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Effects of Standardized Ileal Digestible Histidine:Lysine Ratio on Growth Performance of 15- to 25-lb Pigs[1]

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Summary

Two experiments were conducted to determine the standardized ileal digestible (SID) His:Lys requirement of 15- to 25-lb nursery pigs. A total of 360 and 350 pigs (DNA 241 × 600), initially 15.6 and 14.5 lb body weight (BW), were used in Exp. 1 and 2, respectively. There were 5 pigs per pen and 12 and 10 replicates per treatment in Exp. 1 and 2, respectively. After weaning, pigs were fed a common pelleted diet for 10 d in Exp. 1 and 7 d in Exp. 2. Then, pens were assigned to treatments in a randomized complete block design with BW as the blocking factor. Dietary treatments consisted of SID His:Lys ratios of 24, 28, 32, 36, 40, and 44% in Exp. 1 and 24, 28, 30, 32, 34, 36, and 42% in Exp. 2. Experimental diets were fed in pellet form for 10 d in Exp. 1 and 14 d in Exp. 2 followed by a common mash diet for 15 d in Exp. 1 and 14 d in Exp. 2. Data were analyzed using the GLIMMIX and NLMIXED procedures of SAS. Competing statistical models were quadratic polynomial (QP), broken-line linear (BLL), and broken-line quadratic (BLQ). In Exp. 1, increasing SID His:Lys increased (quadratic, $P < 0.001$) average daily gain (ADG), average daily feed intake (ADFI), and BW and improved (quadratic, $P < 0.001$) feed-to-gain ratio (F/G). In Exp. 2, ADG increased (quadratic, $P = 0.001$) and F/G improved (quadratic, $P = 0.001$) and ADFI linearly increased ($P = 0.001$) with increasing SID His:Lys. The best-fitting model for all response variables analyzed was the BLL. In Exp. 1, requirement estimates were 29.7%, 29.1%, and 29.8% SID His:Lys for ADG, ADFI, and gain-to-feed ratio (G:F), respectively. In Exp. 2, the SID His:Lys requirements were estimated at 31.0% for ADG and 28.6% for G:F. These results suggest that the NRC[4] may overestimate the SID His:Lys requirement for 15- to 25-lb pigs. Therefore, nursery diets can be formulated with higher inclusion of crystalline amino acids before His becomes limiting.

Introduction

Practical nursery diets are formulated with high inclusion of crystalline amino acids (AA). In most situations, it is economical to add L-Lys, L-Thr, L-Trp, DL-Met, and L-Val. In such cases, the NRC[4] AA requirement estimates suggest that His may become the sixth limiting in 15- to 25-lb BW nursery diets supplemented with high amounts of these amino acids. Thus, the His concentration may limit the inclusion of higher levels of crystalline amino acids in nursery diets. Amino acid requirements are often expressed as a SID ratio to Lys (SID His:Lys). The NRC[4] estimates the SID His:Lys requirement at 34% for nursery pigs from 15- to 25-lb. Recent research suggests that the NRC[4] recommendations may overestimate the His requirement. Gloaguen et al.[5] determined that 32% SID His:Lys was the requirement for 24- to 43-lb pigs and Wessels et al.[6] estimated the SID His:Lys requirement at 28% for 18- to 46-lb pigs. However, there is a lack of research investigating the SID His:Lys requirement of younger pigs. Therefore, the objective of our study was to determine the SID His:Lys requirement for 15- to 25-lb pigs.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocols used in these experiments. Two experiments were conducted at the Kansas State University Swine Teaching and Research Center in Manhattan, KS. All diets were manufactured at the Kansas State University O.H. Kruse Feed Technology Innovation Center in Manhattan, KS. Corn, soybean meal, spray-dried whey, and whey protein concentrate were analyzed for total amino acid content prior to diet formulation (Ajinomoto Heartland, Chicago, IL) and diets were formulated using these values.

In Exp. 1, a total of 360 pigs (DNA 241 × 600; initial average BW of 15.6 lb) were used in a 25-d growth trial, where test diets were fed for 10 d and a common diet was fed for 15 d. In Exp. 2, 350 pigs (DNA 241 × 600; initial average BW of 14.5 lb) were used in a 28-d growth trial, where test diets were fed for 14 d and a common diet was fed for 14 d. Pigs were weaned at approximately 21 d of age and placed in pens of 5 pigs each based on initial BW and gender. A common phase 1 pelleted diet was fed for 10 d in Exp. 1 and 7 d in Exp. 2. At d 7 or 10 after weaning, which was considered d 0 of the trial, pens of pigs were randomly allotted to treatment in a randomized complete block design with BW as the blocking factor. There were 12 replicates per treatment in Exp. 1 and 10 replicates per treatment in Exp. 2.

In Exp. 1 and 2, the same basal diet containing corn, spray-dried whey, and whey protein concentrate was formulated to 24% SID His:Lys. Then, L-His was added at the expense of corn to create the high SID His:Lys diets at 44% (Exp. 1) or 42% (Exp. 2). Within each experiment, the low and high diets were blended to achieve intermediate SID His:Lys (Table 1). In Exp. 1, six dietary treatments were created to contain 24, 28, 32, 36, 40, and 44% SID His:Lys. In Exp. 2, there were seven dietary treatments consisting of 24, 28, 30, 32, 34, 36, and 42% SID His:Lys. The SID Lys was 1.25%

[5]Gloaguen, M., N. Le Floc'h, Y. Primot, E. Corrent, and J. van Milgen. 2013. Response of piglets to the standardized ileal digestible isoleucine, hidistine and leucine supply in cereal-soybean meal-based diets. Animal. 7:901-908.

[6]Wessels, A.G., H. Kluge, N. Mielenz, E. Corrent, J. Bartelt, and G.I. Stangl. 2016. Estimation of the leucine and histidine requirements for piglets fed a low-protein diet. Animal 11:1803-1811.

to ensure Lys was the second limiting amino acid and all other amino acids met or exceeded the NRC[4] requirement estimates. Experimental diets were fed for 10 d in Exp. 1 and 14 d in Exp. 2 followed by a common phase 3 diet for 15 d in Exp. 1 and 14 d in Exp. 2. Experimental diets were pelleted and the processing parameters were: 123 °F average conditioning temperature, 156 °F average hot pellet temperature, 13/64 in. die size (L/D = 5.0), 1,560 lb/h production rate, 85.7 °F ambient temperature, and 82% relative humidity. The common diet was provided in mash form.

Each pen (5 × 5 ft) was equipped with a 4-hole, dry self-feeder and a cup waterer to provide *ad libitum* access to feed and water. Pigs were weighed and feed disappearance was measured on d 0, 7, 10, 18, and 25 in Exp. 1 and on d 0, 7, 14, 21, and 28 in Exp. 2.

Representative diet samples were obtained from all feeders of each treatment. Samples were analyzed for dry matter, crude protein, calcium, phosphorus, sodium, and chloride (Ward Laboratories, Inc., Kearney, NE) as well as total amino acid content (Ajinomoto Heartland, Inc., Chicago, IL).

Data were analyzed as a randomized complete block design with block as a random effect and pen as the experimental unit. Polynomial contrasts were constructed to evaluate the linear and quadratic effects of increasing SID His:Lys on ADG, ADFI, F/G (modeled as G:F), and BW. Contrast coefficients were adjusted for unequally spaced treatments in Exp. 2. Data were analyzed using the GLIMMIX procedure of SAS (SAS Institute Inc., Cary, NC). Results were considered significant at $P \leq 0.05$ and marginally significant at $0.05 < P \leq 0.10$.

Competing dose response models consisted of quadratic polynomial (QP), broken-line linear (BLL), and broken-line quadratic (BLQ). Broken-line regression models were fitted using the NLMIXED procedure of SAS according to the procedures of Gonçalves et al.[7] Models were expanded to account for heterogeneous variance when needed. Competing models were compared using the Bayesian information criteria (BIC), with decreases by 2 or more units considered an improved fit. Results reported correspond to the best fitting model.

Results and Discussion

The proximate analyses and total amino acids were consistent with formulated estimates (Tables 2 and 3). Amino acid analysis showed a stepwise increase in total His levels.

In Exp. 1, ADG and ADFI increased, then plateaued (quadratic, $P < 0.001$) and F/G improved, then plateaued (quadratic, $P < 0.001$) with increasing SID His:Lys from d 0 to 10, when experimental diets were fed (Table 4). For all response variables, the best fitting model was the BLL. The estimated regression equation for ADG (Figure 1) was:

ADG, g = 463.23 – 23.955 × (29.69 – SID His:Lys) if SID His:Lys < 29.7%

[7]Gonçalves, M.A.D., N.M. Bello, S.S. Dritz, M.D. Tokach, J.M. DeRouchey, J.C. Woodworth, and R.D. Goodband. 2016. An update on modeling dose-response relationships: Accounting for correlated data structure and heterogeneous error variance in linear and nonlinear mixed models. Journal of Animal Science. 94:1940-1950.

ADG, g = 463.23 if SID His:Lys ≥ 29.7%

Based on the previous model, the estimated breakpoint was 29.7% (95% CI: [27.8, 31.6%]) SID His:Lys.

For ADFI, the estimated breakpoint was 29.1% (95% CI: [27.6, 30.6%]) SID His:Lys and the regression equation for the BLL model (Figure 2) was:

ADFI, g = 562.24 – 19.448 × (29.1 – SID His:Lys) if SID His:Lys < 29.1%
ADFI, g = 562.24 if SID His:Lys ≥29.1%

For G:F, the maximum mean value was estimated at 29.8% (95% CI: [27.6, 31.2%]) SID His:Lys and the estimated regression equation for the BLL model (Figure 3) was:

G:F, g/kg = 815.95 – 18.344 × (29.8 – SID His:Lys) if SID His:Lys < 29.8%
G:F, g/kg = 815.95 if SID His:Lys ≥ 29.8%

During the post-test period (d 10 to 25), ADG decreased (linear, $P = 0.025$) and F/G was poorer (linear, $P = 0.002$) in pigs previously fed diets with increasing SID His:Lys. There was a quadratic response ($P < 0.01$) for BW on d 10 and 25. Overall (d 0 to 25), ADG and ADFI were greater (quadratic, $P < 0.05$) and F/G marginally improved (quadratic, $P = 0.095$) with increasing SID His:Lys.

In Exp. 2, from d 0 to 14 when experimental diets were fed, ADG increased, then plateaued (quadratic, $P = 0.001$) and F/G improved, then plateaued (quadratic, $P = 0.001$), and ADFI linearly increased ($P = 0.001$) with increasing SID His:Lys (Table 5). The response for ADFI was not modeled due to its linear nature. Similar to Exp. 1, the best fitting model was the BLL for ADG and G:F. The maximum mean ADG was estimated at 31.0% (95% CI: [29.7, 32.3%]) SID His:Lys and the estimated regression equation (Figure 4) was:

ADG, g = 355.0 – 17.22 × (31.0 – SID His:Lys) if SID His:Lys < 31.0%
ADG, g = 355.0 if SID His:Lys ≥ 31.0%

For G:F, the estimated breakpoint was 28.6% (95% CI:[27.1, 30.0%]) SID His:Lys and the regression equation for the BLL model (Figure 5) was:

G:F, g/kg = 726.4 – 38.48 × (28.6 – SID His:Lys) if SID His:Lys < 28.6%
G:F, g/kg = 726.4 if SID His:Lys ≥ 28.6%

During the post-test period (d 14 to 28), ADFI increased (linear, $P = 0.003$) and F/G worsened (quadratic, $P = 0.002$) in pigs previously fed diets with increasing SID His:Lys. There was a quadratic response ($P < 0.01$) for BW on d 14 and 28. Overall (d 0 to 28), ADG and ADFI were greater (quadratic, $P < 0.01$) and F/G improved (quadratic, $P = 0.011$) with increasing SID His:Lys.

In conclusion, SID His:Lys requirement estimates were similar in Exp. 1 and 2. The treatments in Exp. 2 were more closely spaced around the anticipated breakpoint.

The narrower range of SID His:Lys in Exp. 2 allowed the modeling of a more precise requirement estimate. Practical implications are due to a marginal increase in growth rate of the pigs fed the SID His:Lys of 30%, resulting in a slightly higher breakpoint for ADG in the second experiment. Results suggest that the SID His:Lys ratio to optimize performance ranges from 28.6 to 31.0%. The requirement estimates observed in this study are lower than the current NRC[4] recommendation of 34% SID His:Lys. Therefore, nursery diets can be formulated with high inclusions of crystalline amino acids before His becomes limiting.

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

Item	Exp. 1 and 2 24% SID His:Lys	Exp. 1 44% SID His:Lys	Exp. 2 42% SID His:Lys
Ingredients, %			
Corn	60.20	59.94	59.97
Whey protein concentrate	7.75	7.75	7.75
Spray-dried whey	7.25	7.25	7.25
Soybean meal (45% CP)	5.63	5.63	5.63
Sucrose	10.00	10.00	10.00
Monocalcium phosphate (21.5% P)	1.43	1.43	1.43
Calcium carbonate	0.98	0.98	0.98
Sodium chloride	0.30	0.30	0.30
Sodium bicarbonate	0.75	0.75	0.75
Potassium chloride	0.11	0.11	0.11
L-Lys HCl	0.65	0.65	0.65
DL-Met	0.24	0.24	0.24
L-Thr	0.24	0.24	0.24
L-Trp	0.07	0.07	0.07
L-Val	0.26	0.26	0.26
L-Ile	0.14	0.14	0.14
L-Phe	0.34	0.34	0.34
L-His	---	0.25	0.23
Glutamic acid	1.50	1.50	1.50
Glycine	1.50	1.50	1.50
Zinc oxide	0.25	0.25	0.25
Vitamin premix	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15
Phytase[2]	0.03	0.03	0.03
Total	100	100	100

continued

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

Item	Exp. 1 and 2 24% SID His:Lys	Exp. 1 44% SID His:Lys	Exp. 2 42% SID His:Lys
SID amino acids, %			
Lysine	1.25	1.25	1.25
Isoleucine:lysine	55	55	55
Leucine:lysine	105	105	105
Methionine:lysine	39	39	39
Methionine and cystine:lysine	60	60	60
Threonine:lysine	65	65	65
Tryptophan:lysine	19.8	19.8	19.8
Valine:lysine	70	70	70
Histidine:lysine	24	44	42
Net energy, kcal/lb	1,139	1,136	1,136
Crude protein, %	18.2	18.3	18.3
Calcium, %	0.72	0.72	0.72
STTD P,[3] %	0.52	0.52	0.52

[1]In Exp. 1, diets were fed from 15.6 to 25.1 lb body weight (BW). Exp. 1 diets were blended to form the intermediate treatments: 28, 32, 36, and 40% standardized ileal digestible (SID) His:Lys. In Exp. 2, diets were fed from 14.5 to 24.6 lb BW. Diets were blended to form the intermediate treatments: 28, 30, 32, 34, and 36% SID His:Lys.
[2]Ronozyme HiPhos 2700 (DSM Nutritional Products, Basel, Switzerland) provided 306 FTU per lb of feed.
[3]STTD P = standardized total tract digestible phosphorus.

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

	Standardized ileal digestible His:Lys, %					
Item	24	28	32	36	40	44
Proximate analysis, %						
Dry matter	90.5	90.9	91.0	91.6	91.4	91.5
Crude protein	17.3	17.0	17.4	17.3	17.9	18.6
Calcium	0.82	0.77	0.85	0.83	0.84	0.85
Phosphorus	0.60	0.58	0.62	0.57	0.58	0.57
Sodium	0.35	0.37	0.37	0.39	0.35	0.42
Chloride	0.48	0.51	0.48	0.48	0.51	0.60
Amino acids, %						
Lysine	1.28	1.32	1.38	1.33	1.33	1.32
Isoleucine	0.68	0.70	0.72	0.70	0.70	0.72
Leucine	1.36	1.39	1.42	1.40	1.39	1.43
Methionine	0.45	0.46	0.46	0.45	0.47	0.45
Methionine and cystine	0.75	0.75	0.77	0.76	0.77	0.77
Threonine	0.87	0.90	0.90	0.89	0.91	0.89
Tryptophan	0.24	0.24	0.26	0.25	0.26	0.26
Valine	0.88	0.91	0.92	0.90	0.91	0.92
Histidine	0.33	0.37	0.43	0.45	0.50	0.55

[1]A representative sample of each diet was collected from all feeders for each treatment, homogenized, and submitted to Ward Laboratories, Inc., Kearney, NE, for proximate analysis. Amino acid analysis was conducted on composite samples by Ajinomoto Heartland, Inc., Chicago, IL.

Table 3. Chemical analysis of diets (as-fed basis; Exp. 2)[1]

	Standardized ileal digestible His:Lys, %						
Item	24	28	30	32	34	36	42
Proximate analysis, %							
Dry matter	91.8	91.4	91.2	92.1	91.4	91.2	91.7
Crude protein	16.6	17.2	17.6	17.4	17.5	16.9	18.1
Calcium	0.90	0.78	0.84	0.84	0.83	0.84	0.90
Phosphorus	0.58	0.59	0.60	0.59	0.57	0.59	0.61
Sodium	0.43	0.40	0.39	0.41	0.46	0.41	0.42
Chloride	0.53	0.54	0.53	0.53	0.57	0.54	0.54
Amino acids, %							
Lysine	1.19	1.25	1.26	1.20	1.22	1.24	1.27
Isoleucine	0.67	0.70	0.71	0.68	0.69	0.69	0.73
Leucine	1.29	1.31	1.31	1.28	1.29	1.29	1.30
Methionine	0.41	0.43	0.42	0.41	0.42	0.42	0.44
Methionine and cystine	0.66	0.70	0.69	0.66	0.68	0.69	0.69
Threonine	0.80	0.82	0.81	0.81	0.82	0.82	0.83
Tryptophan	0.22	0.24	0.23	0.23	0.21	0.23	0.24
Valine	0.84	0.86	0.87	0.84	0.85	0.86	0.87
Histidine	0.33	0.36	0.38	0.39	0.39	0.44	0.50

[1] A representative sample of each diet was collected from all feeders for each treatment, homogenized, and submitted to Ward Laboratories, Inc., Kearney, NE, for proximate analysis. Amino acid analysis was conducted on composite samples by Ajinomoto Heartland, Inc., Chicago, IL.

Table 4. Effects of standardized ileal digestible (SID) His:Lys ratio on growth performance of nursery pigs from 15- to 25-lb, Exp. 1[1]

	SID His:Lys, %							Probability, $P <$	
Item[2]	24	28	32	36	40	44	SEM	Linear	Quadratic
BW, lb									
d 0	15.6	15.6	15.6	15.6	15.6	15.6	0.674	0.910	0.679
d 10	22.8	24.9	25.9	26.0	25.4	25.8	0.914	0.001	0.001
d 25	40.1	41.6	42.6	42.2	42.1	41.9	1.316	0.010	0.003
Experimental period (d 0 to 10)									
ADG, lb	0.72	0.93	1.03	1.04	0.99	1.02	0.033	0.001	0.001
ADFI, lb	1.02	1.19	1.26	1.26	1.25	1.25	0.043	0.001	0.001
F/G	1.42	1.28	1.21	1.21	1.27	1.23	0.022	0.001	0.001
Post-test period (d 10 to 25)									
ADG, lb	1.15	1.11	1.11	1.08	1.11	1.07	0.033	0.025	0.440
ADFI, lb	1.77	1.77	1.78	1.75	1.78	1.74	0.055	0.745	0.789
F/G	1.53	1.59	1.60	1.63	1.61	1.62	0.020	0.002	0.090
Overall (d 0 to 25)									
ADG, lb	0.98	1.04	1.08	1.06	1.06	1.05	0.029	0.007	0.002
ADFI, lb	1.47	1.54	1.57	1.55	1.57	1.55	0.046	0.043	0.038
F/G	1.50	1.48	1.45	1.46	1.48	1.47	0.015	0.271	0.095

[1]A total of 360 pigs (DNA 241 × 600, initially 15.6 lb BW) were used in a 25-d growth trial 5 pigs per pen and 12 replicates per treatment.

[2]BW = body weight. ADG = average daily gain. ADFI = average daily feed intake. F/G = feed-to-gain ratio.

Table 5. Effects of standardized ileal digestible (SID) His:Lys ratio on growth performance of nursery pigs from 15- to 25-lb, Exp. 2[1]

| Item[2] | SID His:Lys, % | | | | | | | SEM | Probability, *P* < | |
	24	28	30	32	34	36	42		Linear	Quadratic
BW, lb										
d 0	14.5	14.5	14.5	14.5	14.5	14.5	14.5	0.789	0.826	0.857
d 14	21.7	24.1	24.3	25.3	26.0	25.3	25.5	1.267	0.001	0.001
d 28	37.8	40.3	40.8	41.3	42.1	41.3	41.8	1.778	0.001	0.001
Experimental period (d 0 to 14)										
ADG, lb	0.51	0.68	0.71	0.77	0.82	0.77	0.79	0.037	0.001	0.001
ADFI, lb	0.94	0.97	1.03	1.04	1.09	1.06	1.09	0.047	0.001	0.168
F/G	1.88	1.43	1.46	1.36	1.33	1.38	1.39	0.059	0.001	0.001
Post-test period (d 14 to 28)										
ADG, lb	1.15	1.16	1.18	1.15	1.15	1.14	1.16	0.045	0.960	0.831
ADFI, lb	1.66	1.76	1.82	1.79	1.85	1.82	1.85	0.067	0.003	0.106
F/G	1.44	1.52	1.56	1.56	1.61	1.60	1.60	0.021	0.001	0.002
Overall (d 0 to 28)										
ADG, lb	0.83	0.92	0.94	0.96	0.99	0.96	0.97	0.038	0.001	0.003
ADFI, lb	1.30	1.37	1.42	1.41	1.47	1.44	1.47	0.052	0.001	0.050
F/G	1.58	1.49	1.52	1.48	1.49	1.51	1.51	0.023	0.133	0.011

[1]A total of 350 pigs (DNA 241 × 600, initially 14.5 lb BW) were used in a 28-d growth trial with 5 pigs per pen and 10 replicates per treatment.
[2]BW = body weight. ADG = average daily gain. ADFI = average daily feed intake. F/G = feed-to-gain ratio.
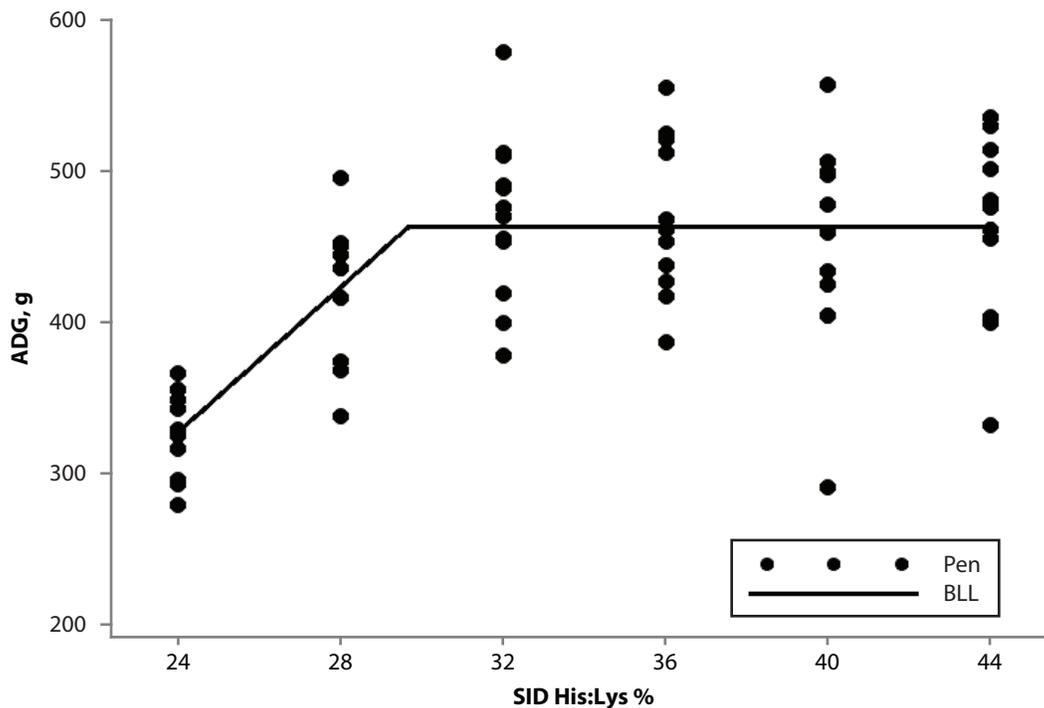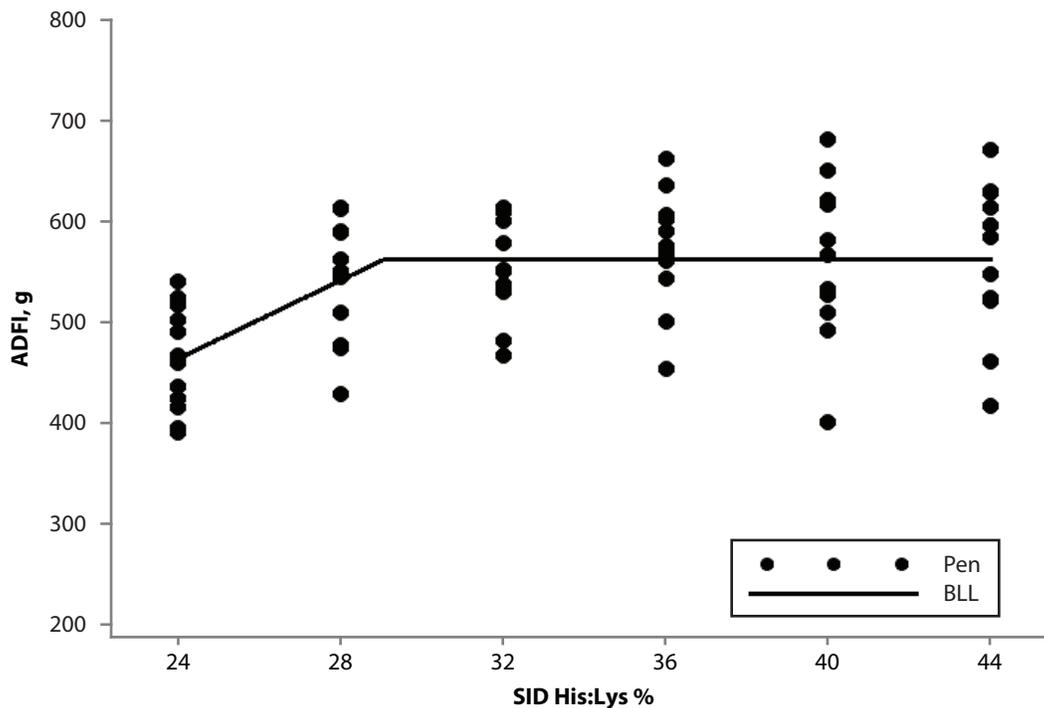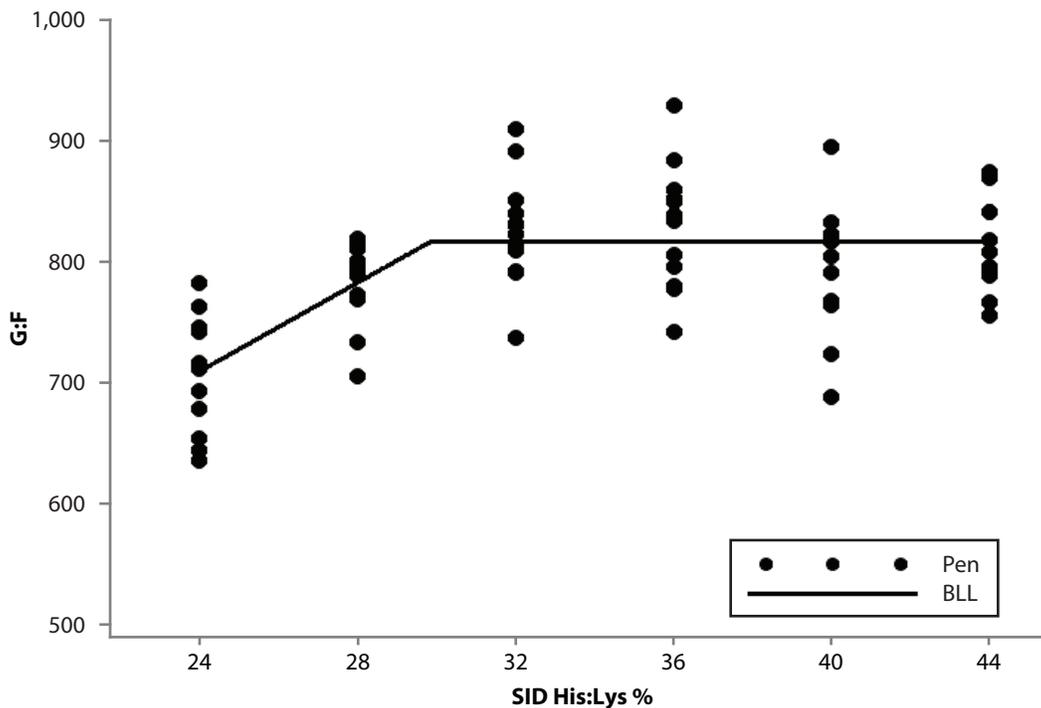
Figure 1. Fitted broken-line linear (BLL) regression model on average daily gain (ADG) as a function of increasing standardized ileal digestible (SID) His:Lys for 15- to 25-lb pigs in Exp. 1. The maximum mean ADG was estimated at 29.7% (95% CI: [27.8, 31.6%]) SID His:Lys. The estimated regression equation was ADG, g = 463.23 – 23.955 × (29.69 – SID His:Lys) for SID His:Lys < 29.7% and ADG, g = 463.23 for SID His:Lys ≥ 29.7%.

Figure 2. Fitted broken-line linear (BLL) regression model on average daily feed intake (ADFI) as a function of increasing standardized ileal digestible (SID) His:Lys for 15- to 25-lb pigs in Exp. 1. The maximum mean ADFI was estimated at 29.1% (95% CI: [27.6, 30.6%]) SID His:Lys. The estimated regression equation was ADFI, g = 562.24 – 19.448 × (29.1 – SID His:Lys) for SID His:Lys < 29.1% and ADFI, g = 562.24 for SID His:Lys ≥ 29.1%.

Figure 3. Fitted broken-line linear (BLL) regression model on gain-to-feed ratio (G:F) as a function of increasing standardized ileal digestible (SID) His:Lys for 15- to 25-lb pigs in Exp. 1. The maximum mean G:F (or minimum F/G) was estimated at 29.8% (95% CI: [27.6, 31.2%]) SID His:Lys. The estimated regression equation was G:F, g/kg = 815.95 − 18.344 × (29.8 − SID His:Lys) for SID His:Lys < 29.8% and G:F, g/kg = 815.95 for SID His:Lys ≥ 29.8%.
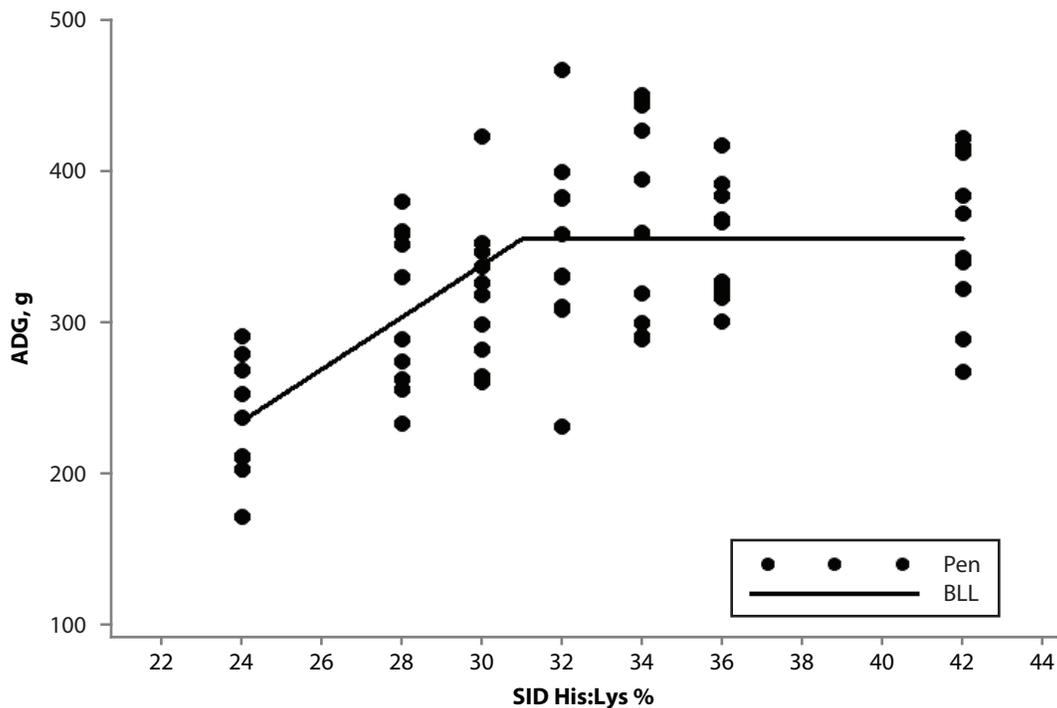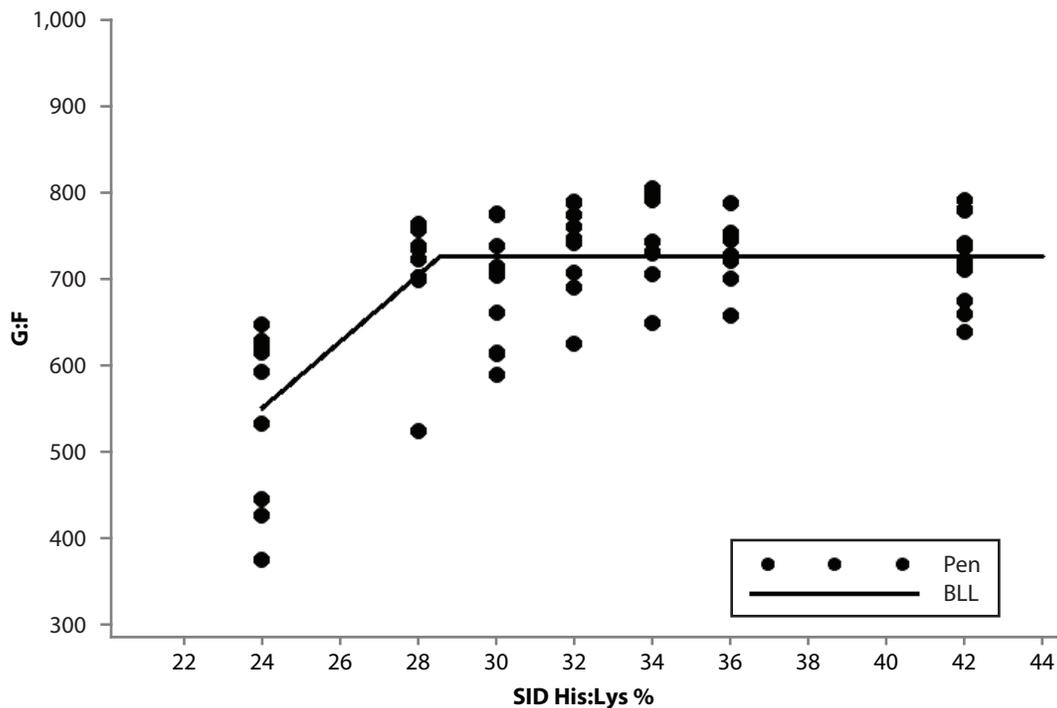
Figure 4. Fitted broken-line linear (BLL) regression model on ADG as a function of increasing standardized ileal digestible (SID) His:Lys for 15- to 25-lb pigs in Exp. 2. The maximum mean ADG was estimated at 31.0% (95% CI: [29.7, 32.3%]) SID His:Lys. The estimated regression equation was ADG, g = 355.0 − 17.22 × (31.0 − SID His:Lys) for SID His:Lys < 31.0% and ADG, g = 355.0 for SID His:Lys ≥ 31.0%.

Figure 5. Fitted broken-line linear (BLL) regression model on G:F as a function of increasing standardized ileal digestible (SID) His:Lys for 15- to 25-lb pigs in Exp. 2. The maximum mean G:F (or minimum F/G) was estimated at 28.6% (95% CI:[27.1, 30.0%]) SID His:Lys. The estimated regression equation was G:F, g/kg = 726.4 − 38.48 × (28.6 − SID His:Lys) for SID His:Lys < 28.6% and G:F, g/kg = 726.4 for SID His:Lys ≥ 28.6%.