Evaluating the effects of fish meal source and level on growth performance of nursery pigs[1,2]

Aaron M. Jones,[*] Fangzhou Wu,[*] Jason C. Woodworth,[*] Mike D. Tokach,[*] Robert D. Goodband,[*,3] Joel M. DeRouchey,[*] and Steve S. Dritz[†]

[*]Department of Animal Sciences, College of Agriculture, Kansas State University, Manhattan, 66506; [†]Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University, Manhattan, KS 66506

ABSTRACT: Three experiments were conducted to determine the effects of fish meal source on nursery pig growth performance. In experiment 1, 250 pigs (PIC 327 × 1,050, initially 7.1 ± 1.00 kg) were fed either a corn-soybean meal-based diet, a diet containing 8.3% enzymatically treated soybean meal (HP 300, Hamlet Protein, Findlay, OH), or diets containing 6% fish meal from one of three sources (IPC 790, The Scoular Company, Minneapolis, MN; Special Select Menhaden, Omega Proteins, Houston, TX; LT Prime Menhaden, Daybrook Fisheries Inc., New Orleans, LA; source 1, 2, and 3, respectively). In a completely randomized design, there were five pigs per pen and 10 pens per treatment with diets fed for 13 d. There was no evidence for differences in ADG or ADFI among pigs fed the three fish meal sources; however, pigs fed source 1 had marginally decreased ($P = 0.068$) G:F compared with pigs fed diets with other protein sources. In experiment 2, 350 barrows (DNA Line 200 × 400; initially 6.5 ± 0.90 kg) were assigned to one of seven dietary treatments including the same control diet and diets containing the three fish meal sources used in experiment 1, but fed at 3% or 6%. There were five pigs per pen and 10 pens per treatment with diets fed for 14 d. A source × level interaction (linear, $P < 0.05$) for ADG and G:F was observed. Increasing fish meal source 1 increased ADG and G:F; however, pigs fed source 2 had improved ADG and G:F at 3%, but decreased performance at 6% compared with control pigs. Pigs fed source 3 had no further improvements in ADG or G:F beyond the 3% inclusion. Fishmeal analysis for total volatile N, and modified Torry digestibility did not appear to correspond with any growth performance differences measured in experiments 1 or 2. In experiment 3, 700 barrows (DNA Line 200 × 400, initially 6.5 ± 0.84 kg) were fed a control diet or four diets with 6% fish meal (source 3) containing either 0.87%, 8.70%, 16.52%, or 24.35% fish solubles. There were five pigs per pen and 28 pens per treatment with diets fed for 21 d. Overall, pigs fed diets with fish meal had increased ($P < 0.05$) ADG and ADFI compared with pigs fed the control diet. There was no evidence for differences in growth performance as fish solubles increased. In conclusion, inconsistencies were observed in growth responses to different fish meal sources, but the amount of fish solubles, total volatile N, or modified Torry digestibility of fishmeal does not appear to explain these differences.

Key words: fish meal, fish solubles, growth, nursery pig

Transl. Anim. Sci. 2018.2:144–155
doi: 10.1093/tas/txy010

[1]Contribution No. 18-277-J of the Kansas Agric. Exp. Stn., Manhattan, 66506-0210.

[2]Appreciation is expressed to Scott Herbert and Jason Smith, Daybrook Fisheries, Inc., New Orleans, LA and Jeff Schaeffer, The Scoular Company, Minneapolis, MN for their technical support. Appreciation is expressed to Daybrook Fisheries, Inc., New Orleans, LA; The Scoular Company, Minneapolis, MN; and Hamlet Protein Inc., Findlay, OH for their donation of LT Prime Menhaden, IPC 790, and HP 300 for the use in this study, respectively.

[3]Corresponding author: goodband@ksu.edu

Received 6, March 2018.
Accepted 22, March 2018.

INTRODUCTION

To encourage feed intake for newly weaned pigs, highly palatable and nutrient dense protein sources, such as fish meal, are commonly added to nursery diets. Fish meal is typically considered a very good protein source due to its balance of AA, vitamins and minerals, and presence of omega 3 fatty acids (Church and Kellems, 1998; Li et al., 2014). However, the quality of fish meal used can vary considerably based on the species of fish, freshness of the raw material, and processing method (Pike et al., 1990). Because of these factors, growth responses to fish meal have sometimes been inconsistent (Kim and Easter, 2001; Jones et al., 2010).

One explanation of the inconsistencies of fish meal may reflect the amount of fish solubles added back into the presscake during the manufacturing process of whole fish meal. Fish solubles are a by-product derived from the intermediate fraction generated during the manufacturing process of fish meal and oil (Soares et al., 1973). Traditionally, fish solubles have been used directly as protein source or palatability enhancer in aquaculture diets (Hertrampf and Piedad-Pascual, 2000). Fish meal produced and marketed today on average contains 8% to 15% fish solubles (Herbert, 2016, personal communication). It is unclear if the amount of fish solubles contained within fish meal will influence growth performance of pigs. Therefore, the objectives of these studies were to evaluate the growth performance of nursery pigs fed different sources of fish meal and determine if differences in growth performance are related to level of fish solubles added in fish meal during processing.

MATERIALS AND METHODS

General

The Kansas State University Institutional Animal Care and Use Committee approved the protocols used in these experiments. These experiments were conducted at the K-State Swine Teaching and Research Center (experiment 1) and K-State Segregated Early Weaning facilities (experiment 2 and 3). Experiments 1 and 2 were conducted during summer 2015 and experiment 3 was conducted during winter 2016. Each pen (1.52 × 1.22 m, experiment 1; 1.22 × 1.22 m, experiment 2 and 3) contained a four-hole dry self-feeder and either a nipple waterer (experiment 1) or cup waterer (experiment 2 and 3) for ad libitum access to feed and water. All diets were fed in meal form and prepared at the O. H. Kruse Feed Technology and Innovation Center located in Manhattan, KS.

Experiment 1

A total of 250 pigs (327 × 1,050 PIC, Hendersonville, TN; initially 7.1 ± 1.00 kg body weight) were used in a 13-d growth trial with five pigs per pen and 10 pens per treatment. Pigs were weaned at approximately 21 d of age, placed in pens and fed a common pelleted starter diet for 5 d prior to the start of the experiment. On day 0 of the experiment, pigs were weighed and pens were allotted to one of five dietary treatments in a completely randomized design. Dietary treatments included a corn-soybean meal-based control diet, a diet containing 8.3% enzymatically treated soybean meal (**ESBM**; HP 300, Hamlet Protein, Findlay, OH), or diets with 6% fish meal from one of three sources (IPC 790, The Scoular Company, Minneapolis, MN; Special Select Menhaden, Omega Proteins, Houston, TX; LT Prime Menhaden, Daybrook Fisheries Inc., New Orleans, LA; sources 1, 2, and 3, respectively; Table 1). Fish meal source 2 was from the 2014 catch year, while sources 1 and 3 were from the 2015 catch year. Diets (Table 2) were formulated such that 6% fish meal provided the same amount of standardized ileal digestible (**SID**) Lys as 8.3% ESBM. Calculated AA values and SID coefficients from NRC (2012) were used in diet formulation for the three fish meal sources, while nutrient values for the ESBM were provided by the manufacturer. Pigs and feeders were weighed on days 0, 7, and 13 of the trial to determine ADG, ADFI, and G:F.

Experiment 2

A total of 350 barrows (Line 200 × 400 DNA, Columbus, NE; initially 6.5 ± 0.90 kg body weight) were used in a 14-d growth trial with five pigs per pen and 10 pens per treatment. Pigs were weaned at approximately 21 d of age, placed in pens, and fed a common pelleted starter diet for 7 d prior to the start of the experiment. On day 0 of the experiment, pigs were weighed and pens were allotted to one of seven dietary treatments in a complete randomized design. Dietary treatments (Table 4) included the same control diets and diets with 6% fish meal from the same three sources, but different batches as in experiment 1. Additionally, diets

Table 1. Chemical analysis of test ingredients, experiment 1 (as-fed basis)[1]

		Fish meal source[3]		
Item	ESBM[2]	1	2	3
Proximate analysis, %[4]				
Dry matter	92.08	90.68	91.72	91.66
Crude protein	55.8	66.5	61.9	64.1
Ca	0.27	3.88	5.85	5.38
P	0.72	2.45	3.07	3.04
Ether extract	1.0	7.3	9.1	7.6
Ash	6.14	15.90	19.77	19.02
Total volatile N[5]	–	0.11	0.15	0.08
Modified Torry digestibility[5]	–	86.7	70.6	83.4
Total amino acids, %[6]				
Arg	3.85	3.63	3.67	3.79
Cys	0.72	0.57	0.41	0.55
His	1.31	1.95	1.09	1.37
Ile	1.89	2.20	1.75	2.07
Leu	3.91	4.66	3.60	4.42
Lys	3.25	5.02	3.86	4.82
Met	0.72	1.84	1.46	1.84
Phe	2.57	2.56	2.09	2.40
Thr	2.07	2.74	2.30	2.67
Trp	0.82	0.80	0.54	0.75
Tyr	2.01	2.04	1.61	1.95
Val	2.03	2.69	2.23	2.53

[1]Samples of protein sources were obtained at the mill during diet manufacturing.

[2]HP300 (Hamlet Protein, Findlay, OH).

[3]Source 1 (IPC 790) was from The Scoular Company (Minneapolis, MN); source 2 (Omega Special Select Menhaden) was from Omega Protein (Houston, TX); and source 3 (LT Prime Menhaden) was from Daybrook Fisheries, Inc. (New Orleans, LA).

[4]Ward Laboratories, Inc. (Kearney, NE).

[5]New Jersey Feed Laboratory (Trenton, NJ).

[6]University of Missouri Agriculture Experiment Station Chemical Laboratories (Columbia, MO).

with 3% fish meal from the same sources were also included in this trial. Pigs and feeders were weighed on days 0, 7, and 14 of the trial to determine ADG, ADFI, and G:F.

Experiment 3

Two groups of 350 barrows (700 total; Line 200 × 400 DNA, Columbus, NE; initially 6.5 ± 0.84 kg body weight) were used in a 21-d growth trial with five pigs per pen and 14 pens per treatment in each group (28 total pens per treatment). Pigs were weaned at approximately 21 d of age, placed in pens, and fed a common pelleted starter diet for 3 d prior to the start of the experiment. On day 0 of the experiment, pigs were weighed and pens were allotted to one of five dietary treatments in a randomized complete block design. Dietary treatments included a control that was corn-soybean meal-based and four diets containing 6% fish meal (source 3) with 0.87%, 8.70%, 16.52%, and 24.35% fish solubles included in the fish meal.

Two batches of fish meal were used for this experiment to form the fish meal treatments. One fish meal batch contained 0.87% solubles and the second batch contained 24.35% solubles. A composite sample from each batch of fish meal was collected and analyzed for AA content and proximate analysis prior to formulation to determine nutrient loading values (Table 5). Then, basal diets containing the 0.87% and 24.35% solubles fish meal were manufactured and then blended to create the intermediate diets (Table 6). Diets were formulated to contain 1.35% SID Lys and balanced on a NE basis by lowering the choice white grease when fish meal was added. Net energy values from the NRC (2012) were used for the high solubles fish meal because the fat level of fishmeal sample provided by NRC (2012) closely resembled the analyzed fat level of high solubles fish meal. Difference in fat concentrations between high and low solubles fish meals was determined, and that amount of choice white grease was added to the low solubles fish

Table 2. Diet composition, experiment 1 (as-fed basis)[1]

Ingredient, %	Control	ESBM	Fish meal[2]
Corn	40.55	41.53	44.86
Soybean meal, 46.5%	32.75	23.36	23.37
Corn **DDGS**[3]	10.00	10.00	10.00
Spray-dried whey	10.00	10.00	10.00
Fish meal	–	–	6.00
ESBM[4]	–	8.30	–
Choice white grease	3.00	3.00	3.00
Limestone	1.05	1.10	0.78
Monocalcium P, 21% P	1.05	1.15	0.35
Sodium chloride	0.30	0.30	0.30
L-Lys HCl	0.35	0.35	0.35
DL-Met	0.15	0.15	0.14
L-Thr	0.11	0.10	0.13
L-Trp	–	–	0.03
L-Val	0.03	–	0.05
Phytase[5]	0.02	0.02	0.02
Zinc oxide	0.25	0.25	0.25
Trace mineral premix[6]	0.15	0.15	0.15
Vitamin premix[7]	0.25	0.25	0.25
Total	100	100	100
Calculated analysis			
SID amino acid, %			
Lys	1.35	1.35	1.35
Ile:Lys	64	62	61
Met:Lys	35	35	37
Met and Cys:Lys	58	58	58
Thr:Lys	63	63	63
Trp:Lys	18.5	18.5	18.5
Val:Lys	71	71	71
Total Lys, %	1.52	1.51	1.53
Metabolizable energy, kcal/kg	3,408	3,439	3,461
Net energy, kcal/kg	2,509	2,535	2,571
SID Lys:metabolizable energy, g/Mcal	3.96	3.92	3.90
Crude protein, %	23.4	23.6	23.1
Ca, %	0.77	0.77	0.77
P, %	0.69	0.65	0.66
STTD P, %	0.54	0.53	0.52

DDGS = dried distillers grains with solubles; STTD = standardized total tract digestibility.

[1]Diets were fed from 7.1 to approximately 10.4 kg body weight.

[2]Fish meal sources were: IPC 790 (2015 catch year, The Scoular Company, Minneapolis, MN); Omega Special Select Menhaden (2014 catch year, Omega Protein, Houston, TX); Daybrook LT Prime Menhaden (2015 catch year, Daybrook Fisheries, Inc., New Orleans, LA).

[3]Dried distillers grain with solubles.

[4]ESBM (HP 300, Hamlet Protein, Findlay, OH).

[5]Ronozyme HiPhos 2700 (DSM Nutritional Products, Parsippany, NJ) provided 476.2 phytase units (FTU/kg) of diet with a release of 0.10% available P.

[6]Provided per kilogram of premix: 22 g Mn from manganese oxide; 73 g Fe from iron sulfate; 73 g Zn from zinc sulfate; 11 g Cu from copper sulfate; 198 mg I from calcium iodate; and 198 mg Se from sodium selenite.

[7]Provided per kilogram of premix: 3,527,360 IU vitamin A; 881,840 IU vitamin D3; 46 17,637 IU vitamin E; 3,307 mg riboflavin; 1,764 mg menadione; 11,023 mg pantothenic acid; 33,069 mg niacin; and 15.4 mg vitamin B12.

meal diet in order to achieve equal amounts of added fat from choice white grease and fish meal. Pigs and feeders were weighed on days 0, 7, 14, and 21 of the trial to determine ADG, ADFI, and G:F.

Diet Sampling and Analysis

Complete diet samples were obtained from feeders, composited, and frozen at −20 °C for subsequent analysis. Samples of ESBM and fish meal

Table 3. Chemical analysis of fish meal sources, experiment 2 (as-fed basis)

Item	Formulated values[1]	Fish meal source[2]		
		1	2	3
Proximate analysis, %[3]				
Dry matter	93.70	91.07	89.64	91.72
Crude protein	63.28	66.53	57.83	62.46
Ca	4.28	4.13	3.97	5.93
P	2.93	2.48	2.51	2.78
Ether extract	9.71	8.78	7.64	8.64
Ash	16.07	17.43	16.45	18.46
Total volatile N[4]	–	0.13	0.10	0.09
Modified Torry digestibility[4]	–	91.70	85.20	89.10
Total amino acids, %[5]				
Arg	3.84	3.66	3.59	3.89
Cys	0.61	0.59	0.49	0.51
His	1.44	2.26	1.35	1.39
Ile	2.56	2.13	1.93	2.18
Leu	4.47	4.75	4.14	4.46
Lys	4.56	5.18	4.54	4.86
Met	1.73	1.86	1.66	1.80
Phe	2.47	2.57	2.29	2.38
Thr	2.58	2.79	2.54	2.64
Trp	0.63	0.87	0.65	0.63
Tyr	1.88	2.09	1.87	2.00
Val	3.06	2.62	2.37	2.67

[1]Recommended values from NRC (2012).

[2]Source 1 (IPC 790) was from The Scoular Company (Minneapolis, MN); source 2 (Omega Special Select Menhaden) was from Omega Protein (Houston, TX); and source 3 (LT Prime Menhaden) was from Daybrook Fisheries, Inc. (New Orleans, LA). Samples were obtained at the mill during diet manufacturing and composited. All fish meal sources were from the 2014 catch year.

[3]Ward Laboratories, Inc., (Kearney, NE).

[4]New Jersey Feed Laboratory (Trenton, NJ).

[5]University of Missouri Agriculture Experiment Station Chemical Laboratories (Columbia, MO).

sources were collected at the feed mill at the time of feed manufacturing. Composite samples of diets, ESBM, and fish meal were split using a riffle splitter (Humboldt Mfg. Co., Norridge, IL) and processed through a 1-mm screen in a Willey mill (Thomas Scientific, Swedesboro, NJ) prior to analysis. All samples of diets and protein sources were submitted (Ward Laboratories Inc., Kearney, NE) for analysis of DM (method 935.29; AOAC International, 2012), CP (method 990.03; AOAC International, 2012), and ash (method 942.05; AOAC International, 2012); ether extract (method 920.39; AOAC International, 2012) was prepared and analyzed using an ANKOM XT20 Fat Analyzer (Ankom Technology, Fairport, NY), and Ca and P (method 968.08; AOAC International, 2012) were prepared using ICAP 6500 (ThermoElectron Corp., Waltham, MA). Samples of ESBM and fish meal used in all experiments were analyzed for complete AA profile (method 982.30; AOAC International, 2006) by the University of Missouri-Columbia College of Agriculture Experiment Station Chemical Laboratories (Columbia, MO). Fish meal samples were submitted to New Jersey Feed Laboratories, Inc. (Trenton, NJ) for analysis of modified Torry digestibility (method 971.09 – 0.0002% pepsin; AOAC International, 2006) and total volatile N analysis (method 971.09; AOAC International, 2006). Biogenic amines (method by CSL Food Science Lab, Torry, Aberdeen Scotland) were also measured for fish meal source 3 from experiment 3 by New Jersey Feed Laboratories, Inc. (Trenton, NJ).

Statistical Analysis

Data were analyzed using the GLIMMIX procedure in SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Experiments 1 and 2 were analyzed in a complete randomized design. For experiment 1, the statistical model contained the fixed effect of dietary treatment. In experiment 2, the statistical model contained the fixed effects of fish meal source, level, and their interaction; single degree-of-freedom contrasts were performed

Table 4. Diet composition, experiment 2 (as-fed basis)[1]

		Fish meal[2]	
Ingredient, %	Control	3%	6%
Corn	40.55	42.70	44.86
Soybean meal, 46.5%	32.75	28.06	23.37
Corn DDGS[3]	10.00	10.00	10.00
Spray-dried whey	10.00	10.00	10.00
Fish meal	–	3.00	6.00
Choice white grease	3.00	3.00	3.00
Limestone	1.05	0.91	0.78
Monocalcium P, 21% P	1.05	0.70	0.35
Sodium chloride	0.30	0.30	0.30
L-Lys HCl	0.35	0.35	0.35
DL-Met	0.15	0.14	0.14
L-Thr	0.11	0.12	0.13
L-Trp	–	0.01	0.03
L-Val	0.03	0.04	0.05
Phytase[4]	0.02	0.02	0.02
Zinc oxide	0.25	0.25	0.25
Trace mineral premix[5]	0.15	0.15	0.15
Vitamin premix[6]	0.25	0.25	0.25
Total	100	100	100
Calculated analysis			
SID amino acid, %			
Lys	1.35	1.35	1.35
Ile:Lys	64	62	61
Met:Lys	35	36	37
Met and Cys:Lys	58	58	58
Thr:Lys	63	63	63
Trp:Lys	18.5	18.5	18.5
Val:Lys	71	71	71
Total Lys, %	1.52	1.53	1.53
Metabolizable energy, kcal/kg	3,408	3,435	3,461
Net energy, kcal/kg	2,509	2,540	2,571
SID Lys:metabolizable energy, g/Mcal	3.96	3.93	3.90
Crude protein, %	23.4	23.2	23.1
Ca, %	0.77	0.77	0.77
P, %	0.69	0.68	0.66
STTD P, %	0.54	0.53	0.52

STTD = standardized total tract digestibility.

[1]Diets were fed from 6.5 to approximately 10.2 kg body weight.

[2]Fish meal sources were: IPC 790 (The Scoular Company, Minneapolis, MN); Omega Special Select fish meal (Omega Protein, Houston, TX); Daybrook LT Prime Menhaden Fishmeal (Daybrook Fisheries, Inc., New Orleans, LA). All fish meal sources were from the 2014 catch year.

[3]Dried distillers grain with solubles.

[4]Ronozyme HiPhos 2700 (DSM Nutritional Products, Parsippany, NJ) provided 476.2 phytase units (FTU/kg) of diet with a release of 0.10% available P.

[5]Provided per kilogram of premix: 22 g Mn from manganese oxide; 73 g Fe from iron sulfate; 73 g Zn from zinc sulfate; 11 g Cu from copper sulfate; 198 mg I from calcium iodate; and 198 mg Se from sodium selenite.

[6]Provided per kilogram of premix: 3,527,360 IU vitamin A; 881,840 IU vitamin D3; 46 17,637 IU vitamin E; 3,307 mg riboflavin; 1,764 mg menadione; 11,023 mg pantothenic acid; 33,069 mg niacin; and 15.4 mg vitamin B12.

to test the linear and quadratic effects of increasing fishmeal level on growth performance for each fishmeal source. Experiment 3 was analyzed in a randomized complete block design with the fixed effect of dietary treatment and a random effect of group. Preplanned linear and quadratic contrasts were used to determine the effects of increasing fish solubles on performance criteria. In all experiments, means were reported as least-squares means and results were considered significant at $P \leq 0.05$ and marginally significant between $P > 0.05$ and $P \leq 0.10$.

Table 5. Chemical analysis of fish meal[1], experiment 3 (as-fed basis)

Item	0.87% soluble fish meal	24.35% soluble fish meal
Proximate analysis, %[2]		
Dry matter	92.60	93.01
Crude protein	66.05	63.25
Ca	7.07	5.17
P	3.30	2.61
Ether extract	6.95	10.61
Ash	19.23	19.11
Total volatile N[3]	0.07	0.06
Pepsin digestibility[3]	94.37	93.29
Modified Torry digestibility[3]	86.4	92.4
Total amino acids, %[4]		
Arg	4.16	3.69
Cys	0.60	0.48
His	1.62	1.51
Ile	2.96	2.52
Leu	4.96	4.28
Lys	5.53	4.82
Met	1.95	1.68
Thr	2.78	2.40
Trp	0.76	0.61
Tyr	2.29	1.79
Val	3.50	3.09
Biogenic amines concentrations[3]		
Group 1[5]		
Tyramine	6	130
Putrescine	11	135
Cadaverine	38	508
Histamine	4	134
Agmatine	28	181
Spermidine	24	42
Spermine	4	21
Group 2[5]		
Tyramine	16	129
Putrescine	16	133
Cadaverine	52	483
Histamine	2	103
Agmatine	33	170
Spermidine	36	48
Spermine	21	14

[1]LT Prime Menhaden Fishmeal (Daybrook Fisheries Inc., New Orleans, LA). Samples of fish meal were obtained at the mill during diet manufacturing and composited.

[2]Ward Laboratories, Inc., (Kearney, NE).

[3]New Jersey Feed Laboratory (Trenton, NJ).

[4]University of Missouri Agriculture Experiment Station Chemical Laboratories (Columbia, MO).

[5]Group 2 pigs were placed on test 5 mo after group 1, thus, biogenic amines were tested on the same batch of fish meal to monitor the stability of the product over a 5-mo storage period in 25 kg bags located in an unregulated environment subject to fluctuations in temperature and humidity.

RESULTS

Chemical Analysis

Fish meal sources used in experiments 1, 2, and 3 were of high quality as indicated by the low total volatile N concentration (Tables 1, 3, and 5). Total volatile N was similar among fish meal sources. Fish meal source 2 used in experiment 1 and 2 contained less CP and Lys than other sources with greater deviation from the formulated values being observed in experiment 1 compared with experiment 2. Despite these differences, chemical composition of the complete diets was within analytical variation of their estimated values (Tables 7, 8, and 9).

Pepsin digestibility were similar (Table 5) between the low soluble and high soluble fish meal used in experiment 3 with the high soluble fish meal having a higher modified Torry digestibility than the low soluble fish meal (92.4% vs. 86.4%). The low soluble fish meal had a higher CP content and concentrations of AA, but lower ether extract than the high soluble fish meal. Biogenic amine concentrations (Table 5) were lower in the low soluble fish meal compared with the high soluble fish meal.

Experiment 1

There was no evidence for any treatment effects on ADG or ADFI (Table 10). However, pigs fed fish meal source 1 had a marginally lower (P = 0.068) G:F compared with pigs fed diets with other protein sources.

Experiment 2

Overall, a source × level interaction (linear, P < 0.05) for ADG, G:F, and final body weight was observed (Table 11). Increasing fish meal source 1 from 0% to 6% increased (linear, P < 0.05) ADG but had no effect on G:F. However, a quadratic effect (P < 0.05) of increasing fish meal level was observed for source 2 as pigs had improved ADG and G:F at 3%, but no different performance at 6% inclusion compared with control pigs. Feeding fish meal source 3 did not affect ADG and G:F regardless of inclusion level. No evidence for differences was detected among the dietary treatments for ADFI.

Table 6. Diet composition, experiment 3 (as-fed basis)[1]

		Soluble fractions, %[2]	
Ingredient, %	Control	0.87	24.35
Corn	40.31	48.65	48.33
Soybean meal, 46.5% CP	32.77	21.35	21.35
Corn DDGS[3]	10.00	10.00	10.00
Spray-dried whey	10.00	10.00	10.00
Fish meal[4]	–	6.00	6.00
Choice white grease	3.00	1.45	1.25
Limestone	1.07	0.42	0.62
Monocalcium P, 21% P	1.05	0.25	0.45
Sodium chloride	0.50	0.50	0.50
L-Lys HCl	0.35	0.35	0.39
DL-Met	0.15	0.14	0.16
L-Thr	0.11	0.14	0.17
L-Trp	–	0.03	0.04
L-Val	0.03	0.06	0.08
Phytase[5]	0.02	0.02	0.02
Zinc oxide	0.25	0.25	0.25
Trace mineral premix[6]	0.15	0.15	0.15
Vitamin premix[7]	0.25	0.25	0.25
Total	100	100	100
Calculated analysis			
SID amino acids, %			
Lys	1.35	1.35	1.35
Ile:Lys	64	60	58
Leu:Lys	131	127	124
Met:Lys	35	37	38
Met and Cys:Lys	58	58	58
Thr:Lys	63	63	63
Trp:Lys	18.5	18.5	18.5
Val:Lys	71	71	71
Metabolizable energy, kcal/kg	3,402	3,371	3,377
NE, kcal/kg	2,502	2,502	2,502
CP, %	23.4	22.7	22.6
Ca, %	0.78	0.78	0.78
P, %	0.69	0.66	0.66
STTD P, %	0.54	0.52	0.52

STTD = standardized total tract digestibility.

[1]Diets were fed from 6.5 to approximately 13.1 kg body weight.

[2]Treatments 0.87% and 24.35% solubles were manufactured and blended to create the intermediate levels of 8.70% and 16.52% solubles.

[3]Dried distillers grain with solubles.

[4]LT Prime Menhaden Fishmeal (Daybrook Fisheries Inc., New Orleans, LA).

[5]Ronozyme HiPhos 2700 (DSM Nutritional Products, Parsippany, NJ) provided 476.2 phytase units (FTU/kg) of diet with a release of 0.10% available P.

[6]Provided per kilogram of premix: 22 g Mn from manganese oxide; 73 g Fe from iron sulfate; 73 g Zn from zinc sulfate; 11 g Cu from copper sulfate; 198 mg I from calcium iodate; and 198 mg Se from sodium selenite.

[7]Provided per kilogram of premix: 3,527,360 IU vitamin A; 881,840 IU vitamin D3; 46 17,637 IU vitamin E; 3,307 mg riboflavin; 1,764 mg menadione; 11,023 mg pantothenic acid; 33,069 mg niacin; and 15.4 mg vitamin B12.

Experiment 3

Overall, pigs fed diets with fishmeal had increased ($P < 0.05$) final body weight, ADG, and ADFI compared with pigs fed the control diet without fish meal (Table 12). There was no evidence for differences detected for growth performance when the amount of fish solubles was increased.

Table 7. Chemical analysis of complete diets, experiment 1 (as-fed basis)[1]

			Fish meal source[3]		
Item, %	Control	ESBM[2]	1	2	3
Dry matter	90.27	88.73	88.58	90.46	90.18
Crude protein	24.20	24.20	22.30	24.00	23.20
Ca	0.81	0.89	0.84	0.89	0.89
P	0.71	0.73	0.64	0.69	0.72
Ether extract	5.70	5.10	5.50	5.40	5.60
Ash	6.11	5.36	5.76	5.73	6.21

[1]Samples were collected at the feeder, pooled, mixed, and then split using a riffle splitter to create a composite sample and submitted to Ward Laboratories (Kearney, NE) for analysis.

[2]HP 300 (Hamlet Protein, Findlay, OH).

[3]Source 1 (IPC 790) was from The Scoular Company (Minneapolis, MN); source 2 (Omega Special Select Menhaden) was from Omega Protein (Houston, TX); and source 3 (LT Prime Menhaden) was from Daybrook Fisheries, Inc. (New Orleans, LA).

Table 8. Chemical analysis of complete diets, experiment 2 (as-fed basis)[1]

		1[2]		2[2]		3[2]	
Item, %	Control	3%	6%	3%	6%	3%	6%
Dry matter	92.08	90.14	90.40	90.48	89.25	90.75	90.94
Crude protein	24.80	24.70	24.20	24.50	23.90	23.30	23.70
Ca	0.81	0.76	0.87	0.81	0.92	0.78	0.87
P	0.73	0.77	0.70	0.71	0.66	0.69	0.68
Ether Extract	5.60	4.90	6.10	5.10	6.20	5.40	5.60
Ash	5.72	5.86	5.43	5.91	6.23	5.83	5.76

[1]Samples were collected at the feeder, pooled, mixed, and then split using a riffle splitter to create a composite sample and submitted to Ward Laboratories (Kearney, NE) for analysis.

[2]Fish meal source 1 (IPC 790) was from The Scoular Company (Minneapolis, MN); source 2 (Omega Special Select Menhaden) was from Omega Protein (Houston, TX); and source 3 (LT Prime Menhaden) was from Daybrook Fisheries, Inc. (New Orleans, LA).

Table 9. Chemical analysis of complete diets, experiment 3 (as-fed basis)[1]

		Soluble fractions, %[2]			
Item, %	Control	0.87	8.70	16.52	24.35
Dry matter	89.04	88.94	89.30	89.64	89.56
Crude protein	22.70	22.60	21.60	22.60	22.30
Ca	1.15	0.82	0.77	0.93	0.81
P	0.81	0.72	0.70	0.78	0.77
Ether extract	4.70	4.20	4.20	4.80	4.80
Ash	6.50	5.62	5.59	6.02	5.86

[1]Samples were collected at the feeder, pooled, mixed, and then split using a riffle splitter to create a composite sample and submitted to Ward Laboratories (Kearney, NE) for analysis.

[2]Treatments 0.87% and 24.35% solubles were manufactured and blended to create the intermediate levels of 8.70% and 16.52% solubles. Fish meal source was LT Prime Menhaden Fishmeal (Daybrook Fisheries Inc., New Orleans, LA).

DISCUSSION

To encourage feed intake post-weaning, highly palatable and nutrient dense protein sources are often included in nursery diets. Historically, research has observed that including fish meal in early nursery diets improves growth performance and health (Stoner et al., 1990; Bergström et al., 1997; Young et al., 2002). However, the magnitude of the growth response observed when feeding fish meal in nursery diets can be inconsistent (Kim and Easter, 2001; Jones et al., 2010; Sinn et al., 2017).

Stoner et al. (1990) reported that the addition of 4% to 8% select Menhaden fish meal improved growth performance when replacing soybean meal. Similarly, Young et al. (2002) conducted an experiment in which pigs (approximately 6.4 kg body weight) were fed two sources of fish meal included at either 2.5% or 5%. The authors reported a linear improvement in ADG when pigs were fed increasing levels of fish meal. In contrast, Jones et al. (2010) reported that 3% select Menhaden fish meal was optimal to marginally improve ADG and ADFI;

Table 10. Effects of fish meal source on nursery growth performance, experiment 1[1]

			Fish meal source[2]				
Item	Control	ESBM[3]	1	2	3	SEM	Probability, *P*
Body weight, kg							
Day 0	7.06	7.07	7.06	7.06	7.06	0.057	<1.000
Day 13	10.45	10.27	10.30	10.46	10.55	0.181	<0.791
Day 0–13							
ADG, g	261	247	249	262	269	11.6	<0.652
ADFI, g	370	342	388	361	367	16.4	<0.406
G:F	0.720[x]	0.732[x]	0.657[y]	0.730[x]	0.743[x]	0.0221	<0.068

[1]A total of 250 pigs (327 × 1,050 PIC, Hendersonville, TN; initially 7.1 kg body weight) were used in a 13-d growth trial with five pigs per pen and 10 replications per treatment.

[2]HP 300 (Hamlet Protein, Findlay, OH).

[3]Fish meal source 1 (IPC 790) was from The Scoular Company (Minneapolis, MN); source 2 (Omega Special Select Menhaden) was from Omega Protein (Houston, TX); and source 3 (LT Prime Menhaden) was from Daybrook Fisheries, Inc. (New Orleans, LA).

[xy]Within the a row with different superscripts differ ($P < 0.10$).

Table 11. Effects of fish meal source and level on nursery growth performance, experiment 2[1]

		Fish meal source[2]							Probability, *P*	
		1		2		3			Source × level	
Item	Control	3%	6%	3%	6%	3%	6%	SEM	Linear	Quadratic
Body weight[3], kg										
Day 0	6.49	6.51	6.49	6.50	6.49	6.51	6.50	0.091	<0.996	<0.998
Day 14	10.07	10.23	10.52	10.40	9.87	10.26	10.19	0.176	<0.039	<0.207
Day 0–14										
ADG[3], g	255	266	288	277	238	268	264	10.5	<0.006	<0.110
ADFI[3], g	329	344	354	349	330	332	335	11.3	<0.303	<0.493
G:F[3]	0.774	0.777	0.811	0.793	0.725	0.808	0.790	0.0201	<0.010	<0.171

[1]A total of 350 maternal line barrows (200 × 400 DNA, Columbus, NE; initially 6.5 kg body weight) with five pigs per pen and 10 replications per treatment were used in a 14-d growth trial.

[2]Source 1 (IPC 790) was from The Scoular Company (Minneapolis, MN); source 2 (Omega Special Select Menhaden) was from Omega Protein (Houston, TX); and source 3 (LT Prime Menhaden) was from Daybrook Fisheries, Inc. (New Orleans, LA). All fish meal sources were from the 2014 catch year.

[3]No evidence of significant main effects of source or level ($P > 0.10$).

Table 12. Effects of increasing fish solubles on nursery growth performance, experiment 3[1]

							Probability, *P*		
		Soluble fractions, %[2]						Soluble fractions	
	Control	0.87	8.70	16.52	24.35	SEM	Control vs. Fishmeal	Linear	Quadratic
Body weight, kg									
Day 0	6.49	6.49	6.50	6.50	6.49	0.274	<0.568	<0.914	<0.180
Day 21	12.70	13.24	13.06	13.36	13.33	0.147	<0.001	<0.332	<0.566
Day 0–21									
ADG, g	293	322	309	322	321	14.9	<0.001	<0.704	<0.395
ADFI, g	412	442	431	447	449	13.9	<0.001	<0.282	<0.424
G:F	0.711	0.729	0.717	0.722	0.716	0.0133	<0.258	<0.341	<0.740

[1]A total of 700 maternal line barrows (200 × 400 DNA, Columbus, NE; initially 6.5 kg body weight) with five pigs per pen and 28 replications per treatment were used in 21-d growth trial.

[2]Two batches of LT Prime Menhaden Fishmeal were manufactured with 0.87% and 24.35% soluble fractions (Daybrook Fisheries Inc., New Orleans, LA). Treatment diets with 0.87% and 24.35% solubles were then blended to create the intermediate diets with 8.70% and 16.52% solubles that were all added at 6% to the diet.

however, when pigs were fed either 5% or 6% fish meal, performance was similar to pigs fed a standard corn-soybean meal control diet with no specialty protein sources added. Our results from experiment 1 and experiment 2 also found inconsistencies in growth responses among fish meal sources.

Traditional measurements for determining the freshness and quality of fish meal were measured in both studies. Total volatile N and modified Torry digestibility are indicators of the degrees of freshness of the raw fish used in the manufacturing process and protein quality of the finished product, respectively. The total volatile N analysis measures free N, which is an indication of volatilization of crude protein (Kjeldsen et al., 1983). A value less than 0.15% is thought to indicate that the fish meal is of good quality. The modified Torry digestibility is calculated as a portion of acid insoluble N that is soluble in acid pepsin solution (Bimbo, 1998). All fish meal sources used in the present experiments contained total volatile N contents less than 0.15% and reasonably high modified Torry digestibilities. In addition, concentrations of biogenic amines, products of AA degradation via bacterial AA decarboxylases overtime (Opstvedt et al., 1996), did not change significantly during the extended storage period (5 mo) between the groups of pigs that were used in experiment 3. This observation suggests that the fish meal product used was stable. Based on these findings, chemical analyses could not explain the differences in performance found among the fish meal sources as total volatile N and modified Torry digestibility values were similar among fish meal sources and indicated fish meal of high quality. Noticeable differences in the nutrient composition between the sources of fish meal and formulated values used in experiment 1 and 2 were observed. The reason for the differences between analyzed and formulated values are most likely due to the fact that formulated values from NRC (2012) represent the average nutrient composition across various species of fish. Previous researches (Huss, 1995; Olsson et al., 2003; Boran and Karaçam 2011) have indicated that nutrient composition varies greatly from species to species depending on age of the fish, environments in which the fish are reared, and season among others.

In our study, Peruvian Anchovy (*Engraulis ringens*) fish were used in the manufacturing of source 1 fish meal; whereas, source 2 and 3 were derived from Gulf Menhaden (*Brevoortia patronus*). In addition, source 3 was dried at 70 °C as opposed to the traditional 90 °C. The reduction in drying temperature has been demonstrated to reduce the risk of negatively influencing protein quality (Pike et al., 1990; Ariyawansa, 2000). This was particularly relevant in an experiment conducted by Kim and Easter (2001) where the nutritional values of four fish meal sources (Menhaden, Mackerel – dried at 85 °C, Mackerel – dried at 70 °C, and Herring – dried at 70 °C) were fed to nursery pigs for 4 wk. The authors reported that apparent ileal digestibilities of all AA were 16% and 11% greater for Mackerel and Herring fish meals dried at 70 °C, respectively, compared with Mackerel fish meal dried at 85 °C. In addition, apparent ileal digestibilities of all AA were on average 14% and 11% higher for Herring and Mackerel fish meal, respectively, than Menhaden fish meal. Consequently, processing procedure and species of fish used to produce the fish meal may influence the fish meal composition and may lead to different growth performance responses when fish meal is fed to weanling pigs.

Fish solubles (sometimes known as stickwater concentrate) are a by-product derived from the intermediate fraction (liquid phase) during the manufacturing process of fish meal (Wu and Bechtel, 2012). Fish solubles contain various water-soluble and insoluble fractions that are rich sources of B vitamins and minerals (Soares et al., 1973). For this reason, the value of collecting and reincorporating solubles into the final product is of importance, but can also be expensive to recover due to the viscous nature of the solubles. Fish meal commonly produced and sold today on average contains 8% to 15% fish solubles in the final product (Herbert, 2016, personal communication).

Early work conducted by Laksesvela (1958) examining fish solubles and their relative feeding value to chicks indicated that solubles were a negligible protein source alone, but when fed in combination with presscake fish meal, feed intake was increased. Furthermore, Hulan and Proudfoot (1987) reported improved growth performance when broilers were fed a diet containing fish meal with added fish solubles compared with those fed fish meal with no added fish solubles. In addition, fish solubles have been used extensively as a protein source in aquaculture diets as an attractant/palatability enhancer to increase feed intake (Hertrampf and Piedad-Pascual, 2000; Kousoulaki et al., 2009).

Ours is the first study that we are aware of to determine the influence of fish solubles contained within fish meal on growth performance of pigs. In contrast to the poultry and aquaculture studies cited above, we observed no growth benefit when increasing fish solubles inclusion from 0.87% to 24.35% when 6% fish meal was included in the diet. It is unclear if swine are less sensitive to increasing

fish solubles. It is also possible that the improved performance with increased fish solubles observed by Hulan and Proudfoot (1987) was a result of not accounting for the additional AA from increased soluble content. Nevertheless, our study would indicate that the response to fish meal is not dependent on the amount of fish solubles added to the fish meal.

In conclusion, based on the analyses of total volatile N, modified Torry digestibility, and biogenic amine concentration, all fish meal sources tested were of high quality. Still, differences in growth performance were observed for pigs offered different amounts or sources of fish meal. Reason for the inconsistent growth responses remains unclear but does not appear to be a reflection of the levels of fish solubles included in the whole fish meal.

LITERATURE CITED

AOAC International. 2006. Official methods of analysis of AOAC Int. 18th ed. Gaithersburg (MD): Association of Official Analytical Chemists.

AOAC International. 2012. Official methods of analysis of AOAC Int. 19th ed. Gaithersburg (MD): Association of Official Analytical Chemists.

Ariyawansa, S. 2000. The evaluation of functional properties of fish meal. Fisheries training program Reykjavik, Iceland. Tokyo (Japan): The United Nations University; p. 1–24.

Bergström, J. R., J. L. Nelssen, M. D. Tokach, R. D. Goodband, S. S. Dritz, K. Q. Owen, and W. B. Nessmith, Jr. 1997. Evaluation of spray-dried animal plasma and select menhaden fish meal in transition diets of pigs weaned at 12 to 14 days of age and reared in different production systems. J. Anim. Sci. 75:3004–3009. doi:10.2527/1997.75113004x

Bimbo, A. P. 1998. An evaluation of pepsin digestibility methods as practiced and interpreted by IFOMA and associated laboratories. London: International Association of fish meal manufactures.

Boran, G., and H. Karaçam. 2011. Seasonal changes in proximate composition of some fish species from the Black Sea. Turk. J. Fish Aquat. Sci. 11:1–5. doi:10.4194/trjfas.2011.0101.

Church, D. C., and R. O. Kellems. 1998. Supplemental protein sources. In: R. O. Kellems, and D. C. Church, editors. Livestock feed and feeding. Upper Saddle River (NJ): Prentice Hall.

Hertrampf, J. W., and F. Piedad-Pascual. 2000. Fish solubles (de-hydrated). In: Hertrampf, J. W., and F. Piedad-Pascual, editors. Handbook on ingredients for aquaculture feeds. Cham (Switzerland): Springer International Publishing.

Hulan, H. W., and F. G. Proudfoot. 1987. The effect of adding white fish meal containing enzyme digested or untreated stickwater solids to diets for broiler chickens. Anim. Feed. Sci. Tech. 16:253–259. doi:10.1016/0377-8401(87)90014-9.

Huss, H. H. 1995. Quality and quality changes in fresh fish. Rome (Italy): FAO; p. 348.

Jones, C. K., M. D. Tokach, S. S. Dritz, B. W. Ratliff, N. L. Horn, R. D. Goodband, J. M. DeRouchey, R. C. Sulabo, and J. L. Nelssen. 2010. Efficacy of different commercial phytase enzymes and development of an available phosphorus release curve for *Escherichia coli*-derived phytases in nursery pigs. J. Anim. Sci. 88:3631–3644. doi:10.2527/jas.2010-2936.

Kim, S. W., and R. A. Easter. 2001. Nutritional value of fish meals in the diet for young pigs. J. Anim. Sci. 79:1829–1839. doi:10.2527/2001.7971829x

Kjeldsen, N. J., V. Daniel, A. Just, H. E. Nielsen, and B. O. Eggum. 1983. Inclusion of fish meal manufactured from fish with different degrees of freshness in diets for early weaned pigs. Natl. Inst. Anim. Sci., Copenhagen Newsletter No. 390.

Kousoulaki, K., S. Albrektsen, E. Langmyhr, H. J. Olsen, P. Campbell, and A. Ksnes. 2009. The water soluble fraction in fish meal (stickwater) stimulates growth in Atlantic salmon (*Salmo salar* L.) given high plant protein diets. Aqua 289:74–83. doi:10.1016/j.aquaculture.2008.12.034

Laksesvela, B. 1958. Protein value and amino-acid balance of condensed herring solubles and spontaneously heated herring meal. Chick experiments. J. Agric. Sci. 51:164–176. doi:10.1017/S002185960003416

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

NRC. 2012. Nutrient requirements of swine. 11th rev. ed. Natl. Acad. Press, Washington, DC.

Olsson, G. P., R. L. Olsen, M. Carlehög, R. Ofstad. 2003. Seasonal variations in chemical and sensory characteristics of farmed and wild Atlantic halibut (*Hippoglossus hippoglossus*). Aqua 217:191–205. doi:10.1016/S0044-8486(02)00191-6

Opstvedt, J., H. Mundheim, and H. Nygaard. 1996. Freshness of fish used in making fish meal for salmonids and the effects of biogenic amines. London: International Fishmeal & Oil Manufacturers Association.

Pike, I. H., G. Andorsdóttir, and H. Mundheim. 1990. The role of fish meal in diets for salmonids. In: 1990 International Association of fish meal manufactures No. 24. p. 1–41. Hertfordshire, England: Publishers Royal House.

Sinn, S. M., W. R. Gibbons, M. L. Brown, J. M. DeRouchey, and C. L. Levesque. 2017. Evaluation of microbially enhanced soybean meal as an alternative to fishmeal in weaned pig diets. Animal 11:784–793. doi:10.1017/S1751731116002020

Soares, J., D. Miller, S. Cuppett, and P. Baursfeld. 1973. A review of the chemical and nutritive properties of condensed fish solubles. In: 1973 Fishery Bulletin Vol. 71 No. 1. p. 255–265. Orono, Maine: US Dept. of Commerce, NOAA, NMFS Scientific Publications Office.

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. doi:10.2527/1990.6892729x

Wu, T. H., and P. J. Bechtel. 2012. Screening for low molecular weight compounds in fish meal solubles by hydrophilic interaction liquid chromatography coupled to mass spectrometry. Food Chem. 130:739–745. doi:10.1016/j.foodchem.2011.05.088

Young, M. G., M. D. Tokach, R. D. Goodband, J. L. Nelssen, S. S. Dritz, and M. Cici. 2002. Comparison of International Corporation 740 fish meal and Special Select menhaden fish meal in nursery pig diets. J. Anim. Sci. 80(Suppl. 2):71(Abstr.).