Published online December 7, 2017

Evaluation of the optimal standardized ileal digestible tryptophan:lysine ratio in lactating sow diets

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ABSTRACT: Three hundred and fifteen primiparous and multiparous sows were evaluated in a study to determine the effect of standardized ileal digestible (SID) Trp:Lys ratio in lactating sow diets. Camborough sows (PIC USA, Hendersonville, TN) ranging from first parity to eighth parity were blocked by parity and randomly allotted to 1 of 4 experimental diets containing different levels of added L-Trp (0.006, 0.026, 0.045, and 0.064%, respectively) while soybean meal, 30% corn dried distiller's grain with solubles (DDGS), and L-Lys levels were held constant. The SID Lys level for the rations was 0.95% so that the SID Trp:Lys ratios were formulated to be 14, 16, 18, and 20%, respectively. All diets were formulated to have 3.2 Mcal ME/kg and to contain vitamins and minerals that exceeded NRC (1998) recommendations. Sows were fed twice a day with a Howema computerized feed system and were allowed a maximum intake (5.9 kg/d). Average daily feed intake had a tendency to be quadratically improved when the SID ratio was increased (5.11, 5.28, 5.24, 5.21 kg/d, $P = 0.09$). In addition, sow wean to estrus (6.71, 5.53, 5.58, 6.33, $P < 0.02$) was quadratically improved as SID Trp:Lys ratio increased. Percent of sows bred by 10 d (84.39, 90.82, 90.28, 90.61) was not linearly ($P = 0.25$) or quadratically ($P = 0.40$) improved. There was no difference in litter gain (2.44, 2.52, 2.60, 2.57 kg/d, $P = 0.16$). Based on a broken-line quadratic model, when sows are fed 30% DDGS, the SID Trp:Lys ratio of 17.6 is required for optimal sow average daily feed intake and 17.2 for wean to estrus interval.

Key words: lactation, sow, tryptophan ratio

Transl. Anim. Sci. 2017.1:526–532
doi:10.2527/tas2017.0059

INTRODUCTION

Little work has been conducted to understand the standardized ileal digestible (SID) Trp level in lactating sows. Work conducted by Lewis and Speer (1974) estimated that a sow nursing nine piglets requires 0.12% Trp in lactation. Pettigrew (1993) estimated that lactating sows nursing a litter gaining 2,500 g/d would require 11.29 g of total Trp/d. Furthermore, Paulicks et al. (2006) demonstrated that a sow nursing for 28 d with an average intake of 4.7 kg would require 2.6 g of total Trp/kg of feed for a total of 12.2 g of total Trp/d. Fan et al. (2016) demonstrated that the optimal SID Trp:Lys ratio for lactating sows was between 0.22 and.026. With only 3 peer-reviewed published trials with a low number of replications in addition to higher number of piglets weaned per sow and larger litter growth rates with current litters, there is a need for additional evaluation of the Trp requirement and the relative relationship to Lys. Therefore, the objective of the study was to further determine the Trp:Lys ratio for lactating sows.

MATERIALS AND METHODS

The study was conducted in a commercial 6,000 sow farm located in Western Illinois of the United States. All animal care practices were conducted by following the routine farm management procedures and Pork Quality Assurance guidelines (National Pork Board, 2012). In addition, an internal Carthage Innovative Swine

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Received August 30, 2017.
Accepted October 18, 2017.

Solutions Animal Care Committee had approved dietary lactation trial protocols with standard measurements and criteria in 2010. The trial protocol complied with the approved standard protocol and was documented into the approved study list for the animal care committee.

Animals

The study was conducted in March through May 2012. Three hundred and fifteen multiparous and primiparous sows (PIC Camborough, PIC USA, Hendersonville, TN) were evaluated. Sows were blocked as parity 1 (58 animals), parity 2 (47 females) or parity 3+ (210 females). The females were porcine reproductive and respiratory syndrome virus (PRRS) and *Mycoplasma hyopneumonaie* stable. The piglets were PRRS and porcine epidemic diarrhea virus negative and there was no detectable PRRS virus in the sows. Only PRRS antibodies were present from the infection 6 mo prior to the start of the study. In addition, no clinical signs of *Mycoplasma hyopneumonaie* was present.

Diets

Diets consisted of corn, soybean meal, and 30% dried distiller's grains with solubles (DDGS; Table 1). Diets were held to a constant SID Lys level and all ratios except for Trp:Lys were held constant. Four treatments to be fed to sows were designed with increasing SID Trp:Lys ratios of 14, 16, 18, and 20, respectively. Diets were formulated to be isocaloric (3.2 Mcal ME/kg) and contained vitamins and minerals that exceeded recommendations (NRC, 1998). Energy values for individual ingredients were calculated using the ME values from the NRC (1998).

Lactation Feeding

Upon entering the farrowing room and prior to farrowing, sows were fed 1.8 kg/d of the respective lactation diet. After farrowing, sows were fed 1.8 kg on d 1, 2.7 kg on d 2, 3.6 kg on d 3 of lactation, and then allowed a maximum of 5.9 kg/d to provide sows 54 g of total Lys intake per d.

Feed was delivered to each sow through the automated Howema Feed System (Big Dutchman, Vechta, Germany). The low (14 SID Trp:Lys) and high (20 SID Trp:Lys) diets were manufactured at a local feed mill and delivered to the facility. The feed system on site blended the intermediate diets by delivering a set percentage of each diet into a mixing hopper and recording the actual weight of each diet as it was added to the hopper and then proceeded to mix the diet prior to delivering each batch of feed to the corresponding sow. At the time of delivery, the system recorded the amount of feed delivered and tracked total lactation consumption per sow. Feed was delivered to each sow via a cable system and was held in a 6.8 kg plastic hopper (Automated Production Systems, Assumption, IL) attached to an InTak feeder (Automated Production Systems, Assumption, IL). Sows had ad libitum access to water throughout lactation.

Table 1. Diet composition of lactation diets for the evaluation of the standardized ileal digestible Trp:Lys ratio for lactating primiparous and multiparous sows. Ingredients are presented as percent inclusion in the diet and are reported on an "as-fed" basis

	SID Trp:Lys ratio[1]			
Ingredient, %	14	16	18	20
Corn	57.55	57.53	57.51	57.49
Dried distillers grain w/solubles	30.00	30.00	30.00	30.00
Soybean meal, 48%	8.63	8.63	8.63	8.63
Limestone	1.43	1.43	1.43	1.43
Monocalcium phosphate, 21%	0.63	0.63	0.63	0.63
Choice white grease	0.25	0.25	0.25	0.25
Salt	0.45	0.45	0.45	0.45
L-Lys HCl[2]	0.60	0.60	0.60	0.60
L-threonine	0.15	0.15	0.15	0.15
L-Trp	0.01	0.03	0.04	0.06
VTM with phytase[3]	0.23	0.23	0.23	0.23
Choline chloride	0.10	0.10	0.10	0.10
Planned composition				
ME, Mcal/kg[4]	3.22	3.22	3.22	3.22
CP, %	16.77	16.78	16.80	16.82
Total Lys, %	1.11	1.11	1.11	1.11
SID Lys, %	0.95	0.95	0.95	0.95
Total Trp, %	0.17	0.19	0.21	0.23
SID Trp, %	0.14	0.15	0.17	0.18
SID M+C:Lys[5]	0.71	0.71	0.71	0.71
SID Thr:Lys	0.64	0.64	0.64	0.64
SID Trp:Lys	0.14	0.16	0.18	0.20
SID Val:Lys	0.67	0.67	0.67	0.67

[1]SID, Standardized ileal digestibility.

[2]HCl = Hydrochloride.

[3]Vitamin Trace Mineral (VTM) premix supplied per kilogram of diet: Vitamin A, 11,000 IU; vitamin D_3, 1760 IU; vitamin E, 44.0 IU; vitamin K (menadione activity), 4.4 mg; riboflavin, 8.25 mg; D-pantothenic acid, 27.5 mg; niacin, 49.5 mg; vitamin B12,.04 mg; D-biotin,.22 mg; folic acid, 1.65 mg; pyridioxine, 5.1 mg; Zn (ZnSO4), 170 mg; Cu (CuSo4), 20 mg; Fe (FeSO4), 170 mg; Mn (MnSO4), 50 mg; I (ethylenediamine dihydriodide), 0.35 mg; and Se (Na2Se), 0.30 mg. Phytase was provided as Optiphos (Huevepharma, Sofia, Bulgaria) and added 750 phytase units/kg diet.

[4]Calculated from NRC (1998).

[5]M+C = Methionine + cysteine.

Animal Husbandry

Sows were moved into the farrowing house at 112 ± 2 d of gestation length and allocated to the experimental diets on entry into the farrowing house and were fed the allotted treatments from the time of entry into the farrowing house until weaning. Sows were housed in conventional farrowing stalls in an environmentally regulated commercial farrow to wean facility (18 to 24° C) with lights on from 0600 to 1500. Sows were housed in a standard farrowing stall with a total dimension of 1.5 × 2.1 m. Sows farrowed at 114 ± 3 d of gestation and piglets were cross-fostered within treatment within 24 h of birth. In addition, the number of piglets per sow was equalized across all treatment groups. Tails of piglets were clipped and 200 mg of iron dextran was injected at 3 d of age. Male piglets were surgically castrated on d 3. Piglets were not offered creep feed during the study, but did have access to water. In addition, rubber mats and heat lamps were provided as a source of supplemental heat to the piglets.

Sow/Sow and Litter Criteria

Sows were weighed at the time of entry into the farrowing house (Tru-Test, Mineral Wells, TX and J&H Automation, Gridley, IL) and again at the time of weaning. Sow 48 h post-farrow body weight was determined using the prediction equation: post-farrow weight, kg = [(112 d gestation weight, kg) × 0.98] – 20.81 (R^2 = 0.93) [Greiner, unpublished data]. In addition, piglet litter weights were recorded at 48 h of age and at weaning (Tru-Test, Mineral Wells, TX and J&H Automation, Gridley, IL). Piglets were cross-fostered within experimental treatment assignments within 24 h of birth to equalize litter size and weight across treatments. Any mortalities and morbidities were recorded along with the piglet weights as the piglets were removed from trial. The removal weights and nursing days were calculated back into litter growth rate [(total litter wean weight – total starting litter weight + mortality weights) / {(number of piglets weaned × lactation length) + days moralities nursed}]. After weaning, sows were fed ad libitum a conventional gestation diet containing 3.17 Mcal ME/kg and 0.61% total Lys. Sows were checked daily for signs of estrus using a mature boar beginning d 3 after weaning. Estrus was recorded when sows stood to be mounted by a boar, and days from weaning to estrus were also recorded. In addition, the number of sows bred within 10 d of weaning was recorded. The gestation feed was consumed at approximately 3.6 kg/d from weaning to mating. After mating, feeding levels were adjusted for visual body condition based on a farm specific feeding scale that allowed body condition to be maintained at a 3.0 (scale of 0 to 5) during the remainder of the gestation period. Weaning to mating interval, farrow to subsequent farrow interval and subsequent litter size, total born, born alive, stillborns, and mummies were recorded. For subsequent litter characteristics, only sows mated within 21 d post-weaning and farrowing as a result of first mating were used.

Diet Analysis

The low Trp and high Trp diets were submitted for dietary amino acid analysis after manufacturing. Diets were submitted to Ajinomoto Heartland, LLC (Chicago, IL) for amino acid and CP analysis (AOAC, 1995).

Statistical Analysis

Data were analyzed using procedures of SAS (SAS Inst. Inc., Cary, NC) and reported as LS means. The statistical model included treatment and parity (block). The sow was the experimental unit. Overall trial averages were calculated using Proc MEANS. Evaluation of treatment effects was analyzed by ANOVA using MIXED procedures. Polynomial coefficients were used to determine linear effects on increasing SID Trp:Lys ratio. A value of $P < 0.05$ was considered significant. Broken-line models were fitted to daily litter gain, sow ADFI and wean to estrus interval to further estimate SID Trp:Lys requirements using NLMIXED in SAS (Robbins et al., 2006 and Pesti et al., 2009). Statistical models fitted to the data included a broken-line linear ascending (BLL) model and a broken-line quadratic ascending (BLQ) model. For the BLL ascending model: $yij = L_{BLL} + Ul (R_{BLL} – Xi) + bj + eij$, for $Xi < R_{BLL}$, $yij = L_{BLL} + bj + eij$ for $Xi \geq R_{BLL}$. For the BLQ ascending model: $yij = L_{BLQ} + Uq (R_{BLQ} – Xi)2 + bj + eij$, for $Xi < R_{BLQ}$, $yij = L_{BLQ} + bj + eij$ *for* $Xi \geq R_{BLQ}$. In these equations, y*ij* is the response of the sow in the block *j* assigned to treatment *i*,Xi is the SID Tryp level of the *i*th dietary treatment, and L_{BLL} and L_{BLQ} indicate the unknown maximum response to the dietary treatments to reach plateau using the BLL and BLQ models. R_{BLL} and R_{BLQ} are the unknown minimum levels of the SID Trp required to reach plateau using the the BLL and BLQ models. Furthermore, *bj* is the random blocking effect of the parameter associated with the *j*th block and *eij* is the random error associated with the sow in the *j*th block that received the *i*th treatment.

Statistical models were compared using maximum likelihood–based fit criteria, Schwarz Bayesian information criterion (BIC; Milliken and Johnson, 2009). The best-fitting model was reported with a 95% confidence interval.

RESULTS

In this study, the average days on study were 19.8, which resulted in a total of 21.8 d of lactation for the sow. Sows lost on average 2.37% of their body weight with an ADFI of 5.28 kg/d. Sow wean to estrus interval was 5.41 d. Sows started the trial with an average of 13.0 piglets/sow and weaned 11.6 piglets/sow with a piglet ADG of 0.214 kg/d and a daily litter growth rate of 2.51 kg/d. Thirty sows did not complete the lactation period of the study. Reasons for removal included mortality, illness, weaning 7 or fewer piglets as this can cause early onset of estrus, or feed valve failure resulting in incorrect feed delivery. The number of replications by treatment for the subsequent number of total born were 48, 59, 52, and 70 sows, respectively, with reasons for removal such as failure to conceive, low weaning numbers, old age, or mortality.

Diet analysis demonstrated that the planned ratios were slightly lower than the actual ratios (Table 2).

Increasing the SID Trp:Lys ratio resulted in a quadratic improvement ($P < 0.05$; Table 3) in wean to estrus interval and a tendency for a quadratic response in feed intake ($P < 0.10$;Table 3). Litter ADG was not linearly improved ($P = 0.16$; Table 3) when the SID Trp:Lys ratio increased.

Broken-line regression analysis was used to determine the optimal ratio for performance. The quadratic model for estimating the minimum SID Trp:Lys ratio provided the best fit. Schwarz Bayesian information criterion values for ADFI andwean to estrus interval were 2,986 and 1,401, respectively. Based on the results, sow ADFI and wean to estrus were optimized when the SID Trp:Lys ratio was at 17.6 and 17.2 (Fig. 1 and 2, respectively).

DISCUSSION

Trp is a precursor to serotonin, which controls satiety and appetite. As Trp crosses the blood-brain barrier, it competes for transport mechanisms with the large neutral amino acids (LNAA; Phe, Tyr, Ile, Val, Leu; Henry et al., 1992). As the Trp:LNAA ratio increase, feed intake is reduced. Therefore, lowering the CP level with synthetic amino acids or increasing the concentration of Trp in the diet can improve feed intake.

Table 2. Planned versus analyzed CP, total Lys and total Trp values of the low (14) and high (20) SID[1] Trp:Lys diets. Analyzed values represented as total percentage in the diet

	SID Trp:Lys ratio	
Item	14	20
Planned		
CP, %	16.77	16.82
Total Lys, %	1.11	1.11
Total Trp, %	0.17	0.23
Total Trp:Lys	0.15	0.21
SID Trp:Lys	0.14	0.20
Analyzed		
CP, %	16.51	16.64
Total Lys	1.05	1.11
Total Trp	0.16	0.21
Total Trp:Lys	0.15	0.19

[1]SID = standardized ileal digestible.

Table 3. Evaluation of lactating primiparous and multiparous sow and litter performance as dietary SID[1] Trp:Lys ratio increases in sow lactation diets

	SID Trp:Lys Ratio									
Parameter	14	16	18	20	SEM	Trt[2]	Parity	Trt × Parity	Linear	Quadratic
Sow										
Number of sows	70	75	67	72						
Average parity, n	2.54	2.47	2.55	2.47	0.09	0.87				
Entry backfat, mm	14.2	13.6	14.1	13.3	0.6	0.63	0.31	0.13	0.40	0.88
Weaning backfat, mm	10.9	10.5	10.5	10.0	0.4	0.45	0.69	0.95	0.12	0.92
Backfat difference, mm	1.40	0.17	0.56	1.62	0.70	0.31	0.88	0.96	0.71	< 0.10
Sow 48 h body weight, kg	194	195	194	193	4.4	0.99	< 0.01	0.95	0.82	0.86
Lactation length, d	20.00	19.5	19.9	19.8	0.4	0.77	0.93	0.91	0.97	0.57
ADFI, kg	5.11	5.28	5.24	5.21	0.06	0.21	< 0.01	0.77	0.35	< 0.10
Weight change, %	–3.13	–3.28	–2.27	–4.42	1.31	0.67	0.01	0.32	0.59	0.40
Bred by 10 d, %	84.4	90.8	90.3	90.6	3.5	0.49	< 0.01	0.15	0.25	0.40
Wean to Estrus, d	6.71	5.53	5.58	6.33	0.49	0.12	< 0.01	0.18	0.55	< 0.05
Subsequent total born, n	12.6	12.5	13.1	13.2	0.7	0.81	0.65	0.74	0.41	0.86
Piglet										
Number of piglets started/sow, n	13.3	13.2	13.5	13.5	0.3	0.70	< 0.01	0.18	0.37	0.86
Number of piglets weaned/sow, n	11.8	11.9	12.0	11.8	0.3	0.90	< 0.01	0.75	0.80	0.47
Pig ADG, kg/d	0.205	0.210	0.211	0.212	0.005	0.75	< 0.01	0.22	0.30	0.68
Daily litter ADG, kg/d	2.44	2.52	2.60	2.57	0.08	0.49	< 0.10	0.12	0.16	0.47

[1]SID = standardized ileal digestibility.

[2]Treatment.

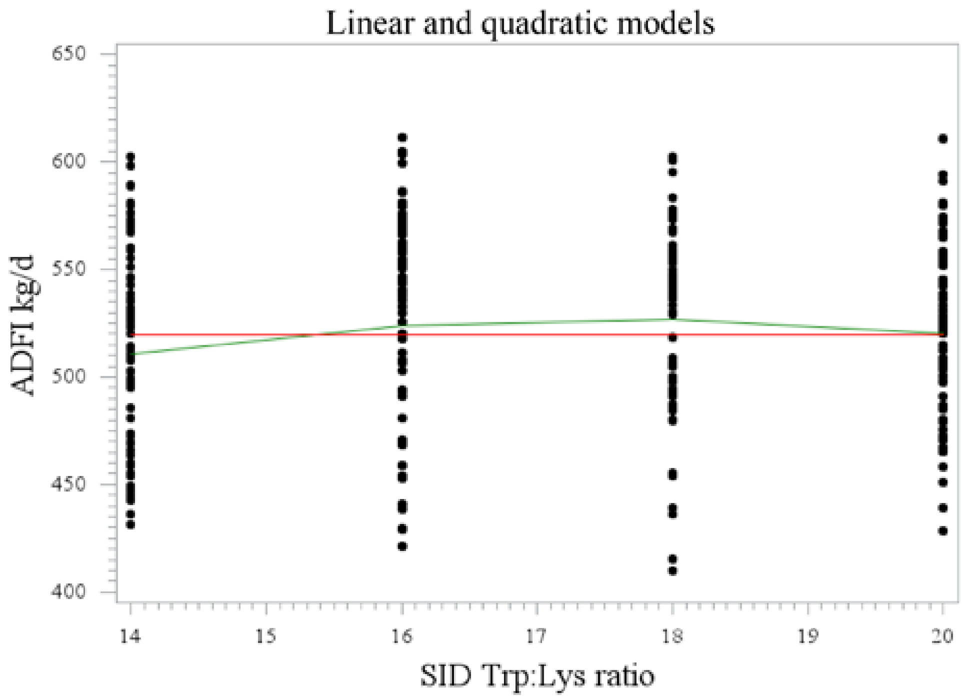

Figure 1. Linear and quadratic broken line regression analysis for the standardized ileal digestible (SID) Trp:Lys ratio on lactating primiparous and multiparous sow ADFI. The BIC for the linear model (red line) was 2,994 with an estimate of the ratio at 14.0 and the BIC value for the quadratic analysis (green line) was 2,986 with the ratio estimate of 17.6.

Furthermore, the feeding of tryptophan increases the gene expression of the ghrelin hormone in the stomach and duodenum (Zhang et al., 2007). Ghrelin secretion increases appetite and resulting protein synthesis.

Feed intake in this study was allocated to 5.91 kg/d to allow sows to consume above the NRC (2012) calculated requirements, but to minimize the variation in digestible Lys intake as other articles would indicate a Lys response above the NRC values (Greiner, 2009; Greiner, 2011; Srichana et al., 2007). Based on the litter growth rate of 2.45 kg/d, NRC (2012) SID Lys requirements for a sow/d would be 47.1 g. In this study, sows consumed on average 50 g of SID Lys/d. Research conducted by Touchette et al. (1998) would indicate that the SID Lys requirement for the sows in this study to be higher than that of the NRC recommendations at 56 g SID Lys/d. Furthermore, studies conducted by Srichana et al. (2007) and Greiner et al. (2009 and 2011) would indicate that 62 g of SID Lys/d was required for optimal sow and litter growth rate. Therefore, the sows were consuming just at or below the expected Lys requirement to support litter growth rate in this study.

Additionally, Lys and Trp:Lys ratios could be determined based on anticipated milk output. Estimated CP milk output can be calculated using the following equation: $\{[(0.0257 \times \text{mean litter gain (g)}] + 0.42 \times \text{litter size})\} \times 6.38$ (NRC, 2012). From milk CP output, calculations can then be made on g of amino acids per day. Milk has approximately 7.01 g Lys/100 g CP and Trp is 18 g/100 g of Lys (NRC, 2012). From these estimates, milk output was 31.33 g Lys/d and 5.6 g Trp/d. The efficiency of the SID amino acid utilization for the lactating sow is 0.670 and 0.674 for Lys and Trp, respectively (NRC, 2012) resulting in the estimated requirements of 46.76 g SID Lys/d and 8.3 g SID Trp/d. Based on the milk output calculation, sows in this study were consuming slightly above the estimated Lys requirement for milk output.

The sow 48 h body weight equation was developed specifically for the genetic line. Sow weights were collected prior to farrowing along with variables such as total litter weight at birth, total number of pigs born, and sow body weight 48 h after farrowing. A stepwise backward linear regression model was used to determine the sow 48 h body weight equation. The actual sow body weight at 48 h was then crossed against the equation to confirm the equation.

The 30% DDGS inclusion was used in this study to provide for the lower Trp diet by allowing the DDGS and feed grade AA to replace soybean meal. The use of 30% DDGS does not impact feed intake based on work published by Greiner et al. (2015) and should not have impacted the significance of sow feed intake in this study. Furthermore, the feeding of the higher feed grade lysine, further reduced soybean meal to result in lower Trp:LNAA ratio to minimize the potential of determining a higher Trp:Lys ratio based on elevated Trp:LNAA.

In this study, there were parity effects on parameters such as ADFI, weight change percentage, wean to

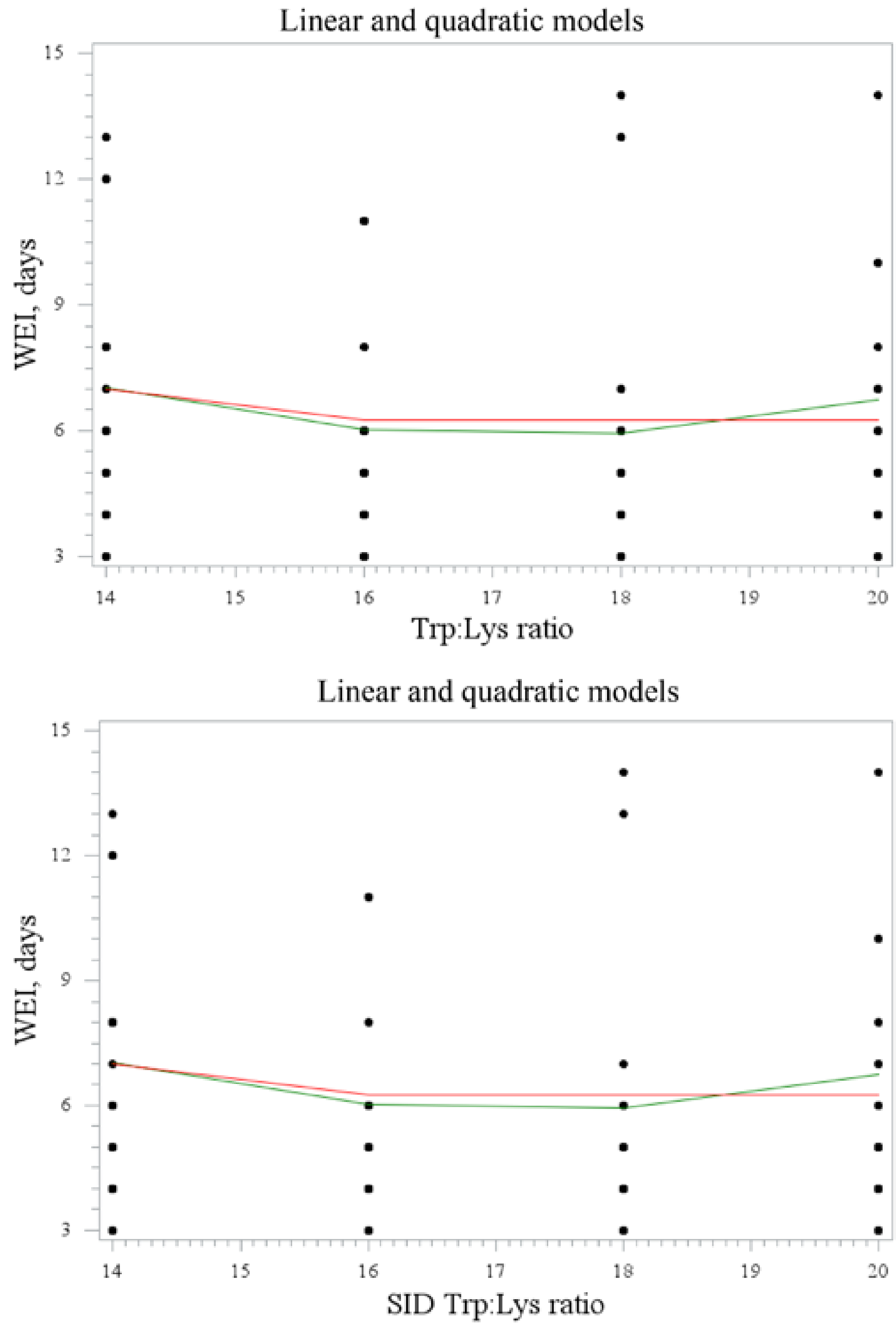

Figure 2. Linear and quadratic broken line regression analysis for the standardized ileal digestible (SID) Trp:Lys ratio response of primiparous and multiparous sows fed different SID Trp:Lys ratios on wean to estrus interval (WEI). The linear regression (red line) BIC value was 1404 with the SID Trp:Lys ratio estimate of 15.3 and the quadratic regression (green line) BIC value was 1401 with an estimated ratio of 17.2.

estrus interval and litter performance. However, there were no parity ×/ treatment interactions indicating that the optimal SID Trp:Lys ratio is the same for all animals.

NRC (2012) recommends 8.4 g SID Trp/d for the mature female that is nursing piglets gaining approximately 190 g/d, and 9.3 g SID Trp/d for sows nursing piglets gaining 230 g/d. In this study, piglet ADG was 214 g/d. Sows in this study consumed between 6.8 and 9.9 g SID Trp/d. Thebroken line quadratic models for sow wean to estrus and ADFI would indicate that the SID Trp requirement would be 8.96 and 9.17 g SID Trp/d, respectively. Using the growth data from this study, the NRC (2012) requirement for litters of the current growth rate would be 8.9 g SID Trp/d or 8.3 per milk output requirements. The findings from this study would indicate that the NRC (2012) recommendation for daily SID Trp is reflective of the current litter sizes and litter growth rates.

Based on the calculated NRC (2012) SID Trp and SID Lys requirements for the sows in this study, the optimal SID Trp:Lys ratio would be 18.9. However, both sow ADFI and sow wean to estrus had an optimal SID Trp:Lys ratio of 17.6 and 17.2 respectively, indicating that the optimal SID Trp:Lys ratio may be lower than current NRC (2012) recommendations.

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