Effects of Standardized Ileal Digestible Tryptophan:Lysine Ratio on Growth Performance and Economics of Finishing Pigs[1,2]

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Summary

The high usage of dried distillers grains with solubles (DDGS) in swine diets and the economical availability of feed-grade tryptophan have allowed swine nutritionists to include L-tryptophan in practical diet formulations. The objective of these experiments was to determine the effects of different standardized ileal digestible tryptophan:lysine (SID Trp:Lys) ratios on growth performance and economics in finishing pigs. Three 21-d growth experiments with a total of 1,166, 1,099, and 1,132 gilts (337 × 1050; PIC, Hendersonville, TN) and initial BW of 66.0 ± 1.8, 122.2 ± 4.3, and 156.9 ± 2.8 lb were used in Experiments 1, 2, and 3, respectively. At the beginning of each experiment, pigs were weighed in pens, and pens were ranked by average BW and randomly assigned dietary treatments in a randomized complete block design based on BW. Each experiment had 6 pens per treatment with 23 to 28 pigs per pen. Dietary treatments contained 30% DDGS and were 14.5, 16.5, 18.0, 19.5, 21.0, 22.5, and 24.5% SID Trp:Lys ratio. The SID Trp:Lys ratio was increased by adding crystalline L-Trp to the control diet at the expense of corn. Diets were formulated to ensure that lysine was the second limiting amino acid throughout the experiment.

From 66.0 to 100.6 lb, ADG increased up to 19.5% SID Trp:Lys ratio then had marginal changes at higher ratios (quadratic, $P < 0.02$), whereas F/G improved through 21.0% SID Trp:Lys ratio then also had marginal changes at higher ratios (quadratic, $P < 0.004$). Income over feed cost (IOFC) increased quadratically ($P < 0.02$) up to 24.5% SID Trp:Lys ratio. From 122.2 to 165.2 lb, pigs fed increasing SID Trp:Lys ratio had increased ADG (linear, $P < 0.03$); however, the higher magnitude of improvement in ADG was through the 18% SID Trp:Lys ratio, with a subtle increase up to the highest SID Trp:Lys ratio. Feed efficiency and IOFC were not statistically different between treatments. From 156.9 to 200.8 lb, ADG, F/G, and IOFC improved (quadratic, $P < 0.04$) through 21.0% SID Trp:Lys ratio, then was poorer for pigs fed the 2 highest SID Trp:Lys ratios.

In conclusion, these studies provide good evidence to formulate diets for finishing pigs with at least 18.0% SID Trp:Lys ratio because the growth and economic risk of formulating diets below that ratio is considerably greater than formulating diets above that ratio.

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Introduction

Tryptophan is typically considered the fourth limiting amino acid in corn-soybean meal–based diets for growing pigs; however, the increased usage of dried distillers grains with solubles (DDGS) has resulted in tryptophan (Trp) becoming the second limiting amino acid after lysine (Lys). Tryptophan plays a role in a wide range of functions besides protein synthesis, and limiting dietary tryptophan levels will cause amino acid imbalance at the brain level because of the relative excess of large neutral amino acids compared with tryptophan. This is important because reductions in feed intake will consequently reduce growth rate.

The amino acid requirements of pigs can be expressed in several different ways; however, the most practical approach for diet formulation is the expression of the standardized ileal digestible (SID) Trp requirement as a ratio to Lys (Trp:Lys). Based on NRC (2012[6]), the SID Trp:Lys ratio requirement for finishing pigs below 165 lb BW is 17.2%, and above 165 lb BW the ratio is 17.7%. To accurately determine the SID Trp:Lys ratio requirement, Lys must be limiting; otherwise, the SID Trp:Lys ratio requirement may be underestimated. The current body of literature lacks experiments in which pigs are below their Lys requirement and that encompass the different stages of the finishing phase to estimate the optimum SID Trp:Lys ratios for the different response variables. Therefore, the objective of this series of experiments was to determine the effects of different SID Trp:Lys ratios on growth performance and economics of finishing pigs.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in these experiments. The studies were conducted at a commercial research-finishing barn in southwestern Minnesota. The barn was naturally ventilated and double-curtain-sided. Pens had completely slatted flooring and deep pits for manure storage. Each pen (18 × 10 ft) was equipped with a 4-hole stainless steel dry self-feeder (Thorp Equipment, Thorp, WI) and a cup waterer. The facility was equipped with a computerized feeding system (FeedPro; Feedlogic Corp., Willmar, MN) that delivered and recorded daily feed additions and diets as specified. Pigs had ad libitum access to feed and water.

Five representative samples of corn, soybean meal, and DDGS were collected each week for 5 wk and analyzed in duplicate for total amino acids and CP by Ajinomoto Heartland, Inc. (Chicago, IL), and values were used in diet formulation. Other nutrients and SID amino acid digestibility coefficient values used for diet formulation were obtained from NRC (2012).

Three 21-d growth experiments were conducted with two groups of pigs. Experiments 1 and 3 were conducted with one group of pigs, and Experiment 2 was conducted with a different group of pigs. A total of 1,166, 1,099, and 1,132 gilts (337 × 1050; PIC, Hendersonville, TN) with initial BW of 66.0 ± 1.8, 122.2 ± 4.3, and 156.9 ± 2.8 lb, and final BW of 100.6 ± 2.6, 165.2 ± 4.6, and 200.8 ± 3.2 lb were used in Experiments

[6] NRC. 2012. Nutrient Requirements of Swine. 11th ed. Natl. Acad. Press, Washington, DC.

1, 2, and 3, respectively. At the beginning of each experiment, pigs were weighed in pens and pens were ranked by average BW and randomly assigned dietary treatments in a randomized complete block design based on average pen BW. Each experiment had 6 pens per treatment with 23 to 28 pigs per pen.

Two experimental corn-soybean meal–based diets with 30% DDGS were formulated (Table 1) to have either a 14.5 or 24.5% SID Trp:Lys ratio, then blended using the robotic feeding system to achieve intermediate SID Trp:Lys ratios. The SID Trp:Lys ratio was increased by adding crystalline L-Trp to the control diet at the expense of corn. The percentage of low and high SID Trp:Lys blended to create the treatment diets were 100:0, 80:20, 65:35, 50:50, 35:65, 20:80, and 0:100 to achieve 14.5, 16.5, 18.0, 19.5, 21.0, 22.5, and 24.5% SID Trp:Lys ratios, respectively. The NRC (2012) model was used to estimate the Lys requirement of pigs at the expected BW at the end of each experiment. The SID Lys percentage used in diet formulation was 0.05 percentage points below the SID Lys requirement at the expected BW at the end of Experiments 1 and 3 and 0.10 percentage points below the SID Lys requirement at the expected BW at the end of Experiment 2 to ensure that Lys was the second limiting amino acid throughout the experiments. These reductions in SID Lys were based on a preliminary study conducted by Goncalves et al. (see "Validating a Dietary Approach to Determine Amino Acid:Lysine Ratios for Pigs, p. 83) in the same commercial research barn. Diets were fed in meal form and were manufactured at the New Horizon Farms Feed Mill (Pipestone, MN).

Pens of pigs were weighed and feed disappearance measured at the beginning and at d 21 of each experiment to determine ADG, ADFI, and F/G. There was a 21-d period between Experiments 1 and 3 during which pigs were fed a common diet that met or exceeded NRC (2012) requirements and contained 20% SID Trp:Lys. Caloric efficiency was calculated on a pen basis by multiplying total pen feed intake by the dietary energy level (kcal/lb) and dividing by total pen gain. The total grams of SID Trp intake based on formulated values was divided by total BW gain to calculate the grams of SID Trp intake per kilogram of gain.

Diet samples were taken from 6 feeders per dietary treatment 3 d after the beginning and 3 d before the end of each experiment and stored at -20°C, then CP and total amino acid analysis was conducted on composite samples from each treatment by Ajinomoto Heartland, Inc. Diet samples were also submitted to Ward Laboratories, Inc. (Kearney, NE) for analysis of DM, crude fiber, ash, crude fat, Ca, and P.

For the economic evaluation, total feed cost per pig, cost per pound of gain, revenue, and income over feed cost (IOFC) were calculated. The total feed cost per pig was calculated by multiplying the ADFI by the cost per pound of feed and the number of days. Note that because experimental diets were formulated by adding different levels of L-Trp, diet cost was not optimized on a least-cost basis. Cost per pound of gain was calculated by dividing the total feed cost per pig by the amount of pounds gained overall. Revenue per pig was calculated by multiplying the ADG times the total days in the trial times an assumed live price of $68.00 per cwt. To calculate IOFC, total feed cost was subtracted from pig revenue. Ingredient prices during the fall of 2013 were used for all economic evaluations; therefore, corn was valued at $6.19/bu ($221/ton), DDGS at $220/ton, soybean meal at $440/ton, L-Trp at $10.00/lb, and L-Valine at $7.00/lb.

Data corresponding to Experiments 1, 2, and 3 were analyzed separately. Within each experiment, responses measured at the pen level were analyzed using a general linear mixed model. The model included the fixed effect of dietary treatment and average pen BW block as a random effect. Pen was the experimental unit. Linear and quadratic orthogonal polynomial contrasts were built to evaluate the functional form of the dose response to increasing dietary SID Trp:Lys ratio on ADG, ADFI, F/G, NE caloric efficiency, BW, grams of SID Trp intake per kilogram of gain, feed cost/pig, feed cost/lb of gain, total revenue/pig, and IOFC. Polynomial contrast coefficients were adjusted for unequally spaced treatment intervals. In addition, for Experiment 3, dietary treatment from the previous experiment (Experiment 1) was also considered a random effect. Statistical models were fitted using the MIXED procedure of SAS (SAS Institute Inc., Cary, NC). Results were considered significant at $P \leq 0.05$.

Results and Discussion

The analyzed total amino acids, DM, CP, crude fiber, Ca, P, fat, and ash contents of experimental diets (Tables 2, 3, and 4) were reasonably consistent with formulated estimates. From 66.0 to 100.6 lb, ADG and final BW increased quadratically (Table 5; $P < 0.02$) with increasing SID Trp:Lys ratio, but the rate of increase progressively diminished, particularly above the 19.5% SID Trp:Lys ratio. Feed intake increased quadratically ($P < 0.02$) up to 19.5% SID Trp:Lys ratio with no improvements thereafter. In addition, F/G and caloric efficiency improved quadratically ($P < 0.004$) as the SID Trp:Lys ratio increased, with the greatest rate of change up to 21%, but the best F/G was observed at the 24.5% SID Trp:Lys ratio. The grams of SID Trp intake per kilogram of gain increased linearly ($P < 0.001$).

From 122.2 to 165.2 lb, ADG, ADFI, and final BW increased linearly ($P < 0.03$) with increasing SID Trp:Lys ratio. Feed efficiency and caloric efficiency were not statistically different among treatments. Similar to Experiment 1, grams of SID Trp intake per kilogram of gain increased linearly ($P < 0.001$).

From 156.9 to 200.8 lb, ADG increased quadratically ($P < 0.04$) through 21.0% SID Trp:Lys ratio and then was reduced for pigs fed the 2 highest SID Trp:Lys ratios. Final BW increased in a linear manner ($P < 0.02$) with increasing SID Trp:Lys ratio, although the highest final BW was for pigs fed the 21% SID Trp:Lys ratio. No evidence for differences in ADFI was observed among dietary treatments. Feed efficiency and caloric efficiency improved quadratically ($P < 0.02$) through 21% SID Trp:Lys ratio and then was poorer for pigs fed the 2 highest ratios. In contrast to Experiments 1 and 2, the grams of SID Trp intake per kilogram of gain in Experiment 3 increased quadratically ($P < 0.03$) with increasing SID Trp:Lys ratio.

Overall, the grams of SID Trp intake per kilogram of gain where performance reached a point of diminishing returns in response to increased SID Trp:Lys ratio ranged from 3.3 to 3.7 g, which is on the higher end of the NRC (2012) requirement estimates of 2.3 to 3.6 g per kilogram of gain for finishing pigs.

From 66.0 to 100.6 lb, feed cost per pig, total revenue per pig, and IOFC increased quadratically (Table 6; $P < 0.02$) up to 24.5% SID Trp:Lys ratio. Feed cost per pound of gain was reduced (quadratic, $P < 0.005$) for pigs fed the 16.5% SID Trp:Lys ratio, with a plateau thereafter for pigs fed higher doses. From 122.2 to 165.2 lb, feed cost per pig, feed cost per pound of gain, and total revenue per pig increased linearly (P < 0.001) with increasing SID Trp:Lys ratio; consequently, IOFC was not statistically different among treatments. From 156.9 to 200.8 lb, feed cost per pig increased linearly (P < 0.001) with increasing SID Trp:Lys ratios. Feed cost per pound of gain was reduced (quadratic, P < 0.03) for pigs fed up to 21% SID Trp:Lys ratio and then increased for pigs fed the 2 highest SID Trp:Lys ratios. Conversely, total revenue per pig and IOFC increased (quadratic, P < 0.03) up to 21% SID Trp:Lys ratio and then was reduced thereafter.

The percentage of the response compared with the maximum ADG and IOFC and to the optimum F/G was plotted against the SID Trp:Lys ratio (Figures 1, 2, and 3, respectively) for each of the experiments. Note that the lowest F/G is considered the optimum pig response. The ADG was at least at 95% of maximum response at 19.5, 18.0, and 19.5% SID Trp:Lys ratios for Experiments 1, 2, and 3, respectively. Feed efficiency was at least at 95% of its optimum response at 16.5% for all experiments. Finally, IOFC was at least at 95% of maximum response at 19.5, 16.5, and 19.5% SID Trp:Lys ratios for Experiments 1, 2, and 3, respectively.

The 16.5% SID Trp:Lys ratio for finishing pigs was enough to improve F/G to 97% of its optimum; however, pigs fed the 16.5% SID Trp:Lys ratio were only at 92% of their maximum for ADG and IOFC. In contrast, pigs fed a higher ratio of 21% SID Trp:Lys were at 98% of maximum ADG and 96% of maximum IOFC. This illustrates that different response criteria will result in a different estimate of the requirement. In addition, although diets with increased SID Trp:Lys ratios were more expensive, the cost was offset by the improvement in growth performance. In conclusion, these studies provide good evidence to formulate diets for finishing pigs with at least an 18.0% SID Trp:Lys ratio because the growth and economic risk of formulating diets below that ratio is considerably greater than formulating diets above that ratio.

Table 1. Diet composition, Experiments 1, 2, and 3 (as-fed basis)[1]

	Exp. 1		Exp. 2		Exp. 3	
	Standardized ileal digestible (SID) tryptophan:lysine					
Item	Low (14.5%)	High (24.5%)	Low (14.5%)	High (24.5%)	Low (14.5%)	High (24.5%)
Ingredient, %						
Corn	57.77	57.67	62.69	62.61	63.07	62.99
Soybean meal (46% CP)	9.03	9.03	4.51	4.51	4.13	4.14
DDGS	30.00	30.00	30.00	30.00	30.00	30.00
Corn oil	0.50	0.50	-	-	-	-
Beef tallow	-	-	0.50	0.50	-	-
Choice white grease	-	-	-	-	0.50	0.50
Limestone	1.40	1.40	1.28	1.28	1.20	1.20
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Trace mineral premix[2]	0.100	0.100	0.100	0.100	0.100	0.100
Vitamin premix[3]	0.075	0.075	0.075	0.075	0.075	0.075
L-lysine HCL	0.540	0.540	0.431	0.431	0.455	0.455
DL-methionine	0.045	0.045	-	-	-	-
L-threonine	0.125	0.125	0.045	0.045	0.090	0.090
L-tryptophan	-	0.091	-	0.076	-	0.073
L-valine	0.045	0.045	-	-	-	-
Phytase[4]	0.025	0.025	0.025	0.025	0.025	0.025
Total	100	100	100	100	100	100

continued

Table 1. Diet composition, Experiments 1, 2, and 3 (as-fed basis)[1]

	Exp. 1		Exp. 2		Exp. 3	
	Standardized ileal digestible (SID) tryptophan:lysine					
Item	Low (14.5%)	High (24.5%)	Low (14.5%)	High (24.5%)	Low (14.5%)	High (24.5%)
Calculated analysis						
SID amino acids, %						
Lysine	0.90	0.90	0.75	0.75	0.72	0.72
Isoleucine:lysine	55	55	63	63	58	58
Leucine:lysine	161	161	196	195	187	187
Methionine:lysine	34	34	34	34	34	34
Methionine & Cys:lysine	60	60	64	64	63	63
Threonine:lysine	65	65	65	65	68	68
Tryptophan:lysine	14.5	24.5	14.5	24.5	14.5	24.5
Valine:lysine	70	70	76	76	72	72
Histidine:lysine	39	39	46	46	43	43
Tryptophan:BCAA[5]	5.8	9.8	4.3	7.3	3.0	5.1
Tryptophan:LNAA[6]	4.7	7.9	3.1	5.3	2.2	3.7
ME, kcal/lb	1,521	1,522	1,522	1,523	1,524	1,525
NE, kcal/lb	1,133	1,134	1,144	1,145	1,147	1,147
SID lysine:ME, g/Mcal	3.60	3.60	2.23	2.23	2.14	2.14
SID lysine:NE, g/Mcal	2.68	2.68	2.97	2.97	2.85	2.85
CP, %	17.4	17.5	16.4	16.5	15.4	15.4
Ca, %	0.57	0.57	0.51	0.51	0.48	0.48
P, %	0.39	0.39	0.38	0.37	0.37	0.37
Available P, %	0.31	0.31	0.30	0.30	0.30	0.30

[1] Diets were fed from 66.0 to 100.6, 122.2 to 165.2, and 156.9 to 200.8 lb BW in Experiments 1, 2, and 3, respectively. Corn, dried distillers grains with solubles (DDGS), and soybean meal were analyzed for CP and total amino acid content, and NRC (2012) SID digestibility values were used in the diet formulation.

[2] Provided: 33 ppm Mn from manganese oxide, 110 ppm Fe from iron sulfate, 110 ppm Zn from zinc oxide, 16.5 ppm Cu from copper sulfate, 0.33 ppm I from ethylenediamin dihydroiodide, and 0.30 ppm Se from sodium selenite.

[3] Provided per pound of diet: 2,400 IU vitamin A; 375 IU vitamin D3; 12.0 IU vitamin E; 1.20 mg vitamin K; 7.5 mg pantothenic acid; 13.5 mg niacin; 2.1 mg riboflavin and 9 μg vitamin B12.

[4] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN) provided 568 phytase units (FTU) per pound of diet and a release of 0.14% in available P was considered.

[5] Dietary tryptophan as a ratio to branched-chain amino acids (BCAA; isoleucine, leucine, valine) on SID basis.

[6] Dietary tryptophan as a ratio to large neutral amino acids (LNAA; isoleucine, leucine, valine, phenylalanine, and tyrosine) on SID basis.

Table 2. Chemical analysis of the diets, Experiment 1 (as-fed-basis)[1]

	Standardized ileal digestible tryptophan:lysine, %						
Item	14.5	16.5	18.0	19.5	21.0	22.5	24.5
Proximate analysis, %							
DM	90.77 (88.65)[2]	90.91 (88.65)	90.68 (88.65)	90.81 (88.65)	90.84 (88.65)	90.73 (88.66)	90.66 (88.66)
CP	19.7 (17.4)	19.6 (17.4)	19.4 (17.4)	18.4 (17.4)	19.5 (17.4)	18.7 (17.5)	18.9 (17.5)
Crude fiber	3.8 (4.2)	3.9 (4.2)	3.5 (4.2)	3.6 (4.2)	3.4 (4.2)	3.4 (4.2)	3.3 (4.2)
Ca	0.74 (0.57)	0.87 (0.57)	0.72 (0.57)	0.78 (0.57)	0.85 (0.57)	0.77 (0.57)	0.78 (0.57)
P	0.45 (0.39)	0.46 (0.39)	0.44 (0.39)	0.44 (0.39)	0.45 (0.39)	0.42 (0.39)	0.45 (0.39)
Fat	5.6 (5.3)	5.9 (5.3)	6.0 (5.3)	5.9 (5.3)	5.9 (5.3)	5.3 (5.3)	5.4 (5.3)
Ash	4.44 (2.53)	4.79 (2.53)	4.33 (2.53)	4.2 (2.53)	4.44 (2.53)	3.95 (2.53)	4.10 (2.53)
Amino acids, %							
Lysine	1.13 (1.06)	1.16 (1.06)	1.15 (1.06)	1.11 (1.06)	1.13 (1.06)	1.11 (1.06)	1.10 (1.06)
Isoleucine	0.70 (0.67)	0.69 (0.67)	0.70 (0.67)	0.70 (0.67)	0.72 (0.67)	0.69 (0.67)	0.69 (0.67)
Leucine	1.92 (1.92)	1.84 (1.92)	1.89 (1.92)	1.89 (1.92)	1.91 (1.92)	1.90 (1.92)	1.89 (1.92)
Methionine	0.38 (0.36)	0.38 (0.36)	0.39 (0.36)	0.40 (0.36)	0.39 (0.36)	0.38 (0.36)	0.37 (0.36)
Met & Cys	0.72 (0.67)	0.70 (0.67)	0.72 (0.67)	0.73 (0.67)	0.73 (0.67)	0.70 (0.67)	0.71 (0.67)
Threonine	0.79 (0.75)	0.82 (0.75)	0.81 (0.75)	0.78 (0.75)	0.80 (0.75)	0.80 (0.75)	0.78 (0.75)
Tryptophan	0.18 (0.16)	0.21 (0.18)	0.22 (0.19)	0.21 (0.21)	0.22 (0.22)	0.23 (0.23)	0.23 (0.25)
Valine	0.89 (0.85)	0.85 (0.85)	0.87 (0.85)	0.86 (0.85)	0.88 (0.85)	0.86 (0.85)	0.86 (0.85)
Histidine	0.48 (0.44)	0.47 (0.44)	0.48 (0.44)	0.48 (0.44)	0.49 (0.44)	0.48 (0.44)	0.48 (0.44)
Phenylalanine	0.91 (0.87)	0.88 (0.87)	0.90 (0.87)	0.90 (0.87)	0.92 (0.87)	0.90 (0.87)	0.89 (0.87)

[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 CP and amino acid analysis was conducted on composite samples by Ajinomoto Heartland, Inc. (Chicago, IL). Samples of the diets were also submitted to Ward Laboratories, Inc. (Kearney, NE) for analysis of DM, crude fiber, Ca, P, ash, and crude fat.
[2] Values in parentheses indicate those calculated from diet formulation and are based on values from NRC (2012), with the exception of CP and total amino acid content from corn, soybean meal, and dried distillers grains with solubles, which were analyzed prior to diet formulation by Ajinomoto Heartland, Inc.

Table 3. Chemical analysis of the diets, Experiment 2 (as-fed-basis)[1]

	Standardized ileal digestible tryptophan:lysine, %						
Item	14.5	16.5	18.0	19.5	21.0	22.5	24.5
Proximate analysis, %							
DM	89.97 (88.52)[2]	89.47 (88.53)	89.77 (88.53)	90.17 (88.53)	90.02 (88.53)	89.6 (88.53)	90.08 (88.53)
CP	16.7 (16.4)	16.6 (16.4)	15.5 (16.5)	15.9 (16.5)	16.8 (16.5)	16.6 (16.5)	16.7 (16.5)
Crude fiber	3.5 (4.1)	3.7 (4.1)	3.5 (4.1)	3.3 (4.1)	3.3 (4.1)	3.5 (4.1)	3.7 (4.1)
Ca	0.74 (0.51)	0.61 (0.51)	0.75 (0.51)	0.69 (0.51)	0.72 (0.51)	0.79 (0.51)	0.62 (0.51)
P	0.41 (0.38)	0.40 (0.38)	0.40 (0.38)	0.40 (0.38)	0.41 (0.38)	0.41 (0.38)	0.42 (0.37)
Fat	5.2 (5.4)	5.4 (5.4)	5.3 (5.4)	5.2 (5.4)	5.3 (5.4)	5.0 (5.4)	5.5 (5.4)
Ash	4.22 (3.71)	3.98 (3.71)	4.34 (3.71)	4.06 (3.71)	4.25 (3.71)	4.33 (3.71)	3.98 (3.71)
Amino acids, %							
Lysine	0.94 (0.93)	0.92 (0.93)	0.92 (0.93)	0.91 (0.93)	0.90 (0.93)	0.93 (0.93)	0.95 (0.93)
Isoleucine	0.72 (0.60)	0.66 (0.60)	0.69 (0.60)	0.72 (0.60)	0.67 (0.60)	0.68 (0.60)	0.76 (0.60)
Leucine	1.71 (1.73)	1.68 (1.72)	1.67 (1.72)	1.69 (1.72)	1.67 (1.72)	1.68 (1.72)	1.76 (1.72)
Methionine	0.30 (0.31)	0.31 (0.31)	0.29 (0.31)	0.29 (0.31)	0.30 (0.31)	0.29 (0.31)	0.32 (0.31)
Met & Cys	0.60 (0.61)	0.60 (0.61)	0.57 (0.61)	0.58 (0.61)	0.60 (0.61)	0.58 (0.61)	0.62 (0.61)
Threonine	0.62 (0.67)	0.64 (0.67)	0.63 (0.67)	0.64 (0.67)	0.63 (0.67)	0.63 (0.67)	0.67 (0.67)
Tryptophan	0.16 (0.14)	0.16 (0.16)	0.17 (0.17)	0.17 (0.18)	0.19 (0.19)	0.20 (0.20)	0.21 (0.22)
Valine	0.78 (0.73)	0.78 (0.73)	0.76 (0.73)	0.77 (0.73)	0.76 (0.73)	0.78 (0.73)	0.82 (0.73)
Histidine	0.41 (0.43)	0.42 (0.43)	0.40 (0.43)	0.41 (0.43)	0.42 (0.43)	0.41 (0.43)	0.44 (0.43)
Phenylalanine	0.78 (0.76)	0.80 (0.76)	0.77 (0.76)	0.78 (0.76)	0.80 (0.76)	0.78 (0.76)	0.83 (0.76)

[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 CP and amino acid analysis was conducted on composite samples by Ajinomoto Heartland, Inc. (Chicago, IL). Samples of the diets were also submitted to Ward Laboratories, Inc. (Kearney, NE) for analysis of DM, crude fiber, Ca, P, ash, and crude fat.
[2] Values in parentheses indicate those calculated from diet formulation and are based on values from NRC (2012), with the exception of CP and total amino acid content from corn, soybean meal, and dried distillers grains with solubles, which were analyzed prior to diet formulation by Ajinomoto Heartland, Inc.

Table 4. Chemical analysis of the diets, Experiment 3 (as-fed-basis)[1]

	Standardized ileal digestible tryptophan:lysine, %						
Item	14.5	16.5	18.0	19.5	21.0	22.5	24.5
Proximate analysis, %							
DM	89.74 (88.52)[2]	90.49 (88.52)	90.12 (88.52)	90.54 (88.52)	90.61 (88.52)	90.85 (88.52)	90.45 (88.53)
CP	16.2 (15.4)	16.7 (15.4)	16.3 (15.4)	16.8 (15.4)	17.1 (15.4)	16.4 (15.4)	16.2 (15.4)
Crude fiber	3.8 (4.1)	4.0 (4.1)	4.1 (4.1)	3.9 (4.1)	3.9 (4.1)	3.9 (4.1)	3.9 (4.1)
Ca	1.10 (0.48)	0.62 (0.48)	0.73 (0.48)	0.75 (0.48)	0.73 (0.48)	0.76 (0.48)	0.81 (0.48)
P	0.40 (0.37)	0.37 (0.37)	0.37 (0.37)	0.35 (0.37)	0.38 (0.37)	0.36 (0.37)	0.37 (0.37)
Fat	4.9 (5.4)	5.2 (5.4)	5.0 (5.4)	5.0 (5.4)	5.0 (5.4)	5.1 (5.4)	4.9 (5.4)
Ash	4.63 (2.29)	3.62 (2.29)	4.02 (2.29)	4.03 (2.29)	3.90 (2.29)	4.01 (2.29)	4.02 (2.29)
Amino acids, %							
Lysine	0.87 (0.87)	0.87 (0.87)	0.88 (0.87)	0.93 (0.87)	0.90 (0.87)	0.91 (0.87)	0.90 (0.87)
Isoleucine	0.59 (0.60)	0.61 (0.60)	0.60 (0.60)	0.62 (0.60)	0.61 (0.60)	0.60 (0.60)	0.59 (0.60)
Leucine	1.73 (1.82)	1.78 (1.82)	1.79 (1.82)	1.83 (1.82)	1.80 (1.82)	1.76 (1.82)	1.75 (1.82)
Methionine	0.31 (0.29)	0.32 (0.29)	0.32 (0.29)	0.33 (0.29)	0.33 (0.29)	0.32 (0.29)	0.31 (0.29)
Met & Cys	0.60 (0.58)	0.61 (0.58)	0.63 (0.58)	0.64 (0.58)	0.62 (0.58)	0.62 (0.58)	0.61 (0.58)
Threonine	0.66 (0.65)	0.68 (0.65)	0.68 (0.65)	0.68 (0.65)	0.70 (0.65)	0.68 (0.65)	0.67 (0.65)
Tryptophan	0.13 (0.14)	0.16 (0.15)	0.17 (0.16)	0.18 (0.17)	0.18 (0.18)	0.19 (0.19)	0.19 (0.21)
Valine	0.71 (0.74)	0.73 (0.74)	0.74 (0.74)	0.76 (0.74)	0.75 (0.74)	0.73 (0.74)	0.72 (0.74)
Histidine	0.41 (0.39)	0.42 (0.39)	0.43 (0.39)	0.44 (0.39)	0.43 (0.39)	0.42 (0.39)	0.42 (0.39)
Phenylalanine	0.77 (0.78)	0.80 (0.78)	0.79 (0.78)	0.81 (0.78)	0.8 (0.78)	0.78 (0.78)	0.78 (0.78)

[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 CP and amino acid analysis was conducted on composite samples by Ajinomoto Heartland, Inc. (Chicago, IL). Samples of the diets were also submitted to Ward Laboratories, Inc. (Kearney, NE) for analysis of DM, crude fiber, Ca, P, ash, and crude fat.

[2] Values in parentheses indicate those calculated from diet formulation and are based on values from NRC (2012), with the exception of CP and total amino acid content from corn, soybean meal, and dried distillers grains with solubles, which were analyzed prior to diet formulation by Ajinomoto Heartland, Inc.

Table 5. Least squares mean estimates (and corresponding SEM) for growth performance of finishing pigs subjected to dietary treatments of standardized ileal digestible tryptophan:lysine (SID Trp:Lys) ratio ranging from 14.5 to 24.5%[1,2]

	SID Trp:Lys, %								Probability, $P <$	
	14.5	16.5	18.0	19.5	21.0	22.5	24.5	SEM	Linear	Quadratic
Exp. 1										
d 0 BW, lb	66.0	65.9	65.9	66.0	66.0	65.9	66.0	1.8	0.994	0.922
ADG, lb	1.38	1.58	1.64	1.68	1.69	1.72	1.74	0.04	0.001	0.001
ADFI, lb	2.95	3.12	3.20	3.30	3.25	3.30	3.30	0.10	0.001	0.017
F/G	2.13	1.98	1.95	1.96	1.92	1.92	1.90	0.03	0.001	0.004
d 21 BW, lb	95.4	99.2	100.4	101.3	101.6	103.0	103.0	2.6	0.001	0.017
NE caloric efficiency[3]	2,420	2,247	2,215	2,224	2,183	2,181	2,149	31.0	0.001	0.004
SID Trp, g/kg gain	2.78	2.94	3.16	3.44	3.64	3.89	4.18	0.05	0.001	0.099
Exp. 2										
d 0 BW, lb	122.3	122.3	122.2	122.3	122.2	122.2	122.2	4.3	0.902	0.976
ADG, lb	1.94	1.98	2.07	2.02	2.06	2.06	2.12	0.03	0.001	0.647
ADFI, lb	5.09	4.88	5.08	5.29	5.40	5.55	5.38	0.15	0.001	0.822
F/G	2.62	2.46	2.45	2.63	2.63	2.69	2.54	0.06	0.221	0.897
d 21 BW, lb	163.3	164.1	165.7	165.2	165.4	165.6	166.8	4.6	0.030	0.737
NE caloric efficiency	3,002	2,819	2,809	3,006	3,006	3,081	2,903	67.1	0.221	0.897
SID Trp, g/kg gain	2.85	3.04	3.31	3.84	4.14	4.54	4.66	0.09	0.001	0.791
Exp. 3										
d 0 BW, lb	157.0	156.8	156.9	156.8	157.0	157.0	156.9	2.8	0.956	0.938
ADG, lb	1.96	2.05	2.03	2.11	2.20	2.10	2.12	0.04	0.001	0.034
ADFI, lb	5.30	5.27	5.25	5.26	5.33	5.24	5.35	0.09	0.651	0.496
F/G	2.69	2.57	2.58	2.50	2.43	2.50	2.53	0.05	0.003	0.020
d 21 BW, lb	198.5	200.1	199.6	201.3	203.3	201.0	201.7	3.2	0.021	0.241
NE caloric efficiency	3,090	2,950	2,965	2,872	2,786	2,863	2,899	58.1	0.003	0.020
SID Trp, g/kg gain	2.81	3.06	3.35	3.52	3.67	4.04	4.46	0.07	0.001	0.034

[1] A total of 1,166, 1,099, and 1,132 gilts (PIC 337 x 1050) with initial BW of 66.0 ± 1.8, 122.2 ± 4.3, and 156.9 ± 2.8 lb were used in Experiments 1, 2, and 3, respectively, with 23 to 28 pigs per pen and 6 pens per treatment.

[2] The NRC (2012) model was used to determine the lysine requirement of gilts at the end of expected the phase range of each experiment, and that value was reduced by 0.05 percentage point for Experiments 1 and 3, and by 0.10 percentage point for Experiment 2.

[3] Caloric efficiency is expressed as kcal/lb of gain.

Table 6. Least squares mean estimates (and corresponding SEM) for economics of finishing pigs subjected to dietary treatments of standardized ileal digestible tryptophan:lysine (SID Trp:Lys) ratio ranging from 14.5 to 24.5%[1,2]

	SID Trp:Lys, %								Probability, P <	
	14.5	16.5	18.0	19.5	21.0	22.5	24.5	SEM	Linear	Quadratic
Exp. 1										
Feed cost/pig, $	11.65	12.43	12.84	13.34	13.21	13.52	13.65	0.36	0.001	0.019
Feed cost/lb gain[3], $	0.401	0.376	0.373	0.377	0.373	0.375	0.373	0.005	0.001	0.005
Total revenue/pig[4,5], $	19.78	22.52	23.43	24.06	24.10	24.54	24.91	0.57	0.001	0.001
IOFC[6], $	8.12	10.09	10.60	10.72	10.89	11.01	11.26	0.31	0.001	0.001
Exp. 2										
Feed cost/pig, $	13.02	12.58	13.25	13.93	14.37	14.87	14.57	0.38	0.001	0.838
Feed cost/lb gain, $	0.319	0.303	0.305	0.329	0.332	0.343	0.327	0.007	0.001	0.646
Total revenue/pig, $	27.73	28.32	29.53	28.80	29.39	29.46	30.29	0.42	0.001	0.933
IOFC, $	14.74	15.72	16.28	14.88	15.03	14.59	15.71	0.37	0.886	0.728
Exp. 3										
Feed cost/pig, $	13.49	13.59	13.66	13.80	14.11	13.97	14.43	0.22	0.001	0.487
Feed cost/lb gain, $	0.325	0.316	0.319	0.313	0.307	0.315	0.325	0.007	0.630	0.030
Total revenue/pig, $	28.05	29.24	29.05	30.22	31.39	30.07	30.26	0.63	0.001	0.034
IOFC, $	14.57	15.67	15.40	16.41	17.27	16.07	15.84	0.55	0.012	0.012

[1] A total of 1,166, 1,099, and 1,132 gilts (PIC 337 x 1050) with initial BW of 66.0 ± 1.8, 122.2 ± 4.3, and 156.9 ± 2.8 lb were used in Experiments 1, 2, and 3, respectively, with 23 to 28 pigs per pen and 6 pens per treatment.
[2] The NRC (2012) model was used to determine the lysine requirement of gilts at the end of expected the phase range of each experiment, and that value was reduced by 0.05 percentage point for Experiments 1 and 3, and by 0.10 percentage point for Experiment 2.
[3] Feed cost/lb gain = total feed cost divided by total gain per pig.
[4] One pound of live gain was considered to be worth $0.68.
[5] Total revenue/pig = total gain/pig × $0.68.
[6] Income over feed cost = total revenue/pig – feed cost/pig.

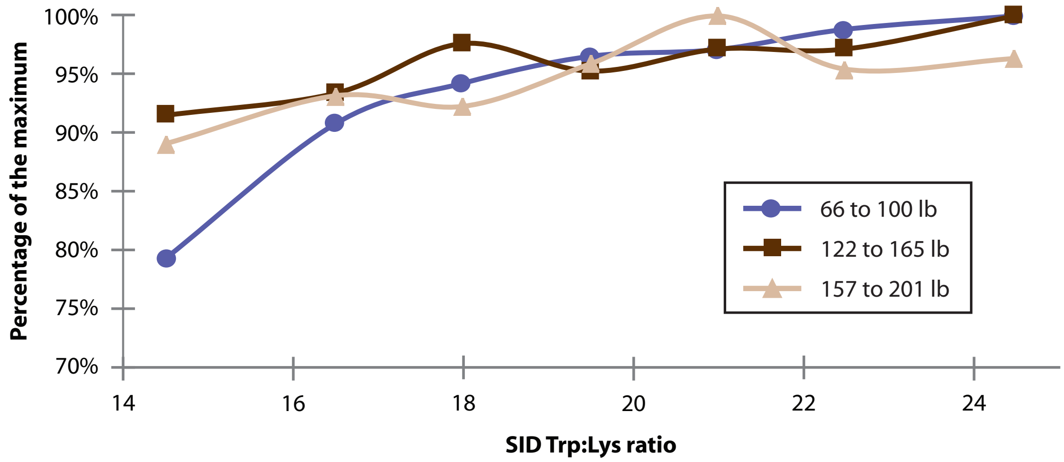

Figure 1. Effects of different standardized ileal digestible tryptophan:lysine (SID Trp:Lys) ratios on ADG of finishing pigs as a percentage of the maximum response.

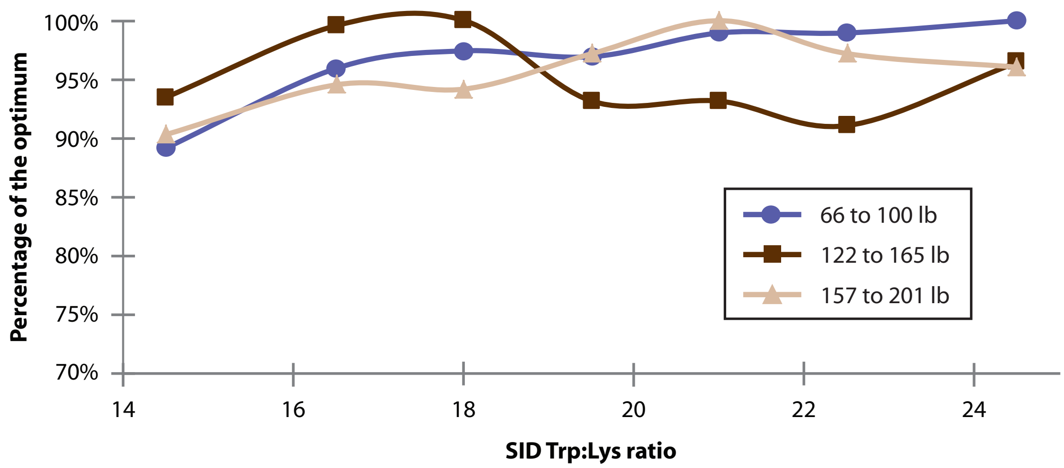

Figure 2. Effects of different standardized ileal digestible tryptophan:lysine (SID Trp:Lys) ratios on F/G of finishing pigs as a percentage of the optimum response (note that the lowest F/G is considered the optimum response).

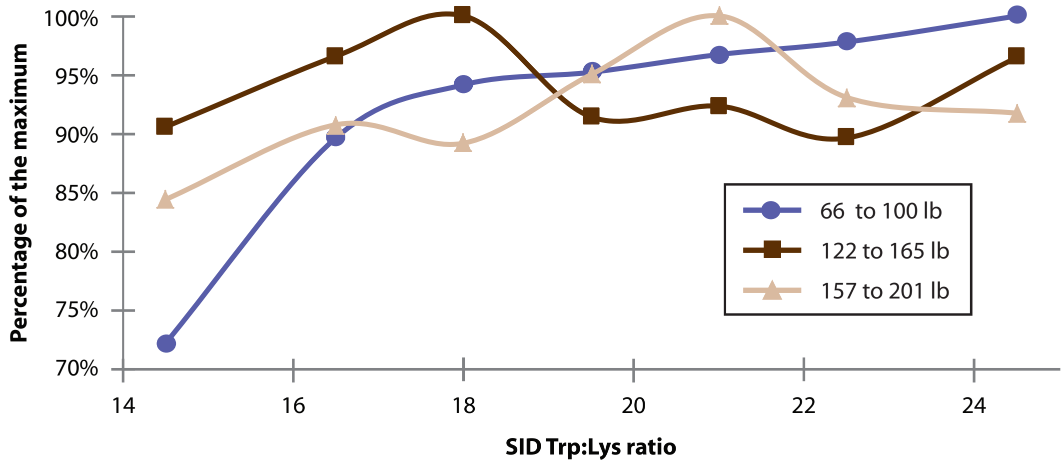

Figure 3. Effects of different standardized ileal digestible tryptophan:lysine (SID Trp:Lys) ratios on income over feed cost of finishing pigs as a percentage of the maximum response.