Effects of porcine circovirus type 2 vaccine and increasing standardized ileal digestible lysine:metabolizable energy ratio on growth performance and carcass composition of growing and finishing pigs[1]

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ABSTRACT: Four experiments were conducted to examine the effect of porcine circovirus type 2 (PCV2) vaccination on the response of growing and finishing pigs (PIC 337 × 1050) to increasing dietary Lys. Experiments 1 and 2 evaluated 38- to 65-kg gilts and barrows, respectively, and Exp. 3 and 4 evaluated 100- to 120-kg gilts and barrows, respectively. Gilts and barrows were housed separately in different barns. Treatments were allotted in a completely randomized design into 2 × 4 factorials with 2 PCV2 treatments (PCV2-vaccinated and nonvaccinated) and 4 standardized ileal digestible (SID) Lys:ME ratios (2.24, 2.61, 2.99, and 3.36 g/Mcal in Exp. 1 and 2 and 1.49, 1.86, 2.23, and 2.61 g/Mcal in Exp. 3 and 4) within each experiment. There were 5 pens per treatment. At the start of Exp. 1 and 2, there were more pigs per pen ($P < 0.001$) in vaccinated pens because vaccinated pigs had a greater survival rate than nonvaccinated pigs, and this increase was maintained throughout the experiments. Removal rate approached 30% in nonvaccinated barrows and more than 20% in nonvaccinated gilts. Observation suggested that the removals were largely due to PCV2-associated disease. No PCV2 vaccination × SID Lys:ME ratio interactions ($P > 0.10$) were observed in any of the 4 studies. In Exp. 1 and 2, PCV2-vaccinated pigs had increased ($P < 0.001$) ADG compared with nonvaccinated pigs. The growth response was primarily due to increases in ADFI, which suggests that vaccinated pigs have a greater Lys requirement (g/d) than nonvaccinated pigs. In Exp. 1, increasing the SID Lys:ME ratio increased (quadratic; $P < 0.04$) ADG and G:F, with pigs fed the 2.99 g/Mcal ratio having the greatest ADG and G:F. In Exp. 2, increasing the SID Lys:ME ratio improved (linear; $P < 0.001$) G:F. In Exp. 3, ADG and G:F increased ($P < 0.05$) in a quadratic manner as the SID Lys:ME ratio fed increased. In Exp. 4, increasing the SID Lys:ME ratio increased ADG (linear; $P < 0.001$) and G:F (quadratic; $P = 0.03$). Although PCV2 vaccination improved growth, the corresponding increase in ADFI did not increase the optimal SID Lys:ME ratio for growing and finishing barrows and gilts.

Key words: finishing pig, growth, lysine, porcine circovirus type 2 vaccine

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INTRODUCTION

Porcine circovirus type 2 (**PCV2**)-associated disease, which is characterized by increased mortality and decreased growth rate, greatly increased in the US pig population in the mid-2000s (Segalés et al., 2006). As a result of porcine circovirus disease (**PCVD**), it was not uncommon to see growing-finishing pig mortality approach 20% (Horlen et al., 2007). Clinical signs of PCVD include, but are not limited to, enlarged lymph nodes, labored breathing, poor body condition, and muscle wasting (Harding et al., 1998; Sorden, 2000). Vaccination for PCV2 has been shown to increase growth rates and reduce mortality in growing and finishing pigs (Horlen et al., 2008, Potter et al., 2008; Jacela et al., 2011). The increased ADG and G:F of pigs vaccinated for PCV2 might increase their dietary AA needs as well. Williams et al. (1997a,b) observed increased Lys requirement estimates in pigs with low immune system activity and speculated that this was

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a result of increased lean tissue deposition in pigs with low immune system activity compared with pigs under a greater health challenge.

The estimated Lys requirement of pigs without PCV2 vaccination has been reported previously (De La Llata et al., 2007; Main et al., 2008); however, recent studies by Shelton et al. (2008, 2009) showed improvements in growth and efficiency attributable to feeding dietary Lys concentrations that were greater than these earlier published estimates. Advancement in genetic lines along with increases in health status and growth rate attributable to PCV2 vaccination may be driving the increase in Lys requirements observed by Shelton et al. (2008, 2009). Therefore, the objective of these experiments was to evaluate the effects of PCV2 vaccination on pig performance and determine whether PCV2 vaccination influences the dietary Lys requirement of the pigs.

MATERIALS AND METHODS

The experimental procedures used in these studies were approved by the Kansas State University Institutional Animal Care and Use Committee.

General

The study was conducted at commercial research finishing facilities in southwestern Minnesota. These facilities were double-curtain sided with completely slatted flooring. Each of the 4 research barns contained 48 pens (3.05 × 5.49 m), and each pen contained a 5-hole conventional dry feeder (STACO Inc., Schaefferstown, PA) and a cup waterer to allow for ad libitum consumption of feed and water. An automated feeding system (FeedPro, Feedlogic Corp., Willmar, MN) was used to deliver and record feed amounts on an individual pen basis. Clinical signs of PCVD and histopathologic lesions consistent with PCV2 infection had been noted previously in pigs in these facilities (Jacela et al., 2011). In addition, pigs in these facilities were considered positive for the presence of porcine reproductive and respiratory virus (**PRRSv**) by the attending veterinarian. Diagnostic testing in this production system indicated frequent seroconversion for PRRSv antibody during the late nursery and early finisher period.

Allotment and Application of PCV2 Vaccine

For all experiments, a total of 2,571 barrows and gilts (PIC 337 × 1050; PIC, Hendersonville, TN; initially 5.7 kg) were weaned into 1 of the research finisher barns. Pens were double stocked with 56 pigs per pen, and gilts and barrows were penned separately. Forty-six pens were used; 24 pens contained barrows, and 22 pens contained gilts. Industry-standard nursery diets that met or exceeded all nutrient requirements as outlined by the NRC (1998) were fed to all pigs during this phase. All pigs were vaccinated for *Mycoplasma hyopneumoniae* while in the farrowing facility. The PCV2 vaccination treatments were allotted by pen at placement to both barrow and gilt pens in a completely randomized design (**CRD**) within sex. The number of vaccinated and nonvaccinated pigs was equal within sex. Vaccine treatments were no PCV2 vaccine or vaccination with 2 doses of a commercial PCV2 vaccine (Circumvent PCV, Intervet Inc., Millsboro, DE) given according to label directions on d 1 and 22 after weaning. Staff taking care of pigs on a daily basis were unaware of the vaccine treatment arrangement.

As part of the standard production protocol on this farm, all pigs were injected with diluted serum containing PRRSv on d 30 after weaning. The serum was derived from a PRRSv-infected pig obtained within the same production system in which the trial was performed. The PRRSv viral particle quantity was estimated using real-time PCR. The particles were then diluted 1:1,000 with sterile water, and 1 mL per pig was administered to pigs (intramuscularly). Further analysis with real-time PCR revealed that the diluted serum contained 1.7×10^3 viral particles per milliliter. The intent of this practice was to provide planned exposure of the growing pigs to PRRSv and reduce the effects of PRRSv exposure later in the growing pig period.

Pig BW (by pen) and feed disappearance were measured at approximately 14-d intervals throughout the nursery period. On the basis of these measurements, ADG, ADFI, and G:F were calculated for each pen. On d 51, the original pens of barrows or gilts, which were double stocked at 56 pigs per pen, were split to form 2 new pens of pigs of 22 to 27 pigs per pen, depending on the number of pigs remaining. All gilts were moved to an adjacent barn of similar design, and barrows remained in the original barn. The proportion of pigs remaining in the pens throughout the pretest and experimental periods was also determined, enabling us to observe any differences in removal and mortality between vaccine treatments. Pigs were allowed to acclimate for 20 d before being assigned to the dietary Lys treatments within PCV2 vaccination status in Exp. 1 and 2. Pen feed intake data was not collected at this time.

Finishing Period

For Exp. 1 and 2, a total of 1,008 gilts (initially 38.3 kg) and 1,002 barrows (initially 38.9) were used in 28-d trials, with gilts and barrows being housed separately within different barns. All pens that had originally been assigned the PCV2 vaccine treatments and then split into 2 pens were used for these experiments. Four experimental diets were used in Exp. 1 and 2. Diets had standardized ileal digestible (**SID**) Lys:ME ratios of 2.24, 2.61, 2.99, and 3.36 g/Mcal, which corresponded to SID concentrations of 0.78, 0.91, 1.04, and 1.17%, or total Lys concentrations of 0.88, 1.02, 1.17, and 1.31% (Table 1). Standardized ileal digestible AA values from

Table 1. Composition of diets fed to 40- to 60-kg gilts in Exp. 1[1] and 40- to 65-kg barrows in Exp. 2[2] (as-fed basis)

	SID[3] Lys:ME, g/Mcal			
Item	2.24	2.61	2.99	3.36
Ingredient, %				
Corn	75.52	70.16	64.81	59.44
Soybean meal (45% CP)	19.38	24.74	30.09	35.45
Choice white grease	3.00	3.00	3.00	3.00
Monocalcium P (21% P)	0.54	0.51	0.48	0.45
Limestone	0.90	0.90	0.90	0.90
Salt	0.35	0.35	0.35	0.35
L-Thr	0.005	0.015	0.020	0.030
Met hydroxy analog	—	0.015	0.045	0.070
Vitamin and trace mineral premix[4]	0.10	0.10	0.10	0.10
Phytase[5]	0.013	0.013	0.013	0.013
Liquid Lys (60% Lys)	0.195	0.195	0.195	0.195
Total	100.00	100.00	100.00	100.00
Calculated analysis				
SID AA, %				
Lys	0.78	0.91	1.04	1.17
Ile:Lys	70	69	69	69
Leu:Lys	167	156	148	142
Met:Lys	29	29	30	31
Met + Cys:Lys	61	59	58	58
Thr:Lys	62	62	62	62
Trp:Lys	19	19	20	20
Val:Lys	81	79	77	76
ME, kcal/kg	3,483	3,483	3,481	3,481
Total Lys, %	0.88	1.02	1.17	1.31
CP, %	15.4	17.5	19.5	21.6
Ca, %	0.53	0.54	0.56	0.57
P, %	0.46	0.47	0.49	0.51
Available P,[6] %	0.27	0.27	0.27	0.27

[1]A total of 1,008 gilts (PIC 337 × 1050; PIC, Hendersonville, TN) were used in this 28-d trial with 5 replications per porcine circovirus type 2 (PCV2) vaccination (Circumvent PCV, Intervet Inc., Millsboro, DE) and diet combination.

[2]A total of 1,002 barrows (PIC 337 × 1050; PIC) were used in this 28-d trial with 5 replications per PCV2 vaccination and diet combination.

[3]Standardized ileal digestible.

[4]Vitamin and trace mineral premix provided per kilogram of diet: 4,509 IU of vitamin A, 701.5 IU of vitamin D_3, 24.05 IU of vitamin E, 1.40 mg of vitamin K, 3.01 mg of riboflavin, 15.03 mg of vitamin B_{12}, 18.04 mg of niacin, 12.03 mg of pantothenic acid, 40.08 mg of Mn from MnO, 100.21 mg of Zn from $ZnSO_4$, 90.19 mg of Fe from $FeSO_4$, 10.02 mg of Cu from $CuSO_4$, 0.30 mg of Se from $NaSeO_3$, and 0.50 mg of I from ethylenediamine dihydroiodide.

[5]OptiPhos 2000 (Enzyvia, Sheridan, IN) provided (per kilogram of complete diet) 500 phytase units (FTU) of phytase.

[6]Phytase provided 0.10% available P to the diet.

NRC (1998) were used in diet formulation. Diets were corn and soybean meal based, with 0.15% added L-Lys HCl. Corn and soybean meal concentrations were changed to achieve the desired SID Lys:ME ratio in the diet. All diets also contained 3% added fat from choice white grease. Diets were formulated to meet all other requirements recommended by NRC (1998). Test diets were sampled in each experiment, and a subsample of each diet was analyzed for AA concentrations. Amino acid analysis was performed by Ajinimoto Heartland LLC (Chicago, IL) via HPLC (AOAC, 2000). At the conclusion of Exp. 1 and 2, all pigs were placed on the same diet within sex, which contained at least 2.58 g of SID Lys/Mcal of ME, for a period of 72 d between Exp. 1 and 3 and for 55 d between Exp. 2 and 4. Before beginning Exp. 3 and 4, some pigs were removed from each pen, and more pigs were removed from vaccinated pens in an attempt to minimize the difference in pig density and initial BW between PCV2-vaccinated and nonvaccinated pigs. Removing additional pigs from vaccinated pens did not equalize pen counts between PCV2-vaccinated and nonvaccinated pens, but simply reduced the differences in pig density.

A total of 930 gilts (initially 101.8 kg) and 825 barrows (initially 97.7 kg) were used in Exp. 3 and 4 for 28 and 21 d, respectively. For these experiments, dietary Lys treatments were reallotted randomly to pens, again with equal numbers of pens per Lys dose within sex and PCV2 vaccination treatment. This was done to eliminate bias from a particular Lys treatment that was used in the previous experiments. The 4 experimental diets for these experiments had SID Lys:ME ratios of

1.49, 1.86, 2.23, and 2.61 g/Mcal, which corresponded to dietary SID Lys concentrations of 0.52, 0.65, 0.78, and 0.91%, or total Lys concentrations of 0.59, 0.74, 0.88, and 1.02% (Table 2). As in Exp. 1 and 2, diets were corn and soybean meal based, with 0.15% added L-Lys HCl and 3% added fat from choice white grease. Diet samples were collected from each diet in each experiment and analyzed for AA concentrations.

For each experiment, dietary treatments were allotted within PCV2-vaccinated and nonvaccinated pens. Each experiment had 5 replications for each diet and vaccine treatment combination. Pen density ranged from 18 to 27 pigs per pen, depending on the experiment.

Pig BW (by pen) and feed disappearance were measured throughout the experiments. On the basis of these measurements, ADG, ADFI, G:F, daily SID Lys intake, and SID Lys intake per kilogram of BW gain were calculated for each pen. At the conclusion of the growth portion of Exp. 3 and 4, pigs were marketed to a USDA-inspected packing plant (processing plant of JBS Swift & Company, Worthington, MN) and carcass data were collected. Pen data for yield, backfat depth, loin depth, percentage lean, fat-free lean index, and live value were determined by the packing plant. Yield reflects the percentage of HCW relative to BW, which was obtained at the packing plant.

Table 2. Composition of diets fed to 100- to 125-kg gilts in Exp. 3[1] and 97- to 118-kg barrows in Exp. 4[2] (as-fed basis)

	SID[3] Lys:ME, g/Mcal			
Item	1.49	1.86	2.23	2.61
Ingredient, %				
Corn	86.46	81.12	75.77	70.41
Soybean meal (45% CP)	8.66	14.01	19.36	24.72
Choice white grease	3.00	3.00	3.00	3.00
Monocalcium P (21% P)	0.40	0.38	0.35	0.32
Limestone	0.85	0.85	0.85	0.85
Salt	0.35	0.35	0.35	0.35
L-Thr	—	0.01	0.02	0.035
Met hydroxy analog	—	—	0.005	0.025
Vitamin and trace mineral premix[4]	0.08	0.08	0.08	0.08
Phytase[5]	0.013	0.013	0.013	0.013
Liquid Lys (60% Lys)	0.195	0.195	0.195	0.195
Total	100.00	100.00	100.00	100.00
Calculated analysis				
SID AA, %				
Lys	0.52	0.65	0.78	0.91
Ile:Lys	71	70	70	69
Leu:Lys	204	182	167	156
Met:Lys	35	32	30	30
Met + Cys:Lys	73	66	61	60
Thr:Lys	65	65	64	65
Trp:Lys	18	18	19	19
Val:Lys	89	84	81	79
ME, kcal/kg	3,494	3,494	3,492	3,492
Total Lys, %	0.59	0.74	0.88	1.02
CP, %	11.4	13.4	15.5	17.5
Ca, %	0.45	0.46	0.48	0.49
P, %	0.39	0.40	0.42	0.43
Available P,[6] %	0.23	0.23	0.23	0.23

[1]A total of 930 gilts (PIC 337 × 1050; PIC, Hendersonville, TN) were used in this 28-d trial with 5 replications per porcine circovirus type 2 (PCV2) vaccination (Circumvent PCV, Intervet Inc., Millsboro, DE) and diet combination.

[2]A total of 825 barrows (PIC 337 × 1050; PIC) were used in this 21-d trial with 5 replications per PCV2 vaccination and diet combination.

[3]Standardized ileal digestible.

[4]Vitamin and trace mineral premix provided per kilogram of diet: 3,608 IU of vitamin A, 561.2 IU of vitamin D_3, 19.24 IU of vitamin E, 1.12 mg of vitamin K, 2.41 mg of riboflavin, 12.03 mg of vitamin B_{12}, 14.43 mg of Niacin, 9.62 mg of pantothenic acid, 32.07 mg of Mn from MnO, 80.17 mg Zn from $ZnSO_4$, 72.15 mg Fe from $FeSO_4$, 8.02 mg of Cu from $CuSO_4$, 0.24 mg of Se from $NaSeO_3$, and 0.40 mg of I from ethylenediamine dihydroiodide.

[5]OptiPhos 2000 (Enzyvia, Sheridan, IN) provided (per kilogram of complete diet) 500 phytase units (FTU) of phytase.

[6]Phytase provided 0.10% available P to the diet.

Statistical Analysis

Data from the nursery pretest period were analyzed as a CRD with treatments arranged in a 2 × 2 factorial array (sex and PCV2 vaccination status). Vaccine treatment and sex were treated as fixed effects in the model. Nursery growth and finishing BW responses were analyzed with a mixed model (PROC MIXED procedure; SAS Inst. Inc., Cary, NC). The original pen was used as the experimental unit in all analyses.

Data from Exp. 1, 2, 3, and 4 were analyzed as a CRD with treatments arranged as a 2 × 4 factorial in a split plot for each experiment. The PCV2-vaccinated and nonvaccinated treatments were analyzed as the whole plot, and the 4 dietary Lys concentrations served as the split-plot treatment factor. The denominator degrees of freedom were calculated using the Kenward-Roger correction. Vaccine treatments and dietary Lys concentrations were treated as fixed effects for analysis. Growth and carcass data were analyzed with the MIXED procedure in SAS, and because the pen inventory counts were not continuously distributed, the counts were analyzed with the GENMOD procedure in SAS using a Poisson distribution. Dietary Lys values were used as the dose to test for linear and quadratic responses to dietary treatments. Pen was used as the experimental unit in all analyses. Effects were considered significant at P-values <0.05 and were considered trends at P-values ranging from 0.05 to 0.10.

RESULTS

For each experiment, analyzed concentrations of AA in the feed samples were similar to calculated values (data not shown). Nursery pretest performance is shown in Table 3. From d 0 to 15, no difference was observed in ADG, ADFI, or G:F ($P > 0.10$) between vaccinated and nonvaccinated pigs, which indicates that the first injection of PCV2 vaccine did not affect performance. However, in the period after the second injection (d 15 to 29), PCV2-vaccinated pigs had decreased ($P = 0.02$) ADG compared with nonvaccinated pigs; this appeared to be a result of decreased ($P = 0.04$) ADFI. Gilts had greater ($P < 0.04$) ADG and ADFI than barrows. A trend was also observed ($P = 0.07$) for a sex × vaccine interaction for G:F from d 15 to 29. This interaction was due to a slight improvement in G:F in vaccinated barrows and a slight decrease in G:F in vaccinated gilts compared with nonvaccinated gilts. In the period after inoculation with PRRSv (d 29 to 50), PCV2-vaccinated pigs had improved ($P = 0.001$) G:F and a trend for increased ($P = 0.08$) ADG compared with nonvaccinated pigs. Gilts also had poorer ($P < 0.005$) G:F than barrows from d 29 to 50. Over the entire 50-d nursery period, no differences ($P > 0.10$) were observed in ADG, ADFI, or final BW between sexes or between PCV2-vaccinated and nonvaccinated pigs. However, G:F was improved ($P = 0.001$) with PCV2 vaccination and was improved ($P < 0.03$) for barrows compared with gilts. In addition, no difference ($P > 0.10$) was observed in the percentage of pigs remaining in pens throughout the nursery portion of the study (PCV2-vaccinated barrows 98.7% and gilts 97.5%; nonvaccinated barrows 95.1% and gilts 96.2%). However, at the initiation of the dietary treatments on d 71 after weaning PCV2-vaccinated pens contained 97.3% of the barrows and 96.4% of the gilts on test at weaning, whereas nonvaccinated pens contained only 81.6% of the barrows and 83.6% of the gilts placed on test. During this 20-d acclimation period, clinical evidence of PCVD was evident. Almost all the pigs removed either died or had clinical evidence of muscle wasting and visually appeared to lose BW.

In each of the 4 experiments, no PCV2 vaccine × Lys interactions ($P > 0.10$) were observed for any of the growth or carcass criteria (Tables 4, 5, 6, and 7). In Exp. 1 (38- to 60-kg gilts), PCV2-vaccinated pigs tended ($P = 0.08$) to be heavier (1.6 kg) at initiation of the trial (d 0) and had a greater ($P = 0.001$) number of pigs per pen (3.6 pigs more per pen) than nonvaccinated pigs (Table 4). This initial difference was due to the increase in removals and decrease in pretrial performance of pigs in nonvaccinated pens. Vaccinated pigs had increased ($P < 0.001$) ADG, final BW, and daily SID Lys intake and tended to have increased ($P = 0.10$) G:F compared with nonvaccinated pigs. The increased growth for PCV2-vaccinated pigs was primarily driven by increased ($P = 0.001$) ADFI compared with that of nonvaccinated pigs. In addition, at the conclusion of the experiment, pens of pigs vaccinated with PCV2 vaccine maintained a greater ($P = 0.001$) pen count (5.0 more pigs per pen) than pens of nonvaccinated pigs. This resulted in the PCV2-vaccinated pens containing 96.3% of the pigs placed on test at weaning, whereas the nonvaccinated pens contained only 78.2% of the gilts placed on test at weaning. Average daily gain and G:F improved (quadratic; $P < 0.04$) as the SID Lys:ME ratio increased through 2.99 g/Mcal. Feed intake tended to decrease (linear; $P = 0.06$) as the SID Lys:ME increased. Increasing dietary Lys also increased (linear; $P < 0.001$) daily Lys intake and SID Lys/kg of BW gain. The optimal SID Lys:ME ratio for 38- to 60-kg gilts was 2.99 g/Mcal; at this amount, PCV2-vaccinated and nonvaccinated gilts consumed 21.5 g of SID Lys/kg of BW gain.

Like the gilts in Exp. 1, PCV2-vaccinated pigs in Exp. 2 (39- to 65-kg barrows) tended to be heavier ($P = 0.06$) at the beginning of the experiment and had a greater ($P = 0.001$) initial pen count (4.4 more pigs per pen) than did nonvaccinated pigs (Table 5). Vaccination for PCV2 also increased ($P < 0.04$) ADG, final BW, and daily Lys intake and tended to improve ($P = 0.10$) G:F. As in Exp.1, the increased growth in PCV2-vaccinated pigs compared with nonvaccinated pigs was driven primarily by increased ($P = 0.001$) ADFI. At

Table 3. Effects of porcine circovirus type 2 (PCV2) vaccination and sex on growth performance of 5.7- to 24-kg pigs during the pretrial period[1]

	Barrow		Gilt			P-value		
Item	No vaccination	Yes vaccination	No vaccination	Yes vaccination	SEM	Sex × vaccine	Vaccine	Sex
Initial BW, kg	5.7	5.7	5.7	5.7	0.17	<0.99	<0.99	<0.99
d 0 to 15[2]								
ADG, g	266	264	270	270	15.2	<0.95	<0.93	<0.75
ADFI, g	394	372	396	392	18.4	<0.62	<0.46	<0.55
G:F	0.67	0.71	0.68	0.69	0.017	<0.30	<0.15	<0.48
d 15 to 29[3]								
ADG, g	420	403	445	417	9.2	<0.56	<0.02	<0.04
ADFI, g	651	614	682	651	15.9	<0.88	<0.04	<0.04
G:F	0.65	0.66	0.65	0.64	0.006	<0.07	<0.87	<0.45
d 29 to 50[4]								
ADG, g	408	437	382	418	18.3	<0.85	<0.08	<0.22
ADFI, g	731	725	706	726	29.6	<0.66	<0.81	<0.69
G:F	0.56	0.60	0.54	0.58	0.007	<0.54	<0.001	<0.005
d 0 to 50								
ADG, g	369	375	366	373	13.8	<0.99	<0.62	<0.86
ADFI, g	607	588	606	604	21.4	<0.69	<0.63	<0.71
G:F	0.61	0.64	0.60	0.62	0.006	<0.09	<0.001	<0.03
Final BW, kg	24.4	24.5	24.2	24.5	0.80	<0.94	<0.82	<0.88

[1]A total of 2,571 barrows and gilts (PIC 337 × 1050; PIC, Hendersonville, TN) were double stocked into a weaning-to-finish barn and observed for 50 d to determine the effects of PCV2 vaccine on growth performance.

[2]The first PCV2 vaccine (Circumvent PCV, Intervet Inc., Millsboro, DE) was given on d 1 of this study to the selected pens of pigs.

[3]The second PCV2 vaccine was given on d 22 of the study to the selected pens of pigs.

[4]All pigs were injected with live porcine reproductive and respiratory virus on d 30.

the conclusion of Exp. 2, PCV2-vaccinated pens had 7 more pigs per pen than did nonvaccinated pens ($P = 0.001$). This resulted in the PCV2-vaccinated pens containing 96.6% of the pigs placed on test at weaning, whereas the nonvaccinated pens contained only 71.8% of the barrows placed on test at weaning. Increasing the SID Lys:ME ratio had no effect ($P > 0.10$) on ADG but increased (linear; $P < 0.001$) G:F, daily SID Lys intake, and SID Lys intake/kg of BW gain. However, similar to Exp. 1, ADFI tended to decrease (linear; $P = 0.07$) as dietary Lys increased. Optimal performance for 39- to 65-kg barrows was observed at 3.36 g of SID Lys/Mcal of ME; at this quantity, barrows consumed 25.0 g of SID Lys/kg of BW gain.

In Exp. 3 (102- to 125-kg gilts), PCV2-vaccinated pigs had an increased ($P < 0.002$) beginning BW and 2 more pigs per pen than did nonvaccinated pigs. The smaller difference in pigs per pen was a result of removing more pigs from PCV2-vaccinated pens than from nonvaccinated pens at initial barn marketing, which began just before the start of Exp. 3 and 4 (Table 6). No differences in ADG or ADFI ($P > 0.10$) were observed between PCV2-vaccinated and nonvaccinated pigs. However, PCV2-vaccinated pigs had increased ($P < 0.03$) G:F, final BW, final count, and backfat thickness. Pigs vaccinated with PCV2 also had decreased ($P < 0.02$) SID Lys intake per kilogram of BW gain compared with their nonvaccinated counterparts. Both ADG and G:F improved (quadratic; $P < 0.05$) as the SID Lys:ME ratio increased; ADG improved through 1.86 g/Mcal, and G:F improved through 2.23 g/Mcal. Feed intake tended to decrease (linear; $P = 0.09$) as dietary Lys increased. However, despite the decreases in feed intake, daily SID Lys intake and SID Lys intake/kg of BW gain increased (linear; $P < 0.001$) with increasing dietary Lys. No dietary Lys effects were observed ($P > 0.10$) for any of the carcass criteria. On the basis of the improvement in G:F, the optimal SID Lys:ME ratio for 102- to 125-kg gilts appeared to be 2.23 g/Mcal; at this quantity, gilts consumed 24.1 g of SID Lys/kg of BW gain.

In Exp. 4 (98- to 118-kg barrows), a difference ($P = 0.001$) was observed in initial average pen count; vaccinated pens had almost 3 more pigs per pen than did nonvaccinated pens (Table 7). However, no difference ($P = 0.10$) was observed in beginning BW between vaccination treatments. Both ADG and ADFI were decreased ($P < 0.04$) in vaccinated pens compared with nonvaccinated pens, and the average pen count was greater ($P = 0.001$) at the conclusion of the trial for vaccinated pens. In this experiment, ADG, G:F, daily SID Lys intake, and SID Lys intake per kilogram of BW gain increased (linear; $P < 0.001$) through the greatest SID Lys:ME ratio of 2.61 g/Mcal, and the greatest change occurred when the ratio increased from 2.23 to 2.61 g/Mcal. Increasing dietary Lys tended to first increase and then decrease (quadratic; $P = 0.06$) ADFI. As in Exp. 3, no differences were observed in any carcass characteristics ($P > 0.10$) as the SID Lys:ME ratio increased. The optimal SID Lys:ME ratio for 97- to 118-kg barrows was 2.61 g/Mcal; at this ratio, barrows consumed 27.3 g of SID Lys/kg of BW gain.

Table 4. Effects of standardized ileal digestible (SID) Lys:ME ratio (2.24, 2.61, 2.99, or 3.36 g/Mcal) and porcine circovirus type 2 (PCV2) vaccination on 40- to 60-kg gilts (Exp. 1)[1]

	PCV2 vaccine[2]									P-value				
	No				Yes								Lys	
Item	2.24	2.61	2.99	3.36	2.24	2.61	2.99	3.36	SEM	Vaccine × Lys	Vaccine	Lys	Linear	Quadratic
Initial BW, kg	37.5	37.5	37.5	37.5	39.1	39.1	39.2	39.1	1.25	<1.00	<0.08	<1.00	<0.99	<0.99
Initial pen animal count	23.0	23.8	23.0	23.8	26.8	27.2	27.0	27.0	0.77	<0.96	<0.001	<0.84	<0.69	<0.86
ADG, kg	0.69	0.73	0.78	0.74	0.81	0.87	0.86	0.84	0.017	<0.33	<0.001	<0.002	<0.02	<0.002
ADFI, kg	1.63	1.64	1.61	1.59	1.84	1.84	1.79	1.75	0.038	<0.88	<0.001	<0.22	<0.06	<0.45
G:F	0.42	0.44	0.48	0.47	0.44	0.47	0.49	0.48	0.012	<0.67	<0.10	<0.001	<0.001	<0.04
Final BW, kg	58.0	59.4	60.4	59.1	61.7	63.5	63.4	62.5	1.35	<0.99	<0.001	<0.48	<0.46	<0.18
Final pen animal count	21.2	22.0	21.6	22.8	26.8	27.2	26.8	27.0	0.71	<0.80	<0.001	<0.60	<0.31	<0.93
Daily SID Lys intake, g	12.68	14.92	16.78	18.58	14.33	16.77	18.56	20.43	0.390	<0.99	<0.001	<0.001	<0.001	<0.37
SID Lys intake, g/kg of BW gain	18.43	20.55	21.56	25.11	17.79	19.30	21.48	24.50	0.578	<0.80	<0.13	<0.001	<0.001	<0.09

[1]A total of 1,008 gilts (PIC 337 × 1050; PIC, Hendersonville, TN) were used in this 28-d trial with 5 replications per PCV2 vaccination and diet combination.

[2]Vaccination for PCV2 (Circumvent PCV, Intervet Inc., Millsboro, DE) was administered at placement into the weaning-to-finish facility and again 3 wk later.

Table 5. Effects of standardized ileal digestible (SID) Lys:ME ratio (2.24, 2.61, 2.99, or 3.36 g/Mcal) and porcine circovirus type 2 (PCV2) vaccination on 40- to 65-kg barrows (Exp. 2)[1]

	PCV2 vaccine[2]									P-value				
	No				Yes								Lys	
Item	2.24	2.61	2.99	3.36	2.24	2.61	2.99	3.36	SEM	Vaccine × Lys	Vaccine	Lys	Linear	Quadratic
Initial BW, kg	37.8	37.8	37.8	37.9	39.9	39.9	39.8	39.9	1.47	<1.00	<0.06	<1.00	<0.97	<0.99
Initial pen animal count	23.0	22.4	22.6	23.4	27.4	27.0	27.4	27.2	0.72	<0.91	<0.001	<0.85	<0.80	<0.44
ADG, kg	0.80	0.78	0.87	0.87	0.93	0.94	0.93	0.96	0.032	<0.44	<0.001	<0.39	<0.13	<0.66
ADFI, kg	1.98	1.87	1.90	1.84	2.15	2.15	2.05	2.05	0.067	<0.77	<0.001	<0.31	<0.07	<0.86
G:F	0.40	0.42	0.46	0.47	0.43	0.44	0.45	0.47	0.009	<0.18	<0.10	<0.001	<0.001	<0.63
Final BW, kg	61.8	63.1	64.3	64.9	66.1	66.5	65.8	66.9	1.79	<0.87	<0.04	<0.77	<0.30	<0.99
Final pen animal count	21.4	18.8	19.8	20.4	27.2	26.6	27.4	27.0	0.90	<0.67	<0.001	<0.38	<0.76	<0.19
Daily SID Lys intake, g	15.45	17.03	19.80	21.47	16.77	19.58	21.32	23.95	0.653	<0.71	<0.001	<0.001	<0.001	<0.96
SID Lys intake, g/kg of BW gain	19.40	21.94	22.86	24.84	17.99	20.79	22.97	25.13	0.480	<0.22	<0.13	<0.001	<0.001	<0.37

[1]A total of 1,002 barrows (PIC 337 × 1050; PIC, Hendersonville, TN) were used in this 28-d trial with 5 replications per PCV2 vaccination and diet combination.

[2]Vaccination for PCV2 (Circumvent PCV, Intervet Inc., Millsboro, DE) was administered at placement into the weaning-to-finish facility and again 3 wk later.

Table 6. Effects of standardized ileal digestible (SID) Lys:ME ratio (1.49, 1.86, 2.23, or 2.61 g/Mcal) and porcine circovirus type 2 (PCV2) vaccination on 100- to 125-kg gilts (Exp. 3)[1]

	PCV2 vaccine[2]									*P*-value				
	No				Yes								Lys	
Item	1.49	1.86	2.23	2.61	1.49	1.86	2.23	2.61	SEM	Vaccine × Lys	Vaccine	Lys	Linear	Quadratic
Initial BW, kg	100.1	100.0	100.1	100.1	103.3	103.4	103.3	103.4	1.37	<0.99	<0.002	<0.99	<0.98	<0.98
Initial pen animal count	20.4	20.2	20.4	20.6	22.6	22.2	22.4	22.4	0.69	<0.99	<0.001	<0.97	<0.93	<0.69
ADG, kg	0.74	0.83	0.84	0.82	0.76	0.84	0.84	0.87	0.027	<0.79	<0.24	<0.005	<0.003	<0.05
ADFI, kg	2.72	2.71	2.62	2.59	2.68	2.68	2.56	2.64	0.061	<0.79	<0.60	<0.21	<0.09	<0.75
G:F	0.27	0.31	0.32	0.32	0.29	0.31	0.33	0.33	0.006	<0.91	<0.02	<0.001	<0.001	<0.001
Final BW, kg	120.7	123.2	123.5	123.1	125.0	126.8	126.9	127.8	1.46	<0.97	<0.001	<0.27	<0.10	<0.36
Final pen animal count	20.4	20.2	20.4	20.4	22.2	22.2	22.4	22.4	0.70	<0.99	<0.001	<0.99	<0.83	<0.92
Daily SID Lys intake, g	14.14	17.64	20.44	23.56	13.91	17.39	19.94	24.0	0.44	<0.72	<0.70	<0.001	<0.001	<0.86
SID Lys intake, g/kg of BW gain	19.37	21.31	24.47	28.92	18.28	20.82	23.76	27.67	0.470	<0.85	<0.02	<0.001	<0.001	<0.007
Carcass measurement														
Backfat, mm	16.0	15.4	14.9	15.8	16.5	16.5	16.3	16.4	0.66	<0.84	<0.03	<0.67	<0.62	<0.32
Lean, %	56.4	55.9	56.5	56.0	56.3	56.5	56.4	56.4	0.70	<0.91	<0.71	<0.97	<0.89	<0.91
Loin depth, cm	6.13	6.22	6.27	6.19	6.27	6.43	6.23	6.28	0.177	<0.86	<0.35	<0.87	<0.95	<0.51
Yield, %	75.6	75.7	75.9	75.5	76.4	75.6	75.5	75.4	0.50	<0.54	<0.87	<0.67	<0.25	<0.94
Fat-free lean index, %	50.9	51.1	51.4	51.0	50.8	50.9	50.9	50.9	0.28	<0.86	<0.18	<0.67	<0.54	<0.35

[1]A total of 930 gilts (PIC 337 × 1050; PIC, Hendersonville, TN) were used in this 28-d trial with 5 replications per PCV2 vaccination and diet combination.

[2]Vaccination for PCV2 (Circumvent PCV, Intervet Inc., Millsboro, DE) was administered at placement into the weaning-to-finish facility and again 3 wk later.

Table 7. Effects of standardized ileal digestible (SID) Lys:ME ratio (1.49, 1.86, 2.23, or 2.61 g/Mcal) and porcine circovirus type 2 (PCV2) vaccination on 97- to 118-kg barrows (Exp. 4)[1]

	PCV2 vaccine[2]									P-value				
	No				Yes								Lys	
Item	1.49	1.86	2.23	2.61	1.49	1.86	2.23	2.61	SEM	Vaccine × Lys	Vaccine	Lys	Linear	Quadratic
Initial BW, kg	97.6	97.6	97.4	97.6	97.8	97.8	97.8	97.8	1.97	<1.00	<0.86	<1.00	<0.99	<0.99
Initial pen animal count	18.2	19.0	19.2	18.2	22.8	22.6	22.6	22.4	0.89	<0.91	<0.001	<0.91	<0.86	<0.48
ADG, kg	0.92	0.97	0.97	1.02	0.86	0.91	0.95	1.02	0.019	<0.36	<0.02	<0.001	<0.001	<0.81
ADFI, kg	3.04	3.24	3.23	3.08	2.94	2.98	3.11	3.04	0.083	<0.62	<0.04	<0.19	<0.31	<0.06
G:F	0.30	0.30	0.30	0.33	0.30	0.31	0.31	0.34	0.008	<0.81	<0.70	<0.001	<0.001	<0.03
Final BW, kg	117.5	118.0	117.9	119.0	116.1	117.0	117.8	119.3	1.81	<0.96	<0.68	<0.63	<0.21	<0.84
Final pen animal count	18.0	19.0	19.0	18.2	22.4	22.6	22.4	22.4	0.90	<0.94	<0.001	<0.89	<0.95	<0.44
Daily SID Lys intake, g	15.80	21.07	25.20	28.07	15.29	19.38	24.25	27.65	0.583	<0.69	<0.04	<0.001	<0.001	<0.07
SID Lys intake, g/kg of BW gain	17.28	21.72	25.89	27.58	17.78	21.25	25.66	27.04	0.561	<0.79	<0.65	<0.001	<0.001	<0.005
Carcass measurements														
Backfat, mm	19.5	19.1	19.3	19.5	20.5	20.1	19.5	19.3	0.61	<0.74	<0.24	<0.70	<0.29	<0.63
Lean, %	54.0	54.1	54.0	53.8	53.0	53.4	53.9	54.0	0.48	<0.59	<0.29	<0.79	<0.37	<0.66
Loin depth, cm	5.84	5.73	5.72	5.63	5.44	5.62	5.79	5.77	0.164	<0.38	<0.52	<0.92	<0.63	<0.72
Yield, %	74.3	74.6	74.6	74.1	74.8	74.8	74.8	74.8	0.51	<0.95	<0.25	<0.96	<0.93	<0.60
Fat-free lean index, %	48.8	49.1	49.0	48.9	48.2	48.5	48.8	49.0	0.28	<0.55	<0.11	<0.47	<0.16	<0.48

[1]A total of 825 barrows (PIC 337 × 1050; PIC, Hendersonville, TN) were used in this 21-d trial with 5 replications per PCV2 vaccination and diet combination.

[2]Vaccination for PCV2 (Circumvent PCV, Intervet Inc., Millsboro, DE) was administered at placement into the weaning-to-finish facility and again 3 wk later.

DISCUSSION

Before the initiation of the dietary treatments at 71 d after weaning, the removal rate was more than 4 times greater in gilt pens and more than 6 times greater in barrow pens that were not vaccinated for PCV2 compared with those pens that were vaccinated. Porcine circovirus type 2 is the main causative agent for PCVD, which is characterized by chronic muscle wasting and lymph node enlargement resulting from postweaning multisystemic wasting syndrome (Horlen et al., 2007). Porcine circovirus type 2-associated clinical disease, which results in increased mortality and decreased growth rate, increased greatly in the US pig population in the mid-2000s (Horlen et al., 2007). Vaccination for PCV2 has been shown to reduce mortality and increase growth performance (Horlen et al., 2008; Potter et al., 2008; Jacela et al., 2011). Results of the current experiments also demonstrated the same benefit of reduced mortality and increased growth rate. In 2 prior studies evaluating the same PCV2 vaccine in these facilities, removal rate of the nonvaccinated groups ranged from 4.3% to a high of 12% (Jacela et al., 2011), whereas the rate approached 30% in the current study at the end of the first dietary experiment in barrows. Porcine circovirus type 2 vaccination had the greatest effect in the period immediately after the challenge of PRRSv inoculation and in the early finisher phase during the first set of dietary treatments in this study. One theory is that PCV2 weakens the immune system of the pig and enhances the virulence of other pathogens. This theory is supported by the results of Kixmöller et al. (2008), who observed reduced quantities of coinfecting agents in pigs vaccinated against PCV2 compared with those in their nonvaccinated counterparts. In addition, our observations are consistent with those of Opriessnig et al. (2004), who demonstrated that cofactors, such as PRRSv, increase the severity of PCVD.

Our data also agree with those of Kane et al. (2009) and Potter et al. (2009), who demonstrated that the PCV2 vaccine used in the present experiments reduced nursery performance. The reduced nursery growth performance appears to be due to decreased feed intake after vaccination. The second injection in a 2-dose program seems to decrease feed intake to a greater degree than the initial injection (Potter et al., 2009).

The use of PCV2 vaccine created a model to demonstrate differences in pig performance resulting from an immune challenge in Exp. 1 and 2. Results from Exp. 1 indicated that 38- to 60-kg gilts require 2.99 g of SID Lys/Mcal of ME for maximal performance, whereas in Exp. 2, 39- to 65-kg barrows showed a linear response in G:F to an increasing SID Lys:ME ratio through 3.36 g of SID Lys/Mcal of ME. Shelton et al. (2008) observed similar improvements in growth and feed efficiency for 38- to 65-kg gilts up to 3.16 g of SID Lys/Mcal of ME. Main et al. (2008) observed increases in BW gain and efficiency through only 2.84 g of SID Lys/Mcal of ME for 35- to 60-kg gilts and 43- to 70-kg barrows. The present study was conducted in the same facilities with the same genetic lines used in the studies by Main et al. (2008) and Shelton et al. (2008). Responses to greater SID Lys:ME ratios in the present study were similar to those reported by Shelton et al. (2008) and slightly greater than those reported by Main et al. (2008). Results indicate that the reduced growth performance from the immune challenge decreased the Lys requirement when expressed on a gram per day basis, but not when expressed relative to the energy level of the diet (g/Mcal of ME), relative to the BW gain of the pigs (g/kg of BW gain), or as a percentage of the diet.

Health status has been shown to affect Lys requirement estimates for weanling and finishing pigs (Williams et al., 1997a,b). Williams et al. (1997a,b) observed increased Lys requirements in pigs with decreased immune system stimulation, and they hypothesized that pigs needed additional Lys to accommodate the increased protein deposition. If this is the case, healthy pigs may require a greater concentration of dietary Lys than health-challenged pigs. Data from Williams et al. (1997a,b) confirm the findings of Klasing and Austic (1984). Klasing and Austic (1984) observed increased skeletal muscle breakdown in broiler chicks with increased immune system stimulation (accomplished by injecting either *Escherichia coli* or sheep red blood cells), which suggests that animals with less immune system activity will have a greater rate of protein deposition. Thus, healthy animals may require a greater dietary Lys concentration than animals with increased immune activation because of increased protein accretion. Our study showed no difference in response to increasing the SID Lys:ME ratio between PCV2-vaccinated and nonvaccinated pigs. However, PCV2-vaccinated pigs had increased ADFI in Exp. 1 and 2 compared with that of nonvaccinated pigs, which suggests that at that growth stage, PCV2-vaccinated pigs would have an increased daily Lys requirement to accommodate their greater protein deposition rates.

In Exp. 1 and 2, PCV2-vaccinated pigs had increased growth performance compared with nonvaccinated pigs, but that growth advantage was not observed in Exp. 3 or 4. Pens vaccinated for PCV2 had greater pen counts (up to 5 pigs per pen) in each of the 4 experiments than did nonvaccinated pens. The difference in pig density may have limited the improvements in growth for PCV2-vaccinated pigs because of pig and feeder space limitations. Limited research has been done to estimate feeder trough space requirements for growing and finishing pigs. Throughout these 4 experiments, feeder trough space ranged from 5.4 to 8.4 cm per pig. Feeder space recommendations range from 2.5 cm (Farrin, 1990) to 7.4 cm of feeder trough space for a 100-kg pig (English et al., 1988). Studies have also shown that when feeder space is decreased, pigs will alter their behavior to compensate and that growth performance will be maintained (Hyun and Ellis, 2002). Therefore, feeder space was likely not a limiting factor in this study. On the basis of equations from Gonyou et al. (2006), pig space would not have been limiting in Exp. 1 and 2 between vaccinated and nonvaccinated pens because pens had not reached the critical k-value of 0.0336 [k = ($BW^{0.667}$)/(floor space/pig)], at which space becomes a liming factor for growth rate despite the differences in number of pigs per pen. In Exp. 3 and 4, pig space may have been a confounding factor because PCV2-vaccinated pens would have reached the k-value during the early portion of the experiments and nonvaccinated pens would have reached the critical limit at a later time in the trial. However, Jacela (2009) showed that improved growth from PCV2 vaccination was primarily observed early in the finishing stage; therefore, we did not expect any performance differences between between vaccine treatments in Exp. 3 and 4.

In Exp. 3, performance was maximized in 102- to 125-kg gilts at 2.23 g of SID Lys/Mcal of ME. Main et al. (2008) determined an optimal SID Lys:ME ratio of 1.90 g/Mcal for similar-sized pigs, and Friesen et al. (1995) observed optimal performance in 104- to 136-kg gilts at 2.16 g of apparent ileal digestible Lys/Mcal of ME. If converted to SID Lys/Mcal of ME with NRC (1998) conversion factors, the optimal SID Lys:ME ratio observed by Friesen et al. (1995) would be 2.29 g of SID Lys/Mcal of ME, similar to the value in our experiment. Shelton et al. (2008) observed linear improvements in ADG and G:F through 2.55 g of SID Lys/Mcal of ME for 85- to 110-kg gilts. This greater requirement estimate may be due to the reduced BW of pigs in that study, but it is still greater than the requirement estimate from previous trials.

Performance in Exp. 4 was maximized at the greatest SID Lys:ME ratio of 2.61 g/Mcal for 97- to 118-kg barrows consuming 27.3 g of SID Lys/kg of BW gain. This response was similar to that observed by Shelton et al. (2008) for 85- to 110-kg gilts; in that study, performance increased linearly through to 2.55 g of SID Lys/Mcal of ME, with gilts consuming 23.0 g of SID Lys/kg of BW gain. However, Main et al. (2008) observed a much less optimal SID Lys:ME ratio of 1.90 g of SID Lys/Mcal of ME for 102- to 120-kg barrows.

There were no significant responses in carcass measurements to an increasing SID Lys:ME ratio in Exp. 3 or 4. We anticipated that the lean composition of the carcass would increase as the SID Lys:ME ratio increased up to the requirement because of increased protein accretion (Cromwell et al., 1993; Hahn et al., 1995; De La Llata et al., 2007). Johnston et al. (2009) concluded that increases in whole-body growth from increasing the Lys curve above the recommendations of the genetic supplier (PIC, 2008) may not be reflective of carcass growth and that increases in dietary Lys may be negatively correlated with carcass yield. However, we did not observe any difference in yield with increasing dietary Lys or any advantage in backfat reduction or loin depth with increasing SID Lys:ME ratio.

In conclusion, this study showed advantages to increasing the SID Lys:ME ratio that were similar to those reported by Shelton et al. (2008, 2009) and at a greater in magnitude than those previously reported in the same facility by Main et al. (2008). There were no differences in optimal SID Lys:ME ratio between PCV2-vaccinated and nonvaccinated pigs; however, the increased growth from increased ADFI in Exp. 1 and 2 suggests that PCV2-vaccinated pigs have an increased daily Lys requirement on a gram per day basis compared with nonvaccinated pigs from 40 to 60 kg.

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