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Effects of dietary fiber on the ideal standardized ileal digestible threonine:lysine ratio for twenty-five to fifty kilogram growing gilts[1]

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ABSTRACT: Four experiments were conducted to determine effects of fiber on the ideal Thr:Lys ratio for 25- to 50-kg gilts. In Exp. 1, the objective was to determine the requirement for standardized ileal digestible Lys for gilts from 25 to 50 kg BW. Seventy gilts (24.54 ± 3.28 kg BW) were used in a growth assay with 2 pigs per pen, 5 diets, and 7 replicate pens per diet. The 5 diets were based on corn and soybean meal and contained between 0.80 and 1.32% SID Lys. Results indicated that 1.09% SID Lys was needed to optimize ADG and G:F. In Exp. 2, the objective was to determine the standardized ileal digestibility of AA in corn, soybean meal, field peas, fish meal, and soybean hulls. Six ileal-cannulated gilts (26.5 ± 0.74 kg BW) were allotted to a 6 × 6 Latin square design with 6 diets and 6 periods. Values for standardized ileal digestibility of AA were calculated for all ingredients. In Exp. 3, the objective was to determine the effect of fiber on the ideal SID Thr:Lys ratio for gilts from 25 to 50 kg BW. A total of 192 gilts (26.29 ± 4.64 kg BW) were used in a growth assay with 2 pigs per pen and 8 replicate pens per treatment. Six low-fiber diets and 6 high-fiber diets were formulated using the same batches of ingredients as in Exp. 2. Within each level of fiber, diets with SID Thr:Lys ratios ranging from 45:100 to 90:100 were formulated using the SID values calculated in Exp. 2. In both types of diets, ADG and G:F linearly and quadratically ($P < 0.05$) increased as the Thr:Lys ratio increased. Regression analysis estimated the ideal SID Thr:Lys ratio at 0.66 and 0.63 for ADG and G:F, respectively, for pigs fed low-fiber diets and at 0.71 and 0.63, respectively, for pigs fed high-fiber diets. In Exp. 4, the objective was to determine the N balance in pigs fed low-fiber or high-fiber diets that were formulated to have SID Thr:Lys ratios of 45:100 or 60:100. The 4 diets were formulated using the same batches of ingredients as in Exp. 2, and the SID values determined in Exp. 2 were used in diet formulations. Thirty-six gilts (29.0 ± 0.74 kg BW) were individually housed in metabolism crates with 9 replicate pigs per diet. Retention of N (% of intake) was greater (P < 0.05) for pigs fed the low-fiber diets compared with pigs fed the high-fiber diets regardless of the Thr:Lys ratio. Results of these experiments indicate that increased fiber levels in diets fed to growing gilts increase the requirement for Thr and that diets with higher fiber levels should be formulated to a greater SID Thr:Lys ratio.

Key words: amino acids, fiber, ideal protein, lysine, pigs, threonine

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INTRODUCTION

Requirements for indispensable AA for pigs are often expressed as a ratio to Lys in the diet (Wang and Fuller, 1989; Chung and Baker, 1992; NRC, 2012), but there is some confusion about the ideal Thr:Lys ratio. A standardized ileal digestible (**SID**) Thr:Lys ratio of 0.60 for 25- to 50-kg growing pigs was recently estimated as being adequate (NRC, 2012), and this value is in agreement with a previous estimate

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(ARC, 1981). However, ideal Thr:Lys ratios as high as 0.67 and 0.72 have also been suggested for 25- to 50-kg pigs (Wang and Fuller, 1989; Baker, 1997).

It is possible that one reason for the conflicting recommendations for the ideal Thr:Lys ratio is that increased dietary fiber will increase endogenous losses of AA and other nutrients, thereby influencing the requirement for Thr (Dilger et al., 2004; Hansen et al., 2006; Cervantes-Pahm et al., 2014). Endogenous protein that is lost from the small intestine is rich in mucin, which lines the intestinal tract (Stein et al., 1999), and the synthesis of mucin is increased as dietary fiber is increased (de Lange et al., 1989; Easter, 1994). Because the concentration of Thr in endogenous protein is greater than the concentration of any other indispensable AA (Stein et al., 1999), increased fiber in the diet will induce increased losses of Thr, which may increase the requirement for Thr in the diet (de Lange et al., 1989; Zhu et al., 2005). Indeed, dietary fermentable fiber increases the SID Thr losses estimated from modeling (NRC, 2012), and as a consequence, it is likely that increased dietary fiber results in an increase in the ideal Thr:Lys ratio in the diet. It was, therefore, the objective of this research to test the hypothesis that increased dietary fiber will result in an increase in the ideal Thr:Lys ratio for 25- to 50-kg growing gilts as measured via growth performance and N balance in pigs with a known requirement for SID Lys and batches of feed ingredients that had been characterized in terms of SID AA.

MATERIALS AND METHODS

The protocol for 4 experiments were reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois (Urbana, IL). All pigs used in the experiments were the offspring of G-Performer boars mated to Fertilis-25 dams (Genetiporc USA LLC, Alexandria, MN). A locally grown commercial hybrid of yellow dent corn was obtained from the University of Illinois Feed Mill (Champaign, IL). Field peas and fish meal (Select Menhaden) were obtained from commercial sources (Central Ingredients, West Bend, WI, and Omega Protein Corp., Houston, TX, respectively). Soybean meal (**SBM**) was procured from Solae LLC (Gibson City, IL), and soybean hulls (**SBH**) were obtained from Archer Daniels Midland Company (Decatur, IL). The same batches of these ingredients were used in Exp. 2, 3, and 4, and ingredients were stored at 15°C until used.

Experiment 1: Lys Requirement

Experiment 1 was conducted to determine the requirement for SID Lys in gilts from 25 to 50 kg BW. Seventy gilts (24.54 ± 3.28 kg initial BW) were allotted to 5 diets with 7 pen replicates per diet and 2 pigs per pen. The 5 diets were based on corn and SBM, and the calculated concentrations of SID Lys in the diets were 0.80, 0.93, 1.06, 1.19, and 1.32% (Table 1). The different diets were created by changing the proportion of corn and SBM in the diets using principles

Table 1. Composition of experimental diets (Exp. 1), as-is basis

	Standardized ileal digestible Lys, %				
Item	0.80	0.93	1.06	1.19	1.32
Ingredient, %					
Ground corn	68.55	63.30	58.17	52.97	47.78
Soybean meal, 48% CP	25.55	30.80	36.10	41.40	46.68
Soybean oil	3.00	3.00	3.00	3.00	3.00
Ground limestone	0.90	0.90	0.93	0.93	0.94
Dicalcium phosphate	1.30	1.20	1.10	1.00	0.90
Salt	0.40	0.40	0.40	0.40	0.40
Vitamin mineral premix[1]	0.30	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00
Analyzed composition					
ME,[2] kcal/kg	3,421	3,419	3,416	3,414	3,412
CP, %	17.41	19.52	21.65	23.79	25.91
Digestible P,[2] %	0.34	0.34	0.34	0.34	0.34
Indispensable AA, %					
Arg	1.18	1.33	1.39	1.52	1.65
His	0.47	0.52	0.55	0.58	0.63
Ile	0.78	0.88	0.93	1.00	1.08
Leu	1.70	1.85	1.92	2.01	2.12
Lys	1.00	1.14	1.21	1.33	1.46
Met	0.29	0.31	0.32	0.34	0.36
Met + Cys	0.59	0.63	0.65	0.69	0.72
Phe	0.96	1.07	1.12	1.20	1.29
Thr	0.70	0.78	0.82	0.89	0.96
Trp	0.19	0.21	0.24	0.27	0.31
Val	0.87	0.97	1.01	1.09	1.17
Dispensable AA, %					
Ala	0.99	1.07	1.11	1.17	1.24
Asp	1.82	2.06	2.18	2.39	2.61
Cys	0.30	0.32	0.33	0.35	0.36
Glu	3.37	3.75	3.91	4.19	4.50
Gly	0.78	0.86	0.90	0.97	1.05
Pro	1.17	1.24	1.27	1.33	1.40
Ser	0.83	0.91	0.96	1.02	1.11
Tyr	0.62	0.68	0.69	0.75	0.80

[1]The vitamin–micromineral premix provided the following quantities of vitamins and microminerals per kilogram of complete diet: 11,136 IU vitamin A as retinyl acetate, 2,208 IU vitamin D_3 as cholecalciferol, 66 IU vitamin E as DL-alpha tocopheryl acetate, 1.42 mg vitamin K as menadione dimethylprimidinol bisulfite, 0.24 mg thiamin as thiamine mononitrate, 6.59 mg riboflavin, 0.24 mg pyridoxine as pyridoxine hydrochloride, 0.03 mg vitamin B12, 23.5 mg D-pantothenic acid as D-calcium pantothenate, 44.1 mg niacin, 1.59 mg folic acid, 0.44 mg biotin, 20 mg Cu as copper sulfate and copper chloride, 126 mg Fe as ferrous sulfate, 1.26 mg I as ethylenediamine dihydriodide, 60.2 mg Mn as manganese sulfate, 0.3 mg Se as sodium selenite and selenium yeast, and 125.1 mg Zn as zinc sulfate.

[2]These values were not analyzed but calculated (NRC, 2012).

Table 2. Analyzed composition of ingredients (Exp. 2, 3, and 4), as-is basis

Item	Corn	Soybean meal	Field peas	Fish meal	Soybean hulls
CP, %	8.66	47.44	22.11	63.84	8.59
ADF, %	4.65	6.63	7.97	3.16	43.17
NDF, %	11.60	7.16	12.82	9.43	59.18
Indispensable AA, %					
Arg	0.44	3.36	1.67	3.67	0.34
His	0.25	1.19	0.50	1.44	0.22
Ile	0.32	2.15	0.89	2.51	0.30
Leu	1.07	3.60	1.52	4.35	0.54
Lys	0.31	2.85	1.54	4.80	0.56
Met	0.16	0.63	0.19	1.66	0.08
Met + Cys	0.34	1.26	0.29	0.50	0.13
Phe	0.45	2.41	1.03	2.42	0.33
Thr	0.30	1.82	0.79	2.50	0.27
Trp	0.09	0.63	0.17	0.56	0.05
Val	0.42	2.29	0.99	2.95	0.38
Dispensable AA, %					
Ala	0.65	2.01	0.92	3.76	0.35
Asp	0.59	5.17	2.33	5.40	0.70
Cys	0.18	0.63	0.29	0.50	0.13
Glu	1.64	8.32	3.47	7.75	0.82
Gly	0.40	1.95	0.94	4.25	0.73
Pro	0.75	2.44	0.83	2.90	0.42
Ser	0.41	2.05	0.89	2.18	0.43
Tyr	0.34	1.48	0.63	1.87	0.31

described by Cline et al. (2000). Diets were formulated using published values for the standardized ileal digestibility of AA in corn and SBM (NRC, 2012).

Pigs were housed in pens with concrete slatted floors. There were a feeder and a nipple drinker in each pen, and the room was temperature was controlled at approximately 22°C. Pigs had free access to feed and water throughout the experiment. Daily feed allocations were recorded, and individual pig weights were recorded at the beginning of the experiment and at the end of the 33-d experiment. The amount of feed left in the feeders was recorded at the conclusion of the experiment. The ADG, ADFI, and G:F were calculated for each treatment group at the conclusion of the experiment.

All diets were analyzed for CP (method 990.03; AOAC Int., 2007) and AA (method 982.30 E(a,b,c); AOAC Int., 2007). Data were analyzed by ANOVA using the UNIVARIATE and MIXED procedures of SAS (SAS Inst. Inc., Cary, NC). Linear and quadratic effects of treatments were determined using orthogonal CONTRAST statements. Pen was the experimental unit for all analyses and an α-value of 0.05 was used to assess statistical significance. Broken-line analyses were performed using the NLIN procedure of SAS (Robbins et al., 2006) for all variables that had significant linear effects, and quadratic-plateau analyses were performed using the NLIN procedure of SAS for all variables with significant quadratic effects. Broken-line analyses and quadratic analyses were used to determine the Lys requirement for pigs using ADG and G:F as the response criteria. The average for the concentration of dietary SID Lys required to maximize ADG and G:F was considered the Lys requirement of the pigs.

Experiment 2: AA Digestibility

Six growing gilts (26.5 ± 0.74 kg initial BW) were equipped with a T-cannula in the distal ileum and allotted to a 6 × 6 Latin square design with 6 diets and six 7-d periods in each square. There were 6 replicate pigs per treatment. Pigs were housed in individual pens (1.2 by 1.5 m) in an environmentally controlled room. Pens had solid-sided walls and fully slatted, tri-bar floors. A feeder and a nipple drinker were installed in each pen.

Four diets with corn, SBM, field peas, or fish meal as the sole source of AA were formulated, and 1 diet containing SBM and SBH as the sources of AA was also formulated (Tables 2 and 3). A N-free diet was formulated to determine basal endogenous losses of AA and to enable the calculation of standardized ileal digestibility of AA. Vitamins and minerals were included in all diets to meet or exceed current requirement estimates (NRC, 2012), and chromic oxide was the indigestible marker. Feed was provided at 0700 h in a quantity that was equivalent to 3 times the estimated daily energy requirement for maintenance (i.e., 197 kcal ME/kg$^{0.60}$; NRC, 2012). Water was available at all times.

Pig weights were recorded at the beginning of each period and at the conclusion of the experiment. The amount of feed supplied each day was recorded as well. Ileal digesta were collected for 8 h on d 6 and 7 of each 7-d period (Stein et al., 1998).

Digesta samples were lyophilized and finely ground prior to chemical analysis, and diets and digesta were analyzed for DM (method 930.15; AOAC Int., 2007) and chromium (method 990.08; AOAC Int., 2007); CP and AA were analyzed as explained for Exp.1. A sample of each ingredient was also analyzed for CP, AA, ADF (method 973.18; AOAC Int., 2007), and NDF (Holst, 1973).

Values for apparent ileal digestibility, basal ileal endogenous losses, and standardized ileal digestibility of AA in each diet were calculated (Stein et al., 2007). Values for apparent ileal digestibility and standardized ileal digestibility of AA in corn, SBM, fish meal, and field peas were calculated using the direct procedure and values for SBH were calculated using the difference procedure (Fan and Sauer, 1995). Data were analyzed using PROC MIXED of SAS. An ANOVA was conducted with pigs, periods, and diets as the main

Table 3. Composition of experimental diets (Exp. 2), as-is basis

	Diet					
Ingredient, %	Corn	Soybean meal	Field peas	Fish meal	Soybean hulls	N free
Ground corn	96.58	–	–	–	–	–
Soybean meal, 48%	–	30.00	–	–	22.50	–
Field peas	–	–	65.00	–	–	–
Fish meal	–	–	–	23.00	–	–
Soybean hulls	–	–	–	–	35.00	–
Soybean oil	–	3.00	3.00	–	3.00	4.00
Solka floc	–	–	–	–	–	4.00
Dicalcium phosphate	1.50	1.40	1.30	–	2.10	2.40
Limestone	0.82	0.75	0.90	–	0.10	0.50
Sucrose	–	20.00	20.00	20.00	20.00	20.00
Chromic oxide	0.40	0.40	0.40	0.40	0.40	0.40
Cornstarch	–	43.75	8.70	55.90	16.20	67.50
Magnesium oxide	–	–	–	–	–	0.10
Potassium carbonate	–	–	–	–	–	0.40
Sodium chloride	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin–micromineral premix[1]	0.30	0.30	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.0	100.00
Analyzed composition						
CP, %	13.78	15.08	8.16	13.90	13.11	0.29
Indispensable AA, %						
Arg	0.41	0.95	1.14	0.84	0.91	0.01
His	0.23	0.34	0.34	0.34	0.36	0.00
Ile	0.31	0.62	0.60	0.60	0.63	0.01
Leu	1.04	1.05	1.04	1.06	1.06	0.06
Lys	0.30	0.85	1.05	1.15	0.90	0.02
Met	0.15	0.17	0.13	0.39	0.16	0.00
Met + Cys	0.30	0.35	0.31	0.50	0.25	0.00
Phe	0.44	0.69	0.71	0.61	0.71	0.01
Thr	0.29	0.55	0.54	0.56	0.51	0.01
Trp	0.09	0.18	0.12	0.16	0.17	0.04
Val	0.40	0.65	0.67	0.70	0.68	0.01
Dispensable AA, %						
Ala	0.63	0.61	0.64	0.92	0.63	0.02
Asp	0.56	1.53	1.58	1.28	1.48	0.02
Cys	0.15	0.18	0.18	0.11	0.09	0.00
Glu	1.57	2.47	2.36	1.93	2.33	0.05
Gly	0.38	0.59	0.67	1.08	0.78	0.02
Pro	0.71	0.67	0.57	0.67	0.68	0.00
Ser	0.37	0.64	0.63	0.50	0.65	0.01
Tyr	0.33	0.42	0.47	0.42	0.47	0.01

[1]The vitamin–micromineral premix provided the following quantities of vitamins and microminerals per kilogram of complete diet: 11,136 IU vitamin A as retinyl acetate, 2,208 IU vitamin D_3 as cholecalciferol, 66 IU vitamin E as DL-alpha tocopheryl acetate, 1.42 mg vitamin K as menadione dimethylprimidinol bisulfite, 0.24 mg thiamin as thiamine mononitrate, 6.59 mg riboflavin, 0.24 mg pyridoxine as pyridoxine hydrochloride, 0.03 mg vitamin B12, 23.5 mg D-pantothenic acid as D-calcium pantothenate, 44.1 mg niacin, 1.59 mg folic acid, 0.44 mg biotin, 20 mg Cu as copper sulfate and copper chloride, 126 mg Fe as ferrous sulfate, 1.26 mg I as ethylenediamine dihydriodide, 60.2 mg Mn as manganese sulfate, 0.3 mg Se as sodium selenite and selenium yeast, and 125.1 mg Zn as zinc sulfate.

effects. Pig was the experimental unit for all analyses, and an α-value of 0.05 was used to assess significance among means. Mean values for each ingredient were calculated using the LSMeans statement. When significant differences were detected, treatment means were separated using the LSD test in PROC MIXED.

Experiment 3: Thr Titration

A total of 192 gilts (26.29 ± 4.64 kg initial BW) were used with 2 pigs per pen and 8 pen replicates per diet. The performance of pigs was measured during a 28-d growth assay. Pigs were housed in pens with slatted concrete floors. There was a feeder and a nipple drinker in each pen, and the room was temperature

Table 4. Ingredient composition of experimental diets (Exp. 3), as-is basis

	Standardized ileal digestible Thr:Lys ratio											
	Low fiber						High fiber					
Item	0.45	0.54	0.63	0.72	0.81	0.90	0.45	0.54	0.63	0.72	0.81	0.90
Ingredient, %												
Ground corn	57.17	57.07	56.99	56.90	56.82	56.74	55.15	55.06	54.98	54.90	54.82	54.73
Field peas	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Soybean meal, 48% CP	5.25	5.25	5.25	5.25	5.25	5.25	3.25	3.25	3.25	3.25	3.25	3.25
Fish meal	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Corn starch	15.00	15.00	15.00	15.00	15.00	15.00	–	–	–	–	–	–
Soybean hulls	–	–	–	–	–	–	15.00	15.00	15.00	15.00	15.00	15.00
Soybean oil	1.00	1.00	1.00	1.00	1.00	1.00	5.25	5.25	5.25	5.25	5.25	5.25
Limestone	0.80	0.80	0.80	0.80	0.80	0.80	0.62	0.62	0.62	0.62	0.62	0.62
Dicalcium phosphate	1.02	1.02	1.02	1.02	1.02	1.02	0.95	0.95	0.95	0.95	0.95	0.95
Salt	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
L-Lysine HCl	0.39	0.39	0.39	0.39	0.39	0.39	0.38	0.38	0.38	0.38	0.38	0.38
DL-Methionine	0.24	0.24	0.24	0.24	0.24	0.24	0.27	0.27	0.27	0.27	0.27	0.27
L-Threonine	–	0.09	0.17	0.25	0.33	0.41	–	0.09	0.17	0.25	0.33	0.42
L-Tryptophan	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
L-Isoleucine	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
L-Valine	0.16	0.16	0.16	0.16	0.16	0.16	0.14	0.14	0.14	0.14	0.14	0.14
L-Phenylalanine	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Histidine	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Vitamin–mineral premix[1]	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30

[1]The vitamin–micromineral premix provided the following quantities of vitamins and microminerals per kilogram of complete diet: 11,136 IU vitamin A as retinyl acetate, 2,208 IU vitamin D_3 as cholecalciferol, 66 IU vitamin E as DL-alpha tocopheryl acetate, 1.42 mg vitamin K as menadione dimethylprimidinol bisulfite, 0.24 mg thiamin as thiamine mononitrate, 6.59 mg riboflavin, 0.24 mg pyridoxine as pyridoxine hydrochloride, 0.03 mg vitamin B12, 23.5 mg D-pantothenic acid as D-calcium pantothenate, 44.1 mg niacin, 1.59 mg folic acid, 0.44 mg biotin, 20 mg Cu as copper sulfate and copper chloride, 126 mg Fe as ferrous sulfate, 1.26 mg I as ethylenediamine dihydriodide, 60.2 mg Mn as manganese sulfate, 0.3 mg Se as sodium selenite and selenium yeast, and 125.1 mg Zn as zinc sulfate.

controlled. Pigs had free access to feed and water throughout the experiment.

A low-fiber basal diet was formulated with 0.40% SID Thr and 0.90% SID Lys. This level of Lys was chosen because results of Exp. 1 indicated that the requirement for SID Lys for 25- to 50-kg gilts is 1.09%, and 0.90% SID Lys, therefore, was expected to be well below the Lys requirement for the pigs. Five additional diets were formulated by adding crystalline L-Thr to the basal diet in increments of 0.08% to create diets containing approximately 0.49, 0.57, 0.65, 0.73, and 0.81% SID Thr (Table 4). Thus, diets with SID Thr:Lys ratios at 45:100, 54:100, 63:100, 72:100, 81:100, and 90:100 were created (Table 5). It was believed that both the linear and the plateau regions of the growth curve were represented by these inclusion levels of Thr (NRC, 2012). A high-fiber basal diet that also contained 0.40% SID Thr and 0.90% SID Lys was formulated by adding 15% SBH to the low-fiber basal diet at the expense of corn starch, and 5 additional diets were formulated by adding crystalline Thr to this diet as explained for the low-fiber diets. Diets were considered high fiber due to the inclusion of SBH, which has high concentration of ADF and NDF. All diets were formulated using the SID values for corn, SBM, field peas, fish meal, and SBH that were calculated in Exp. 2.

Feed allocations were recorded, and individual pig weights were recorded at the beginning and at the end of the experiment. The amount of feed left in the feeders was recorded as pigs were weighed off the experiment. The ADG, ADFI, and G:F were calculated for each pen of pigs and for each treatment group at the conclusion of the experiment. The concentration of AA in the diets was analyzed as explained for Exp. 1, and the daily intake of Thr was calculated for each treatment group.

Normality of data was verified and outliers were tested using the UNIVARIATE procedure of SAS. Data were analyzed by ANOVA using the UNIVARIATE and MIXED procedures of SAS. Linear and quadratic effects of Thr in diets containing low or high concentrations of fiber were determined using orthogonal CONTRAST statements. Pen was the experimental unit for all analyses, and an α-value of 0.05 was used to assess significance among treatments.

Data were subjected to regression analyses using the NLIN procedure of SAS. Broken-line and nonlinear quadratic regression equations were developed to establish inflection points for ADG and G:F (Robbins et al., 1979, 2006; Baker et al., 2002). The concentration of Thr that resulted in the first intercept value of the quadratic regression curve and the plateau value

Table 5. Analyzed nutrient composition of diets (Exp. 3), as-is basis

	Standardized ileal digestible Thr:Lys ratio											
	Low fiber						High fiber					
Item	0.45	0.54	0.63	0.72	0.81	0.90	0.45	0.54	0.63	0.72	0.81	0.90
ME,[1] kcal/kg	3,404	3,401	3,398	3,395	3,393	3,390	3,318	3,315	3,312	3,310	3,307	3,304
NE,[1] kcal/kg	2,522	2,519	2,517	2,515	2,513	2,510	2,519	2,517	2,515	2,513	2,510	2,508
Ca,[1] %	0.70	0.70	0.70	0.70	0.70	0.70	0.69	0.69	0.69	0.69	0.69	0.69
STTD P,[1] %	0.33	0.33	0.33	0.33	0.33	0.33	0.32	0.32	0.32	0.32	0.32	0.32
ADF, %	3.48	3.39	3.17	3.39	3.45	3.56	10.10	9.88	9.44	10.22	9.88	10.91
NDF, %	7.77	7.69	9.00	8.24	8.00	9.32	16.66	16.27	15.33	15.60	17.90	17.77
CP, %	12.64	12.63	12.63	12.62	12.61	12.61	12.81	12.80	12.79	12.79	12.78	12.77
Standardized ileal digestibility of AA,[2] %												
Lys	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Met + Cys	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58
Thr	0.40	0.49	0.57	0.65	0.73	0.81	0.40	0.49	0.57	0.65	0.73	0.81
Trp	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Val	0.68	0.68	0.68	0.68	0.68	0.68	0.67	0.67	0.67	0.67	0.67	0.67
Ile	0.54	0.54	0.54	0.54	0.54	0.54	0.53	0.53	0.53	0.53	0.53	0.53
Indispensable AA, %												
Arg	0.81	0.83	0.79	0.80	0.77	0.78	0.73	0.79	0.78	0.73	0.72	0.72
His	0.39	0.39	0.38	0.37	0.36	0.39	0.37	0.39	0.38	0.37	0.38	0.36
Ile	0.63	0.65	0.60	0.61	0.57	0.62	0.60	0.60	0.60	0.60	0.56	0.56
Leu	1.17	1.18	1.14	1.16	1.13	1.13	1.10	1.15	1.15	1.12	1.06	1.04
Lys	0.92	0.92	0.94	1.03	0.90	0.99	0.92	0.96	1.00	0.95	0.92	0.90
Met	0.47	0.22	0.47	0.39	0.43	0.42	0.44	0.43	0.50	0.41	0.43	0.42
Met + Cys	0.67	0.42	0.66	0.58	0.61	0.61	0.64	0.63	0.70	0.60	0.61	0.60
Phe	0.69	0.66	0.66	0.65	0.64	0.63	0.65	0.64	0.65	0.63	0.61	0.64
Thr	0.47	0.57	0.58	0.75	0.83	0.88	0.45	0.65	0.61	0.70	0.81	0.72
Trp	0.18	0.18	0.18	0.18	0.18	0.19	0.17	0.16	0.16	0.16	0.15	0.13
Val	0.72	0.76	0.74	0.74	0.73	0.75	0.69	0.74	0.72	0.69	0.70	0.67
Dispensable AA, %												
Ala	0.74	0.74	0.72	0.72	0.71	0.71	0.69	0.73	0.72	0.70	0.67	0.66
Asp	1.18	1.21	1.14	1.16	1.13	1.14	1.10	1.17	1.16	1.11	1.08	1.08
Cys	0.20	0.20	0.19	0.19	0.18	0.19	0.20	0.20	0.20	0.19	0.18	0.18
Glu	2.15	2.18	2.09	2.12	2.07	2.08	1.95	2.06	2.02	1.98	1.90	1.87
Gly	0.60	0.59	0.58	0.57	0.57	0.57	0.63	0.66	0.64	0.62	0.60	0.62
Pro	0.76	0.76	0.75	0.73	0.73	0.73	0.71	0.76	0.75	0.72	0.70	0.69
Ser	0.55	0.56	0.54	0.54	0.53	0.53	0.54	0.57	0.56	0.54	0.52	0.51
Tyr	0.39	0.36	0.35	0.36	0.34	0.34	0.40	0.41	0.41	0.40	0.41	0.40

[1]STTD = standardized total tract digestible. Values not analyzed but calculated (NRC, 2012).

[2]Values not analyzed but calculated based on results from Exp. 2.

from the broken-line analysis was used to calculate the ideal SID Thr:Lys ratio for ADG and G:F.

Experiment 4: Effect of Thr:Lys Ratio on N Balance

Thirty-six growing gilts (29.0 ± 0.74 kg initial BW) were housed in metabolism crates that were equipped with a feeder and a nipple drinker, fully slatted floors, a screen floor, and urine trays, which allowed for the total, but separate, collection of urine and feces from each pig. Urine buckets were placed under the urine trays and after being emptied, clean cheese cloth was placed on top of each urine bucket to ensure clean separation of urine and feces. A total of 50 mL of 6 *N* HCl were added to each urine bucket daily. Pigs were allotted to 4 diets with 9 replicate pigs per diet using a randomized complete block design. There were 3 blocks of 12 pigs.

Four diets were prepared (Tables 6 and 7) using the SID values for corn, SBM, field peas, fish meal, and SBH that were calculated in Exp. 2. Two diets were low-fiber diets and 2 diets were high-fiber diets. Within each level of fiber, 1 diet was formulated to contain Thr at a SID Thr:Lys ratio of 0.45, whereas the other diet was formulated to contain Thr at a SID Thr:Lys ratio of 0.60. These ratios were used based on the results of Exp. 3 and were believed to be approximately 70 and 95%, respectively, of the optimum Thr:Lys ratio.

Table 6. Ingredient composition of experimental diets (Exp. 4), as-is basis

	Low fiber		High fiber	
Item	0.45 SID[1] Thr:Lys ratio	0.60 SID Thr:Lys ratio	0.45 SID Thr:Lys ratio	0.60 SID Thr:Lys ratio
Ingredient, %				
Ground corn	57.17	57.01	55.15	55.01
Field peas	15.0	15.0	15.0	15.0
Soybean meal, 48% CP	5.25	5.25	3.25	3.25
Fish meal	3.00	3.00	3.00	3.00
L-Isoleucine	0.09	0.09	0.09	0.09
L-Lysine HCl	0.39	0.39	0.38	0.38
DL-Methionine	0.23	0.23	0.27	0.27
L-Threonine	–	0.14	–	0.1425
L-Tryptophan	0.06	0.06	0.07	0.07
L-Valine	0.16	0.16	0.14	0.14
L-Histidine	0.06	0.06	0.06	0.06
Corn starch	15.0	15.0	–	–
Soybean oil	1.0	1.0	5.25	5.25
Soybean hulls	–	–	15.0	15.0
Limestone	0.8	0.8	0.62	0.62
Dicalcium phosphate	1.02	1.02	0.95	0.95
Sodium chloride	0.40	0.40	0.40	0.40
Vitamin–mineral premix[2]	0.30	0.30	0.30	0.30

[1]SID = standardized ileal digestible.

[2]The vitamin–micromineral premix provided the following quantities of vitamins and microminerals per kilogram of complete diet: 11,136 IU vitamin A as retinyl acetate, 2,208 IU vitamin D_3 as cholecalciferol, 66 IU vitamin E as DL-alpha tocopheryl acetate, 1.42 mg vitamin K as menadione dimethylprimidinol bisulfite, 0.24 mg thiamin as thiamine mononitrate, 6.59 mg riboflavin, 0.24 mg pyridoxine as pyridoxine hydrochloride, 0.03 mg vitamin B_{12}, 23.5 mg D-pantothenic acid as D-calcium pantothenate, 44.1 mg niacin, 1.59 mg folic acid, 0.44 mg biotin, 20 mg Cu as copper sulfate and copper chloride, 126 mg Fe as ferrous sulfate, 1.26 mg I as ethylenediamine dihydriodide, 60.2 mg Mn as manganese sulfate, 0.3 mg Se as sodium selenite and selenium yeast, and 125.1 mg Zn as zinc sulfate.

Table 7. Chemical composition of experimental diets (Exp. 4), as-is basis

	Low fiber		High fiber	
Item	0.45 SID[1] Thr:Lys ratio	0.60 SID Thr:Lys ratio	0.45 SID Thr:Lys ratio	0.60 SID Thr:Lys ratio
ME,[2] kcal/kg	3,404	3,399	3,318	3,314
Ca,[2] %	0.69	0.69	0.70	0.71
STTD P,[3] %	0.33	0.33	0.33	0.34
ADF, %	3.64	4.21	9.49	10.07
NDF, %	8.39	8.54	17.83	16.97
CP, %	14.37	14.89	13.92	13.86
Standardized ileal digestibility of AA,[4] %				
Lys	0.90	0.90	0.90	0.90
Met + Cys	0.57	0.58	0.58	0.58
Thr	0.40	0.54	0.40	0.40
Trp	0.18	0.18	0.18	0.18
Val	0.68	0.68	0.67	0.67
Ile	0.54	0.54	0.53	0.53
Indispensable AA, %				
Arg	0.82	0.96	0.82	0.80
His	0.39	0.47	0.42	0.43
Ile	0.59	0.63	0.61	0.61
Leu	1.16	1.23	1.17	1.19
Lys	0.98	1.10	1.05	1.04
Met	0.39	0.46	0.52	0.50
Phe	0.68	0.73	0.70	0.69
Thr	0.47	0.64	0.48	0.59
Trp	0.19	0.18	0.16	0.15
Val	0.73	0.79	0.74	0.74
Dispensable AA, %				
Ala	0.71	0.76	0.73	0.74
Asp	1.16	1.35	1.19	1.17
Cys	0.19	0.21	0.20	0.20
Glu	2.15	2.37	2.11	2.13
Gly	0.57	0.63	0.64	0.65
Pro	0.77	0.79	0.77	0.79
Ser	0.55	0.61	0.58	0.58
Tyr	0.42	0.45	0.44	0.44

[1]SID = standardized ileal digestible.

[2]Values not analyzed but calculated (NRC, 2012).

[3]STTD = standardized total tract digestible.

[4]Values calculated based on results from Exp. 2.

All pigs were fed 810 g of feed at 0800 and 1600 h, which was believed to be 90% of ad libitum feed intake for gilts based on the ADFI observed in Exp. 3 in which similar diets were fed. Water was available at all times.

The amount of feed supplied each day was recorded and orts were collected each day. Urine and fecal samples were collected for 5 d following a 7-d adaptation period according to standard procedures for the marker-to-marker method (Adeola, 2001). Daily collections of feces were immediately frozen at −20°C. Daily collections of urine were weighed and mixed and a 20% subsample was stored at −20°C.

Fecal samples were dried in a forced-air oven and finely ground before analysis. Diets and ingredients were analyzed for CP and AA, and fecal samples were analyzed for DM and CP. Urine samples were filtered and analyzed for CP. All samples were analyzed as explained for Exp. 1 and 2.

Apparent total tract digestibility (**ATTD**) and retention of N for each pig were calculated as previously described (Pedersen et al., 2007). Data were analyzed as a 2-way ANOVA, with 2 concentrations of fiber (high and low) and 2 SID Thr:Lys ratios (0.45 and 0.60) using the MIXED procedure of SAS. Interactions between fiber level and the SID Thr:Lys ratio were included in the model. Mean values for each diet were calculated using the LSMeans statement, and means were separated if the interaction was significant. The pig was the experimental unit for all analyses, and an α-value of 0.05 was used to assess significance between means.

Table 8. Growth performance of pigs fed experimental diets (Exp. 1)[1]

	Standardized ileal digestible Lys, %						Contrasts (*P*-value)	
Item	0.80	0.93	1.06	1.19	1.32	SEM	Linear	Quadratic
Initial BW, kg	24.55	24.59	24.53	24.58	24.46	0.72	0.94	0.94
ADG, g	782	809	825	846	794	17.36	0.27	0.03
ADFI, g	1,758	1,826	1,738	1,775	1,658	92.74	0.12	0.20
G:F	432	444	462	465	467	13.13	0.003	0.28
Final BW, kg	53.60	54.52	54.99	55.74	53.92	0.80	0.33	0.03

[1]Data are means of 7 observations per treatment.

RESULTS AND DISCUSSION

The approach used to test our hypothesis for this experiment included determination of the actual requirement for SID Lys in the particular population of pigs we have available at the University of Illinois. We believe this is an important step for this type of work because required AA ratios relative to Lys can be accurately determined only by using diets that have SID Lys included below the requirement of the pigs. Likewise, to make sure accurate values for standardized ileal digestibility of AA were used in diet formulations, we determined the standardized ileal digestibility of all AA in the particular batches of ingredients that we used in the titration and N-balance experiments. We used this approach to make sure that we captured possible differences between the actual ingredients we used and values for standardized ileal digestibility of AA that could be copied from feed tables. This was specifically important for SBH because very few values for the standardized ileal digestibility of AA in SBH have been reported. To confirm the results we obtained in the titration experiment, we also conducted an N-balance experiment, which increased our confidence in the conclusions drawn from the titration experiment. Therefore, the 4 experiments all were conducted with the aim of answering the questions we addressed in the hypothesis for this work. We are not aware of studies that have reported that there are differences between gilts and barrows in optimum AA to Lys ratios, but to avoid possible influences of sex on the optimum Thr:Lys ratio, only gilts were used in this experiment.

Experiment 1: Lys Titration

All pigs stayed healthy throughout the experiment and readily consumed their diets. Average daily gain increased (quadratic, $P < 0.05$) as SID Lys increased from 0.80 to 1.32% (Table 8). Average daily feed intake was not influenced by dietary treatments, but G:F increased (linear, $P < 0.05$) as the concentration of Lys in the diets increased. Quadratic-plateau regression estimated the optimal SID Lys requirement at 1.08% for ADG (Fig. 1). Broken-line regression estimated the optimal SID Lys requirement for G:F at 1.10% (Fig. 2).

Our requirement estimate of 1.09% SID Lys is greater than that indicated by the NRC (2012). There are several potential reasons for this observation. The NRC requirement of 0.98% SID Lys is for both barrows and gilts, whereas our estimate is for gilts only. Gilts may require more Lys than barrows as they approach the finishing period because of reduced feed intake and increased lean deposition compared with barrows (Cromwell et al., 1993, 1996; Cline et al., 2000). The requirement estimated in this experiment is in agreement with those determined from a series of experiments conducted in commercial facilities using gilts at 3 different weight categories (Shelton et al.,

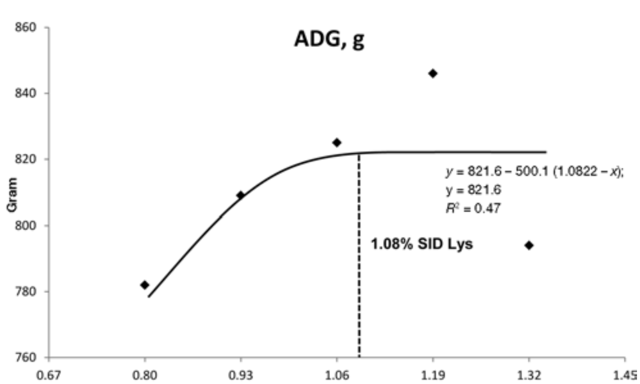

Figure 1. Fitted curvilinear plateau plot of ADG ($R^2 = 0.47$) as a function of standardized ileal digestible (SID) Lys (Exp. 1).

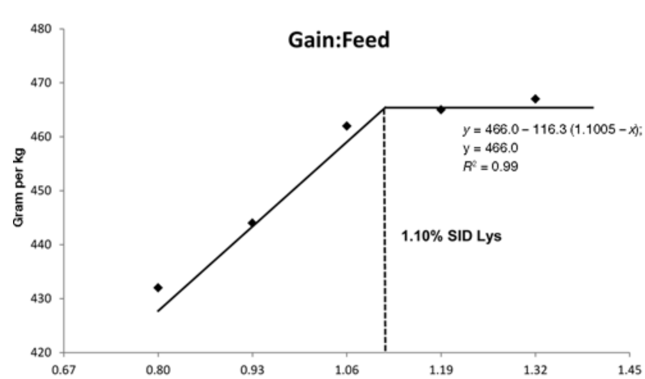

Figure 2. Fitted broken-line plot of G:F ($R^2 = 0.99$) as a function of standardized ileal digestible (SID) Lys (Exp. 1).

2011). As was the case in this experiment, Lys concentration in the diets used by Shelton et al. (2011) was increased by altering the inclusions of corn and SBM in the diets and the requirement for SID Lys for gilts from 38 to 65 kg was estimated to be between 1.03 and 1.10%. Therefore, the value estimated in the present experiment for gilts between 25 and 50 kg is in agreement with the values estimated by Shelton et al. (2011).

Experiment 2: AA Digestibility

All pigs stayed healthy throughout the experiment and no problems with palatability of diets were observed. Gross chemical composition of the ingredients was generally in agreement with published values (NRC, 2012).

The ingredients used in this experiment were chosen because of their relatively low Thr:Lys ratios. The standardized ileal digestibility of AA in the ingredients (Table 9) was generally in agreement with published data (NRC, 2012), with the exception of SBH, which contained less CP and AA than expected (NRC, 2012; Stewart et al., 2013). As an example, the standardized ileal digestibility of Lys, Met, Thr, and Trp in SBH is 58, 70, 62, and 62%, respectively, according to the NRC (2012), whereas we calculated SID values for Lys, Met, Thr, and Trp of 69.8, 97.1, 85.9, and 76.4%, respectively. It is possible that these differences are caused by differences in the techniques used among soybean crushing plants to dehull soybeans. There are, however, limited data on AA digestibility in SBH, which is likely due to the fact that SBH is a relatively uncommon feed ingredient in diets for growing pigs and the NRC (2012) values are based on only 1 observation. However, results of this experiment indicate that AA in SBH are relatively well digested by growing pigs.

Table 9. Standardized ileal digestibility of AA in field peas, fish meal, corn, soybean meal (SBM), and soybean hulls (SBH) fed to growing gilts (Exp. 2)[1,2]

	Ingredients					Pooled	
Item	Corn	SBM	Field peas	Fish meal	SBH	SEM	*P*-value
Indispensable AA, %							
Arg	100.31[a]	96.00[ab]	96.52[ab]	92.90[bc]	114.8[d]	1.82	<0.05
His	93.26[a]	90.24[b]	92.65[ab]	87.34[c]	69.5[d]	1.20	<0.05
Ile	90.66[a]	87.71[ab]	87.57[ab]	86.70[b]	83.4[c]	1.25	<0.05
Leu	94.06[a]	87.61[b]	88.48[b]	87.72[b]	83.0[c]	1.14	<0.05
Lys	73.14[b]	86.31[a]	90.64[a]	87.72[a]	69.8[c]	2.14	<0.05
Met	92.14[b]	87.42[c]	87.94[bc]	87.20[c]	97.1[a]	1.51	<0.05
Phe	92.94[a]	88.41[b]	89.21[b]	86.04[bc]	89.2[b]	1.21	<0.05
Thr	89.24[a]	85.42[ab]	86.94[ab]	84.26[b]	85.9[ab]	1.92	<0.05
Trp	95.03[a]	90.60[b]	85.83[c]	91.21[ab]	76.4[d]	1.88	<0.05
Val	90.18[b]	85.93[c]	86.49[bc]	84.90[c]	100.5[a]	1.64	<0.05
Mean	92.55[a]	89.03[b]	90.72[ab]	87.88[b]	88.4[c]	1.24	<0.05
Dispensable AA, %							
Ala	94.36[a]	86.70[b]	88.72[b]	84.82[b]	86.9[b]	1.80	<0.05
Asp	90.47[a]	85.55[b]	88.79[a]	81.43[c]	62.6[d]	1.40	<0.05
Cys	90.11[a]	81.82[b]	82.36[b]	69.82[c]	−82.0[d]	2.53	<0.05
Glu	94.25[a]	88.75[b]	91.12[ab]	87.57[b]	67.1[c]	1.46	<0.05
Gly	99.15[a]	93.56[ab]	92.11[ab]	84.62[b]	70.8[c]	5.13	<0.05
Ser	92.31[a]	89.47[a]	88.53[ab]	84.98[b]	65.1[c]	1.69	<0.05
Tyr	93.00[a]	87.41[b]	90.31[ab]	87.15[b]	71.7[c]	1.34	<0.05
Mean	90.28[a]	89.24[a]	89.45[a]	86.41[a]	78.83[b]	2.55	<0.05
Total AA	89.10[a]	89.14[a]	88.80[a]	87.11[ab]	80.79 [b]	2.59	<0.05

[a–d]Means within a row lacking a common superscript letter differ ($P < 0.05$).

[1]Data are means of 6 observations per treatment.

[2]Standardized ileal digestibility values were calculated by correcting values for apparent ileal digestibility for the basal ileal endogenous losses. Endogenous losses (g/kg of DMI) of AA were as follows: Arg, 1.06; His, 0.21; Ile, 0.33; Leu, 0.51; Lys, 0.58; Met, 0.08; Phe, 0.29; Thr, 0.58; Trp, 0.15; Val, 0.59; Ala, 0.77; Asp, 0.88; Cys, 0.20; Glu, 1.06; Gly, 2.43; Ser, 0.57; and Tyr, 0.27.

Experiment 3: Thr Titration

All pigs stayed healthy throughout the experiment and readily consumed their diets. In the low-fiber diets, ADG and G:F increased both linearly and quadratically ($P < 0.01$ and $P < 0.05$, respectively) as the concentration of Thr increased in the diets (Table 10). Likewise, in the high-fiber diets, ADG and G:F increased both linearly and quadratically ($P < 0.001$ and $P < 0.05$, respectively) as the concentration of Thr increased. Final BW linearly increased in both low-fiber and high-fiber diets ($P < 0.01$ and $P < 0.05$, respectively) as Thr concentration in diets increased. There were no effects of Thr level on ADFI among low-fiber diets, but ADFI linearly increased ($P < 0.05$) as Thr concentration increased in high-fiber diets. Overall, ADG was greater ($P < 0.05$) in pigs fed high-fiber diets than in pigs fed low-fiber diets.

For pigs fed the low-fiber diets, broken-line analyses estimated the optimum SID Thr:Lys ratio as 0.60 and 0.59 for ADG and G:F, respectively (Fig. 3 and 4). For pigs fed high-fiber diets, broken-line analyses estimated the optimum SID Thr:Lys ratio requirement as 0.66 and 0.55 for ADG and G:F, respectively (Fig. 5 and 6). For pigs fed the low-fiber diets, quadratic analyses estimated the optimum SID Thr:Lys ratio as 0.76 and 0.73 for ADG and G:F, respectively, but quadratic analyses estimated the optimum SID Thr:Lys ratio requirement as 0.80 and 0.75 for ADG and G:F, respectively, for pigs fed the high-fiber diets. For pigs fed the low-fiber diets, combined broken-line and quadratic analyses estimated the optimum SID Thr:Lys ratio as 0.66 and 0.63 for ADG and G:F, respectively, whereas these estimates were 0.71 and 0.63 for ADG and G:F, respectively, for pigs fed the high-fiber diets.

To overcome the weaknesses of both broken-line and quadratic models, the combined broken-line and quadratic model was proposed (Baker et al., 2002; Parr et al., 2003). This method uses both broken lines

Table 10. Growth performance of pigs fed experimental diets (Exp. 3)[1,2]

	Standardized ileal digestible Thr:Lys ratio							Contrasts (P-value)	
Item	0.45	0.54	0.63	0.72	0.81	0.90	SEM	Linear	Quadratic
Low fiber									
Initial BW, kg	26.16	26.68	26.68	25.73	26.73	26.39	0.80	0.963	0.969
ADG, g	696	769	797	830	836	803	28.9	<0.01	<0.05
ADFI, g	1,785	1,799	1,777	1,812	1,862	1,830	102	0.376	0.917
G:F	382	423	450	455	445	435	20.9	0.001	<0.001
Final BW, kg	45.66	49.43	49.56	49.5	50.13	50.36	1.15	<0.01	0.132
High fiber									
Initial BW, kg	26.47	26.85	26.72	26.57	26.28	26.72	1.31	0.924	0.964
ADG, g	763	882	878	900	933	915	35.48	<0.001	<0.05
ADFI, g	1,828	1,872	1,835	1,864	1,945	1,989	64.9	<0.05	0.409
G:F	421	461	465	472	470	464	12.91	<0.01	<0.01
Final BW, kg	48.14	51.86	51.67	52.08	52.70	52.64	1.61	<0.05	0.145

[1]Data are means of 8 observations per treatment.

[2]Values for ADG and G:F were greater ($P < 0.05$) for the high-fiber diets than for the low-fiber diets, but for ADFI, initial BW, and final BW, no differences between low- and high-fiber diets were observed.

and quadratic curves that are fitted to the data, and the requirement is determined as the first intersection of the quadratic line with the plateau region of the broken line. It has been suggested that this combined analysis provides a more robust requirement estimate, which is adequate for a larger portion of the population than the broken-line method but at the same time more conservative than the quadratic-curve method (Baker et al., 2002; Parr et al., 2003; Nemechek et al., 2012). Using this combined method yields requirement estimates very similar to requirements estimated as 90% of quadratic model estimates, with the benefit of being completely objective (Parr et al., 2003).

The broken-line and quadratic-curve models are both susceptible to subjective determinations of requirements. However, by using a combination of the broken-line and the quadratic-curve models, the strengths of both broken-line and curvilinear models are combined by offering a means for not dramatically over- or underestimating the requirement of a given population but also for determining the requirement through the use of a reproducible method and an objectively calculated value (Baker et al., 2002; Parr et al., 2003). The limitation of the use of this combined model is that it requires the data to have both significant linear and quadratic effects; otherwise, any benefits conferred by objectivity are lost. For these reasons, the requirements determined through the use of the combined models are considered the best estimations of the ratio requirement for this particular population of pigs.

The Thr:Lys ratios estimated by the combined models for G:F and ADG in both low- and high-fiber diets are within the range of previously published values (Mitchell et al., 1968; Li et al., 1998; Chang et al., 2000; Pedersen et al., 2003; NRC, 2012; Zhang et al., 2013). However, the objectives for this study were not only to determine the ideal Thr:Lys ratio for 25- to 50-kg growing gilts but to also determine the effects of fiber on that requirement.

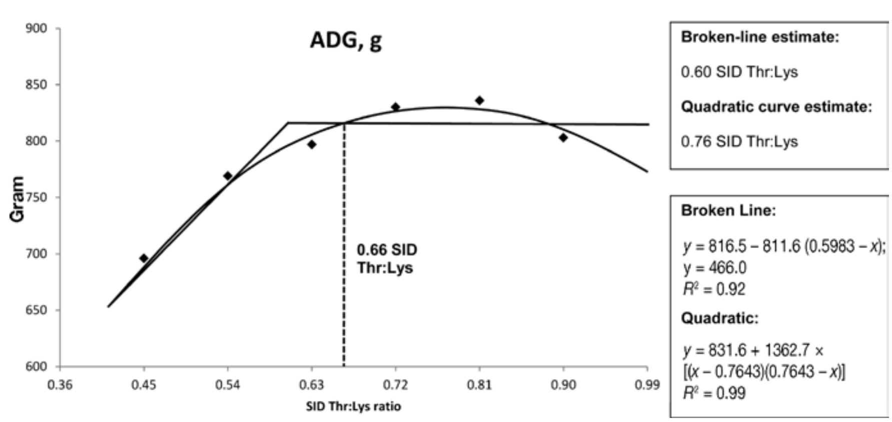

Figure 3. Combined fitted broken-line ($R^2 = 0.92$) and quadratic-curve ($R^2 = 0.99$) plots of ADG as a function of standardized ileal digestible (SID) Thr to Lys ratio with observed treatment means in pigs fed low-fiber diets (Exp. 3).

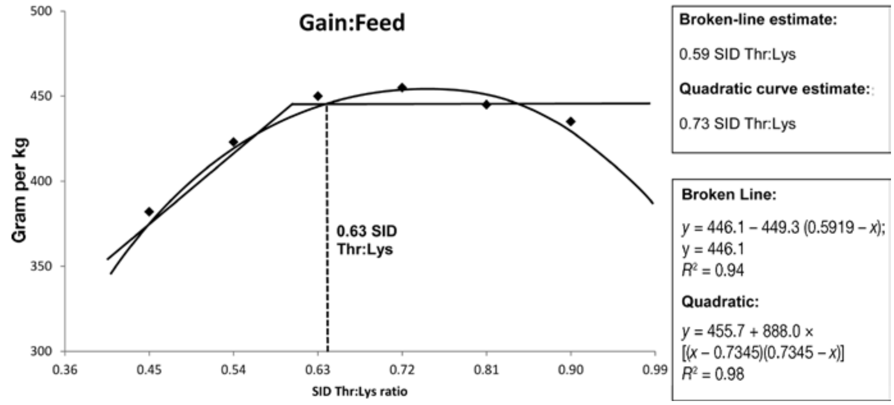

Figure 4. Combined fitted broken-line ($R^2 = 0.94$) and quadratic-curve ($R^2 = 0.98$) plots of G:F as a function of standardized ileal digestible (SID) Thr to Lys ratio with observed treatment means in pigs fed low-fiber diets (Exp. 3).

The estimated requirement for the ideal Thr:Lys ratio for optimizing G:F was the same for both low- and high-fiber diets at 0.63. However, the estimated requirement for the ideal Thr:Lys ratio for optimizing ADG was greater for pigs fed the high-fiber diets (0.71) than for the pigs fed the low-fiber diets (0.66). This increase in the estimated requirement indicates that the presence of SBH, a source of both soluble and insoluble fiber, in the diet increases the requirement for Thr in the growing pig. The reason for this observation may be that fiber may have negative effects on energy digestibility (Wenk, 2001; Urriola et al., 2013; Cervantes-Pahm et al., 2014) and possibly also on lipid digestibility (Zervas and Zijlstra, 2002; Urriola et al., 2013) and N digestibility (Bach Knudsen and Hansen, 1991; Dégen et al., 2009; Kil et al., 2010; Cervantes-Pahm et al., 2014). Fibrous ingredients may also affect transit rate and passage time of digesta (Dikeman and Fahey, 2006). Generally, an increase in fiber concentration in the diets will reduce transit time of digesta due to an increased passage rate (Rose and Hamaker, 2011). Dietary fiber may also result in a greater requirement of Thr in animals fed high-fiber diets because of increased endogenous losses and increased microbial activity in the hindgut (Sakata, 1987; de Lange et al., 1989; Easter, 1994; Zhu et al., 2005).

Experiment 4: Effect of Thr:Lys Ratio on N Balance

The total intake of N was greater ($P < 0.05$) for pigs fed the low-fiber diets than for pigs fed the high-fiber diets (Table 11), but the daily output of N in the feces was greatest ($P < 0.05$) in pigs fed the high-fiber, high-Thr diet and least ($P < 0.05$) in pigs fed 1 of the 2 low-fiber diets. Output of N in urine was greatest ($P < 0.05$) in pigs fed the low-fiber, low-Thr diet and least ($P < 0.05$) in pigs fed the high-fiber, high-Thr diet. The ATTD of N was greater ($P < 0.05$) in pigs fed the low-fiber diets than in pigs fed the high-fiber diets. Retention of N (% of intake) was greatest ($P < 0.05$) in pigs fed the low-fiber, high-Thr diet and least ($P < 0.05$) in pigs fed the high-fiber, low-Thr diets. However, retention of N was greater ($P < 0.05$) in pigs fed the high-Thr diets than in pigs fed the low-Thr diets, regardless of the concentration of fiber in the diet.

The retention of N was greater ($P < 0.05$) in pigs fed the low-fiber diet when compared with pigs fed the high-fiber diet with the same level of digestible

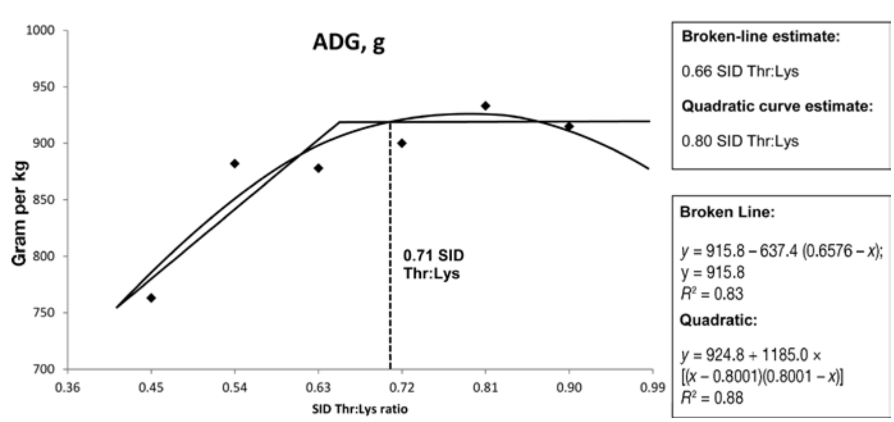

Figure 5. Combined fitted broken-line ($R^2 = 0.83$) and quadratic-curve ($R^2 = 0.88$) plots of ADG as a function of standardized ileal digestible (SID) Thr to Lys ratio with observed treatment means in pigs fed high-fiber diets (Exp. 3).

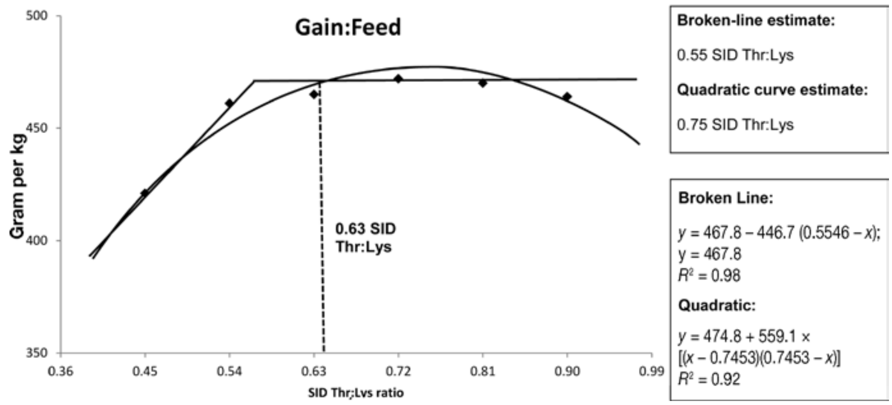

Figure 6. Combined fitted broken-line (R^2 = 0.98) and quadratic-curve (R^2 = 0.92) plots of G:F as a function of standardized ileal digestible (SID) Thr to Lys ratio with observed treatment means in pigs fed high-fiber diets (Exp. 3).

Thr. There was greater ($P < 0.05$) output of N in the urine from pigs fed the low-Thr diets than from pigs fed the high-Thr diets, and there was greater ($P < 0.05$) N retention in pigs fed the high-Thr diets compared with pigs fed the low-Thr diets. There was also an interaction ($P < 0.05$) between fiber level and Thr for the output of N in feces, with N output increasing ($P < 0.05$) as Thr increased in the high-fiber diet, whereas this was not the case for the low-fiber diet.

The increased fecal N excretion from pigs fed the high-fiber diets compared with pigs fed the low-fiber diets is consistent with observations from other studies and represents the shift in excretion of N from the urine to the feces as microbial utilization of N increases (Dilger et al., 2004). The increased N output in the feces of pigs fed high-fiber diets compared with pigs fed low-fiber diets may represent microbial proteins generated in the hindgut and the potentially negative effect that microbial substrates in the form of fiber in the hindgut can have on an animal's utilization of protein (Libao-Mercado et al., 2006).

The decrease in N output in the urine of pigs fed the high-fiber, high-Thr diet compared with pigs fed the high-fiber, low-Thr diets is consistent with the increase in N output in the feces of pigs fed the high-fiber diets. However, regardless of the fiber level, pigs fed the high-Thr diets had reduced N output in the urine when compared with the low-Thr diets, which is indicative of the increased utilization of N from the diet as Thr level approached the requirement of the animal. The substantial decrease in urinary N for pigs fed the low-fiber, high-Thr diet compared with pigs fed the high-fiber, high-Thr diet indicates that the requirement for Thr may be greater in high-fiber diets than in low-fiber diets. However, it is possible that if pigs had been allowed ad libitum access to feed, results might have been different because results of Exp. 3 indicated that pigs given ad libitum access to feed will consume more feed if provided a high-fiber diet. Therefore, it is possible that ad libitum feeding would have negated the negative influence of the high-fiber diet on N balance.

Conclusions

The objective of this research was to determine if the optimal SID Thr:Lys ratio for 25- to 50-kg growing gilts is influenced by the level of fiber in the diet. Results of the experiments indicate that the optimal

Table 11. Nitrogen balance of pigs fed diets with major deficiency or marginal deficiency of Thr and with low or high concentrations of fiber (Exp. 4)[1]

	Low fiber		High fiber			*P*-value		
Item	0.45 SID[2] Thr:Lys ratio	0.60 SID Thr:Lys ratio	0.45 SID Thr:Lys ratio	0.60 SID Thr:Lys ratio	Pooled SEM	Fiber level	Thr level	Fiber level × Thr level
N intake, g/5 d	182	185	162	171	4.8	<0.05	0.17	0.48
N output in feces, g/5 d	38[bc]	35.2[c]	41[b]	47[a]	2.6	<0.05	0.30	<0.05
N output in urine, g/5 d	29	23	26	15	2.1	<0.05	<0.05	0.22
ATTD[3] of N, %	80.1	81.6	75.6	73.2	1.5	<0.05	0.69	0.06
N retention, g/5 d	119	131	99	113	3.6	<0.05	<0.05	0.85
N retention, %	64.5	69.77	59.5	64.9	2.1	<0.05	<0.05	0.99

[a–c]Means within a row lacking a common superscript letter differ ($P < 0.05$).

[1]Data are means of 9 observations per treatment, except for the treatment with high fiber and the 0.60 SID Thr:Lys ratio, which had only 7 observations.

[2]SID = standardized ileal digestible.

[3]ATTD = apparent total tract digestibility.

SID Thr:Lys ratio is greater in pigs fed high-fiber diets than in pigs fed low-fiber diets. Therefore, to maximize growth performance, the concentration of digestible Thr may need to be increased if fiber levels of diets are increased. This conclusion is important because feeding of higher-fiber ingredients is becoming more common in the swine industry. Understanding the relationships between fiber, AA utilization, and AA requirements will enable producers to improve efficiency by feeding to the requirements of the animals while simultaneously minimizing N excretions. The current results indicate that in low-fiber diets, the optimal SID Lys:Thr ratio is 0.66 whereas to optimize ADG in high-fiber diets, the ratio has to be increased to 0.71. For 25- to 50-kg gilts with a requirement for SID Lys of 1.09% as determined in Exp. 1, this translates to a SID Thr requirement of 0.72% in low-fiber diets and 0.77% in high-fiber diets. However, data from this experiment were obtained in diets that contained both soluble and insoluble fiber and it is possible that if only insoluble fibers were used, results could be different.

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