Determining the Effects of Standardized Ileal Digestible Tryptophan:Lysine Ratio and Tryptophan Source in Diets Containing Dried Distillers Grains with Solubles on Growth Performance and Carcass Characteristics of Finishing Pigs[1]

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Summary
A total of 2,290 pigs (PIC 1050 × 337; initially 157 lb) were used to determine the effect of tryptophan source (L-tryptophan vs. soybean meal) and increasing SID tryptophan:lysine ratio in diets containing 30% dried distillers grains with solubles (DDGS) on finishing pig performance. Pens of pigs were balanced by initial weight and randomly allotted to 1 of 7 dietary treatments in a completely randomized design with 26 to 28 pigs per pen and 10 to 13 replications per treatment. Treatments were arranged as a 2 × 3 factorial with main effects of tryptophan source (L-tryptophan or soybean meal) and SID tryptophan:lysine ratio (18, 20, and 22% of lysine). The seventh treatment was a negative control diet formulated to a 16% SID tryptophan:lysine ratio.

Overall, a tryptophan source × SID tryptophan:lysine ratio interaction (linear, $P = 0.03$) was observed for F/G. Increasing SID tryptophan:lysine ratio improved (quadratic, $P < 0.01$) F/G up to 20% when soybean meal was the source of tryptophan, but the optimum was at only 18% when L-tryptophan was added. Increasing the SID tryptophan:lysine ratio increased (linear, $P = 0.01$) carcass yield when using L-tryptophan; however, the greatest yield was observed (quadratic, $P = 0.03$) at 18% SID tryptophan:lysine ratio when soybean meal was used, resulting in a tryptophan source × SID tryptophan:lysine ratio interaction (linear, $P = 0.01$). For the main effect of SID tryptophan:lysine ratio, ADG and F/G improved (quadratic, $P < 0.01$), with increasing SID tryptophan:lysine ratio demonstrating the best performance when SID tryptophan was at 20% of lysine. Loin depth was greatest in the control diet (16% SID tryptophan:lysine ratio) and lowest in 18% SID tryptophan:lysine ratio (quadratic, $P = 0.02$). For the main effect of tryptophan source, no differences were observed in feed intake or feed efficiency among sources of tryptophan; however, we saw a trend ($P = 0.07$) for greater ADG when soybean meal was the tryptophan source. Backfat was greater ($P = 0.04$) and percentage lean ($P = 0.02$) was lower in pigs fed with L-tryptophan than those with soybean meal as the tryptophan source. This study indicated an optimum SID tryptophan:lysine ratio of 20% for 157- to 279-lb pigs. Because using

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soybean meal or L-tryptophan provided a similar response in growth performance, the difference in feed cost when adding soybean meal or crystalline tryptophan to the diet will be a major factor in choosing the optimal source of tryptophan.

Key words: amino acids, DDGS, finishing pig, lysine, tryptophan

Introduction

Dried distillers grains with solubles are widely used in swine diets in the United States. Tryptophan is the second limiting amino acid after lysine in diets containing DDGS. A previous study (Barnes et al., 2011[4]) observed a linear increase in ADG and ADFI as the SID tryptophan:lysine ratio increased through 18% of lysine in pigs fed 30% DDGS using soybean meal (SBM) as a source of tryptophan; however, the response was not replicated in a recent trial (Nitikanchana et al., 2011[5]) that used L-tryptophan to increase the SID tryptophan:lysine ratio from 15 to 21%. This result suggests that tryptophan sources (L-tryptophan vs. SBM) may be important to obtain the growth response. Therefore, we conducted this experiment to evaluate tryptophan sources (L-tryptophan vs. SBM) used to increase the SID tryptophan:lysine ratio in diets containing 30% DDGS for finishing pigs from 157 to 279 lb.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment.

The studies were conducted at a commercial research-finishing barn in southwestern Minnesota. The barns were naturally ventilated and double-curtain-sided. Pens had completely slatted flooring and deep pits for manure storage. Each pen was equipped with a 5-hole stainless steel dry self-feeder and a cup waterer for ad libitum access to feed and water. 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.

Two replicated studies were conducted using a total of 2,290 gilts (PIC 1050 × 337) with initial BW of 153 and 161 lb in Exp. 1 and 2, respectively, with 26 to 28 gilts per pen and 10 to 13 pens per treatment. Pens of pigs were assigned to 1 of 7 dietary treatments in a completely randomized design while balancing for initial BW within study. Treatments were arranged as a 2 × 3 factorial with the main effects of tryptophan source (L-tryptophan or SBM) and SID tryptophan:lysine ratio (18, 20, and 22% of lysine) with the addition of a control diet that contained 16% SID tryptophan:lysine. Soybean meal and DDGS sources used in each experiment were analyzed for total amino acid content (Table 1; Ajinomoto Heartland LLC, Chicago, IL). These values along with standardized digestibility coefficients from NRC (1998) for SBM and Stein (2007[6]) for DDGS were used in diet formulation for each study. The SID tryptophan:lysine ratio was increased by adding crystalline tryptophan to the control diet at the expense of corn or by replacing crystalline lysine and corn with SBM. All

[4] Barnes et al., Swine Day 2010, Report of Progress 1038, pp. 156–165.

[5] Nitikanchana et al., Swine Day 2011, Report of Progress 1056, pp. 162–167.

[6] Stein, H. H., and G.C. Shurson. 2009. Board-invited review: The use and applicaiton of distillers dried grains with solubles (DDGS) in swine diets. J. Anim. Sci. 87:1292–1303.

diets were fed in meal form and fed in 3 phases from 161 to 205 lb, 205 to 240 lb, and 240 to 270 lb in Exp.1, and 153 to 195 lb, 195 to 244 lb, and 244 to 287 lb in Exp. 2 (Tables 2 through 7). All diets contained 30% DDGS except diets fed in the last phase, in which DDGS level was lowered to 15% to reduce the impact on carcass fat quality and yield. Diets in phase 3 also contained 9 g/ton of Ractopamine HCl (Paylean; Elanco Animal Health, Greenfield, IN). Diet samples were collected from feeders during every phase and stored at −20°C, then amino acid analysis was conducted on composite samples by Ajinomoto Heartland LLC.

Pens of pigs were weighed and feed disappearance was recorded at d 22, 40, and 56 in Exp.1 and at d 21, 47, and 68 in Exp. 2 to determine ADG, ADFI, and F/G. On d 40 of Exp. 1 and d 47 of Exp. 2, the 5 heaviest pigs per pen were weighed and sold according to the farm's normal marketing procedure. At the end of the trial, pigs were individually tattooed by pen number to allow for carcass data collection. Pigs were transported to JBS Swift and Company (Worthington, MN) for processing and carcass data collection. Hot carcass weights were measured immediately after evisceration, and carcass criteria of backfat depth, and loin depth were collected using an optical probe. Carcass yield percentage was calculated by dividing live weight at the plant with carcass weight at the plant as reported by the processor, and percentage lean was calculated by the processor using a proprietary equation that depended on backfat and loin depth.

The experimental data were analyzed using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). Pen was the experimental unit for all data analysis, and experiment was included in the statistical model as a random effect. Significance and tendencies were set at $P < 0.05$ and $P < 0.10$, respectively. Analysis of backfat depth, loin depth, and percentage lean were adjusted to a common HCW. Contrast coefficients were used to evaluate linear and quadratic responses to SID tryptophan:lysine ratio (16, 18, 20, and 22%) to compare the two tryptophan sources (L-tryptophan vs. SBM) and to determine linear and quadratic SID tryptophan:lysine ratio by tryptophan source interactions.

Results and Discussion

The analyzed total amino acids were within an acceptable range in both experiments except for a control diet and 22% SID tryptophan:lysine ratio during one phase in Exp. 1 that had a lower lysine level than the formulated value; however, the growth rate was not significantly affected and appeared to be due to random analytic variation. During Phase 1, a linear interaction ($P = 0.04$; Table 8) occurred between tryptophan source and SID tryptophan:lysine ratio for F/G. This was a result of an improvement in F/G (linear, $P < 0.01$; Table 8) when SID tryptophan:lysine ratio was increased using SBM whereas the best F/G (quadratic, $P = 0.13$) was achieved at 18% SID tryptophan:lysine when using L-tryptophan. An interaction in ADG (quadratic, $P = 0.02$) and ADFI (quadratic, $P = 0.01$) was observed during Phase 2 due to the difference in pattern of response between sources. For pigs fed supplemental L-tryptophan, the highest ADG and ADFI was for pigs fed 20% with a slight decrease at 22%, whereas pigs fed with SBM also had the greatest response at 20%, but the response was numerically decreased at 22%. No interaction was detected ($P > 0.25$) during phase 3 when Ractopamine was included in the diets. For the overall period (d 0 to market), an interaction (linear, $P = 0.03$) occurred between tryptophan source and SID tryptophan:lysine ratio for F/G. Increasing the SID tryptophan:lysine ratio improved (quadratic, $P < 0.01$) F/G, with the best F/G observed at 20% of SID lysine when SBM was a source of tryptophan and 18% of lysine when L-tryptophan was the source. For carcass characteristics, increasing the SID tryptophan:lysine ratio increased (linear, $P = 0.01$; Table 8) carcass yield when using L-tryptophan as a tryptophan source; however, the greatest yield was observed (quadratic, $P = 0.03$; Table 8) at an 18% SID tryptophan:lysine ratio when adding SBM resulting in a tryptophan source by SID tryptophan:lysine ratio interaction (linear, $P = 0.01$). An interaction trend also was observed in loin depth (quadratic, $P = 0.08$) and lean percentage (quadratic, $P = 0.07$). Increasing SID tryptophan:lysine ratio with L-tryptophan from 16 to 22% decreased loin depth (quadratic, $P < 0.01$) and lean percentage, but no differences ($P > 0.11$) occurred when increasing tryptophan with SBM.

For the main effects, as the SID tryptophan:lysine ratio increased, ADG tended to improve (quadratic, $P = 0.10$; Table 9) during Phase 1. Feed efficiency improved (linear, $P = 0.05$) when the SID tryptophan:lysine ratio increased, but ADFI was unaffected ($P > 0.41$). During Phase 2, increasing the SID tryptophan:lysine ratio resulted in an increase in ADG (quadratic, $P = 0.09$) and ADFI (linear, $P < 0.01$), but no differences in F/G ($P > 0.19$). The greatest ADG and ADFI were observed at the 20% SID tryptophan:lysine ratio. During Phase 3 when Ractopamine HCl was added to diets, ADG increased (quadratic, $P = 0.01$) and F/G improved (quadratic, $P < 0.01$) up to a 20% SID tryptophan:lysine ratio.

For the overall period (d 0 to market), ADG and F/G improved (quadratic, $P < 0.01$) with the increasing SID tryptophan:lysine ratio, but with no differences in ADFI ($P > 0.44$). This was the result of pigs fed the 20% SID tryptophan:lysine ratio diets having the greatest growth rate and best F/G. For carcass characteristics, pigs fed the 20% SID tryptophan:lysine ratio had the heaviest (quadratic, $P = 0.01$) HCW. Loin depth was greatest in the control diet (16% SID tryptophan:lysine ratio) and was lowest in the pigs fed 18% SID tryptophan:lysine ratio (quadratic, $P = 0.02$). Other carcass characteristics were unaffected ($P > 0.15$) by increasing the SID tryptophan:lysine ratio.

For the main effect of tryptophan source, growth performance during Phase 1 did not differ ($P > 0.55$; Table 10) between pigs fed the two sources of tryptophan. During Phase 2, pigs fed diets with SBM as a source of tryptophan had greater ADG ($P = 0.03$) than those fed diets with L-tryptophan as the source; however, there were no differences ($P > 0.25$) in ADFI or F/G. During Phase 3, ADFI was greater ($P = 0.02$) when using L-tryptophan as a source of tryptophan compared with using SBM, but ADG and F/G ($P > 0.11$) did not differ between pigs fed the two sources of tryptophan. For the overall period, a tendency was observed toward greater ADG ($P = 0.07$) when using SBM as a tryptophan source. Backfat was greater ($P = 0.04$) and percentage of lean was lower ($P = 0.02$) in pigs fed with L-tryptophan as the tryptophan source, but no difference in other carcass characteristics was detected.

In this study, an improvement in yield was observed at 18 and 22% SID tryptophan:lysine ratio when using L-tryptophan as a source of tryptophan, and at 18% when using SBM with no improvement afterward. The influence of the tryptophan:lysine ratio on yield and other carcass traits is not conclusive in this study, but increasing the SID tryptophan:lysine ratio in late finishing pigs fed high levels of

DDGS might offer an opportunity to improve carcass traits, as suggested by Nitikanchana et al. (2011[7,8]).

Increasing the SID tryptophan:lysine ratio from 16 to 22% quadratically improved ADG and F/G, resulting in an optimum SID tryptophan:lysine ratio of 20% for pigs from 157 to 279 lb. The results of this experiment agree with Barnes (2011[9]) that concluded the optimum SID tryptophan:lysine ratio for 160- to 265-lb pigs was at least 18%.

Because SBM or L-tryptophan provided a similar response in growth performance, the difference in feed cost when adding SBM or crystalline tryptophan to the diet will be a major factor in choosing the optimal source of tryptophan in diet formulation; however, our study showed that pigs fed with supplemental L-tryptophan deposited slightly more backfat and had a lower lean percentage. The difference in CP might explain these responses; several trials have reported fatter carcasses with a low-CP, amino acid–fortified diet (Smith et al., 1997[10]; Kerr et al., 1995[11]) compared with the high-CP diet. Only a small difference in CP (2%) was demonstrated in our trials between diets with L-tryptophan and SBM source; other factors may contribute to these responses.

Table 1. Amino acid analysis of soybean meal and dried distillers grains with solubles (DDGS)[1]

	Exp. 1		Exp. 2	
Amino acid, %	Soybean meal	DDGS	Soybean meal	DDGS
Lysine	2.81	0.86	2.74	0.86
Isoleucine	1.99	0.91	1.88	0.90
Leucine	3.30	2.86	3.18	2.76
Methionine	0.59	0.51	0.57	0.49
Cystein	0.63	0.49	0.63	0.46
Met & Cys	1.22	1.00	1.21	0.95
Threonine	1.78	1.00	1.70	0.95
Tryptophan	0.64	0.25	0.58	0.22
Valine	1.99	1.23	1.86	1.15

[1]Soybean meal and dried distillers grains with solubles were analyzed for total amino acid content by Ajinomoto Heartland LLC, Chicago, IL. These values along with standardized digestibility coefficients from NRC (1998) for soybean meal and Stein (2007) for DDGS were used in diet formulation for each study.

[7] Nitikanchana et al., Swine Day 2011, Report of Progress 1056, pp. 155–161.
[8] Nitikanchana et al., Swine Day 2011, Report of Progress 1056, pp. 168–173.
[9] Barnes et al., Swine Day 2010, Report of Progress 1038, pp. 156–165.
[10] Smith et al., Swine Day 1997, Report of Progress 795, pp. 85–89.
[11] Kerr, B.J., F.K. McKeith, and R.A. Easter. 1995. Effect on performance and carcass characteristics of nursery and finisher pigs fed reduced crude protein, amino acid supplemented diets. J. Anim. Sci. 73:433–440.

Table 2. Composition of diets (Exp. 1, Phase 1, 161 to 205 lb; as-fed basis)[1]

		Tryptophan source[2]	
Item	Control diet[3]	L-tryptophan	Soybean meal
Ingredient, %			
Corn	60.30	60.30	57.55–51.91
Soybean meal	7.35	7.35	10.40
DDGS[4]	30.00	30.00	30.00
Limestone	1.25	1.78	1.15–1.10
Salt	0.35	0.35	0.35
Vitamin premix	0.09	0.09	0.09
L-lysine sulfate	0.635	0.635	0.485–0.185
L-tryptophan	---	0.016	---
Phytase[5]	0.01	0.01	0.01
Total	100	100	100
Calculated analysis			
Standardized ileal digestible (SID) amino acids, %			
Lysine	0.79	0.79	0.78
Isoleucine:lysine	61	61	74
Leucine:lysine	188	188	207
Methionine:lysine	33	33	36
Met & Cys:lysine	66	66	73
Threonine:lysine	60	60	71
Tryptophan:lysine	16.0	18.0–22.0	18.0–22.0
Valine:lysine	78	78	90
Phenylalanine:lysine	88	88	103
Tyrosine:lysine	63	63	75
Total lysine, %	0.94	0.94	0.94
ME, kcal/lb	1,526	1,527	1,526
SID lysine:ME, g/Mcal	2.35	2.35	2.32
CP, %	17.2	17.2	19.3
Ca, %	0.50	0.50	0.50
P, %	0.43	0.43	0.46
Available P, %	0.20	0.20	0.21

[1] Phase 1 diet of Exp.1 was fed from 161 to 205 lb. Corn and soybean meal were analyzed for total amino acid content and used in the diet formulation.

[2] L-tryptophan was added at 0.016, 0.032, and 0.048% to the control diet at the expense of corn to provide SID tryptophan:lysine ratios of 18, 20, and 22%. Soybean meal replaced corn and crystalline lysine in the control diet for total soybean meal levels of 10.40, 13.37, and 16.38% to achieve SID tryptophan:lysine ratios of 18, 20, and 22%.

[3] Control diet was formulated to 16% SID tryptophan:lysine ratio.

[4] DDGS: dried distillers grains with solubles from Valero (Aurora, SD).

[5] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN).

Table 3. Composition of diets (Exp.1, Phase 2, 205 to 240 lb; as-fed basis)[1]

		Tryptophan source[2]	
Item	Control diet[3]	L-tryptophan	Soybean meal
Ingredient, %			
Corn	64.95	64.95	62.60–57.99
Soybean meal	2.80	2.80	5.30
DDGS[4]	30.00	30.00	30.00
Limestone	1.23	1.23	1.20-1.15
Salt	0.35	0.35	0.35
Vitamin premix	0.09	0.09	0.09
L-lysine sulfate	0.545	0.545	0.430–0.205
L-threonine	0.005	0.005	---
L-tryptophan	---	0.013	---
Phytase[5]	0.01	0.01	0.01
Total	100	100	100
Calculated analysis			
Standardized ileal digestible (SID) amino acids, %			
Lysine	0.64	0.64	0.64
Isoleucine:lysine	65	65	77
Leucine:lysine	218	218	233
Methionine:lysine	38	38	41
Met & cys:lysine	76	76	82
Threonine:lysine	65	65	75
Tryptophan:lysine	16.0	18.0–22.0	18.0–22.0
Valine:lysine	86	86	97
Phenylalanine:lysine	96	96	110
Tyrosine:lysine	68	68	79
Total lysine, %	0.78	0.78	0.79
ME, kcal/lb	1,527	1,527	1,526
SID Lysine:ME, g/Mcal	1.90	1.90	1.90
CP, %	15.4	15.4	17.1
Ca, %	0.50	0.50	0.50
P, %	0.42	0.42	0.44
Available P, %	0.19	0.19	0.20

[1] Phase 2 diet of Exp. 1 was fed from 205 to 240 lb. Corn and soybean meal were analyzed for total amino acid content and used in the diet formulation.
[2] L-tryptophan was added at 0.013, 0.026, and 0.038% to the control diet at the expense of corn to provide SID tryptophan:lysine ratios of 18, 20, and 22%. Soybean meal replaced corn and crystalline lysine in the control diet for total soybean meal levels of 5.30, 7.70, and 10.20% to achieve SID tryptophan:lysine ratios of 18, 20, and 22%.
[3] Control diet was formulated to 16% SID tryptophan:lysine ratio.
[4] DDGS: dried distillers grains with solubles from Valero (Aurora, SD).
[5] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN).

Table 4. Composition of diets (Exp. 1, Phase 3, 240 to 270 lb; as-fed basis)[1]

		Tryptophan source[2]	
Item	Control diet[3]	L-tryptophan	Soybean meal
Ingredient, %			
Corn	68.91	68.91	65.90–59.62
Soybean meal	13.70	13.70	16.95
DDGS[4]	15.00	15.00	15.00
Limestone	1.13	1.13	1.10-1.05
Salt	0.35	0.35	0.35
Vitamin premix	0.09	0.09	0.09
L-lysine sulfate	0.620	0.620	0.470–0.160
L-threonine	0.115	0.115	0.075–0.03
Methionine hydroxy	0.040	0.040	0.010–0
L-tryptophan	---	0.018	---
Phytase[5]	0.01	0.01	0.01
Ractopamine HCl, 9 g/lb[6]	0.05	0.05	0.05
Total	100	100	100
Calculated analysis			
Standardized ileal digestible (SID) amino acids, %			
Lysine	0.88	0.88	0.88
Isoleucine:lysine	59	59	70
Leucine:lysine	158	158	174
Methionine:lysine	32	32	31
Met & Cys:lysine	60	60	62
Threonine:lysine	68	68	69
Tryptophan:lysine	16.0	18.0–22.0	18.0–22.0
Valine:lysine	70	70	81
Phenylalanine:lysine	79	79	93
Tyrosine:lysine	57	57	68
Total lysine, %	1.01	1.01	1.02
ME, kcal/lb	1,526	1,527	1,524
SID lysine:ME, g/Mcal	2.62	2.61	2.62
CP, %	16.9	16.9	19.1
Ca, %	0.50	0.50	0.50
P, %	0.39	0.39	0.42
Available P, %	0.13	0.13	0.14

[1] Phase 3 diet of Exp. 1 was fed from 205 to 240 lb. Corn and soybean meal were analyzed for total amino acid content and used in the diet formulation.
[2] L-tryptophan was added at 0.018, 0.036, and 0.054% to the control diet at the expense of corn to provide SID tryptophan:lysine ratios of 18, 20, and 22%. Soybean meal replaced corn and crystalline lysine in the control diet for total soybean meal levels of 16.95, 20.40, and 23.65% to achieve SID tryptophan:lysine ratios of 18, 20, and 22%.
[3] Control diet was formulated to 16% SID tryptophan:lysine ratio.
[4] DDGS: dried distillers grains with solubles from Valero (Aurora, SD).
[5] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN).
[6] Ractopamine HCl (Paylean; Elanco Animal Health, Greenfield, IN) at 9.0 g/ton was added.

Table 5. Composition of diets (Exp. 2, Phase 1, 153 to 195 lb; as-fed basis)[1]

		Tryptophan source[2]	
Item	Control diet[3]	L-tryptophan	Soybean meal
Ingredient, %			
Corn	58.07	58.07	54.80–48.45
Soybean meal	9.77	9.77	13.23
DDGS[4]	30.00	30.00	30.00
Limestone	1.17	1.17	1.14–1.09
Salt	0.35	0.35	0.35
Vitamin premix	0.09	0.09	0.09
L-lysine sulfate	0.535	0.535	0.380–0.080
L-tryptophan	---	0.017	---
Phytase[5]	0.01	0.01	0.01
Total	100	100	100
Calculated analysis			
Standardized ileal digestible (SID) amino acids, %			
Lysine	0.79	0.79	0.79
Isoleucine:lysine	65	65	77
Leucine:lysine	190	190	207
Methionine:lysine	33	33	36
Met & Cys:lysine	66	66	73
Threonine:lysine	62	62	72
Tryptophan:lysine	16.0	18.0–22.0	18.0–22.0
Valine:lysine	78	78	90
Phenylalanine:lysine	93	93	109
Tyrosine:lysine	68	68	80
Total lysine, %	0.95	0.95	0.96
ME, kcal/lb	1,526	1,527	1,525
SID Lysine:ME, g/Mcal	2.35	2.35	2.32
CP, %	18.0	18.1	20.4
Ca, %	0.50	0.50	0.50
P, %	0.44	0.44	0.47
Available P, %	0.20	0.20	0.21

[1] Phase 1 diet of Exp.1 was fed from 161 to 205 lb. Corn and soybean meal were analyzed for total amino acid content and used in the diet formulation.
[2] L-tryptophan was added at 0.017, 0.033, and 0.049% to the control diet at the expense of corn to provide SID tryptophan:lysine ratios of 18, 20, and 22%. Soybean meal replaced corn and crystalline lysine in the control diet for total soybean meal levels of 13.23, 16.58, and 19.93% to achieve SID tryptophan:lysine ratios of 18, 20, and 22%.
[3] Control diet was formulated to 16% SID tryptophan:lysine ratio.
[4] DDGS: dried distillers grains with solubles from Valero (Aurora, SD).
[5] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN).

Table 6. Composition of diets (Exp. 2, Phase 2, 195 to 244 lb; as-fed basis)[1]

		Tryptophan source[2]	
Item	Control diet[3]	L-tryptophan	Soybean meal
Ingredient, %			
Corn	63.18	63.16	60.54–55.37
Soybean meal	4.70	4.70	7.49
DDGS[4]	30.00	30.00	30.00
Limestone	1.20	1.20	1.18–1.13
Salt	0.35	0.35	0.35
Vitamin premix	0.09	0.09	0.09
L-lysine sulfate	0.465	0.465	0.340–0.095
L-tryptophan	---	0.013	---
Phytase[5]	0.01	0.01	0.01
Total	100	100	100
Calculated analysis			
Standardized ileal digestible (SID) amino acids, %			
Lysine	0.64	0.64	0.64
Isoleucine:lysine	68	68	81
Leucine:lysine	219	219	236
Methionine:lysine	38	38	41
Met & Cys:lysine	76	76	82
Threonine:lysine	66	66	77
Tryptophan:lysine	16.0	18.0–22.0	18.0–22.0
Valine:lysine	86	86	97
Phenylalanine:lysine	101	101	117
Tyrosine:lysine	72	72	85
Total lysine, %	0.79	0.79	0.80
ME, kcal/lb	1,527	1,527	1,525
SID lysine:ME, g/Mcal	1.90	1.90	1.90
CP, %	16.1	16.1	18.0
Ca, %	0.50	0.50	0.50
P, %	0.42	0.42	0.45
Available P, %	0.20	0.20	0.20

[1] Phase 2 diet of Exp.2 was fed from 195 to 244 lb. Corn and soybean meal were analyzed for total amino acid content and used in the diet formulation.

[2] L-tryptophan was added at 0.013, 0.026, and 0.039% to the control diet at the expense of corn to provide SID tryptophan:lysine ratios of 18, 20, and 22%. Soybean meal replaced corn and crystalline lysine in the control diet for total soybean meal levels of 7.49, 10.17, and 12.96% to achieve SID tryptophan:lysine ratios of 18, 20, and 22%.

[3] Control diet was formulated to 16% SID tryptophan:lysine ratio.

[4] DDGS: dried distillers grains with solubles from Valero (Aurora, SD).

[5] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN).

Table 7. Composition of diets (Exp. 2, Phase 3, 244 to 287 lb; as-fed basis)[1]

		Tryptophan source[2]	
Item	Control diet[3]	L-tryptophan	Soybean meal
Ingredient, %			
Corn	66.65	66.63	63.14–56.00
Soybean meal	16.08	16.08	19.87
DDGS[4]	15.00	15.00	15.00
Limestone	1.10	1.10	1.08–1.03
Salt	0.35	0.35	0.35
Vitamin premix	0.09	0.09	0.09
L-lysine sulfate	0.530	0.530	0.360–0.020
L-threonine	0.100	0.100	0.005–0.00
Methionine hydroxy	0.040	0.040	0.010–0
L-tryptophan	---	0.018	---
Phytase[5]	0.01	0.01	0.01
Ractopamine HCl, 9 g/lb[6]	0.05	0.05	0.05
Total	100	100	100
Calculated analysis			
Standardized ileal digestible (SID) amino acids, %			
Lysine	0.88	0.88	0.88
Isoleucine:lysine	61	61	73
Leucine:lysine	160	160	177
Methionine:lysine	32	32	32
Met & Cys:lysine	61	61	64
Threonine:lysine	68	68	69
Tryptophan:lysine	16.0	18.0–22.0	18.0–22.0
Valine:lysine	71	71	82
Phenylalanine:lysine	84	84	99
Tyrosine:lysine	61	61	73
Total lysine, %	1.01	1.01	1.03
ME, kcal/lb	1,526	1,526	1,524
SID Lysine:ME, g/Mcal	2.62	2.61	2.62
CP, %	17.7	17.7	20.3
Ca, %	0.50	0.50	0.50
P, %	0.40	0.40	0.44
Available P, %	0.13	0.13	0.14

[1] Phase 3 diet of Exp. 1 was fed from 205 to 240 lb. Corn and soybean meal were analyzed for total amino acid content and used in the diet formulation.

[2] L-tryptophan was added at 0.018, 0.036, and 0.054% to the control diet at the expense of corn to provide SID tryptophan:lysine ratios of 18, 20, and 22%. Soybean meal replaced corn and crystalline lysine in the control diet for total soybean meal levels of 19.87, 23.66, and 27.46% to achieve SID tryptophan:lysine ratios of 18, 20, and 22%.

[3] Control diet was formulated to 16% SID tryptophan:lysine ratio.

[4] DDGS: dried distillers grains with solubles from Valero (Aurora, SD).

[5] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN).

[6] Ractopamine HCl (Paylean; Elanco Animal Health, Greenfield, IN) at 9.0 g/ton was added.

Table 8. Effects of tryptophan sources to increasing standardized ileal digestible tryptophan:lysine ratio in diets containing dried distillers grains with solubles (DDGS) on growth performance and carcass characteristics of finishing pigs[1]

	Control	L-trp			SBM				Probability, $P<$					
									Trp × source		L-trp[2]		SBM	
	16.0	18.0	20.0	22.0	18.0	20.0	22.0	SEM	Linear	Quad	Linear	Quad	Linear	Quad
Replications	13	12	13	12	12	13	10							
Initial wt, lb	156.9	156.9	156.6	156.9	156.9	157.0	156.8	4.152	0.99	0.92	0.98	0.93	0.99	0.97
Final wt, lb	275.1	276.9	281.2	277.5	279.8	284.7	278.4	8.112	0.78	0.36	0.29	0.26	0.19	0.03
Phase 1[3]														
ADG, lb	1.93	2.01	2.00	1.95	1.94	2.06	2.00	0.038	0.13	0.50	0.73	0.09	0.05	0.39
ADF, lb	5.69	5.54	5.79	5.56	5.59	5.72	5.51	0.103	0.50	0.89	0.73	0.66	0.30	0.54
F/G	2.95	2.76	2.89	2.86	2.90	2.77	2.76	0.071	0.04	0.38	0.56	0.13	0.01	0.69
Phase 2														
ADG, lb	1.87	1.83	1.95	1.92	1.93	2.04	1.91	0.060	0.78	0.02	0.07	0.86	0.16	0.01
ADF, lb	6.30	6.11	6.64	6.65	6.49	6.66	6.49	0.182	0.05	0.01	0.01	0.24	0.07	0.05
F/G	3.37	3.33	3.41	3.47	3.36	3.28	3.41	0.056	0.21	0.75	0.12	0.40	0.86	0.23
Phase 3														
ADG, lb	2.20	2.30	2.44	2.21	2.34	2.38	2.29	0.071	0.67	0.55	0.52	0.01	0.29	0.09
ADF, lb	6.98	6.54	6.94	6.64	7.01	6.92	6.96	0.203	0.46	0.67	0.29	0.57	0.80	0.98
F/G	3.19	2.85	2.88	3.01	3.01	2.92	3.04	0.125	0.94	0.25	0.06	0.01	0.06	0.01
Overall														
ADG, lb	1.98	2.02	2.09	2.00	2.04	2.13	2.04	0.026	0.20	0.70	0.17	0.01	0.01	0.01
ADF, lb	6.24	5.99	6.38	6.22	6.27	6.35	6.25	0.076	0.51	0.20	0.30	0.52	0.78	0.35
F/G	3.16	2.97	3.06	3.11	3.07	2.98	3.06	0.031	0.03	0.30	0.68	0.01	0.01	0.01

continued

Table 8. Effects of tryptophan sources to increasing standardized ileal digestible tryptophan:lysine ratio in diets containing dried distillers grains with solubles (DDGS) on growth performance and carcass characteristics of finishing pigs[1]

	Control	L-trp			SBM				Probability, *P*<					
									Trp × source		L-trp[2]		SBM	
	16.0	18.0	20.0	22.0	18.0	20.0	22.0	SEM	Linear	Quad	Linear	Quad	Linear	Quad
Carcass wt, lb	205.2	207.5	209.5	206.3	210.3	211.8	206.3	8.382	0.96	0.31	0.54	0.15	0.59	0.01
Yield, %	74.3	75.4	74.7	75.8	75.8	74.6	74.6	0.608	0.01	0.08	0.01	0.99	0.86	0.03
Backfat, in.[4]	0.58	0.58	0.58	0.57	0.56	0.55	0.56	0.040	0.39	0.22	0.50	0.94	0.12	0.13
Loin depth, in.	2.83	2.73	2.77	2.79	2.78	2.79	2.77	0.021	0.50	0.08	0.35	0.01	0.11	0.42
Lean, %	58.5	58.2	58.4	58.5	58.6	58.8	58.6	0.630	0.70	0.07	0.84	0.24	0.55	0.29

[1] A total of 2,290 pigs (PIC 1050 × 337; initially 157 lb) were used in 2 replicated studies with 26 to 28 gilts per pen and 10 to 13 pens per treatment.

[2] *P*-value of effect of standardized ileal digestible tryptophan:lysine ratio dosage within each source of tryptophan.

[3] Phases were from d 0 to 20, 20 to 40, and 40 to 56 in Exp. 1 and from d 0 to 21, 21 to 47, and 47 to 68 in Exp. 2.

[4] Backfat, loin depth, and lean percentage were adjusted to a common HCW.

Table 9. Effects of tryptophan sources to increasing standardized ileal digestible (SID) tryptophan:lysine ratio in DDGS on growth performance and carcass characteristics of finishing pigs (main effect of SID tryptophan:lysine ratio)[1]

	SID trp:lys ratio, %					Probability, $P<$	
						SID trp:lys ratio	
	16	18	20	22	SEM	Linear	Quad
Replications	13	24	26	22			
Initial wt, lb	156.9	157.0	157.0	157.0	4.00	0.98	0.97
Final wt, lb	275.1	278.0	283.0	278.0	7.95	0.24	0.18
Phase 1[2]							
ADG, lb	1.93	1.97	2.03	1.98	0.03	0.17	0.10
ADF, lb	5.69	5.56	5.75	5.54	0.09	0.41	0.50
F/G	2.95	2.83	2.83	2.81	0.06	0.05	0.23
Phase 2							
ADG, lb	1.87	1.88	1.99	1.91	0.06	0.06	0.09
ADF, lb	6.30	6.30	6.65	6.57	0.17	0.01	0.58
F/G	3.37	3.35	3.35	3.44	0.04	0.31	0.19
Phase 3							
ADG, lb	2.20	2.32	2.41	2.25	0.06	0.30	0.01
ADF, lb	6.98	6.78	6.93	6.80	0.18	0.44	0.71
F/G	3.19	2.93	2.90	3.03	0.12	0.03	0.01
Overall							
ADG, lb	1.98	2.03	2.11	2.02	0.02	0.02	0.01
ADF, lb	6.24	6.13	6.37	6.23	0.06	0.44	0.84
F/G	3.16	3.02	3.02	3.09	0.02	0.06	0.01
Carcass wt, lb	205.2	208.9	210.7	206.3	8.28	0.50	0.01
Yield, %	74.3	75.6	74.7	75.2	0.57	0.15	0.16
Backfat, in.[3]	0.58	0.57	0.57	0.57	0.04	0.19	0.30
Loin depth, in.	2.83	2.75	2.78	2.78	0.02	0.13	0.02
Lean, %	58.5	58.4	58.6	58.5	0.62	0.63	0.97

[1] A total of 2,290 pigs (PIC 1050 × 337; initially 157 lb) were used in 2 replicated studies with 26 to 28 gilts per pen. There were 13 pens per control treatment and 22 to 26 pens for main effect of 18 to 22 SID tryptophan:lysine ratio.

[2] Phases were from d 0 to 20, d 20 to 40, and d 40 to 56 in Exp. 1 and from d 0 to 21, d 21 to 47, and d 47 to 68 in Exp. 2.

[3] Backfat, loin depth, and lean percentage were adjusted to a common HCW.

Table 10. Effects of tryptophan sources to increasing standardized ileal digestible tryptophan:lysine ratio in DDGS on growth performance and carcass characteristics of finishing pigs (main effect of tryptophan source)[1]

	Tryptophan source			
	L-trp	SBM	SEM	Probability, *P*<
Replications	37	35		
Initial wt, lb	157.0	157.0	3.93	0.95
Final wt, lb	278.0	281.0	7.87	0.36
Phase 1[2]				
ADG, lb	1.99	2.00	0.02	0.67
ADF, lb	5.63	5.60	0.08	0.73
F/G	2.84	2.81	0.05	0.55
Phase 2				
ADG, lb	1.90	1.96	0.05	0.03
ADF, lb	6.46	6.54	0.17	0.26
F/G	3.41	3.35	0.03	0.25
Phase 3				
ADG, lb	2.32	2.34	0.05	0.74
ADF, lb	6.71	6.96	0.17	0.02
F/G	2.91	2.99	0.12	0.11
Overall				
ADG, lb	2.04	2.07	0.02	0.07
ADF, lb	6.20	6.29	0.05	0.12
F/G	3.05	3.04	0.02	0.70
Carcass wt, lb	207.8	209.5	8.23	0.30
Yield, %	75.3	75.0	0.55	0.23
Backfat, in.[3]	0.58	0.56	0.04	0.04
Loin depth in.	2.76	2.78	0.01	0.23
Lean, %	58.3	58.6	0.62	0.02

[1]A total of 2,290 pigs (PIC 1050 × 337; initially 157 lb) were used in 2 replicated studies with 26 to 28 gilts per pen with 35 to 37 pens per main effect of tryptophan source.

[2]Phases were from d 0 to 20, d 20 to 40, and d 40 to 56 in Exp. 1 and from d 0 to 21, d 21 to 47, and d 47 to 68 in Exp. 2.

[3]Backfat, loin depth, and lean percentage were adjusted to a common HCW.