to evaluate the influence of various protein sources on nursery pig performance.

Procedures

The Kansas State University Animal Care and Use Committee approved the protocol used in this experiment. The experiment was conducted at the Kansas State University Swine Teaching and Research Center. Each pen was equipped with a 4-hole, dry self-feeder and a nipple waterer to provide *ad libitum* access to feed and water.

Animals and diets

A total of 330 pigs (241 × 600, DNA; initially 10.7 lb) were used in a 40-d nursery trial. Pigs were weaned at approximately 19 d of age and placed in pens of 4 or 5 pigs each based on initial weight and gender. At weaning, pigs were randomly allotted to 1 of 6 dietary treatments with 12 replications per treatment. Due to a limited number of pigs, 42 pens were allotted with 5 pigs per pen (7 replications per treatment) and the remaining 30 pens were allotted with 4 pigs per pen (5 replications per treatment). Dietary treatments were arranged in a one-way treatment structure with diets containing different protein sources. Protein sources included enzymatically treated soybean meal (HP 300; Hamlet Protein, Findlay, OH); spray-dried bovine plasma (APC Corp, Ankeny, IA); fermented soybean meal (ME-PRO; Prairie Aquatech, Brookings, SD) with or without fish solubles (TASA, Lima, Peru); fish meal (TASA Prime meal; TASA, Lima, Peru); and custom-made fish meal (TASA Swine; TASA, Lima, Peru). Protein sources were added to the diet on a digestible lysine basis to keep soybean meal level consistent across all treatments. Diets were formulated to contain 1.40% (phase 1) and 1.35% (phase 2) SID Lys and met or exceeded nutrient requirements established by the NRC (2012).[5] Because of a delay in arrival of the fish meal source, all pigs were placed on a common phase 1 diet for 3 d after weaning. On d 3, all feeders were weighed, dumped, and refilled with experimental diets. On average, each pig consumed 0.5 lb of common phase 1 diet. Treatment diets were fed for 9 d in phase 1 (d 3 to 12) and 13 d in phase 2 (d 12 to 25). Following phase 2, all pigs were fed a common diet for an additional 15 d (d 25 to 40).

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[2] Li, Q., J. H. Brendemuhl, K. C. Jeong, and L. Badinga. 2014. Effects of dietary omega-3 polyunsaturated fatty acids on growth and immune response of weanling pigs. J. Anim. Sci. Technol. 56:7. doi:10.1186/2055-0391-56-7.

[3] Jones, A. M., F. Wu, J. C. Woodworth, M. D. Tokach, R. D. Goodband, J. M. DeRouchey, and S. S. Dritz. 2018. Evaluating the effects of fish meal source and level on growth performance of nursery pigs. Trans. Anim. Sci. 2018.2:144-155. https://doi.org/10.1093/tas/txy010.

[4] Jones, C. K., J. M. DeRouchey, J. L. Nelssen, M. D. Tokach, S. S. Dritz, and R. D. Goodband. 2010. Effects of fermented soybean meal and specialty animal protein sources on nursery pig performance. J. Anim. Sci. 88:1725-1732. https://doi.org/10.2527/jas.2009-2110.

[5] National Research Council. 2012. Nutrient Requirements of Swine: Eleventh Revised Edition. Washington, DC: The National Academies Press. https://doi.org/10.17226/13298.

The basal diets for phases 1 and 2 were manufactured at Hubbard Feeds in Beloit, KS. The basal diets were divided into 6 batches and protein sources were added and mixed at the Kansas State University O.H. Kruse Feed Technology Innovation Center in Manhattan, KS, to form the six experimental diets. Individual pig weights and feed disappearance were measured on d 12, 19, 25, 33, and 40 to determine ADG, ADFI, and F/G.

A sample of each protein source was submitted for amino acid profile (Table 1). Representative diet samples were obtained from every fifth bag of manufactured feed. The diet samples were stored at -20°C (-4°F) until they were homogenized, subsampled, and submitted for analysis of crude protein (CP), dry matter (DM), ether extract (EE), Ca, and P (Tables 2 and 3). All samples were submitted to the University of Missouri Experiment Station Chemical Laboratories (Columbia, MO).

Economic analysis

For the economic analysis, total feed cost per pig, feed cost per lb of gain, revenue, and income over feed cost (IOFC) were calculated for high and low ingredient prices and market pig price. Feed cost per pig placed was determined by multiplying total feed intake by diet cost. Feed cost per lb of gain was calculated by dividing the total feed cost per pig by the total weight gained. Revenue per pig placed was determined by total gain times the dressing percentage (0.75) and then multiplied by carcass price to convert to a live price. Income over feed cost (IOFC) was calculated using revenue per pig placed minus feed cost per pig placed. For high ingredient price scenarios, the following prices were used: corn = $6.00/bushel ($214.29/ton); soybean meal = $400/ton; L-Lys HCl = $0.80/lb; DL-Met = $2.50/lb; L-Thr = $1.20/lb; L-Trp = $5.00/lb; L-Val = $4.00/lb; enzymatically treated soybean meal = $0.52/lb; spray-dried bovine plasma = $2.50/lb; fermented soybean meal = $0.61/lb; enriched fermented soybean meal = $0.62/lb; fish meal = $0.70/lb; custom-made fish meal = $0.77/lb. For low ingredient price scenarios, the following prices were used: corn = $3.00/bushel ($107.14/ton); soybean meal = $300/ton; L-Lys HCl = $0.65/lb; DL-Met = $1.70/lb; L-Thr = $0.85/lb; L-Trp = $3.00/lb; L-Val = $2.50/lb; enzymatically treated soybean meal = $0.52/lb; spray-dried bovine plasma = $2.50/lb; fermented soybean meal = $0.61/lb; enriched fermented soybean meal = $0.62/lb; fish meal = $0.70/lb; custom-made fish meal = $0.77/lb.

Statistical analysis

Data were analyzed as a completely randomized design using the RStudio environment (Version 1.3.1093, RStudio, Inc., Boston, MA) using R programming language [Version 4.0.2 (2020-06-22), R Core Team, R Foundation for Statistical Computing, Vienna, Austria] with pen as the experimental unit. Main effects of protein source were tested. Differences between treatments were considered significant at $P \leq 0.05$ and marginally significant at $0.05 < P \leq 0.10$.

Results and Discussion

The analyzed AA profile and proximate analysis (Table 1, 2, and 3) were reasonably consistent compared to formulated values for protein sources and diets.

In all weigh periods and overall (Table 4), there were no differences between treatments for BW, ADG, ADFI, and F/G. Although there was a 5 to 7% improvement in ADG

during the treatment period for the spray-dried bovine plasma and custom-made fish meal treatment, the differences were not significant.

For economic analysis in both ingredient price scenarios, pigs fed spray-dried bovine plasma had the greatest ($P \leq 0.001$) feed cost and feed cost per lb of gain compared to all other treatments. There were no differences between treatments for revenue or IOFC in either price scenario.

In summary, the results of this experiment indicate that the protein sources used in this study did not significantly affect growth performance of nursery pigs differently. However, feeding spray-dried bovine plasma and custom-made fish meal can numerically improve weight gain.

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Table 1. Chemical and calculated analysis of protein sources[1]

Item, %	Enzymatically treated SBM	Bovine plasma	Fermented SBM	Enriched fermented SBM[2]	Fish meal	Custom-made fish meal[3]
DM	92.45	88.68	94.53	92.08	92.43	90.11
CP	55.63	76.21	72.39	70.24	66.73	64.94
EE	2.12	0.00	1.61	1.80	8.76	8.48
Crude fiber	4.08	0.00	6.69	6.26	0.28	0.26
Ash	6.86	8.04	1.33	2.16	16.75	16.58
Amino acids						
Ala	2.37	3.70	3.08	3.02	4.14	4.01
Arg	3.84	4.39	5.09	4.86	3.76	3.62
Asp	6.16	7.74	8.38	7.97	5.91	5.66
Cys	0.81	2.57	1.03	0.97	0.65	0.61
Glu	9.90	10.53	13.20	12.61	8.44	8.16
Gly	2.30	2.68	3.07	3.06	4.09	4.01
His	1.40	2.29	1.85	1.87	2.25	2.25
Ile	2.69	2.46	3.74	3.54	2.86	2.72
Leu	4.20	7.13	5.86	5.59	4.78	4.58
Lys	3.14	6.86	4.36	4.22	5.28	5.08
Met	0.76	0.93	0.99	0.96	1.77	1.69
Phe	2.87	4.05	4.03	3.81	2.71	2.58
Pro	2.72	3.97	3.80	3.64	2.65	2.57
Ser	2.36	4.42	3.27	3.11	2.21	2.12
Thr	2.12	5.01	2.77	2.65	2.71	2.59
Trp	0.71	1.44	1.02	0.96	0.73	0.69
Tyr	2.04	3.90	2.69	2.54	2.08	1.97
Val	2.74	5.35	3.76	3.58	3.29	3.14

[1] A sample of each protein source was collected, homogenized, subsampled, and submitted to the University of Missouri Experiment Station Chemical Laboratories (Columbia, MO) for proximate analysis and amino acid profile.
[2] Analysis of enriched soybean meal was calculated using the chemical analysis of fermented soybean meal (ME-PRO; Prairie Aquatech; Brookings, SD) and fish solubles (TASA; Lima, Peru). SBM = soybean meal.
[3] Analysis of custom-made fish meal (TASA Swine; TASA, Lima, Peru) was calculated using the chemical analysis of fish meal (TASA Prime meal; TASA, Lima, Peru) and fish solubles (TASA, Lima, Peru).
EE = ether extract.

Table 2. Phase 1 diet composition (as-fed basis)[1]

Item	Enzymatically treated SBM[2]	Bovine plasma[2]	Fermented SBM[2]	Enriched fermented SBM[2]	Fish meal[2]	Custom-made fish meal[2]
Ingredients, %						
Corn	37.89	41.67	39.78	39.57	40.77	40.54
Soybean meal (46.5% CP)	23.72	23.72	23.72	23.72	23.72	23.72
Whey powder	25.00	25.00	25.00	25.00	25.00	25.00
Enzymatically treated soybean meal	7.00	---	---	---	---	---
Fermented soybean meal	---	---	5.00	---	---	---
Enriched fermented soybean meal	---	---	---	5.21	---	---
Fish meal	---	---	---	---	4.85	---
Custom-made fish meal	---	---	---	---	---	5.05
Spray-dried bovine plasma	---	3.50	---	---	---	---
Corn oil	3.00	3.00	3.00	3.00	3.00	3.00
Limestone	0.81	0.83	0.76	0.76	0.51	0.53
Monocalcium phosphate (21% P)	0.65	0.55	0.78	0.78	0.18	0.20
Salt	0.33	0.13	0.35	0.35	0.30	0.30
L-Lys-HCl	0.35	0.35	0.35	0.35	0.35	0.35
DL-Met	0.23	0.21	0.23	0.23	0.21	0.21
L-Thr	0.15	0.15	0.15	0.15	0.18	0.18
L-Trp	0.02	0.02	0.02	0.02	0.02	0.02
L-Val	0.08	0.10	0.08	0.08	0.13	0.13
Zinc oxide	0.39	0.39	0.39	0.39	0.39	0.39
Vitamin premix[3]	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15
Total	100	100	100	100	100	100

continued

Table 2. Phase 1 diet composition (as-fed basis)[1]

Item	Enzymatically treated SBM[2]	Bovine plasma[2]	Fermented SBM[2]	Enriched fermented SBM[2]	Fish meal[2]	Custom-made fish meal[2]
SID amino acids, %						
Lys	1.40	1.40	1.40	1.40	1.40	1.40
Ile:Lys	62	56	62	61	58	58
Leu:Lys	116	114	119	118	111	111
Met:Lys	36	34	36	36	38	38
Met and Cys:Lys	58	58	58	58	58	58
Thr:Lys	64	64	64	64	64	64
Trp:Lys	19.5	19.3	19.3	19.2	19.3	19.3
Val:Lys	70	70	70	70	70	70
His:Lys	35	35	36	36	35	35
Total Lys, %	1.53	1.54	1.54	1.54	1.55	1.54
NE NRC,[4] kcal/lb	1,186	1,192	1,188	1,188	1,194	1,194
SID Lys:NE, g/Mcal	5.36	5.33	5.35	5.35	5.32	5.32
CP, %	21.9	21.0	21.8	21.8	21.6	21.6
Ca, %	0.76	0.74	0.75	0.75	0.75	0.75
P, %	0.64	0.61	0.63	0.63	0.63	0.63
STTD P, %	0.54	0.54	0.54	0.54	0.54	0.54
Analyzed values, %						
DM	91.32	91.38	91.66	91.30	91.09	90.87
CP	18.73	18.83	19.29	19.79	19.31	19.18
Ether extract	3.66	3.84	3.83	3.62	3.80	3.72
Crude fiber	2.08	1.85	2.13	2.23	1.67	1.81
Ash	7.37	6.62	6.38	7.69	6.30	6.32
Ca	1.05	0.81	0.76	0.75	0.88	0.69
P	0.64	0.72	0.78	0.68	0.76	0.64

[1] Phase 1 diets were fed from approximately 11 to 13 lb.

[2] 1) HP 300; Hamlet Protein, Findlay, OH. 2) Spray-dried bovine plasma; APC Corp, Ankeny, IA. 3) ME-PRO; Prairie Aquatech, Brookings, SD. 4) ME-PRO with fish solubles; Prairie Aquatech, Brookings, SD; TASA, Lima, Peru. 5) TASA Prime meal; TASA, Lima, Peru. 6) TASA Swine; TASA, Lima, Peru. SBM = soybean meal.

[3] Vitamin premix with phytase provided an estimated release of 0.13% STTD P.

[4] National Research Council. 2012. Nutrient Requirements of Swine: Eleventh Revised Edition. Washington, DC: The National Academies Press. https://doi.org/10.17226/13298.

Table 3. Phase 2 diet composition (as-fed basis)[1]

Item	Enzymatically treated SBM[2]	Bovine plasma[2]	Fermented SBM[2]	Enriched fermented SBM[2]	Fish meal[2]	Custom-made fish meal[2]
Ingredients, %						
Corn	53.37	57.15	55.27	55.07	56.28	56.02
Soybean meal, 46.5% CP	24.82	24.82	24.82	24.82	24.82	24.82
Whey powder	10.00	10.00	10.00	10.00	10.00	10.00
Enzymatically treated soybean meal	7.00	---	---	---	---	---
Fermented soybean meal	---	---	5.00	---	---	---
Enriched fermented soybean meal	---	---	---	5.21	---	---
Fish meal	---	---	---	---	4.85	---
Custom-made fish meal	---	---	---	---	---	5.05
Spray-dried bovine plasma	---	3.50	---	---	---	---
Corn oil	1.00	1.00	1.00	1.00	1.00	1.00
Limestone	0.91	0.93	0.88	0.86	0.61	0.63
Monocalcium phosphate, 21% P	0.90	0.80	1.03	1.03	0.40	0.45
Salt	0.55	0.35	0.55	0.55	0.53	0.53
L-Lys-HCl	0.38	0.38	0.38	0.38	0.38	0.38
DL-Met	0.20	0.18	0.20	0.20	0.19	0.19
L-Thr	0.15	0.15	0.15	0.15	0.18	0.18
L-Trp	0.02	0.02	0.03	0.03	0.03	0.03
L-Val	0.06	0.09	0.07	0.07	0.11	0.11
Zinc oxide	0.25	0.25	0.25	0.25	0.25	0.25
Vitamin premix[3]	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15
Total	100	100	100	100	100	100

continued

Table 3. Phase 2 diet composition (as-fed basis)[1]

Item	Enzymatically treated SBM[2]	Bovine plasma[2]	Fermented SBM[2]	Enriched fermented SBM[2]	Fish meal[2]	Custom-made fish meal[2]
SID amino acids, %						
Lys	1.35	1.35	1.35	1.35	1.35	1.35
Ile:Lys	62	55	61	61	58	58
Leu:Lys	120	119	123	123	116	115
Met:Lys	36	33	36	36	38	38
Met and Cys:Lys	58	58	58	58	58	58
Thr:Lys	63	63	63	63	63	63
Trp:Lys	19.4	19.3	19.2	19.2	19.3	19.2
Val:Lys	70	70	70	70	70	70
His:Lys	37	37	38	38	38	38
Total Lys, %	1.49	1.50	1.50	1.50	1.50	1.50
NE NRC,[4] kcal/lb	1,131	1,137	1,133	1,133	1,140	1,139
SID Lys:NE, g/Mcal	5.41	5.39	5.40	5.40	5.37	5.38
CP, %	22.0	21.1	21.9	21.9	21.7	21.7
Ca, %	0.76	0.73	0.76	0.75	0.74	0.75
P, %	0.63	0.61	0.63	0.63	0.62	0.63
STTD P, %	0.51	0.51	0.51	0.51	0.51	0.51
Analyzed values, %						
DM	90.06	89.98	90.23	90.21	90.25	90.09
CP	22.84	17.08	18.75	18.41	17.58	18.47
Ether extract	2.43	2.27	2.39	2.36	2.94	2.85
Crude fiber	2.13	2.06	2.29	2.32	1.74	1.83
Ash	6.12	5.73	5.50	5.92	5.93	6.69
Ca	0.64	0.66	0.64	0.75	0.67	0.68
P	0.54	0.52	0.52	0.55	0.57	0.59

[1] Phase 2 diets were fed from approximately 13 to 26 lb.
[2] 1) HP 300; Hamlet Protein, Findlay, OH. 2) Spray-dried bovine plasma; APC Corp, Ankeny, IA. 3) ME-PRO; Prairie Aquatech, Brookings, SD. 4) ME-PRO with fish solubles; Prairie Aquatech, Brookings, SD; TASA, Lima, Peru. 5) TASA Prime meal; TASA, Lima, Peru. 6) TASA Swine; TASA, Lima, Peru. SBM = soybean meal.
[3] Vitamin premix with phytase provided an estimated release of 0.13% STTD P.
[4] National Research Council. 2012. Nutrient Requirements of Swine: Eleventh Revised Edition. Washington, DC: The National Academies Press. https://doi.org/10.17226/13298.

Table 4. Effects of protein source on nursery pig performance[1, 2]

Protein source:	Enzymatically treated SBM[3]	Bovine plasma[3]	Fermented SBM[3]	Enriched fermented SBM[3]	Fish meal[3]	Custom-made fish meal[3]	SEM	*P* =
BW, lb								
d 0	10.8	10.7	10.7	10.7	10.7	10.7	0.12	0.996
d 12	13.0	13.4	12.9	13.3	13.5	13.4	0.25	0.507
d 25	25.1	26.2	25.3	25.4	25.8	26.2	0.57	0.652
d 40	43.6	45.2	43.6	43.6	44.2	44.8	0.93	0.731
Day 0 to 12[4]								
ADG, lb	0.19	0.22	0.19	0.19	0.21	0.23	0.018	0.449
ADFI, lb	0.36	0.34	0.31	0.32	0.34	0.36	0.019	0.293
F/G	1.96	1.58	1.68	1.75	1.66	1.70	0.107	0.211
Day 12 to 25								
ADG, lb	0.93	0.99	0.95	0.94	0.94	0.98	0.030	0.601
ADFI, lb	1.27	1.36	1.31	1.25	1.27	1.34	0.040	0.283
F/G	1.36	1.37	1.38	1.34	1.34	1.37	0.017	0.502
Day 0 to 25 (experimental period)								
ADG, lb	0.58	0.62	0.59	0.58	0.59	0.62	0.021	0.426
ADFI, lb	0.83	0.87	0.83	0.80	0.82	0.87	0.026	0.318
F/G	1.45	1.40	1.42	1.39	1.38	1.41	0.021	0.346
Day 25 to 40 (common period)								
ADG, lb	1.23	1.26	1.22	1.21	1.23	1.24	0.035	0.926
ADFI, lb	1.99	1.96	1.96	1.96	1.94	1.94	0.057	0.990
F/G	1.62	1.56	1.61	1.62	1.57	1.56	0.026	0.258
Day 0 to 40								
ADG, lb	0.82	0.86	0.82	0.81	0.83	0.85	0.022	0.601
ADFI, lb	1.26	1.27	1.25	1.24	1.23	1.27	0.030	0.908
F/G	1.54	1.48	1.52	1.52	1.48	1.49	0.020	0.162

continued

Table 4. Effects of protein source on nursery pig performance[1, 2]

Protein source:	Enzymatically treated SBM[3]	Bovine plasma[3]	Fermented SBM[3]	Enriched fermented SBM[3]	Fish meal[3]	Custom-made fish meal[3]	SEM	*P* =
Economics,[5,6] $/pig placed								
Low ingredient prices[7]								
Feed cost	7.14[b]	8.49[a]	7.08[b]	6.80[b]	6.86[b]	7.29[b]	0.202	<0.001
Feed cost/lb gain[8]	0.22[b]	0.25[a]	0.22[b]	0.22[b]	0.21[b]	0.22[b]	0.003	<0.001
Revenue[9]	14.51	15.39	14.82	14.22	14.44	15.09	0.444	0.435
IOFC[10]	7.38	6.91	7.74	7.42	7.58	7.80	0.274	0.240
High ingredient prices[11]								
Feed cost	9.72[b]	11.16[a]	9.71[b]	9.32[b]	9.38[b]	9.98[b]	0.274	0.001
Feed cost/lb gain	0.30[b]	0.33[a]	0.30[b]	0.30[b]	0.29[b]	0.30[b]	0.004	<0.001
Revenue[12]	21.28	22.58	21.73	20.86	21.18	22.13	0.652	0.435
IOFC	11.57	11.42	12.02	11.54	11.75	12.15	0.417	0.781

[1] A total of 330 pigs (initial BW of 10.7 ± 0.38 lb) were used in a 40-d nursery trial with 4 or 5 pigs per pen and 12 pens per treatment. Pigs were weaned at approximately 19 d of age and allotted to treatment in a completely randomized design. Dietary treatments were arranged in a one-way treatment structure with main effects of protein source.

[2] Pens of pigs were fed diets in 2 phases. Pigs were fed phase 1 diets from 0 to 12 d after weaning. Following phase 1, pigs were fed phase 2 diets from d 12 to 25. Following the experimental period, all pigs were fed a common diet from d 25 to 40.

[3] 1) HP 300; Hamlet Protein, Findlay, OH. 2) Spray-dried bovine plasma; APC Corp, Ankeny, IA. 3) ME-PRO; Prairie Aquatech, Brookings, SD. 4) ME-PRO with fish solubles; Prairie Aquatech, Brookings, SD; TASA, Lima, Peru. 5) TASA Prime meal; TASA, Lima, Peru. 6) TASA Swine; TASA, Lima, Peru. SBM = soybean meal

[4] All pigs were placed on a common phase 1 diet for 3 d after weaning. Once experimental diets arrived, all feeders were weighed, dumped, and refilled with experimental diets. On average, each pig consumed 0.5 lb of the common phase 1 diet.

[5] In the low ingredient price scenario the total feed cost per ton were calculated: Phase 1) enzymatically treated soybean meal = $511.87; spray-dried bovine plasma = $617.91; fermented soybean meal = $502.97; enriched fermented soybean meal = $506.75; fish meal = $510.50; custom-made fish meal = $513.90; Phase 2) enzymatically treated soybean meal = $352.85; spray-dried bovine plasma = $459.06; fermented soybean meal = $344.19; enriched fermented soybean meal = $347.97; fish meal = $351.40; custom-made fish meal = $354.88.

[6] In the high ingredient price scenarios the total feed cost per ton were calculated: Phase 1) enzymatically treated soybean meal = $597.53; spray-dried bovine plasma = $707.89; fermented soybean meal = $590.99; enriched fermented soybean meal = $594.54; fish meal = $600.30; custom-made fish meal = $608.33; Phase 2) enzymatically treated soybean meal = $447.73; spray-dried bovine plasma = $558.38; fermented soybean meal = $441.58; enriched fermented soybean meal = $445.15; fish meal = $450.41; custom-made fish meal = $458.53.

[7] Corn = $3.00/bushel ($107.14/ton); soybean meal = $300/ton; L-Lys HCl = $0.65/lb; DL-Met = $1.70/lb; L-Thr = $0.85/lb; L-Trp = $3.00/lb; L-Val = $2.50/lb; enzymatically treated soybean meal = $0.52/lb; spray-dried bovine plasma = $2.00/lb; fermented soybean meal = $0.61/lb; enriched fermented soybean meal = $0.62/lb; fish meal = $0.70/lb; custom-made fish meal = $0.77/lb.

[8] Feed cost/lb gain = total feed cost per pen ÷ total gain per pen.

[9] Revenue = (total gain/pig placed × 0.75) × $0.60.

[10] Income over feed cost = revenue – feed cost.

[11] Corn = $6.00/bushel ($214.29/ton); soybean meal = $400/ton; L-Lys HCl = $0.80/lb; DL-Met = $2.50/lb; L-Thr = $1.20/lb; L-Trp = $5.00/lb; L-Val = $4.00/lb; enzymatically treated soybean meal = $0.52/lb; spray-dried bovine plasma = $2.00/lb; fermented soybean meal = $0.61/lb; enriched fermented soybean meal = $0.62/lb; fish meal = $0.70/lb; custom-made fish meal = $0.77/lb.

[12] Revenue = (total gain/pig placed × 0.75) × $0.88.

[a,b] Means with different superscript differ ($P < 0.05$).