Standardized ileal digestible valine:lysine dose response effects in 25- to 45-kg pigs under commercial conditions

Marcio A. D. Gonçalves,[†] Mike D. Tokach,[‡] Steve S. Dritz,[†,1] Nora M. Bello,[‖] Kevin J. Touchette,[$] Robert D. Goodband,[‡] Joel M. DeRouchey,[‡] and Jason C. Woodworth[‡]

[†]Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Manhattan, KS 66506; [‡]Department of Animal Sciences and Industry, College of Agriculture, Manhattan, KS 66506; [‖]Department of Statistics, College of Arts and Sciences, Manhattan, KS 66506-0201; [$]Ajinomoto Heartland Inc., Chicago, IL 60631

ABSTRACT: Two experiments were conducted to estimate the standardized ileal digestible valine:-lysine (**SID Val:Lys**) dose response effects in 25- to 45-kg pigs under commercial conditions. In experiment 1, a total of 1,134 gilts (PIC 337 × 1050), initially 31.2 kg ± 2.0 kg body weight (BW; mean ± SD) were used in a 19-d growth trial with 27 pigs per pen and seven pens per treatment. In experiment 2, a total of 2,100 gilts (PIC 327 × 1050), initially 25.4 ± 1.9 kg BW were used in a 22-d growth trial with 25 pigs per pen and 12 pens per treatment. Treatments were blocked by initial BW in a randomized complete block design. In experiment 1, there were a total of six dietary treatments with SID Val at 59.0, 62.5, 65.9, 69.6, 73.0, and 75.5% of Lys and for experiment 2 there were a total of seven dietary treatments with SID Val at 57.0, 60.6, 63.9, 67.5, 71.1, 74.4, and 78.0% of Lys. Experimental diets were formulated to ensure that Lys was the second limiting amino acid throughout the experiments. Initially, linear mixed models were fitted to data from each experiment. Then, data from the two experiments were combined to estimate dose-responses using a broken-line linear ascending (**BLL**) model, broken-line quadratic ascending (**BLQ**) model, or quadratic polynomial (**QP**). Model fit was compared using Bayesian information criterion (**BIC**). In experiment 1, ADG increased linearly ($P = 0.009$) with increasing SID Val:Lys with no apparent significant impact on G:F. In experiment 2, ADG and ADFI increased in a quadratic manner ($P < 0.002$) with increasing SID Val:Lys whereas G:F increased linearly ($P < 0.001$). Overall, the best-fitting model for ADG was a QP, whereby the maximum mean ADG was estimated at a 73.0% (95% CI: [69.5, >78.0%]) SID Val:Lys. For G:F, the overall best-fitting model was a QP with maximum estimated mean G:F at 69.0% (95% CI: [64.0, >78.0]) SID Val:Lys ratio. However, 99% of the maximum mean performance for ADG and G:F were achieved at, 68% and 63% SID Val:Lys ratio, respectively. Therefore, the SID Val:Lys requirement ranged from73.0% for maximum ADG to 63.2% SID Val:Lys to achieve 99% of maximum G:F in 25- to 45-kg BW pigs.

Key words: amino acid ratio, growth, growing pig, lysine, valine

J. Anim. Sci. 2018.96:591–599
doi: 10.1093/jas/skx059

INTRODUCTION

Valine (**Val**) is commonly considered to be the fifth limiting amino acid after Trp in corn-soybean meal–based diets for finishing pigs (Figueroa et al., 2003). Yet, Val can easily become limiting in diets supplemented with feed-grade amino acids, such as lysine (**Lys**), Met, Thr, and Trp. However, there is limited data characterizing the Val requirement in growing pigs. In fact in the most recent edition of the NRC, there were no studies summarized in the growing pig that were reported with greater

[1]Corresponding author: dritz@vet.ksu.edu

Received September 30, 2017.
Accepted December 12, 2017.

than a 27 kg final body weight (BW). Also, following a practical recommendation to express amino acid requirement is as a ratio to Lys (Stein et al., 2007), few studies have attempted to define a specific point estimate for the requirement of Val:Lys in pigs (Lewis and Nishimura, 1995; Waguespack et al., 2012). In fact, the NRC (2012) published a single overall standardized ileal digestible (**SID**) Val:Lys requirement of 65% for 25- to 45-kg pigs. Yet, it is possible that Val requirements to optimize different measurements of performance such as ADG, G:F, or economics may vary substantially as has been shown for other AA (Gonçalves et al., 2015). Finally, recent evidence suggests that the SID Val:Lys requirement may be greater than 65% if a broader range of BW in growing pigs is considered (Liu et al. 2015; Soumeh et al., 2015). Therefore, the objective of these studies was to estimate ADG and G:F in 25- to 45-kg pigs fed increasing dietary SID Val:Lys under commercial conditions. Also, our objective was to estimate the maximum or breakpoints for SID Val:Lys ratio and describe confidence intervals around these estimates.

MATERIALS AND METHODS

General

The Kansas State University Institutional Animal Care and Use Committee approved the protocols used in these experiments. Each experiment was conducted in a different commercial research-finishing barn in Minnesota. Both barns were naturally ventilated and double-curtain-sided and pens had completely slatted flooring and deep pits for manure storage. In experiment 1, pens were equipped with a four-hole stainless steel dry self-feeder (Thorp Equipment, Thorp, WI) and a cup waterer. In experiment 2, each pen was equipped with a three-hole stainless steel dry self-feeder (Thorp Equipment) and a cup waterer. Both facilities were equipped with a computerized feeding system (FeedPro; Feedlogic Corp., Willmar, MN) that delivered and recorded daily feed additions. During the experiments, pigs had ad libitum access to feed and water.

In experiment 1, a total of 1,134 gilts (PIC 337 × 1050), initially 31.2 kg ± 2.0 kg BW (mean ± SD) were used in a 19-d growth trial with 27 pigs per pen (0.62 m^2/pig) and seven pens per treatment. In experiment 2, a total of 2,100 gilts (PIC 327 × 1050), initially 25.4 ± 1.9 kg BW (mean ± SD) were used in a 22-d growth trial with 25 pigs per pen (0.67 m^2/pig) and 12 pens per treatment. In both experiments, pens were blocked by initial BW and dietary treatments were randomly assigned to pens within each block in a randomized complete block design. In experiment 1, there were six dietary treatments with dietary SID Val at 59.0, 62.5, 65.9, 69.6, 73.0, and 75.5% of Lys. For experiment 2, there were seven dietary treatments with SID Val at 57.0, 60.6, 63.9, 67.5, 71.1, 74.4, and 78.0% of Lys fed in meal form. In both experiments, the intermediate Val:Lys ratios were obtained by blending different proportions of source diets consisting of low and high Val:Lys ratios (Tables 1 and 2 for experiments 1 and 2, respectively). The NRC (2012) model was used to estimate the Lys requirement of gilts at the expected BW at the end of each experiment using the respective net energy per kg used in each experiment. All other model parameters were kept as default. The SID Lys as a percentage of the diet was reduced by 0.10 percentage points below the requirement at the expected BW by end of experiment to ensure that Lys was the second limiting amino acid throughout the experiment. This specification was based on results from a preliminary study performed in the same facility and with the same pigs as those used in experiment 1 (Gonçalves et al., 2015). This experiment indicated that diets formulated 0.10 percentage units below the SID Lys requirement estimated by NRC (2012) at the end of the experiment's weight range would ensure pigs were below the Lys requirement.

Diet Sampling and Analysis

Five representative samples of corn, soybean meal, and DDGS were collected weekly for 5 wk and analyzed in duplicate for total AA (except Trp; method 994.12; AOAC Int., 2012), Trp (method 13904:2005; ISO, 2005), and CP (method 990.03; AOAC Int., 2012) by Ajinomoto Heartland Inc. (Chicago, IL) for each experiment. The averages of these values were then used in diet formulation. Other nutrients and SID AA digestibility coefficient values used for diet formulation were obtained from NRC (2012). Ratios of other essential amino acids were evaluated in the final diet formulations as well as ensuring that enough nonessential amino acids were present to ensuring enough nitrogen was available for their synthesis.

In experiments 1 and 2, diet samples were taken from six 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 CP (method 990.03; AOAC Int., 2012) and total AA analyses were conducted in duplicate on composite samples (Ajinomoto Heartland Inc., Chicago, IL). Dietary samples were also analyzed for DM (method

Table 1. Diet composition on an as-fed basis[a]

	SID Val:Lys	
Item	Experiment 1: 75.5%[b]	Experiment 2: 78.0%[b]
Ingredient		
Corn	73.16	74.37
Soybean meal (46% CP)	8.21	6.78
Dried distillers grains with solubles	15.00	15.00
Corn Oil	0.50	—
Choice white grease	—	0.50
Limestone	1.20	1.10
Monocalcium phosphate (21.5% P)	0.30	—
Dicalcium phosphate (18.5% P)	—	0.45
Salt	0.35	0.35
Trace mineral premix[c]	0.100	—
Vitamin premix[d]	0.075	—
Vitamin-mineral premix[e]	—	0.200
Phytase[f]	—	0.050
L-Lys HCl	0.540	0.591
DL-Met	0.105	0.105
L-Thr	0.175	0.195
L-Trp	0.071	0.073
L-Val	0.142	0.181
L-Ile	0.043	0.062
TOTAL	100	100
Calculated analysis		
Standardized ileal digestible (SID) AA, %		
Lys	0.85	0.85
Ile:Lys	55	55
Leu:Lys	139	139
Met:Lys	36	36
Met & Cys:Lys	60	60
Thr:Lys	65	65
Trp:Lys	20.1	20.1
Val:Lys	75.5	78.0
ME, kcal/kg	3,358	3,355
NE NRC, kcal/kg	2,555	2,560
SID Lysine:NE, g/Mcal	3.33	3.32
CP, %	14.0	13.7
Ca, %	0.57	0.57
Stand. Total Tract Dig. (STTD) P, %	0.33	0.29
Ca:P	1.41	1.38
Ca:P (STTD P)	1.74	2.00

[a]Diets were fed from 31.3 to 44.9 kg BW in experiment 1 and 25.4 to 40.7 kg BW in experiment 2. Corn, dried distillers grains with solubles (DDGS), and soybean meal prior to each experiment were analyzed for CP and total amino acid concentrations and NRC (2012) SID digestibility values were used in the diet formulation.

[b]The lowest diet within the experiment was the the same as the listed high diet with the exception of the lack of L-Val addition which resulted in a Val:Lys of 62.5% for experiment 1 and 60.6% for experiment 2. Within each experiment the low and high diet were blended in the appropriate proportions to result in intermediate dietary treatments: 62.5, 65.9, 69.6, and 73.0, SID Val:Lys in experiment 1 and 60.6, 63.9, 67.5, 71.1, and 74.4 SID Val:Lys in experiment 2.

[c]Provided per kg of premix: 33 g Mn from manganese oxide, 110 g Fe from iron sulfate, 110 g Zn from zinc oxide, 16.5 g Cu from copper sulfate, 0.33 g I from ethylenediamine dihydriodide, and 0.30 g Se from sodium selenite.

[d]Provided per kg of premix: 7,054,720 IU vitamin A; 1,102,300 IU vitamin D3; 35,274 IU vitamin E; 3,527 mg vitamin K; 6.173 mg riboflavin; 22,046 mg pantothenic acid; 39,683 mg niacin; and 26.5 mg vitamin B12.

[e]Provided per kg of premix: 3.3 g Mn from manganese oxide, 30.9 g Fe from iron sulfate, 30.9 g Zn from zinc oxide, 3.1 g Cu from copper sulfate, 0.16 g I from ethylenediamine dihydriodide, and 0.12 g Se from sodium selenite, 2,910,072 IU vitamin A; 440,920 IU vitamin D3; 8,047 IU vitamin E; 1,047 mg vitamin K; 1,984 mg riboflavin; 6,854 mg pantothenic acid; 14,991 mg niacin; and 7.94 mg vitamin B12.

[f]Provided 500 phytase units (OptiPhos, Huvepharma, Peachtree, GA) per kg of diet in experiment 1 and provided 330 phytase units (Axtra PHY, DuPont, Wilmington, DE) per kg of diet in experiment 2.

Table 2. Diet chemical (calculated) analysis on an as-fed-basis[a]

	Experiment 1: standardized ileal digestible Val:Lys ratio, %						
Item	59.0	62.5	66.0	69.5		73.0	75.5
DM	86.8 (87.0)	86.9 (87.0)	87.2 (87.0)	86.9 (87.0)		87.0 (87.0)	87.2 (87.0)
CP	14.6 (13.9)	14.2 (13.9)	14.4 (13.9)	14.2 (14.0)		14.3 (14.0)	14.5 (14.0)
Lys	0.97 (0.97)	0.98 (0.97)	1.03 (0.97)	0.94 (0.97)		0.94 (0.97)	0.96 (0.97)
Ile	0.55 (0.53)	0.53 (0.53)	0.57 (0.53)	0.52 (0.53)		0.52 (0.53)	0.54 (0.53)
Leu	1.38 (1.34)	1.38 (1.34)	1.44 (1.34)	1.32 (1.34)		1.34 (1.34)	1.40 (1.34)
Met	0.33 (0.36)	0.33 (0.36)	0.34 (0.36)	0.32 (0.36)		0.31 (0.36)	0.32 (0.36)
Met & Cys	0.60 (0.60)	0.59 (0.60)	0.62 (0.60)	0.56 (0.60)		0.56 (0.60)	0.57 (0.60)
Thr	0.65 (0.66)	0.67 (0.66)	0.68 (0.66)	0.63 (0.66)		0.63 (0.66)	0.64 (0.66)
Trp	0.18 (0.20)	0.18 (0.20)	0.18 (0.20)	0.18 (0.20)		0.18 (0.20)	0.19 (0.20)
Val	0.65 (0.59)	0.64 (0.62)	0.69 (0.65)	0.66 (0.68)		0.69 (0.71)	0.73 (0.73)
	Experiment 2: standardized ileal digestible Val:Lys ratio, %						
Item	57.0	60.6	63.9	67.5	71.1	74.4	78.0
DM	87.9 (86.7)	87.8 (86.7)	86.9 (86.7)	87.0 (86.7)	87.4 (86.7)	87.6 (86.7)	87.5 (86.7)
CP	13.8 (13.6)	13.8 (13.7)	14.5 (13.7)	13.8 (13.7)	13.8 (13.7)	13.9 (13.7)	13.9 (13.7)
Lys	0.97 (0.96)	0.95 (0.96)	0.98 (0.96)	1.01 (0.96)	1.05 (0.96)	1.03 (0.96)	0.98 (0.96)
Ile	0.54 (0.52)	0.54 (0.52)	0.57 (0.52)	0.54 (0.52)	0.55 (0.52)	0.55 (0.52)	0.55 (0.52)
Leu	1.34 (1.31)	1.37 (1.31)	1.38 (1.31)	1.34 (1.31)	1.30 (1.31)	1.35 (1.31)	1.33 (1.31)
Met	0.32 (0.35)	0.30 (0.35)	0.33 (0.35)	0.32 (0.35)	0.33 (0.35)	0.32 (0.35)	0.33 (0.35)
Met & Cys	0.57 (0.59)	0.55 (0.59)	0.57 (0.59)	0.56 (0.59)	0.57 (0.59)	0.58 (0.59)	0.57 (0.59)
Thr	0.69 (0.66)	0.64 (0.66)	0.67 (0.66)	0.63 (0.66)	0.66 (0.66)	0.67 (0.66)	0.69 (0.66)
Trp	0.17 (0.19)	0.17 (0.19)	0.17 (0.19)	0.17 (0.19)	0.17 (0.19)	0.17 (0.19)	0.17 (0.19)
Val	0.63 (0.56)	0.64 (0.59)	0.68 (0.62)	0.66 (0.65)	0.72 (0.68)	0.73 (0.71)	0.75 (0.74)

[a]Diet samples were taken from six 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 CP and amino acid analysis was conducted on composite samples by Ajinomoto Heartland, Inc. (Chicago, IL). Values in parentheses indicate those calculated from diet formulation. Ingredient values for CP and SID coefficiets from NRC (2012) along with analyzed total amino acid content from corn, soybean meal, and distillers dried grains with solubles were used to derive the calculated values.

935.29; AOAC Int., 2012), crude fiber (method 978.10; AOAC Int., 2012 for preparation and Ankom 2000 Fiber Analyzer [Ankom Technology, Fairport, NY]), ash (method 942.05; AOAC Int., 2012), ether extract (method 920.39 a; AOAC Int., 2012 for preparation and ANKOM XT20 Fat Analyzer [Ankom Technology, Fairport, NY], Ward Laboratories, Inc. Kearney, NE).

Data Collection

Pens of pigs were weighed and feed disappearance measured at the beginning and at the end of each experiment to determine ADG, ADFI, and G:F. The total g of SID Val intake based on formulated values were divided by total BW gain to calculate the g of SID Val intake per kg of gain.

Statistical Analysis

First, responses measured at the pen level were analyzed separately for each experiment using a general linear mixed model, that included the fixed effect of SID Val:Lys as a categorical treatment and BW block as a random effect using procedures outlined by Gonçalves et al., 2016. Briefly, restricted maximum likelihood (REML) was used for estimation of variance components and degrees of freedom were estimated using the Kenward-Roger's method (Kenward and Roger, 1997). Orthogonal polynomial contrasts with coefficients adjusted for unequally spaced treatments were used to conduct a preliminary evaluation of the functional form of the relationship of ADG, ADFI, G:F, BW, g of SID Val intake per d, and g of SID Val intake per kg of gain. Model assumptions were checked for each response and heterogeneous residual variances were fitted as needed. Results from the base model analyses were then used to inform dose response modeling for ADG and G:F.

Data from the two experiments were combined and fitted using a single general linear mixed model that included the fixed effect of treatment and the random effects of experiment and BW block nested within experiment. No evidence for an experiment by treatment response was detected so the interaction term was removed from the model. Specification of heterogeneous residual variances were fitted where appropriate using procedures outlined by Gonçalves et al. (2016).

Table 3. Effects of standardized ileal digestible (SID) Val:Lys ratio on the growth performance of finishing pigs from 30 to 45 kg, experiment 1[a]

	SID Val:Lys ratio, %						Probability, $P <$	
Item	59.0	62.5	66.0	69.5	73.0	75.5	Linear	Quadratic
d 0 to 19								
ADG, g	680	717	717	712	744	726	0.009	0.305
SEM	17.1	17.1	17.1	17.1	17.1	17.1		
ADFI, g	1461	1538	1520	1501	1551	1542	0.098	0.578
SEM	48.7	48.7	37.3	48.7	37.3	48.7		
G:F	0.467	0.467	0.472	0.474	0.481	0.472	0.370	0.648
SEM	0.0084	0.0036	0.0036	0.0084	0.0084	0.0084		
BW, kg								
d 0	31.3	31.3	31.2	31.3	31.2	31.2	0.762	0.962
SEM	0.77	0.77	0.77	0.77	0.77	0.77		
d 21	44.2	45.0	44.8	45.0	45.4	45.0	0.064	0.349
SEM	1.00	1.07	1.00	1.07	1.00	1.07		
SID Val intake, g/d	7.33	8.17	8.53	8.87	9.63	9.89	0.001	0.716
SEM	0.28	0.28	0.21	0.28	0.21	0.28		
SID Val, g/kg gain	10.7	11.3	11.9	12.3	12.9	13.6	0.001	0.490
SEM	0.23	0.10	0.10	0.23	0.23	0.23		

[a]A total of 1,134 gilts (PIC 337 × 1050), initially 31.2 ± 2.0 kg BW (mean ± SD) were used in a 19-d growth trial with 27 pigs per pen and seven pens per treatment.

Results from the base analyses were then used to develop the linear and nonlinear regression mixed models using the approach outlined by Gonçalves et al. (2016) and Robbins (2006)to estimate SID Val:Lys dose responses for ADG and G:F. Briefly, competing models included a broken-line linear ascending (**BLL**) model, a broken-line quadratic ascending (**BLQ**) model, and a quadratic polynomial (**QP**). For ADG and G:F the competing models were specified with dosage of SID Val:Lys as a continuous variable and BW block within experiment as a random effect. Additionally, the dose response models was expanded to accommodate heterogeneous residual variances. Competing statistical models were compared using maximum-likelihood-based fit criteria and the Bayesian information criteria (BIC; Milliken and Johnson, 2009). The best fitting model (lowest BIC) was then chosen for each response criteria.

The initial analysis within experiment data as performed using the GLIMMIX procedure of SAS (V 9.4, SAS Institute Inc., Cary, NC). For the dose response the QP models were fit using the GLIMMIX procedure and the broken-line regression models were fitted using the NLMIXED procedures of SAS. Results were considered significant at $P \leq 0.05$ and marginally significant at $0.05 > P \leq 0.10$.

RESULTS AND DISCUSSION

The analyzed diet CP and total AA concentrations (Table 2) were considered consistent with formulated values based on analytic variability reported by AFFCO (2015).

In experiment 1, ADG increased linearly ($P = 0.009$) with increasing SID Val:Lys (Table 3). A marginally significant increase was apparent for ADFI (linear, $P = 0.098$) and final BW (linear, $P = 0.064$) with increasing SID Val:Lys fed. Both g of SID Val intake per d and g of SID Val per kg of gain increased linearly ($P < 0.001$) with increasing SID Val:Lys. In experiment 2, ADG and ADFI increased in a quadratic manner ($P < 0.002$) with increasing SID Val:Lys whereas G:F increased linearly ($P < 0.001$; Table 4). Final BW increased (quadratic, $P = 0.010$), g of SID Val intake increased per d (quadratic, $P = 0.005$) and g of SID Val per kg of gain (linear, $P < 0.001$) increased with increasing Val:Lys. Satterplots of the observed data and predicted dose responses for ADG and G:F combined for experiments 1 and 2 as a function of SID Val:Lys ratio in 25- to 45-kg pigs are presented in Figures 1 and 2.

The best-fitting model for ADG pigs was a QP (BIC: 1482.9). In comparison the BLL model resulted in a BIC of 1491.1 and the BLQ model resulted in a BIC of 1488.6. The corresponding estimated regression equation for the QP model was:

Predicted ADG, kg = –1.5004 + 5.1325 × (SID Val:Lys) – 3.5172 × (SID Val:Lys)^2 + 0.012696 × (Initial BW, kg)

Note, the SID Val:Lys ratio explanatory variable is expressed as a proportion (i.e., 0.700). The maximum ADG was estimated at a 73.0% (95% CI:

Table 4. Effects of standardized ileal digestible (SID) Val:Lys ratio on the growth performance of finishing pigs from 25 to 40 kg, experiment 2[a]

	SID Val:Lys ratio, %							Probability, $P <$	
Item	57.0	60.6	63.9	67.5	71.1	74.4	78.0	Linear	Quadratic
d 0 to 22									
ADG, g	621	662	717	708	708	726	717	0.001	0.002
SEM	16.1	10.5	16.1	16.1	16.1	10.1	16.1		
ADFI, g	1488	1569	1633	1642	1633	1651	1637	0.001	0.001
SEM	28.2	28.2	28.2	28.2	28.2	28.2	28.2		
G:F	0.415	0.420	0.437	0.429	0.433	0.441	0.439	0.001	0.132
SEM	0.0044	0.0044	0.0044	0.0046	0.0044	0.0036	0.0044		
BW, kg									
d 0	25.4	25.4	25.5	25.4	25.4	25.4	25.4	0.989	0.584
SEM	0.55	0.55	0.55	0.55	0.55	0.55	0.55		
d 21	39.1	39.9	41.2	41.1	41.1	41.5	41.2	0.001	0.010
SEM	0.77	0.69	0.77	0.78	0.77	0.69	0.77		
SID Val intake, g/d	7.6	8.5	9.3	9.9	10.3	11.0	11.4	0.001	0.005
SEM	0.17	0.17	0.17	0.17	0.17	0.17	0.17		
SID Val, g/kg gain	10.5	11.1	11.2	12.0	12.6	13.0	13.6	0.001	0.368
SEM	0.12	0.12	0.12	0.12	0.12	0.12	0.12		

[a]A total of 2,100 gilts (PIC 327 × 1050), initially 25.4 ± 1.9 kg BW (mean ± SD) were used in a 22-d growth trial with 25 pigs per pen and 12 pens per treatment.

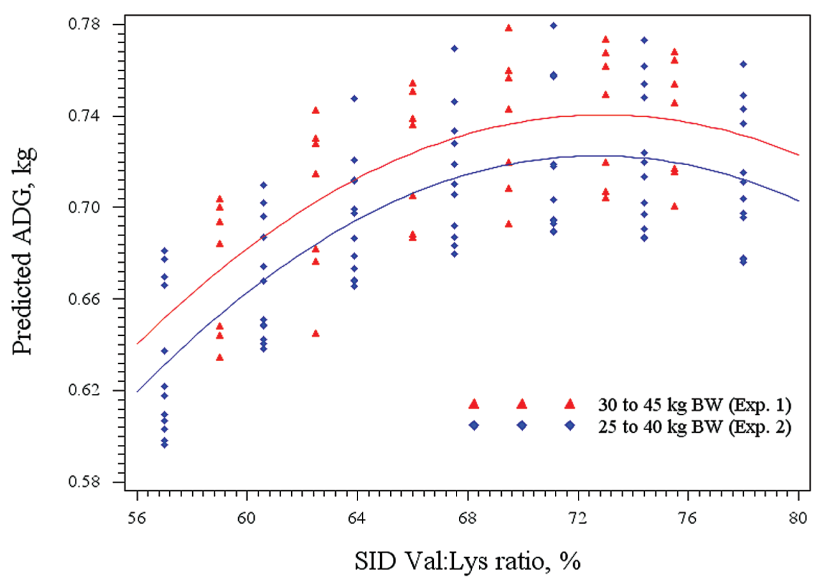

Figure 1. Predicted ADG and corresponding fitted QP regression equation as a function of increasing SID Val:Lys ratio in 25- to 45-kg pigs. The maximum mean ADG was estimated at 73.0% (95% CI: [69.5, >78.0%]) SID Val:Lys ratio. Each point represents the predicted ADG for a typical pen of pigs after adjusting for random effects.

[69.5, >78.0%]) SID Val:Lys. Note the estimate of the upper limit of the confidence interval estimate was outside the range of diet SID Val:Lys dose tested. Thus, due to the uncertaintiy past the dose range the upper confidence limit was reported as greater than the highest dosage.

The overall best-fitting model for G:F was a QP (BIC: 1156.3) compared with the BLL and BLQ models (BIC: 1158.7 and 1161.7, respectively). The estimated regression equation for the QP model was:

Predicted G:F = – 0.21495 + 1.81744 × (SID Val:Lys ratio) – 1.31678 × (SID Val:Lys ratio)^2

Based on the best-fitting QP model, the maximum mean G:F was estimated at 69.0% (95% CI: [64.0, >78.0]) SID Val:Lys.

For the ADG and G:F models the relatively wide range in the confidence intervals suggest that

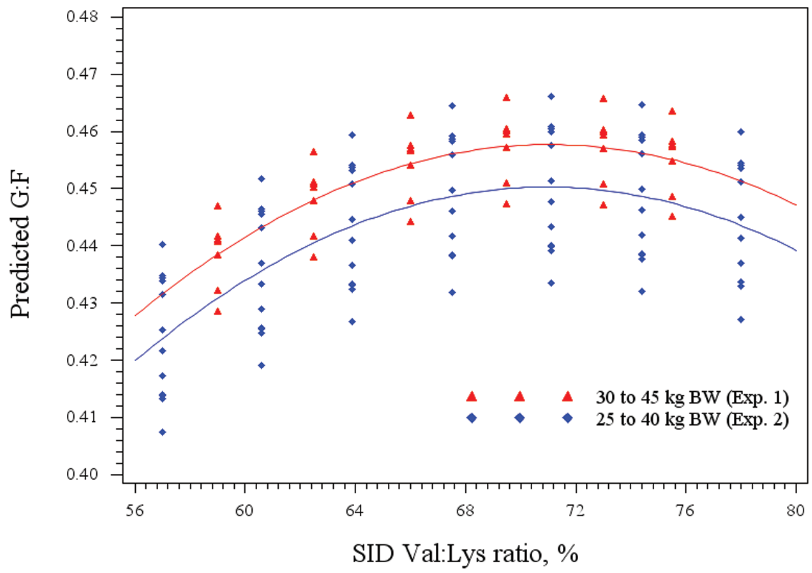

Figure 2. Predicted G:F and corresponding fitted QP regression equation as a function of increasing SID Val:Lys ratio in 25- to 45-kg pigs. The maximum mean G:F was estimated at 69.0% (95% CI: [64.0, >78.0]) SID Val:Lys ratio. Each point represents the predicted G:F value after adjustment for random effects.

the increases in ADG or G:F are relatively small over a wide range of dietary SID Val:Lys. Because of the modest responses, the wide range in optimum or breakpoint dosages may actually be in agreement.

Our results are consistent to the results by Barea et al. (2009), where the authors observed that, for 12 to 25 kg pigs, the SID Val:Lys for optimal ADG may be greater than those for G:F. In fact, in that study, the SID Val:Lys requirement for ADG was 70% in the BLL model and 75% in the BLQ whereas for G:F the requirements were 68% in the BLL and 72% in the BLQ. Noteworthy, different statistical models can yield different requirement estimates (Barea et al., 2009; Gaines et al., 2011) that likely depend on the model assumptions. This is not trivial as difference between estimates of alternative models can be substantial (as high as 6 percentage points in the study by Gaines et al., 2011), both from a practical and economic standpoint. Carefully choosing the model that fits the data for estimation and inference is important. In previous studies, it is not always clear how well the actual data were fitted by each of alternative models, and thus, how relevant their estimates for optimums might be. The relative fit of statistical models can be more objectively assessed and compared using fit statistics such as the Bayesian Information Criterion (Milliken and Johnson, 2009), as used in this study.

The NRC (2012) estimated the SID Val:Lys requirement of 25- to 45-kg pigs at 65%. Based on our results, the NRC (2012) recommendation appears to be adequate to maximize G:F, as the estimate 65% was within the 95% CI for SID Val:Lys observed in our study (95% CI: [64.0, >78.0]). The NRC and little previous literature provide a confidence interval around estimated requirements so it is difficult to determine if different estimates are significantly different. We believe differences in statistical approaches contribute as a source of variability in the scientific literature

In contrast, the NRC recommendation is below our estimate for the requirement to maximize average ADG (95% CI: [69.5, >78.0%]). This agrees with other studies that have shown that the SID Val:Lys requirement of nursery and finishing pigs ranges from 67% to 70% (Waguespack et al. 2012; Liu et al. 2015; Soumeh et al., 2015) for maximum ADG.

Estimated mean lowest-level SID Val:Lys for selected target performance levels of ADG and G:F based on corresponding best fitting models are listed in Table 5. Note that 99% of the maximum performance of ADG and G:F can be achieved with a SID Val:Lys of approximately 68% and 63.2%, respectively. A recent meta-analysis conducted by van Milgen et al. (2013) which evaluated 28 dose-response experiments in young pigs indicated a SID Val:Lys requirement of 69%, similar to our findings.

In conclusion, the results herein indicate that the SID Val:Lys requirement ranged from 73% for maximum ADG to 69% SID for G:F in 25- to 45-kg BW pigs. However because of the slope of the response curve in ADG, a 68% SID Val:Lys was able to yield more than 99% of maximum

Table 5. Estimated mean lowest standardized ileal digestible (SID) Val:Lys ratio for selected target mean performance levels of growing pigs

	Percent of maximum performance, %					
Item	95%	96%	97%	98%	99%	100%
ADG[a]	62.1	63.3	64.5	66.0	68.0	73.0
G:F[b]	<57.0	57.8	59.2	61.0	63.2	69.0

[a]QP equation for predicted ADG, kg = –1.5004 + 5.1325 × (SID Val:Lys) – 3.5172 × (SID Val:Lys)^2 + 0.012696 × (Initial BW, kg), estimated to 35 kg pigs.

[b]QP equation for predicted G:F = – 0.21495 + 1.81744 × (SID Val:Lys ratio) – 1.31678 × (SID Val:Lys ratio)^2.

mean ADG. Swine nutritionists may consider the amino acid ratio used in actual diet formulation to optimize performance and economic return is likely to vary with availability and prices of the dietary ingredients, as well as with market conditions for hogs (De La Llata et al., 2001). Using the estimated growth performance equations provided and the relative dose-response to increasing Val:Lys aid in an analysis to determine the most economical AA ratio for a given situation.

ACKNOWLEDGMENTS

Contribution no. 16-149-J from the Kansas Agric. Exp. Stn., Manhattan, KS 66506-0210. Appreciation is expressed to New Horizon Farms (Pipestone, MN) and Holden Farms (Northfield, MN) for providing the animals and research facilities, and to M. Brown, C. Steck, M. Heintz, M. Allerson, and J. Tebay for technical assistance. Appreciation is also expressed to Ajinomoto Heartland Inc. (Chicago, IL) for partial funding of the studies.

LITERATURE CITED

AFFCO. 2015. AFFCO official publication. Oxford (IN): Assoc. Am. Feed Control Off.

AOAC International. 2012. Official Methods of Analysis of AOAC Int. 19th ed. Gaithersburg (MD): AOAC Int.

Barea, R., L. Brossard, N. Le Floc'h, Y. Primot, D. Melchior, and J. Van Milgen. 2009. The standardized ileal digestible valine-to-lysine requirement ratio is at least seventy percent in postweaned piglets. J. Anim. Sci. 87:935–947. doi:10.2527/jas.2008-1006

De La Llata, M., S. S. Dritz, M. R. Langemeier, M. D. Tokach, R. D. Goodband, and J. L. Nelssen. 2001. Economics of increasing lysine: calorie ratio and adding dietary fat for growing-finishing pigs reared in a commercial environment. J. Swine Health Prod. 9:215–224. https://www.aasv.org/shap/issues/v9n5/v9n5p215.html.

Figueroa, J. L., A. J. Lewis, P. S. Miller, R. L. Fischer, and R. M. Diedrichsen. 2003. Growth, carcass traits, and plasma amino acid concentrations of gilts fed low-protein diets supplemented with amino acids including histidine, isoleucine, and valine. J. Anim. Sci. 81:1529–1537. doi:10.2527/2003.8161529x

Gaines, A. M., D. C. Kendall, G. L. Allee, J. L. Usry, and B. J. Kerr. 2011. Estimation of the standardized ileal digestible valine-to-lysine ratio in 13-to 32-kilogram pigs. J. Anim. Sci. 89:736–742. doi:10.2527/jas.2010-3134

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 structures and heterogeneous variance in linear and non-linear mixed models. J. Anim. Sci. 94:1940–1950. doi:10.2527/msasas2016-042

Gonçalves, M. A. D., S. Nitikanchana, M. D. Tokach, S. S. Dritz, N. M. Bello, R. D. Goodband, K. J. Touchette, J. L. Usry, J. M. DeRouchey, and J. C. Woodworth. 2015. Effects of standardized ileal digestible tryptophan: lysine ratio on growth performance of nursery pigs. J. Anim. Sci. 93:3909–3918. doi:10.2527/jas.2015-9083

Kenward, M. G., and Roger, J. H. 1997. Small sample inference for fixed effects from restricted maximum likelihood. Biometrics. 53:983–997. doi:10.2307/2533558

Lewis, A. J., and N. Nishimura. 1995. Valine requirement of the finishing pig. J. Anim. Sci. 73:2315–2318. doi:10.2527/1995.7382315x

Liu, X. T., W. F. Ma, X. F. Zeng, C. Y. Xie, P. A. Thacker, J. K. Htoo, and S. Y. Qiao. 2015. Estimation of the standardized ileal digestible valine to lysine ratio required for 25- to 120-kilogram pigs fed low crude protein diets supplemented with crystalline amino acids. J. Anim. Sci. 93:4761–4773. doi:10.2527/jas.2015-9308

Milliken, G. A., and D. E. Johnson. 2009. Analysis of messy data: designed experiments. Vol. 1, 2nd ed., Boca Raton (FL): CRC Press.

NRC. 2012. Nutrient requirements of swine. 11th revised edition. Washington (DC): Natl. Acad. Press. doi:10.17226/13298.

Robbins, K. R., A. M. Saxton, and L. L. Southern. 2006. Estimation of nutrient requirements using broken-line regression analysis. J. Anim. Sci. 84:E155–E165. doi:10.2527/2006.8413_supplE155x

Soumeh, E. A., J. van Milgen, N. M. Sloth, E. Corrent, H. D. Poulsen, and J. V. Nørgaard. 2015. Requirement of standardized ileal digestible valine to lysine ratio for 8-to 14-kg pigs. Animal. 9:1312–1318. doi:10.1017/S1751731115000695

Stein, H. H., M. F. Fuller, P. J. Moughan, B. Sève, R. Mosenthin, A. J. M. Jansman, J. A. Fernández, and C. F. M. de Lange. 2007. Definition of apparent, true, and standardized ileal digestibility of amino acids in pigs. Livest. Sci. 109:282–285. doi:10.1016/j.livsci.2007.01.019

Van Milgen, J., M. Gloaguen, N. Le Floc'h, L. Brossard, Y. Primot, and E. Corrent. 2013. Meta-analysis of the response of growing pigs to valine content of the diet. In: Oltjen J., E. Kebreab, and H. Lapierre, editors. Energy and protein metabolism and nutrition in sustainable animal production. Wageningen (Netherlands): Wageningen Academic Publishers, p. 339–340. doi:10.3920/978-90-8686-781-3

Waguespack, A. M., T. D. Bidner, R. L. Payne, and L. L. Southern. 2012. Valine and isoleucine requirement of 20-to 45-kilogram pigs. J. Anim. Sci. 90:2276–2284. doi:10.2527/jas.2011-4454