Optimal dietary standardized ileal digestible lysine and crude protein concentration for growth and carcass performance in finishing pigs weighing greater than 100 kg[1,2]

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ABSTRACT: Three experiments were conducted to determine the optimal dietary standardized ileal digestible (**SID**) lysine and CP concentrations for finishing pigs over 100 kg BW. In Exp. 1, 253 pigs (DNA 600 × 241, initially 102.0 kg) were used in a 23-d trial with 7 to 8 pigs per pen and 8 pens per treatment. Dietary treatments contained 4 SID lysine concentrations (0.45, 0.55, 0.65, or 0.75%). To formulate the experimental diets, a corn-soybean meal diet with 0.45% SID lysine was formulated without L-lysine HCl. Then, a corn-soybean meal diet containing 0.75% SID lysine was formulated including 0.23% L-lysine HCl. The 0.45 and 0.75% SID lysine diets were blended to provide the 0.55 and 0.65% SID lysine diets. Increasing SID lysine increased (quadratic, $P < 0.05$) ADG and ADFI with pigs fed 0.55% SID lysine having the greatest final BW. Marginal improvements in gain:feed (G:F; quadratic, $P = 0.058$) and carcass yield (linear, $P = 0.051$) and reduction in backfat (quadratic, $P = 0.074$) were also observed with increasing SID lysine. The quadratic polynomial models predicted maximum ADG and G:F at 0.62 and 0.63% SID lysine, respectively. The broken-line linear model predicted no further improvement in G:F over 0.55% SID lysine. In Exp. 2, 224 pigs (PIC 327 × 1050, initially 109.4 kg) were used in a 20-d trial with 7 pigs per pen and 7 to 8 pens per treatment. Dietary treatments included 4 concentrations of CP (10, 11, 12, or 13%) that were formed by reducing the amount of L-lysine HCl in a corn-soybean meal diet. Increasing CP increased (linear, $P < 0.05$) ADG and ADFI with the greatest responses observed in pigs fed the diet with 12% CP. Increasing dietary CP also improved (linear, $P < 0.05$) G:F, final BW, and hot carcass weight (HCW). In Exp. 3, 238 pigs (DNA 600 × 241, initially 111.8 kg) were used in a 26-d trial with 7 to 8 pigs and 6 pens per treatment. Dietary treatments included 5 concentrations of CP (9, 10, 11, 12, or 13%). Increasing CP improved (quadratic, $P < 0.05$) ADG and G:F with the greatest response observed in pigs fed 13% CP. Increasing CP marginally increased (quadratic, $P < 0.074$) HCW, with the greatest response observed in pigs fed 12% CP. In conclusion, the SID lysine requirement for pigs from 100 to 122 kg was 0.55 to 0.63% depending on the response criteria with performance maximized with diets containing 12 to 13% CP.

Key words: amino acid, crude protein, finishing pigs, growth, lysine requirements

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INTRODUCTION

Economic and environmental concerns have forced the development of low CP, amino acid (AA) fortified diets that deliver performance equivalent to diets with intact protein sources. However, in some studies, low CP diets have led to decreased performance, particularly in heavy weight finishing pigs. Decreasing dietary CP below 13% may compromise finishing pig growth and carcass performance (Tous et al., 2014; Soto et al., 2017). Conversely, other research has reported no performance effects of lowering CP in finishing pigs when AA ratios are met (Kerr et al., 2003; Ball et al., 2013); however, in these studies, minimum CP levels have been maintained to at least 12%. Continuous advancements in modern pig genetics have resulted in increased growth performance and protein accretion, which may change dietary nutrient requirements (O'Connell et al., 2006). Therefore, defining the optimal dietary lysine to maximize lean growth and optimize feed cost in finishing pigs is critical (Wei and Zimmerman, 2001).

Although considerable research has been conducted to determine the optimal lysine requirement for swine, there are limited data reporting the lysine requirements at heavy market weights (Kendall et al., 2007). Considering the limitations of available research in finishing pig diets, the objective of these studies was to determine the optimal concentrations of dietary standardized ileal digestible (**SID**) lysine and CP for growth and carcass performance of finishing pigs weighing greater than 100 kg.

MATERIALS AND METHODS

General

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in these experiments. All experiments were conducted at the Kansas State University Swine Teaching and Research Center in Manhattan, KS. The facility was totally enclosed and environmentally regulated. Each pen (2.44 × 3.05 m) was equipped with a dry single-sided feeder (Farmweld, Teutopolis, IL) with 2 eating spaces located in the fence line and 1 cup waterer. Pens were located over a completely slatted concrete floor with a 1.20 m deep pit underneath for manure storage. Daily feed additions to each pen were accomplished through a robotic feeding system (FeedPro; Feedlogic Corp., Willmar, MN) capable of providing and measuring feed amounts for individual pens. Prior to the experimental diets, pigs were fed a corn-soybean meal-based diet with 14.2% CP, 0.72% SID lysine, and 2,535 kcal/kg of net energy (NE) in all experiments. Pigs were provided ad libitum access to water and to feed in meal form throughout the experiments.

Experiment 1

To determine the SID lysine requirements of finishing pigs, a total of 253 pigs (DNA 600 × 241; DNA Genetics, Columbus, NE), with initial and final BW of 102.0 ± 1.2 and 123.4 ± 2.2 kg, respectively, were used in a 23-d trial. Pens of pigs were weighed, and pens were assigned randomly to 1 of 4 dietary treatments in a randomized complete block design blocked by initial average pen BW. Each treatment consisted of 8 pens of 7 to 8 pigs per pen with a similar number of barrows and gilts in each pen. The dietary treatments included 4 SID lysine concentrations (0.45, 0.55, 0.65, and 0.75%). To formulate the experimental diets, a corn-soybean meal diet with 0.45% SID lysine was formulated without L-lysine HCl. Then, a corn-soybean meal diet containing 0.75% SID lysine was formulated including 0.23% L-lysine HCl and other feed-grade AA as necessary to maintain ratios relative to SID lysine. Ratios were maintained well above NRC (2012) requirement estimates to ensure that other AA were not limiting. The 0.45 and 0.75% SID lysine diets were blended by the robotic feeding system (FeedPro; Feedlogic Corp., Willmar, MN) to provide the 0.55 and 0.65% SID lysine diets (Table 1).

Experiment 2

A total of 224 pigs (PIC 327 × 1050; PIC, Hendersonville, TN) with initial and final BW of 109.4 ± 1.8 and 126.8 ± 2.5 kg, respectively, were used in a 20-d trial. Pens of pigs were weighed, and pens were assigned randomly to 1 of 4 dietary treatments in a randomized incomplete block design blocked by initial average pen BW. Each treatment consisted of 7 (10% CP treatment) to 8 pens (11, 12, and 13% CP treatments) of 7 pigs per pen with 4 barrows and 3 gilts in each pen.

Dietary treatments included 4 CP concentrations (10, 11, 12, and 13%). To formulate the experimental diets, a 13% CP corn-soybean meal diet with 0.23% L-lysine HCl was formulated. Then L-lysine HCl was included at 0.52, 0.43, and 0.33%

Table 1. Diet composition in Exp. 1 (as-fed basis)[1]

	Standardized ileal digestible (SID) lysine, %			
Ingredient, %	0.45	0.55	0.65	0.75
Corn	86.66	84.87	83.18	81.38
Soybean meal (46.5% CP)	11.00	12.71	14.31	16.02
Choice white grease	0.50	0.50	0.50	0.50
Monocalcium P (21% P)	0.35	0.33	0.32	0.30
Limestone	0.95	0.94	0.93	0.93
Salt	0.35	0.35	0.35	0.35
L-lysine-HCl	---	0.08	0.15	0.23
DL-methionine	---	---	0.01	0.01
L-threonine	---	0.03	0.05	0.08
L-tryptophan	---	0.01	0.01	0.02
Trace mineral premix[2]	0.10	0.10	0.10	0.10
Vitamin premix[3]	0.08	0.08	0.08	0.08
Phytase[4]	0.02	0.02	0.02	0.02
Total	100.00	100.00	100.00	100.00
Calculated analysis				
SID amino acids, %				
Lysine	0.45	0.55	0.65	0.75
Isoleucine:lysine	91	79	71	66
Leucine:lysine	239	202	177	159
Methionine:lysine	43	38	33	31
Methionine and cysteine:lysine	87	75	66	60
Threonine:lysine	80	75	70	68
Tryptophan:lysine	23.9	22.2	20.9	20.0
Valine:lysine	107	93	83	75
Histidine:lysine	67	57	51	46
Total lysine, %	0.54	0.65	0.75	0.86
SID lysine:net energy, g/Mcal	1.74	2.14	2.53	2.93
Net energy, kcal/kg	2,582	2,573	2,563	2,555
Crude protein, %	12.4	13.2	13.9	14.6
Ca, %	0.47	0.47	0.47	0.47
P, %	0.38	0.38	0.39	0.39
STTD P, %[5]	0.27	0.27	0.27	0.27

[1]Diets were fed from day 0 to 23 which correspond to 102.0 to 123.4 kg BW, respectively.

[2]Provided per kilogram of premix: 11 g Cu from copper sulfate, 0.2 g I from Ca iodate, 73 g Fe from ferrous sulfate, 22 g Mn from manganese sulfate, 0.2 g Se from sodium selenite, 73 g Zn from zinc sulfate.

[3]Provided per kilogram of premix: 3,527,360 IU Vitamin A, 881,840 IU vitamin D_3, 17,637 IU vitamin E, 15 mg vitamin B_{12}, 3,307 mg riboflavin, 33,069 mg niacin, 11,023 mg pantothenic acid, 1,764 mg menadione.

[4]Ronozyme Hiphos (GT) 2700 (DSM Nutritional Products, Inc, Parsippany, NJ). Provided 400.8 phytase units (FYT) per kg of diet with a release of 0.088% STTD P.

[5]Standardized total tract digestible P.

Table 2. Diet composition in Exp. 2 (as-fed basis)[1]

	CP, %			
Item	10	11	12	13
Ingredient, %				
Corn	93.09	89.87	86.63	83.38
Soybean meal (46.5% CP)	2.96	6.03	9.17	12.32
Choice white grease	0.55	1.00	1.45	1.90
Monocalcium P (21% P)	0.71	0.68	0.65	0.63
Limestone	0.97	0.98	0.96	0.92
Salt	0.35	0.35	0.35	0.35
L-lysine-HCl	0.52	0.43	0.33	0.23
DL-methionine	0.10	0.07	0.04	0.02
L-threonine	0.19	0.15	0.11	0.06
L-tryptophan	0.06	0.05	0.03	0.01
L-valine	0.16	0.11	0.05	0.00
L-isoleucine	0.16	0.11	0.06	0.00
Trace mineral premix[2]	0.10	0.10	0.10	0.10
Vitamin premix[3]	0.08	0.08	0.08	0.08
Phytase[4]	0.02	0.02	0.02	0.02
Total	100.00	100.00	100.00	100.00
Calculated analysis				
Standardized ileal digestible (SID) amino acids, %				
Lysine	0.66	0.66	0.66	0.66
soleucine:lysine	65	65	65	65
Leucine:lysine	132	143	154	165
Methionine:lysine	38	36	34	32
Methionine and cysteine:lysine	62	62	62	62
Threonine:lysine	66	66	66	66
Tryptophan:lysine	19	19	19	19
Valine:lysine	76	76	75	76
Histidine:lysine	33	38	42	47
Total lysine, %	0.75	0.75	0.74	0.73
SID lysine:net energy, g/Mcal	2.51	2.51	2.51	2.51
Net energy, kcal/kg	2,443	2,443	2,443	2,443
CP, %	10.0	11.0	12.0	13.0
Ca, %	0.51	0.52	0.51	0.51
P, %	0.41	0.42	0.43	0.44
STTD P, %[5]	0.31	0.32	0.32	0.32

[1]Diets were fed from day 0 to 20 which correspond to 109.4 to 126.8 kg BW, respectively.

[2]Provided per kilogram of premix: 11 g Cu from copper sulfate, 0.2 g I from Ca iodate, 73 g Fe from ferrous sulfate, 22 g Mn from manganese sulfate, 0.2 g Se from sodium selenite, 73 g Zn from zinc sulfate.

[3]Provided per kilogram of premix: 3,527,360 IU Vitamin A, 881,840 IU vitamin D_3, 17,637 IU vitamin E, 15 mg vitamin B_{12}, 3,307 mg riboflavin, 33,069 mg niacin, 11,023 mg pantothenic acid, 1,764 mg menadione.

[4]Ronozyme Hiphos (GT) 2700 (DSM Nutritional Products, Inc, Parsippany, NJ). Provided 400.8 phytase units (FYT) per kg of diet with a release of 0.088% STTD P.

[5]Standardized total tract digestible P.

of the diet to reach the desired levels of 10, 11, and 12% dietary CP, respectively (Table 2). Diets were isocaloric (NE = 2,443 kcal/kg) and formulated to contain 0.66% dietary SID lysine. Other AA were added as necessary to maintain ratios at or above NRC (2012) requirements estimates relative to lysine.

Experiment 3

A total of 238 pigs (DNA 600 × 241; DNA Genetics, Columbus, NE), with initial and final BW of 111.8 ± 1.7 and 134.6 ± 2.1 kg, respectively, were used in a 26-d trial. Pens of pigs were weighed, and pens were assigned randomly to 1 of 5 dietary treatments in a randomized complete block design blocked by initial average pen BW. Each treatment consisted of 6 pens of 7 to 8 pigs/pen with a similar number of barrows and gilts in each pen. All pens within each block had the same number of pigs per pen.

The dietary treatments included 5 concentrations of CP (9, 10, 11, 12, and 13%). To create the experimental diets, a 13% CP corn-soybean meal diet with 0.04% L-lysine HCl was formulated. Then, a 9% CP diet was formulated including 0.43% L-lysine HCl and other crystalline AA as necessary to maintain ratios relative to lysine. Ratios were maintained above NRC (2012) requirement estimates to ensure that other AA were not limiting. The 9 and 13% CP diets were blended by the robotic feeding system (FeedPro; Feedlogic Corp., Willmar, MN) to create the 10, 11, and 12% CP diets (Table 3). Based on the results of Exp. 1, diets were formulated to contain 0.55% dietary SID lysine, which was considered marginally deficient for optimal performance, and not underestimate the ratio of other AA to lysine. Diets were isocaloric (NE = 2,451 kcal/kg), which was achieved by adjusting the amount of added fat as corn and soybean meal amounts changed in the diet.

Data Collection

Pens of pigs were weighed, and feed disappearance was measured weekly and at the end of each experiment to calculate ADG, ADFI, and gain:feed ratio (G:F). Prior to marketing, pigs were individually tattooed with a unique ID number to allow for carcass measurements to be recorded on a pig basis in all experiments. At the end of each experiments (day 23, 20, and 26 for Exp. 1, 2, and 3, respectively) individual weights were recorded, and pigs were transported to USDA-inspected packing plants (Triumph, St. Joseph, MO in Exp. 1 and 3; Farmland, Crete, NE in Exp. 2) for processing and carcass data collection. In Exp. 1, carcass measurements only included hot carcass weight (HCW). In Exp. 2 and 3, carcass measurements included HCW, loin depth, backfat, and percentage lean. Backfat and loin depth were measured with an optical probe (Fat-O-Meter, SFK, Herlev, Denmark) inserted between the third and fourth last rib (counting from the ham end of the carcass) at a distance approximately 7 cm from the dorsal midline. Percentage lean was calculated using proprietary equations from the packing plant. In all experiments, carcass yield was calculated by dividing the HCW at the plant by the final live weight at the farm.

Table 3. Diet composition in Exp. 3 (as-fed basis)[1]

	CP, %				
Ingredient, %	9	10	11	12	13
Corn	96.01	92.58	89.16	85.73	82.30
Soybean meal (46.5% CP)	0.47	3.75	7.02	10.30	13.57
Choice white grease	0.35	0.81	1.28	1.74	2.20
Monocalcium P (21% P)	0.60	0.58	0.55	0.53	0.50
Limestone	0.98	0.94	0.91	0.88	0.85
Salt	0.35	0.35	0.35	0.35	0.35
L-lysine-HCl	0.43	0.33	0.23	0.13	0.04
DL-methionine	0.11	0.08	0.05	0.03	---
L-threonine	0.16	0.12	0.08	0.04	---
L-tryptophan	0.07	0.05	0.03	0.02	---
L-valine	0.11	0.08	0.06	0.03	---
L-isoleucine	0.19	0.14	0.09	0.05	---
Trace mineral premix[2]	0.10	0.10	0.10	0.10	0.10
Vitamin premix[3]	0.08	0.08	0.08	0.08	0.08
Phytase[4]	0.02	0.02	0.02	0.02	0.02
Total	100.00	100.00	100.00	100.00	100.00
Calculated analysis					
Standardized ileal digestible (SID) amino acids, %					
Lysine	0.55	0.55	0.55	0.55	0.55
Isoleucine:lysine	78	79	81	82	84
Leucine:lysine	150	164	177	191	204
Methionine:lysine	48	46	44	41	39
Methionine & cysteine:lysine	80	80	80	80	80
Threonine:lysine	70	70	71	72	73
Tryptophan:lysine	22	22	23	23	23
Valine:lysine	79	84	88	92	97
Histidine:lysine	35	40	45	50	55
Total lysine, %	0.65	0.65	0.64	0.63	0.62
SID lysine:net energy, g/Mcal	2.08	2.08	2.08	2.08	2.08
Net energy, kcal/kg	2,451	2,451	2,451	2,451	2,451
CP, %	9.0	10.0	11.0	12.0	13.0
Ca, %	0.50	0.50	0.50	0.50	0.50
P, %	0.41	0.42	0.43	0.43	0.44
STTD P, %[5]	0.29	0.29	0.30	0.30	0.30

[1]Diets were fed from day 0 to 26 which correspond to 111.8 to 134.6 kg BW, respectively.

[2]Provided per kilogram of premix: 11 g Cu from copper sulfate, 0.2 g I from Ca iodate, 73 g Fe from ferrous sulfate, 22 g Mn from manganese sulfate, 0.2 g Se from sodium selenite, 73 g Zn from zinc sulfate.

[3]Provided per kilogram of premix: 3,527,360 IU Vitamin A, 881,840 IU vitamin D_3, 17,637 IU vitamin E, 15 mg vitamin B_{12}, 3,307 mg riboflavin, 33,069 mg niacin, 11,023 mg pantothenic acid, 1,764 mg menadione.

[4]Ronozyme Hiphos (GT) 2700 (DSM Nutritional Products, Inc, Parsippany, NJ). Provided 400.8 phytase units (FYT) per kg of diet with a release of 0.088% STTD P.

[5]Standardized total tract digestible P.

Diet Sampling and Analysis

In all experiments, diet samples were taken from 6 feeders per dietary treatment 3 d after the beginning and 3 d before the end of each trial and stored at −20 °C until analysis. Diet samples were submitted to Cumberland Valley Analytical Service (Hagerstown, MD) in Exp. 1 and 3, and Ward Laboratories, Inc. (Kearney, NE) in Exp. 2. Diets were analyzed for DM (method 935.29; AOAC Int., 2012), CP (method 990.03; AOAC Int., 2012), ash (method 942.05; AOAC Int., 2012), ether extract (method 920.39a; AOAC Int., 2012 for preparation and ANKOM XT20 Fat Analyzer [Ankom Technology, Fairport, NY] for analysis), Ca, and P (method 968.08b; AOAC Int., 2012 for preparation using ICAP 6500 [ThermoElectron Corp., Waltham, MA]). Additionally, diet samples were submitted for total AA analysis (method 994.12; AOAC Int., 2012) from Exp. 1 and 3 and free lysine (method 994.13; AOAC Int., 2012) in Exp. 1 by Ajinomoto Heartland, Inc. (Chicago, IL).

Statistical Analysis

In all experiments, data were analyzed using the GLIMMIX procedure in SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Dietary treatments were the fixed effect and BW blocks served as the random effect in the analysis. Preplanned linear and quadratic contrasts were built using coefficients for equally spaced treatment and used to determine the effects of increasing SID lysine in Exp. 1 and CP in Exp. 2 and 3. Hot carcass weight served as a covariate for the analysis of backfat, loin depth, and lean percentage in all experiments. Heterogeneous residual variances as a function of treatment combinations were fitted as needed according to the procedures suggested by Gonçalves et al. (2017). Model assumptions were checked using studentized residuals and were considered to be appropriately met. In Exp. 1, PROC GLIMMIX and PROC NLMIXED in SAS (SAS Institute, Inc.) were used to predict the SID lysine dose–response curves to optimize ADG and G:F. Dose–response models evaluated were quadratic polynomial (QP), broken-line linear (BLL), and broken-line quadratic (BLQ) models. Best fit was determined using Bayesian Information Criterion (BIC), with a lower number being indicative of an improved fit. A decrease in BIC greater than 2.0 among models for a response criterion was considered an improved fit. Results from all experiments were considered significant at $P < 0.05$ and marginally significant at $0.05 < P \leq 0.10$.

RESULTS

The analyzed nutrient concentrations including total AA of diets in Exp. 1, 2, and 3 (Tables 4–6) were reasonably consistent with formulated estimates considering permitted analytical variation.

Table 4. Chemical analysis of experimental diets in Exp. 1 (as-fed basis)[1]

	Standardized ileal digestible lysine, %			
Item, %	0.45	0.55	0.65	0.75
DM	87.7	87.7	87.7	87.8
CP	12.1	12.3	12.9	14.2
Ca	0.66	0.68	0.72	0.76
P	0.40	0.39	0.39	0.40
Ether extract	4.2	3.7	3.4	3.5
Ash	3.57	4.35	4.04	4.18
Total amino acids				
Lysine	0.54	0.65	0.76	0.82
Isoleucine	0.47	0.54	0.57	0.60
Leucine	1.16	1.29	1.33	1.36
Methionine	0.21	0.24	0.25	0.26
Methionine and cysteine	0.45	0.50	0.53	0.54
Threonine	0.46	0.50	0.57	0.58
Tryptophan	0.12	0.14	0.16	0.17
Valine	0.59	0.65	0.69	0.70
Histidine	0.30	0.33	0.36	0.36
Phenylalanine	0.61	0.69	0.74	0.74
Free lysine	0.01	0.05	0.09	0.11

[1]Diet samples were taken from 6 feeders per dietary treatment 3 d after the beginning of the trial and 3 d prior to the end of the trial and stored at −20 °C, then amino acid analysis was conducted on composite samples by Ajinomoto Heartland, Inc. (Chicago, IL). Samples of the diets were also submitted to Cumberland Valley Analytical Service (Hagerstown, MD) for analysis of DM, CP, Ca, P, ether extract, and ash.

Table 5. Chemical analysis of experimental diets in Exp. 2 (as-fed basis)[1]

	CP, %			
Item, %	10	11	12	13
DM	85.3	85.4	85.4	85.7
CP	9.0	10.9	11.9	13.1
Ca	0.72	0.62	0.60	0.61
P	0.46	0.56	0.48	0.50
Ether extract	3.7	5.4	5.1	5.3
Ash	4.0	4.2	4.0	4.1

[1]Diet samples were taken from 6 feeders per dietary treatment 3 d after the beginning of the trial and 3 d prior to the end of the trial and stored at −20 °C, until analysis (Ward Laboratories, Inc. Kearney, NE).

Table 6. Chemical analysis of experimental diets in Exp. 3 (as-fed basis)[1]

	CP, %				
Item. %	9	10	11	12	13
DM	86.0	86.1	86.2	86.5	86.5
CP	8.9	10.0	10.8	11.9	12.9
Ca	0.63	0.69	0.57	0.61	0.61
P	0.41	0.41	0.41	0.41	0.42
Extract ether	3.6	3.7	3.7	4.1	4.0
Ash	2.0	2.3	2.4	2.8	2.7
Total amino acids					
Lysine	0.55	0.58	0.55	0.59	0.59
Isoleucine	0.45	0.46	0.54	0.48	0.57
Leucine	0.96	1.02	1.15	1.21	1.32
Methionine	0.27	0.26	0.24	0.24	0.23
Methionine and cysteine	0.46	0.47	0.46	0.48	0.48
Threonine	0.46	0.46	0.43	0.48	0.47
Tryptophan	0.12	0.12	0.13	0.13	0.13
Valine	0.51	0.55	0.60	0.61	0.66
Histidine	0.22	0.25	0.26	0.31	0.33
Phenylalanine	0.47	0.52	0.57	0.65	0.69

[1]Diet samples were taken from 6 feeders per dietary treatment 3 d after the beginning of the trial and 3 d prior to the end of the trial and stored at −20 °C, until analysis. Amino acid analysis was conducted on composite samples by Ajinomoto Heartland, Inc. (Chicago, IL). Samples of the diets were also submitted to Cumberland Valley Analytical Service (Hagerstown, MD) for analysis of DM, CP, Ca, P, ether extract, and ash.

Experiment 1

For overall growth performance (day 0 to 23), increasing SID lysine increased ADG and ADFI (quadratic, $P < 0.05$) with pigs fed 0.55% SID Lys having the greatest ADG and ADFI (Table 7). In addition, marginally significant improvement (quadratic, $P = 0.058$) was observed in G:F with increasing SID lysine. Increasing SID lysine increased (linear, $P < 0.05$) grams of SID lysine intake per kg of gain and daily SID lysine intake.

For carcass characteristics, a marginally significant increase in carcass yield (linear, $P = 0.051$) and decrease (quadratic, $P = 0.074$) in backfat was observed with increasing SID lysine. Carcass ADG increased (quadratic, $P = 0.014$) and carcass G:F was marginally improved (quadratic, $P = 0.063$).

The QP model for ADG resulted in the best fit predicting that 95, 98, and 100% of maximum ADG were achieved at 0.50, 0.55, and 0.62% SID lysine, respectively (Fig. 1). The QP model equation was: ADG, g = $-350.1 + 4237.0 \times$ (SID lysine, %) $- 3414.0 \times$ (SID lysine, %)^2. The QP and BLL models had a comparable fit for G:F (BIC = 278.2 for QP and BIC = 279.3 for BLL). The QP model predicted 95, 98, and 100% of maximum G:F at 0.48, 0.54, and 0.63% SID lysine, respectively. The QP

Table 7. Effects of standardized ileal digestibility (SID) lysine on growth and carcass performance of finishing pigs over 100 kg BW (Exp. 1)[1]

	SID lysine, %					Probability, $P <$	
Item	0.45	0.55	0.65	0.75	SEM	Linear	Quadratic
Body weight, kg							
Day 0	102.0	102.0	102.0	102.1	0.44	0.856	0.692
Day 23	121.8	124.9	123.8	123.4	0.72	0.423	0.167
Day 0 to 23							
ADG, kg	0.86	0.97	0.94	0.92	0.027	0.260	0.015
ADFI, kg	2.79	3.01	2.85	2.87	0.049	0.769	0.041
G:F	0.307	0.323	0.329	0.319	0.0071	0.191	0.058
SID lysine intake, g/kg gain	14.7	17.0	19.8	23.6	0.46	0.001	0.110
SID lysine intake, g/d	12.6	16.6	18.5	21.5	0.28	0.001	0.074
Carcass characteristics							
HCW, kg	89.9	92.7	92.0	92.1	0.97	0.173	0.182
Carcass yield, %	73.7	74.2	74.1	74.5	0.25	0.051	0.666
Backfat[2], mm.	15.7	16.3	15.8	15.0	0.36	0.154	0.074
Loin depth[2], mm.	63.7	62.7	64.2	64.4	1.13	0.455	0.611
Lean[2], %	54.9	54.5	54.9	55.3	0.24	0.128	0.121
Carcass performance							
Carcass ADG[3], kg	0.63	0.72	0.70	0.68	0.020	0.179	0.014
Carcass G:F[4]	0.226	0.240	0.244	0.238	0.005	0.095	0.063

G:F = gain:feed ratio; HCW = hot carcass weight.

[1]A total of 253 pigs (DNA 600 × 241; initially 102.0 kg BW) were used with 7 or 8 pigs per pen and 8 replications per treatment.

[2]Adjusted using HCW as a covariate.

[3]Carcass ADG = overall ADG × carcass yield.

[4]Carcass G:F = carcass ADG/overall average feed intake.

model equation was: G:F, g/kg = 71.9 + 809.6 × (SID lysine, %) – 639.2 × (SID lysine, %)^2. The BLL model predicted no further improvement in G:F over 0.55% SID lysine (95% CI: [0.43, 0.67]%). The BLL model equation was: G:F, g/kg = 324.1 – 163.2 × (0.554 – SID lysine, %) if SID lysine < 0.554%, and 324.1 g/kg if SID lysine > 0.5544 (Fig. 2).

Experiment 2

For overall growth performance (day 0 to 20), increasing dietary CP increased (linear, $P < 0.05$; quadratic, $P < 0.10$) ADG, ADFI, and grams of CP intake per kg of gain, with the greatest response observed in pigs fed the diet containing 12% CP with only marginal improvements thereafter (Table 8). In addition, increasing CP also improved (linear, $P < 0.05$) G:F and final BW.

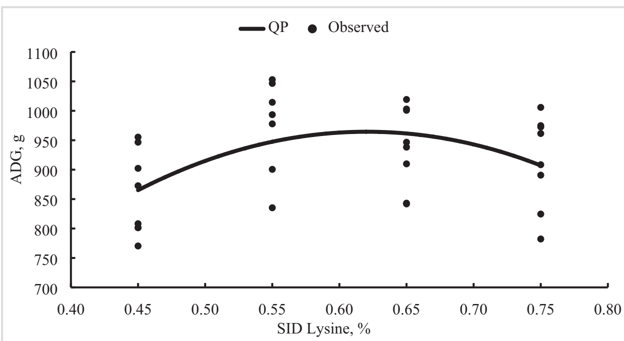

Figure 1. Estimation of standardized ileal digestible (SID) lysine to maximize ADG for mixed gender finishing pigs (Exp. 1). A total of 253 pigs (DNA 600 × 241, initially 102.0 kg BW) were used in a 23-d trial. Quadratic polynomial (QP), broken-line linear (BLL), and broken-line quadratic (BLQ) models were fit to estimate SID lysine level to maximize ADG. The QP model predicted 95, 98, and 100% of maximum growth at 0.50, 0.55, and 0.62% SID lysine, respectively. The QP model equation was: ADG, g = −350.1334 + 4,236.996 × (% SID lysine) – 3,414.007 × (% SID lysine)^2.

For carcass characteristics, HCW increased (linear, $P = 0.040$) with increasing dietary CP without any influence on carcass yield. Increasing CP increased (linear, $P = 0.001$ and quadratic, $P = 0.070$) carcass ADG with the greatest response for pigs fed the diet with 12% CP. Furthermore, carcass G:F improved (linear, $P = 0.050$) with increasing CP.

Experiment 3

For overall growth performance (day 0 to 26), increasing dietary CP improved (quadratic, $P < 0.001$) ADG and G:F with the greatest improvement in ADG as CP was increased from 9 to 11% with smaller improvements as CP was further increased to 13% (Table 9). Similarly, increasing CP marginally increased (linear, $P = 0.073$) ADFI with a large increase in ADFI as CP was increased from 9 to 10% with little change in ADFI thereafter. In addition, increasing CP increased (quadratic, $P = 0.001$) grams of CP per kg of gain.

For carcass characteristics, increasing CP marginally increased (quadratic, $P = 0.074$) HCW, with the greatest response observed for pigs fed the diet with 12% CP. There was no evidence for treatment differences in carcass yield, backfat, loin depth, or percentage lean. Increasing CP increased (quadratic, $P < 0.001$) carcass ADG and carcass G:F

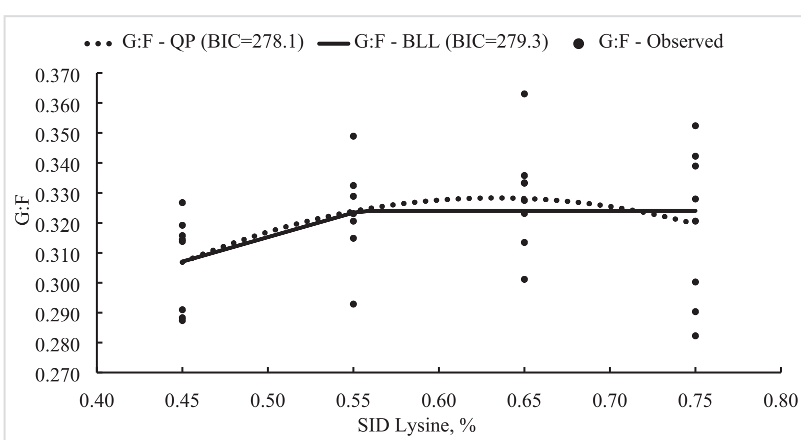

Figure 2. Estimation of standardized ileal digestible (SID) lysine to maximize G:F for mixed gender finishing pigs (Exp. 1). A total of 253 pigs (DNA 600 × 241, initially 102.0 kg BW) were used in a 23-d trial. Quadratic polynomial (QP), broken-line linear (BLL), and broken-line quadratic (BLQ) models were fit to estimate SID lysine level to maximize G:F. The QP and BLL had a comparable fit for G:F (Bayesian Information Criterion [BIC] = 278.2 vs. 279.3, QP and BLL, respectively). The QP model predicted 95, 98, and 100% of maximum feed efficiency at 0.48, 0.54, and 0.63% SID Lys, respectively. The QP model equation was: G:F = 71.9 + 809.67 × (SID lysine, %) – 639.24 × (SID lysine, %)^2. The BLL model predicted no further improvement in G:F over 0.55% SID lysine. The BLL model equation was: G:F = 324.1 – 163.24 × (0.554 – SID lysine, %) if SID lysine < 0.554%, and 324.1 if SID lysine > 0.5544.

Table 8. Effects of increasing dietary CP concentration on growth and carcass performance of finishing pigs over 100 kg BW (Exp. 2)[1]

	CP, %					Probability, $P <$	
Item	10	11	12	13	SEM	Linear	Quadratic
Body weight, kg							
Day 0	109.4	109.4	109.4	109.4	---	---	---
Day 20	125.6	126.5	127.7	127.4	0.61	0.022	0.341
Day 0 to 20							
ADG, kg	0.77	0.86	0.91	0.90	0.029	0.001	0.080
ADFI, kg	2.58	2.72	2.84	2.76	0.054	0.014	0.060
G:F	0.299	0.317	0.323	0.328	0.0081	0.020	0.452
Digestible CP intake, g/kg gain[2]	287.1	297.9	319.1	338.9	8.03	<0.001	0.322
Carcass characteristics							
HCW, kg	94.0	94.0	95.5	95.0	0.47	0.040	0.640
Carcass yield, %	74.8	74.3	74.8	74.6	0.24	0.780	0.510
Carcass performance							
Carcass ADG[3], kg	0.60	0.65	0.69	0.68	0.016	0.001	0.070
Carcass G:F[4]	0.233	0.239	0.242	0.246	0.0046	0.050	0.880

G:F = gain:feed ratio; HCW = hot carcass weight.

[1]A total of 224 pigs (PIC 1050 × 327; initially 109.4 kg BW) were used in a 20-d experiment with 7 pigs per pen. Treatment with 10% CP had 7 replications and 8 replications for the treatments with 11, 12, and 13% CP. Allotment weight was used as a covariate for growth and carcass performance variables.

[2]Assuming an 85% digestibility of CP in a corn-soybean meal diet (Dean, 2005).

[3]Carcass average daily gain = overall ADG × carcass yield.

[4]Carcass G/F = carcass ADG/average feed intake.

Table 9. Effects of increasing dietary CP concentration on growth and carcass performance of finishing pigs over 100 kg BW (Exp. 3)[1]

	CP, %						Probability, $P <$	
Item	9	10	11	12	13	SEM	Linear	Quadratic
BW, kg								
Day 0	111.8	111.8	111.8	111.8	111.8	0.74	0.948	0.961
Day 26	132.8	133.9	135.0	135.5	135.8	0.80	0.463	0.001
Day 0 to 26								
ADG, kg	0.81	0.85	0.89	0.91	0.93	0.022	0.508	0.001
ADFI, kg	2.99	3.14	3.14	3.12	3.11	0.055	0.073	0.322
G:F	0.270	0.271	0.285	0.293	0.299	0.0044	0.336	0.001
Digestible CP intake, g/kg gain[2]	283.5	315.0	328.2	355.8	361.3	5.77	0.107	0.001
Carcass characteristics								
HCW, kg	99.7	100.7	101.4	101.6	101.3	0.87	0.344	0.074
Carcass yield, %	75.0	75.2	75.1	75.0	74.6	0.46	0.533	0.638
Backfat[3], mm.	18.3	18.5	17.9	18.2	17.8	0.46	0.922	0.424
Loin depth[3], mm.	63.5	62.9	63.2	63.5	63.9	0.89	0.538	0.544
Lean[3], %	53.3	53.1	53.3	53.3	53.4	0.27	0.424	0.531
Carcass performance								
Carcass ADG[4,] kg	0.61	0.64	0.67	0.68	0.69	0.017	0.461	0.001
Carcass G:F[5]	0.203	0.203	0.215	0.220	0.223	0.0035	0.535	0.001

G:F = gain:feed ratio; HCW = hot carcass weight.

[1]A total of 238 pigs (DNA 600 × 241; initially 111.8 kg BW) were used in a 26-d experiment with 7–8 pigs per pen and 6 replications per treatment.

[2]Assuming an 85% digestibility of CP in a corn-soybean meal diet (Dean, 2005).

[3]Carcass ADG = overall ADG × carcass yield.

[4]Adjusted using HCW as a covariate.

[5]Carcass G:F = overall average feed intake/carcass ADG.

with the greatest response observed for pigs fed the diet with 13% CP.

DISCUSSION

Determining the Dietary Standardized Ileal Digestible Lysine Requirement Estimates

Because essential AA requirements for finishing pigs are based on ratios to lysine, an accurate requirement estimate for lysine in the late-finishing period becomes crucial to maximize lean growth and optimize feed cost (Wei and Zimmerman, 2001). Continuous advancements in modern pig genetics have resulted in improved growth performance and protein accretion, potentially increasing dietary nutrient requirements (O'Connell et al., 2006). In addition, advanced dose–response models that account for correlated data structures and heterogeneous variances have provided the means for better requirements estimations (Gonçalves et al., 2016).

Early work to determine the lysine requirements of growing-finishing barrows and gilts conducted by Cromwell et al. (1993) suggested that the SID lysine requirement was 0.51 and 0.76 for barrows and gilts, respectively. Similarly, Hahn et al. (1995) suggested that the SID lysine requirement in late-finishing barrows and gilts weighing between 80 and 120 kg was 0.49 and 0.52%, respectively. Dean (2005) reported that growth performance of 90-kg barrows was greatest when diets contained 0.525% SID lysine. Most recently, Goncalves et al. (2017) completed a meta-analysis with Pig Improvement Company (Hendersonville, TN) genetic lines, and determined the SID lysine requirements are 0.70 and 0.75% for barrows and gilts over 100 kg BW, respectively. In our study, 100% of maximum response for ADG and G:F were achieved at 0.62 and 0.63% SID lysine, which is higher than previous reports (Hahn et al., 1995; Dean, 2005). However, our estimates are considerably lower than those of Goncalves et al. (2017).

According to Kendall et al. (2007), variation in lysine requirements could be attributable to differences in the genetic capacity for protein deposition and other factors, such immune stress and differences in AA digestibility between pigs. In Exp. 1, the highest levels of ADFI (3.01 and 2.85 kg/d) were achieved with pigs consuming diets containing 0.55 and 0.65% SID lysine, resulting in a 16.6 and 18.5 g/d SID lysine intake, respectively. Conversely, Goncalves et al. (2017) reported that 100 to 135 kg barrows and gilts had an ADFI of 2.83 and 2.61 kg/d of diets containing 0.70 and 0.75% SID Lys, resulting in SID Lys intake of 19.5 and 19.7 g/d, respectively.

According to Goncalves et al. (2017), a greater gram of lysine intake per day required could be attributable to the increased rate of growth and improved feed efficiency with modern genetic lines. Furthermore, Nyachoti et al. (2004) suggested that feed intake levels and patterns differ among genetics lines, and pigs with a high potential for lean tissue growth tend to have a lower voluntary feed intake compared to those with low muscle accretion rate. We speculate that lower lysine requirements in our study compared with Goncalves et al. (2017) could be associated with the genetic line utilized (DNA 600 × 241) having a 6% higher overall feed intake compared with PIC genetic lines as reported by Goncalves et al. (2017).

Determining the Dietary CP Requirement

Reduction of dietary CP by partially replacing the AA from intact protein sources, such as soybean-meal, with crystalline AA is a cost-effective strategy to improve the efficiency of N utilization. Multiple finishing pig studies have shown that a high CP diet results in greater weight gain and percentage carcass lean compared with feeding a lower CP diet with similar AA concentrations (Adeola and Young, 1989; Chiba et al., 2002; Ruusunen et al., 2007). Conversely, decreasing dietary CP has shown inconsistent results with reports of either no performance effects (Kerr et al., 2003; Ball et al., 2013; Tous et al., 2014) or negative effects (Rojo, 2011; Soto et al., 2017), even when correct AA ratios are met. Gomez et al. (2002) conducted a 55-d experiment to determine the effects of 2 CP concentrations (16 or 12%) in conjunction with 3 intake levels (ad libitum, 90, or 80% of ad libitum intake) on growing barrow growth performance and plasma metabolites. Pigs fed the high CP diet had increased ADG, G:F, and final BW compared with pigs fed the low CP diet. As expected, with decreasing intake, there is a concomitant decrease in ADG. In addition, regardless of the feeding level, plasma urea concentration was decreased in pigs fed low CP compared with pigs fed high CP. Furthermore, Figueroa et al. (2002) conducted a 35-d experiment to determine the CP concentration (11 to 16%) below which growth performance would be reduced in growing gilts fed low CP, AA-fortified, corn-soybean meal diets. They observed that reduction in CP concentration negatively affected growth and carcass performance, with the most substantial reduction in ADG as the CP decreased from 12 to 11%, with a similar response in ADFI. Recent work conducted by Soto et al. (2017) studied the effects of feeding a 10 or 13% CP diet to finishing pigs and found significant performance reduction in pigs fed the diet with 10% CP. The results of our studies (Exp. 2 and 3) are consistent with the findings of Figueroa et al. (2002) and Soto et al. (2018), who observed a 10 to 30% reduction in ADG in pigs fed dietary CP concentrations below 12%.

Figueroa et al. (2002) reported that pigs fed diets with low CP concentrations had a corresponding reduction in ADFI, with the lowest intake observed in pigs fed 11% CP. Conversely, Soto et al. (2018) found no differences in ADFI associated to changes in dietary CP concentration. The results of our studies (Exp. 2 and 3) are consistent with Figueroa et al. (2002) where reduction in ADFI was observed when CP decreased. However, the highest ADFI corresponded with the highest ADG (12% CP) in Exp. 2, whereas the highest intake (10 and 11% CP) did not correspond with the highest ADG (13% CP) in Exp. 3. As previously discussed, we speculate that variation in ADFI in relation to CP reduction could be associated with the different genetic lines used (PIC 327 × 1050 in Exp. 2 and DNA 600 × 241 in Exp. 3, respectively). Pigs in Exp. 3 had 12% greater ADFI than pigs in Exp. 2, which could explain reaching their highest intake at a lower dietary CP level. Assuming 85% digestibility of a corn-soybean meal diet (Dean, 2005), grams of digestible CP intake per kg of gain was 319.1 g with the 12% CP diet, where ADG and ADFI was maximized in Exp. 2. In Exp. 3, similar digestible CP intake per kg of gain (315.0 g) was reached and ADFI maximized with 10% CP diet. A digestible CP intake per kg of gain of 361.3 g was reached with the 13% CP diet, where ADG was maximized. However, regardless of feeding patterns, both genotypes maximized growth and carcass performance with diets containing 12 to 13% CP.

Concentrations of other essential AA may become limiting in low CP diets. Figueroa et al. (2002) indicated that lowering CP could result in a deficiency of other limiting AA for finishing pigs fed corn-soybean meal-based diets. However, all essential AA were above the SID levels suggested by NRC (2012) in our studies.

The current body of literature has suggested that there are several possible explanations for the negative effects on growth when low CP diets are fed. These include possible deficiency of nonessential AA or other nutrients, such as minerals or vitamins in the protein source that are not provided in low CP diets (Rojo, 2011; Ball et al., 2013; Mansilla et al., 2017). Providing a source of nonprotein nitrogen in diets deficient in nonessential AA has been demonstrated to improve nitrogen retention (Mansilla et al., 2017) and carcass lean to fat ratio (Chiba et al., 1995). Furthermore, adding crystalline AA to a typical corn-soybean meal diet leads to a reduction in the concentration of soybean meal. Thus, the question remains whether the reduced performance of pigs fed low CP diets is due to lower CP or decreased concentrations of soybean meal. Soybean meal contains several biologically active compounds, such as isoflavones, saponins, proteins, and peptides that may also be important for growth performance (Omoni and Aluko, 2005; Rochell et al., 2015). Further research is needed to understand the reasons why pigs fed diets with seemingly adequate levels of AA, but with less than 12% CP have decreased growth and carcass performance.

In conclusion, the SID lysine requirement was 0.55 to 0.63% for pigs from 100 to 122 kg depending on response criteria. Growth performance was maximized in both genotypes tested in the present study with diets containing 12 to 13% dietary CP in pigs from 100 to 120 kg.

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