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SID lysine requirement of immunologically and physically castrated male pigs during the grower, early and late finisher periods

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Abstract

The main objective of this experiment was to determine the standardized ileal digestible (SID) Lys requirement of immunologically castrated (IC) and physically castrated (PC) male pigs during 3 growth phases. An additional objective was to compare the ADFI of PC and IC after the second anti-gonadotropin releasing factor (GnRF) injection. Three hundred male pigs (PIC 359 × C29), 150 each of IC and PC, were allotted to 1 of 5 treatments: 80, 90, 100, 110, or 120% of the estimated Lys requirement using the NRC (2012) modeling program. Pigs remained on the same treatment throughout each of the 3 phases. Lysine requirements were determined at 3 stages of growth starting at a BW of 30.0 ± 0.8, 64.7 ± 1.4, and 111.9 ± 1.9 kg for IC and 32.4 ± 0.6, 69.8 ± 1.0, and 114.5 ± 1.3 kg for PC. Anti-GnRF injections were administered to IC at 11.5 and 19 wk (average BW = 96.3 ± 1.8 kg) of age. The one-slope broken line regression and quadratic plateau models were used, and the best model was selected based on the Akaike information criterion. The IC SID Lys requirements based on ADG were 1.03, 0.97, and 0.55% and for G:F, the requirements were 0.99, 0.72, and 0.55% for phases 1, 2, and 3, respectively. For PC, the SID Lys requirements based on ADG were 0.86, 0.62, and 0.47% and for G:F were 0.86, 0.58, and 0.47% for phases 1, 2, and 3, respectively. Immunologically castrated pigs had greater SID Lys requirements for phases 1 and 2 compared to PC (0.17 and 0.35 percentage points greater for ADG and 0.13 and 0.14 percentage points greater for G:F for phases 1 and 2, respectively). After the second injection, when IC pigs are believed to become physiologically more similar to PC pigs, the SID Lys requirements continue to be greater for IC (0.55 vs. 0.47% for both ADG and G:F). The ADFI of IC increased 4 d after the second injection relative to PC. By 2 wk post second injection, the ADFI of IC exceeded that of PC ($P < 0.05$). Adopting immunological castration as a management tool requires an understanding that IC need to be fed differently compared to PC, to maximize growth performance. Immunologically castrated pigs have a greater SID Lys requirement throughout the grower and finishing periods compared to the PC.

Keywords

digestibility, feed intake, immunological castration, lysine, physical castration, pig

Disciplines

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SID lysine requirement of immunologically and physically castrated male pigs during three growth phases.[1]

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ABSTRACT

The main objective of this experiment was to determine the standardized ileal digestible (**SID**) Lys requirement of immunologically castrated (**IC**) and physically castrated (**PC**) male pigs during 3 growth phases. An additional objective was to compare the ADFI of PC and IC after the second anti-gonadotropin releasing factor (**GnRF**) injection. Three hundred male pigs (PIC 359 × C29), 150 each of IC and PC, were allotted to 1 of 5 treatments: 80, 90, 100, 110, or 120% of the estimated Lys requirement using the NRC (2012) modeling program. Pigs remained on the same treatment throughout each of the 3 phases. Lysine requirements were determined at 3 stages of growth starting at a BW of 30.0 ± 0.8, 64.7 ± 1.4, and 111.9 ± 1.9 kg for IC and 32.4 ± 0.6, 69.8 ± 1.0, and 114.5 ± 1.3 kg for PC. Anti-GnRF injections were administered to IC at 11.5 and 19 wk (average BW = 96.3 ± 1.8 kg) of age. The one-slope broken line regression and quadratic plateau models were used, and the best model was selected based on the Akaike information criterion. The IC SID Lys requirements based on ADG were 1.03, 0.97, and 0.55% and for G:F, the requirements were 0.99, 0.72, and 0.55% for phases 1, 2, and 3, respectively. For PC, the SID Lys requirements based on ADG were 0.86, 0.62, and 0.47% and for G:F were 0.86, 0.58, and 0.47% for phases 1, 2, and 3, respectively. Immunologically castrated pigs had greater SID Lys requirements for phases 1 and 2 compared to PC (0.17 and 0.35 percentage points greater for ADG and 0.13 and 0.14 percentage points greater for G:F for phases 1 and 2, respectively). After the second injection, when IC pigs are believed to become physiologically more similar to PC pigs, the SID Lys requirements continue to be greater for IC (0.55 vs. 0.47% for both ADG and G:F). The ADFI of IC increased 4 d after the second injection relative to PC. By 2 wk post second injection, the ADFI of IC exceeded that of PC ($P < 0.05$). Adopting immunological castration as a management tool requires an understanding that IC need to be fed differently compared to PC, to maximize growth performance. Immunologically castrated pigs have a greater SID Lys requirement throughout the grower and finishing periods compared to the PC.

Key words: digestibility, feed intake, immunological castration, lysine, physical castration, pig

INTRODUCTION

In the United States, castration of males is a standard procedure in pork production to avoid an unpleasant flavor or odor in the meat known as boar taint, even though the growth performance advantages of raising entire males (**EM**) vs. physical castrates (**PC**) have been well characterized (Xue et al., 1997). In 2011, an anti-gonadotropin releasing factor (**GnRF**) product (Improvest, Zoetis Inc., Florham Park, NJ) was approved in the United States to temporarily immunologically castrate male pigs. This allows the producer to take advantage of a large portion of the benefits of raising EM and addresses the boar taint issue (Dunshea et al., 2001). The product temporarily blocks testicular function through production of antibodies to GnRF. A recent meta-analysis showed that after the second injection until harvest, the ADG and G:F of immunological castrates (**IC**) exceeded that of EM (Dunshea et al., 2013). While producers currently understand the nutrient requirements of PC, there is a need to better define the nutritional requirements of IC.

It has been well documented that feed intake (**FI**) increases substantially in IC after the second immunization (Dunshea et al., 2011, 2013; Huber et al., 2013), but the nature of this increase has not been extensively characterized. Therefore, the first objective of this experiment was to determine the standardized ileal digestible (**SID**) Lys requirement of IC and PC through 3 growth phases. The second objective was to define the FI pattern change in IC immediately after the second anti-GnRF injection. The third objective was to determine the digestibility of energy in the experimental diets, as a basis for defining the SID Lys requirement as a ratio to dietary energy.

MATERIALS AND METHODS

This experiment was conducted at the Iowa State University Swine Nutrition Farm (Ames, IA). All experimental procedures adhered to the principles of the ethical and humane use of animals for research and were approved by the Iowa State University Institutional Animal Care and Use Committee (#12-12-7479-S).

Animals, housing, and experimental design

Three hundred male pigs (PIC 359 × C29; Pig Improvement Company, Hendersonville, TN), half of which were PC and half of which were EM assigned to be immunologically castrated (referred to as IC, even before the second dose of GnRF was administered), were used in this experiment. Pigs were selected for inclusion in the experiment based on their ADG during a 17 d pre-test period. Pigs with similar pre-test ADG were assigned to 1 of 6 blocks of 25 pigs each based on initial BW. Within each block, pigs were randomly assigned to 1 of 5 dietary treatments (80, 90, 100, 110, or 120% of estimated SID Lys requirements) and remained on these dietary treatments throughout the trial. The experiment was conducted over 3 subsequent growth phases (i.e. Lys titration periods) with initial BW of 30.0 ± 0.8 (grower), 64.7 ± 1.4 (early finisher), and 111.9 ± 1.9 kg (late finisher) for IC and 32.4 ± 0.6, 69.8 ± 1.0, and 114.5 ± 1.3 kg for PC, respectively. Both sexes were similar in age and the experiments were conducted simultaneously with both PC and IC for each of the phases. Each treatment within sex consisted of 6 pens with 5 pigs per pen. The pens consisted of a partially slatted concrete floor, stainless steel dry feeder with 2 covered spaces, and 1 nipple drinker attached to the pen wall. The pens provided 1.0 m^2 per pig. Pigs were provided *ad libitum* access to water and feed. Feed intake was measured at the same time each day to minimize the impact of the variability of pigs' eating patterns throughout the day on the measurement. Both sexes were housed in the same room to avoid confounding of room housed and pig sex.

Performance for the Lys titration was determined during a 5 wk period (d 0 to 34) for phase 1, a 4 wk period (d 35 to 62) for phase 2, and a 5 wk period (d 77 to 112) for phase 3. Pigs were individually weighed and per pen FI was recorded weekly, throughout the experiment, to monitor growth performance (ADG, ADFI, and G:F). To minimize variability in pig weights, pigs were weighed on 2 consecutive days at the beginning of the experiment, at phase changes, and on marketing days, with the average of these 2 weights used in subsequent data analysis. Anti-GnRF injections (Improvest, Zoetis Inc., Florham Park, NJ) were administered at 11.5 and 19 wk of age (average BW = 96.3 ± 1.8 kg for the second injection) for the IC pigs. Timing and dosage of the product were in accordance with manufacturer's directions. The second injection was given at the end of the second phase which corresponded with the start of the third dietary phase (d 63). Pigs were fed the phase 3 diets after the second injection until the end of the experiment. However, the phase 3 Lys titration commenced 2 wk after the start of the phase 3 diets (d 77) to avoid confounding due to the rapidly changing FI known to occur immediately after the second injection (Dunshea et al., 2011, 2013). On the day of the second injection, pigs and feeders were weighed and continued to be weighed every second day for 2 wk (d 63 to 77). This facilitated characterizing the changes in ADFI during this transition period. Thereafter on d 77, the Lys titration was initiated and pigs and feeders were weighed weekly.

Pigs were marketed at 6 or 7 wk post second injection. The pigs selected at wk 6 post injection were the heaviest 90 pigs within each sex. Equal numbers of pigs from each sex were marketed at wk 6 post injection. The remaining pigs were marketed the following week. This procedure was followed to equalize, as much as possible, average market BW across sex.

Diet formulation

The NRC (2012) modeling program was used to estimate the SID Lys requirement for each sex within each period. To maximize model accuracy, inputs for growth rate, initial and final BW, days, and FI were obtained from a prior experiment carried out using similar genetics housed in the same barn (Elsbernd et al., 2015). With this information, the SID Lys projected requirement and protein deposition (**PD**) were defined. Treatment SID Lys levels were set at 80, 90, 100, 110, and 120% of the projected requirement within each sex and within each phase, with the 100% treatment set at the projected requirement as defined by the model.

Diets were formulated to be intentionally simple in design and consisted of corn, soybean meal, crystalline amino acids, minerals, and vitamins (Table 1). Diets were formulated to contain 5% excesses of all essential amino acids other than Lys, to avoid confounding experiment outcomes due to a secondary amino acid deficiency. Calcium and standardized total tract digestible phosphorus were also formulated to be 5% above requirement, according to the NRC (2012) modeling program. In this way, diets were formulated so that Lys was the first limiting nutrient. The contributions to SID Lys from soybean meal and from crystalline Lys were held at a constant proportion within each dietary phase for each sex. This approach helped to avoid confounding the results due to possible differences in Lys digestibility from these 2 sources. Diets were formulated to be isocaloric on an NE basis for each phase and based on ingredient NE content according to NRC (2012).

To manufacture the diets, each ingredient was weighed on a scale: corn and soybean meal to the nearest 0.5 kg and soybean oil, monocalcium phosphate, and limestone to the nearest 0.05 kg. All other ingredients were weighed to the nearest gram. All diet sub-samples were analyzed at the same time to reduce within assay variability. The SID Lys values in each diet were calculated using the actual analyzed total Lys values for corn and soybean meal, determined after diet manufacturing, and multiplying these values by their corresponding SID digestibility values as defined by the NRC (2012). The contribution from crystalline Lys, assumed to be 100% available, was then added to this total. Titanium dioxide was included in the diet at 0.4% as an indigestible marker to allow determination of nutrient and energy digestibility. Diets were offered as a dry mash.

Sample Collection

Diet sub-samples were collected at random at the time of mixing. At the end of each dietary phase, samples were homogenized within diet or ingredient and stored at -20ºC for later analysis. Fresh feces were collected from the floor of the pen once a day for 3 consecutive days for each dietary phase (d 23 to 25, d 51 to 53, and d 93 to 95 for phases 1, 2, and 3 respectively). Samples were collected and stored at -20ºC for later analysis. Fecal samples were thawed, pooled within pen and phase, homogenized, subsampled, and oven dried at 65ºC until dry. The dried samples were transferred to the Iowa State University Monogastric and Comparative Nutrition Laboratory (Ames, IA) for analysis.

Chemical Analysis

Before analysis, diet and fecal samples were ground in a Wiley Mill (Variable Speed Digital ED-5 Wiley Mill; Thomas Scientific, Swedesboro, NJ) through a 1-mm screen. They were analyzed in duplicate for all assays, and repeat analysis occurred for any sample with a CV above 1% for DM or GE and above 3% for titanium dioxide. Dry matter was determined by drying at 105ºC to a constant weight (Isotemp Oven; Fisher Scientific, Waltham, MA). Gross energy was determined by bomb calorimetry (Model 6200; Parr Instrument Co., Moline, IL) using benzoic acid as a standard (6,318 kcal GE/kg; Parr Instrument Co., Moline, IL). The determined GE of the benzoic acid was 6,324 ± 6 kcal GE/kg. Titanium dioxide was determined using the method of Leone (1973). Feed and ingredient samples were analyzed for total AA according to method 994.12 of AOAC. Tryptophan was analyzed according to ISO 13904:2005E, and CP according to AOAC method 990.03 (Ajinomoto Heartland, Inc.; Eddyville, IA). The apparent total tract digestibility (**ATTD**) of DM and GE were determined according to Oresanya et al. (2007).

Statistical Analysis

The data for each sex were analyzed separately except for defining the ADFI pattern post second injection. The experimental unit was pen and fixed main effect source of variation were considered significant if $P < 0.05$ and trending if $P > 0.05$ and $P < 0.10$. Data were evaluated for normality using the PROC UNIVARIATE and PROC ROBUSTREG procedures in SAS 9.3 (SAS Inst. Inc., Cary, NC). An outlier was defined as a value with a standardized robust residual of greater than 3 or less than -3. Statistical analysis of growth performance and digestibility measures was performed using the PROC MIXED procedure with the fixed effects of treatment and block using pen averages. Contrast statements were used to evaluate linear, quadratic, cubic, and quartic effects for growth performance and digestibility.

To achieve our second experimental objective, the PROC MIXED procedure of SAS was used to compare the ADFI of IC and PC post second injection; sex was included in the analysis as a fixed effect. When the fixed effect was a significant source of variation, least square means were calculated and fixed effect level means separated using the PDIFF option of SAS.

To determine the Lys requirement, the one-slope broken line regression and the quadratic plateau PROC NLIN models were used as described in Robbins et al. (2006). If the one-slope broken line regression model produced a Hessian is singular statement, then the quadratic plateau model was not tested. The best model was selected based on the Akaike information criterion.

The least square means, already adjusted for pen and block, for each dietary treatment within each phase was used, providing 5 data points for each sex within each phase. Calculated SID Lys values were used in the analysis.

RESULTS AND DISCUSSION

General observations

During phases 1 and 2, overall growth performance was within the normal range for the barn. However, phase 3 performance was lower than expected. This phase was conducted in late spring during extreme temperature fluctuations in the barn; this may explain the lower than expected performance. One pen from the PC treatment was determined to be an outlier according to the statistical methods described above and was removed from the analysis. Otherwise, pigs remained healthy throughout the duration of the experiment.

Diet manufacturing and analysis

Diet analysis confirmed the amino acids levels were very close to expectation (Tables 2 to 4). The ingredient assays confirmed all essential AA other than Lys were non-limiting relative to Lys. The formulated vs. actual SID Lys percentage values were in agreement and had approximately the 0.10 increment between treatments as desired (Table 5). The largest difference from formulated to **calculated** was 0.05% SID Lys with an overall average difference throughout each of the 3 phases of 0.02%, indicating accurate diet formulation and manufacturing.

Growth performance

Immunological castrates average initial BW was 2.4 kg less than PC, reflecting the weight differences of the 2 sexes at the time of delivery to the farm. At market, IC were heavier than PC (143.2 ± 1.6 vs. 138.8 ± 1.1 kg; Tables 6 and 7). Lysine did not affect the initial BW for

IC ($P > 0.05$). There was a quadratic Lys effect on initial BW in phases 2, 3, the third Lys titration phase, and on market weight ($P < 0.05$). A quadratic effect was observed for IC ADG for phase 1 and overall ($P > 0.05$). There was a linear Lys effect on ADG for phases 2 and 3 for IC ($P < 0.05$). Lysine had no effect on the phase 3 Lys titration ADG or on ADFI in any of the phases for IC ($P > 0.05$). A quadratic Lys effect on G:F for IC for phases 1, 2, 3, and overall was found in the present experiment ($P < 0.05$). However, lysine had no effect on IC phase 3 Lys titration G:F ($P > 0.05$).

Initial BW did not differ among PC treatments ($P > 0.05$). A quadratic Lys effect on initial BW was observed for PC in phases 2, 3, and the phase 3 Lys titration and there was a cubic effect on market weight ($P < 0.05$). There was a quadratic Lys effect in phases 1 and 2 on ADG and a cubic Lys effect in phase 3, phase 3 Lys titration, and overall ($P < 0.05$). There was no Lys effect on ADFI for PC in any of the phases ($P > 0.05$). A linear Lys effect was observed for feed efficiency in phases 1 and 2 and a cubic Lys effect was observed in phase 3 and the phase 3 Lys titration for PC ($P < 0.05$). These results suggest that pigs with an inadequate Lys supply will have similar FI while growing slower and less efficiently compared to pigs with adequate or excess Lys in the diet.

SID Lys requirements

Lysine is 1 of the 9 essential AA for swine and is generally first limiting in swine diets. Other AA are expressed as a ratio to Lys according to the ideal protein ratio concept (Fuller et al., 1989). Using the model that fit these data the best according to the Akaike information criterion, the SID Lys requirement for IC for phases 1, 2, and 3 based on ADG were 1.03, 0.97, and 0.55% and based on G:F were 0.99, 0.72, and 0.55% (Table 8). The SID Lys requirement for PC for phases 1, 2, and 3 based on ADG were 0.86, 0.62, and 0.47% and based on GF were 0.86, 0.58, and 0.47%. It is recognized that some pigs were fed below the determined requirement and that may influence the phase 2 and 3 requirements.

The phase 1 SID Lys requirements for IC and PC aligned well with the NRC requirements after adjusting for the greater PD identified for these pigs. For example, the NRC (2012) requirement for EM between 50 to 75 kg BW with ADFI of 2.062 kg and a PD of 150 g/d is 0.88% SID Lys. Adjusting the NRC (2012) requirement for the greater PD resulted in a very similar SID Lys requirement (1.03 vs. 1.03 and 0.99 for ADG and G:F, respectively). The same approach also provided close agreement with the NRC (2012) for PC (0.87 vs. 0.86% for both G:F and ADG).

Determined phase 2 and 3 SID Lys requirements were lower than the NRC estimates except for IC ADG in phase 2 (0.97 vs. 0.82, respectively). Differences in the Lys requirement may be attributed to differences in FI, genetics, and environmental conditions (Schinckel and de Lange, 1996). This issue illustrates the importance of expressing the SID Lys requirement of pigs in different ways. Nutritionists can then apply these requirements for pigs under their farm conditions by adjusting for differences in PD or FI. This generates a requirement that is more specific to a given set of conditions rather than use a single estimate based on a single growth trial. For example, Table 9 shows other ways of expressing the requirement using the average of the ADG and G:F requirements for each phase.

The Lys requirements for IC were greater than for PC in each phase. This can be explained biologically for the first 2 phases during which IC were essentially EM. Entire males have greater PD than PC (Dunshea et al., 1993; Elsbernd et al., 2015; NRC, 2012.) due to the anabolic effects of androgenic steroids such as testosterone (Dubois et al., 2012). Therefore, the Lys requirement would be expected to be greater for IC.

After the second injection, the SID Lys requirement was still greater for IC than PC even though IC are assumed to become more metabolically similar to PC (Dunshea et al, 2013). The difference in the phase 3 SID Lys requirement of IC relative to PC decreased compared to phases 1 and 2, but was still greater. The results reported herein, although not completely expected, are consistent with the results from a previous nitrogen balance experiment from our lab which revealed that, 2 wk post second injection, nitrogen retention (g/d) in IC was intermediate to that of EM and PC (Elsbernd et al., 2015). Therefore, even though it is widely assumed that the IC become metabolically similar to PC after the second anti-GnRF injection, results from this experiment and the previously described report indicate they are not metabolically identical. There appears to be some carryover effect in IC, reflected in numerically greater nitrogen retention (Elsbernd et al., 2015) and a greater Lys requirement. Nonetheless, IC do deviate from EM characteristics and performance after the second anti-GnRF injection (Dunshea et al., 2013).

Although, IC have a greater SID Lys grams per day requirement than PC, after adjusting for gain the 2 sex's requirements are close (differences of 0.5, 0.9, and 0.3 mg SID Lys/g of gain for phases 1, 2, and 3, respectively).

ADFI post second injection

There are data suggesting that in the period after the second injection until harvest, a transition does occur in IC. For example, IC have decreased testosterone levels (Dunshea et al., 2001; Lealiifano et al., 2011), increased nitrogen excretion and decreased retention (Elsbernd et al., 2015; Huber et al., 2013), and decreased androstenone (Lealiifano et al., 2011) and skatole concentrations at harvest (Dunshea et al., 2001; Zamaratskaia et al., 2008) in relation to EM. In this way, IC become more similar, however, not identical to PC. The transition after the second injection also includes a sharp increase in FI. One meta-analysis showed an average increase in daily FI of 429 g/d after the second anti-GnRF injection until harvest (Dunshea et al., 2013). In this portion of the current experiment, the objective was to identify the FI pattern of IC in relation to PC. It is recognized that IC and PC were fed separate Lys levels and that some pigs were fed below their requirement.

During the week immediately before to the second anti-GnRF injection, as well as up to 4 d after, the FI of IC remained at 83 to 84% of PC (Table 10). On d 5 to 6 post second injection, the FI of IC started to increase (86% of PC). The FI of IC continued to increase so that it was similar to that of PC by d 9 to 10 ($P > 0.05$). However, it exceeded that of PC starting on d 13 to 14 ($P < 0.05$). Interestingly, average daily FI of IC relative to that of PC continued to increase during wk 3 ($P < 0.05$) and wk 4 ($P < 0.05$) after the second anti-GnRF injection. An experiment conducted by Dunshea et al. (2011) evaluating FI after the second anti-GnRF injection had similar results in that the FI of IC increased 2 wk post second injection such that it was greater than EM and became more similar to PC.

Digestibility

Apparent total tract digestibility of GE in IC pigs showed a linear response to Lys for each of the 3 dietary phases ($P < 0.05$; Table 11). The DE of the diet also increased linearly with increasing Lys level for each phase ($P < 0.05$). The diets were formulated to be isocaloric on an NE basis. However, as the Lys level increased, so too did the soybean meal and oil content in the diet. Because soybean meal has a greater DE content than corn, and oil has a very high DE content (NRC, 2012), it is expected that the ATTD of GE and the diet DE content would increase as Lys increased. Given the above, it was surprising to observe that there were no differences in the ATTD of GE in PC in phases 1 and 2 except for a quadratic diet effect on the ATTD of GE in phase 3 (Table 12). In the second and third phase, DE increased linearly as Lys level increased

($P < 0.05$). The absence of statistically significant differences in ATTD of GE and DM in PC was unexpected. The variability in the ATTD of DM and GE measurements were greater in PC when compared to IC.

As the pigs grew, the observed energy digestibility of the diet increased for each of the sexes. In general, the predicted DE was greater than the observed DE. However, they became closer in relation to each other as the pigs matured (predicted/observed DE = 1.08, 1.05, and 1.01% for IC and 1.09, 1.06, and 1.01% for PC, for phases 1, 2, and 3, respectively). It is expected that as pigs get older the DE of a given diet would increase due to a more developed digestive system.

Male pigs which are immunologically castrated must be fed according to their biological requirements, which are different than PC, to maximize the use of this technology. The IC pigs have greater SID Lys requirements as compared to PC which is an important consideration in diet formulation because underestimating the nutrient requirements of IC may result in failure to achieve their full potential in terms of growth performance. Another important consideration is to note the increase in FI after the second injection for IC. Producers must recognize this and adjust their feed budgets accordingly.

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Table 1. Ingredient composition of phase 1, 2, and 3 diets[1] fed to immunologically castrated and physically castrated pigs (as-fed basis)

	Lys percent of NRC (2012) model estimated requirement					
	Phase 1		Phase 2		Phase 3	
Ingredient, %	80%	120%	80%	120%	80%	120%
Immunological castrates						
Ground corn	74.36	60.21	80.46	66.32	87.64	73.29
Soybean meal, 46.5% CP	20.61	33.25	14.57	27.25	8.43	21.29
Soybean oil	0.87	2.23	1.35	2.72	0.85	2.25
Monocalcium phosphate	1.27	1.11	1.06	0.90	0.79	0.63
Limestone	1.34	1.30	1.18	1.14	0.96	0.94
Salt	0.50	0.50	0.50	0.50	0.50	0.50
L-Lys HCl	0.19	0.31	0.15	0.27	0.11	0.22
L-Thr	0.04	0.11	0.02	0.10	0.00	0.10
DL-Met	0.02	0.15	0.00	0.09	0.00	0.05
Titanium dioxide	0.40	0.40	0.40	0.40	0.40	0.40
Mineral premix[2]	0.25	0.25	0.15	0.15	0.15	0.15
Vitamin premix[3]	0.17	0.17	0.17	0.17	0.17	0.17
Physical castrates						
Ground corn	77.93	63.77	87.18	72.93	91.07	76.70
Soybean meal, 46.5% CP	17.93	30.61	9.42	22.21	5.71	18.64
Soybean oil	0.37	1.73	0.40	1.80	0.40	1.80
Monocalcium phosphate	1.07	0.91	0.72	0.56	0.64	0.47
Limestone	1.20	1.16	0.94	0.90	0.87	0.83
Salt	0.50	0.50	0.50	0.50	0.50	0.50
L-Lys HCl	0.17	0.29	0.12	0.23	0.09	0.20
L-Thr	0.02	0.11	0.01	0.11	0.00	0.10
DL-Met	0.00	0.13	0.00	0.05	0.00	0.02
L-Trp	0.00	0.00	0.00	0.00	0.00	0.01
Titanium dioxide	0.40	0.40	0.40	0.40	0.40	0.40
Mineral premix[2]	0.25	0.25	0.15	0.15	0.15	0.15
Vitamin premix[3]	0.17	0.17	0.17	0.17	0.17	0.17

[1] Phase 1 diets fed d 0 to 34 (~ 30 to 65 kg BW). Phase 2 diets fed d 35 to 62 (~ 65 to 100 kg BW). Phase 3 diets fed d 63 to 112 (~ 100 to 140 kg BW); second injection of anti-gonadotropin releasing factor (Improvest, Zoetis Inc., Florham Park, NJ) occurred on d 63.

[2] Phase 1 diet: Provided per kilogram of diet: Zn, 275 mg from zinc sulfate; Fe, 275 mg from iron sulfate; Mn, 65 mg from manganese sulfate; Cu, 28 mg from copper sulfate; I, 0.5 mg from calcium iodate; and Se, 0.5 mg from sodium selenite. Phases 2 and 3 diets: Provided per kilogram of diet: Zn, 165 mg from zinc sulfate; Fe, 165 mg from iron sulfate; Mn, 39 mg from manganese sulfate; Cu, 17 mg from copper sulfate; I, 0.3 mg from calcium iodate; and Se, 0.3 mg from sodium selenite.

[3] Provided per kilogram of diet: vitamin A, 7,496 IU; vitamin D, 937 IU; vitamin E, 30 IU; vitamin K, 3.0 mg; niacin, 33.7 mg; pantothenic acid, 18.7 mg; riboflavin, 5.6 mg; and vitamin B_{12}, 0.026mg.

Table 2. Energy and nutrient composition of phase 1[1] diets for immunologically castrated and physically castrated pigs (as-fed basis)

	Lys percent of NRC (2012) model estimated requirement				
Item	80%	90%	100%	110%	120%
Immunological castrates					
Calculated NE, Mcal/kg[2]	2.49	2.49	2.49	2.49	2.49
Calculated ME, Mcal/kg[2]	3.29	3.31	3.32	3.34	3.36
Calculated DE, Mcal/kg[2]	3.40	3.43	3.45	3.48	3.50
Analyzed values					
DM, %	88.7	88.6	89.0	89.2	89.3
GE, Mcal/kg	3.86	3.88	3.92	3.98	3.98
DE, Mcal/kg	3.13	3.13	3.17	3.30	3.31
CP, %	17.2	17.3	19.4	20.3	21.5
Indispensable AA, total %					
Lys	0.98	1.10	1.20	1.30	1.40
Met	0.27	0.32	0.35	0.40	0.46
Met + Cys	0.54	0.60	0.66	0.71	0.78
Thr	0.66	0.70	0.79	0.83	0.90
Trp	0.18	0.19	0.23	0.23	0.25
Val	0.77	0.82	0.89	0.90	0.96
Ile	0.69	0.74	0.81	0.82	0.88
Physical castrates					
Calculated NE, Mcal/kg[2]	2.49	2.49	2.49	2.49	2.49
Calculated ME, Mcal/kg[2]	3.28	3.29	3.31	3.33	3.34
Calculated DE, Mcal/kg[2]	3.38	3.41	3.43	3.46	3.49
Analyzed values					
DM, %	88.9	88.9	89.2	89.5	90.0
GE, Mcal/kg	3.83	3.85	3.89	3.93	3.96
DE, Mcal/kg	3.15	3.11	3.15	3.19	3.16
CP, %	16.2	16.7	17.4	19.8	19.3
Indispensable AA, total %					
Lys	0.95	1.02	1.10	1.19	1.25
Met	0.25	0.28	0.33	0.37	0.41
Met + Cys	0.51	0.55	0.61	0.67	0.71
Thr	0.62	0.67	0.72	0.79	0.83
Trp	0.16	0.18	0.20	0.22	0.22
Val	0.74	0.77	0.82	0.87	0.89
Ile	0.65	0.69	0.74	0.79	0.80

[1]Phase 1 diets fed d 0 to 34 (~30 to 65 kg BW).
[2] NRC, 2012.

Table 3. Energy and nutrient composition of phase 2[1] diets for immunologically castrated and physically castrated pigs (as-fed basis)

	Lys percent of NRC (2012) model estimated requirement				
Item	80%	90%	100%	110%	120%
Immunological castrates					
Calculated NE, Mcal/kg[2]	2.56	2.56	2.56	2.56	2.56
Calculated ME, Mcal/kg[2]	3.34	3.35	3.37	3.39	3.40
Calculated DE, Mcal/kg[2]	3.43	3.46	3.48	3.51	3.53
Analyzed values					
DM, %	89.3	89.5	89.5	89.5	89.8
GE, Mcal/kg	3.86	3.90	3.91	3.95	3.98
DE, Mcal/kg	3.19	3.31	3.27	3.36	3.38
CP, %	13.4	14.4	15.9	17.3	19.4
Indispensable AA, total %					
Lys	0.78	0.83	0.95	1.03	1.16
Met	0.22	0.25	0.30	0.31	0.35
Met + Cys	0.47	0.50	0.56	0.58	0.65
Thr	0.53	0.57	0.65	0.70	0.80
Trp	0.14	0.16	0.18	0.20	0.22
Val	0.61	0.68	0.72	0.68	0.79
Ile	0.48	0.60	0.64	0.76	0.87
Physical castrates					
Calculated NE, Mcal/kg[2]	2.56	2.56	2.56	2.56	2.56
Calculated ME, Mcal/kg[2]	3.31	3.33	3.35	3.36	3.38
Calculated DE, Mcal/kg[2]	3.39	3.42	3.44	3.47	3.50
Analyzed values					
DM, %	88.9	89.1	88.6	88.9	89.2
GE, Mcal/kg	3.81	3.83	3.87	3.92	3.95
DE, Mcal/kg	3.21	3.19	3.23	3.30	3.34
CP, %	11.4	13.8	14.1	15.3	17.4
Indispensable AA, total %					
Lys	0.59	0.69	0.80	0.89	1.01
Met	0.20	0.23	0.25	0.27	0.30
Met + Cys	0.41	0.46	0.50	0.53	0.58
Thr	0.43	0.51	0.58	0.65	0.72
Trp	0.11	0.14	0.14	0.15	0.19
Val	0.51	0.58	0.62	0.64	0.81
Ile	0.39	0.46	0.51	0.53	0.72

[1] Phase 2 diets fed d 35 to 62 (~ 65 to 100 kg BW).
[2] NRC, 2012.

Table 4. Energy and nutrient composition of phase 3[1] diets for immunologically castrated and physically castrated pigs (as-fed basis)

	Lys percent of NRC (2012) model estimated requirement				
Item	80%	90%	100%	110%	120%
Immunological castrates					
Calculated NE, Mcal/kg[2]	2.59	2.59	2.59	2.59	2.59
Calculated ME, Mcal/kg[2]	3.33	3.35	3.37	3.38	3.40
Calculated DE, Mcal/kg[2]	3.41	3.44	3.46	3.49	3.52
Analyzed values					
DM, %	88.9	88.9	89.0	89.5	89.7
GE, Mcal/kg	3.83	3.90	3.89	3.96	3.98
DE, Mcal/kg	3.32	3.40	3.37	3.48	3.51
CP, %	11.2	12.6	13.2	14.7	16.0
Indispensable AA, total %					
Lys	0.57	0.62	0.77	0.83	0.96
Met	0.20	0.21	0.25	0.26	0.29
Met + Cys	0.42	0.43	0.49	0.50	0.55
Thr	0.42	0.46	0.54	0.59	0.68
Trp	0.11	0.11	0.15	0.16	0.18
Val	0.52	0.53	0.62	0.69	0.75
Ile	0.41	0.42	0.50	0.60	0.66
Physical castrates					
Calculated NE, Mcal/kg[2]	2.59	2.59	2.59	2.59	2.59
Calculated ME, Mcal/kg[2]	3.32	3.34	3.35	3.37	3.39
Calculated DE, Mcal/kg[2]	3.39	3.42	3.44	3.47	3.50
Analyzed values					
DM, %	89.3	88.8	89.3	89.5	88.5
GE, Mcal/kg	3.83	3.84	3.87	3.91	3.95
DE, Mcal/kg	3.35	3.36	3.44	3.41	3.42
CP, %	10.0	11.5	12.4	13.7	15.3
Indispensable AA, total %					
Lys	0.47	0.57	0.67	0.73	0.89
Met	0.19	0.20	0.22	0.23	0.26
Met + Cys	0.39	0.43	0.44	0.46	0.52
Thr	0.38	0.44	0.50	0.55	0.68
Trp	0.10	0.11	0.13	0.15	0.17
Val	0.47	0.53	0.56	0.63	0.68
Ile	0.35	0.40	0.44	0.54	0.59

[1] Phase 3 diets fed d 63 to 112 (~ 100 to 140 kg BW); second anti-gonadotropin releasing factor injection (Improvest, Zoetis Inc., Florham Park, NJ) occurred on d 63.

[2] NRC, 2012.

Table 5. Formulated, analyzed, and "actual" dietary Lys content by phase for immunologically castrated and physically castrated male pigs

	Sex									
	Immunological castrates					Physical castrates				
	Lys percent of NRC (2012) model estimated requirement									
Item, %	80%	90%	100%	110%	120%	80%	90%	100%	110%	120%
Phase 1 (~ 30 to 65 kg BW)										
Formulated total[1]	0.95	1.06	1.17	1.27	1.38	0.86	0.97	1.08	1.18	1.29
Analyzed total[2]	0.98	1.10	1.20	1.30	1.40	0.95	1.02	1.10	1.19	1.25
Formulated SID[1]	0.83	0.93	1.03	1.13	1.23	0.75	0.85	0.95	1.05	1.15
"Actual" SID[3]	0.84	0.93	1.03	1.12	1.22	0.76	0.86	0.95	1.05	1.14
Phase 2 (~ 65 to 100 kg BW)										
Formulated total	0.75	0.86	0.97	1.07	1.18	0.60	0.71	0.82	0.92	1.03
Analyzed total	0.78	0.83	0.95	1.03	1.16	0.59	0.69	0.80	0.89	1.01
Formulated SID	0.65	0.75	0.85	0.95	1.05	0.50	0.60	0.70	0.80	0.90
"Actual" SID	0.63	0.72	0.82	0.91	1.00	0.49	0.58	0.68	0.77	0.86
Phase 3[4] (~ 100 to 140 kg BW)										
Formulated total	0.55	0.66	0.77	0.88	0.99	0.47	0.58	0.69	0.79	0.90
Analyzed total	0.57	0.62	0.77	0.83	0.96	0.47	0.57	0.67	0.73	0.89
Formulated SID	0.47	0.57	0.67	0.77	0.87	0.39	0.49	0.59	0.69	0.79
"Actual" SID	0.46	0.55	0.65	0.74	0.84	0.38	0.47	0.57	0.67	0.76

[1] NRC (2012).
[2] AOAC 994.12 (Ajinomoto Heartland, Inc.; Eddyville, IA).
[3] "Actual" SID = SID contribution of corn + SBM + L-Lys HCl.
SID contribution of ingredient = analyzed total Lys × % contribution of the diet (Table 1) × SID Lys digestibility (NRC, 2012).
[4] Started the day of the second anti-gonadotropin releasing factor injection (Improvest, Zoetis Inc., Florham Park, NJ).

Table 6. Effects of standardized ileal digestible Lys level on growth performance and feed efficiency of immunologically castrated pigs by dietary phase[1]

	Lys percent of NRC (2012) model estimated requirement						*P*-value		
Item	80%	90%	100%	110%	120%	SEM	linear	quadratic	cubic
No. of pens	6	6	6	6	6	-	-	-	-
Initial BW, kg[2]									
phase 1	29.9	30.0	30.0	30.1	30.0	0.08	0.702	0.491	0.738
phase 2	63.0	64.1	65.9	65.9	64.8	0.72	0.029	0.036	0.437
phase 3	93.2	96.0	98.9	99.7	98.1	1.22	0.002	0.024	0.577
phase 3 Lys titration	105.9	110.0	115.3	114.9	113.6	1.44	<0.001	0.006	0.683
market	136.6	141.9	146.6	146.3	144.9	1.83	0.002	0.013	0.994
ADG, kg/d									
phase 1	0.95	0.97	1.03	1.03	0.98	0.018	0.061	0.004	0.205
phase 2	1.08	1.14	1.16	1.20	1.19	0.022	0.001	0.129	0.975
phase 3	0.96	1.03	1.04	1.08	1.05	0.027	0.012	0.117	0.844
phase 3 Lys titration	0.96	1.03	1.01	1.07	1.01	0.034	0.247	0.200	0.746
overall	0.99	1.04	1.07	1.10	1.06	0.018	0.002	0.009	0.528
ADFI, kg/d									
phase 1	2.04	1.97	2.02	2.00	1.91	0.040	0.070	0.483	0.133
phase 2	2.90	2.77	2.80	2.84	2.80	0.062	0.495	0.417	0.255
phase 3	3.49	3.40	3.59	3.59	3.56	0.076	0.209	0.785	0.222
phase 3 Lys titration	3.63	3.56	3.75	3.77	3.72	0.086	0.165	0.607	0.254
overall	2.87	2.77	2.85	2.84	2.79	0.050	0.617	0.994	0.191
G:F									
phase 1	0.45	0.48	0.50	0.50	0.50	0.006	<0.001	0.002	0.376
phase 2	0.37	0.41	0.42	0.42	0.43	0.006	<0.001	0.023	0.119
phase 3	0.28	0.30	0.29	0.31	0.30	0.005	0.002	0.014	0.201
phase 3 Lys titration	0.27	0.29	0.27	0.28	0.27	0.006	0.572	0.149	0.393
overall	0.34	0.37	0.37	0.38	0.38	0.004	<0.001	0.001	0.177

[1] Anti-gonadotropin releasing factor injections (Improvest, Zoetis Inc., Florham Park, NJ) given at 11.5 and 19 wk of age. Phase 1 diets were fed d 0 to 34, phase 2 diets were fed from d 35 to 62, and phase 3 diets were fed from d 63 to 112. The second injection was given at the start of phase 3 (d 63). The phase 3 Lys titration commenced 2 wk post second injection (d 77 to 112).
[2] The average BW of 2 consecutive weigh days.

Table 7. Effects of standardized ileal digestible Lys level on growth performance and feed efficiency of physically castrated pigs by dietary phase[1]

	Lys percent of NRC (2012) model estimated requirement						*P*-value		
Item	80%	90%	100%	110%	120%	SEM	linear	quadratic	cubic
No. of pens	5	6	6	6	6	-	-	-	-
Initial BW, kg[2]									
phase 1	32.1	32.1	32.2	32.2	32.2	0.08	0.509	0.991	0.912
phase 2	67.4	69.3	70.2	70.2	70.0	0.50	0.002	0.017	0.654
phase 3	95.6	100.6	102.5	102.2	102.7	0.88	<0.001	0.003	0.144
phase 3 Lys titration	107.0	113.8	115.5	116.1	117.3	1.12	<0.001	0.010	0.091
market[3]	130.1	139.5	140.3	139.9	141.6	1.09	<0.001	0.001	0.004
ADG, kg/d									
phase 1	1.01	1.07	1.08	1.08	1.08	0.016	0.005	0.024	0.529
phase 2	1.01	1.11	1.16	1.14	1.17	0.022	<0.001	0.019	0.132
phase 3[3]	0.73	0.88	0.86	0.86	0.89	0.019	<0.001	0.015	0.003
phase 3 Lys titration[3]	0.69	0.83	0.81	0.78	0.81	0.023	0.022	0.013	0.006
overall[3]	0.89	1.00	1.01	1.01	1.03	0.013	<0.001	0.001	0.011
ADFI, kg/d									
phase 1	2.39	2.36	2.49	2.37	2.33	0.036	0.278	0.057	0.440
phase 2	3.27	3.35	3.46	3.35	3.38	0.050	0.227	0.105	0.540
phase 3	3.12	3.31	3.24	3.21	3.28	0.054	0.236	0.298	0.052
phase 3 Lys titration	3.05	3.26	3.16	3.14	3.17	0.058	0.529	0.233	0.057
overall	2.93	3.00	3.05	2.97	2.99	0.036	0.441	0.097	0.326
G:F									
phase 1	0.41	0.44	0.43	0.45	0.46	0.005	<0.001	0.953	0.125
phase 2	0.31	0.34	0.34	0.35	0.35	0.004	<0.001	0.052	0.127
phase 3[3]	0.23	0.27	0.27	0.27	0.28	0.004	<0.001	0.012	0.007
phase 3 Lys titration[3]	0.23	0.26	0.26	0.25	0.26	0.006	0.008	0.025	0.030
overall[4]	0.30	0.33	0.33	0.34	0.34	0.003	<0.001	0.004	0.015

[1] Phase 1 diets were fed d 0 to 34, phase 2 diets were fed from d 35 to 62, and phase 3 diets were fed from d 63 to 112. The phase 3 Lys titration commenced 2 wk after the start of the third dietary phase (d 77 to 112).
[2] The average BW of 2 consecutive weigh dates.
[3] Quartic effect not significant ($P > 0.05$).
[4] Quartic effect significant ($P = 0.040$).

Table 8. Standardized ileal digestible Lys requirement (%) as determined by one-slope broken line regression and quadratic plateau regression models for immunologically castrated and physically castrated pigs

	Sex[1]							
	IC				PC			
	One-slope broken line		Quadratic plateau		One-slope broken line		Quadratic plateau	
Item	Require-ment	AIC	Require-ment	AIC	Require-ment	AIC	Require-ment	AIC
Phase 1 (~ 30 to 65 kg BW)								
ADG	1.03	-33.7	1.08	-33.0	0.86[2]			
G:F	0.99	-376.4	1.07	-64.5	0.86[2]			
Phase 2 (~ 65 to 100 kg BW)								
ADG	0.89	-41.5	0.97	-42.6	0.62	-40.4	0.69	-40.3
G:F	0.72[2]				0.58[2]			
Phase 3[3] (~ 115 to 140 kg BW)								
ADG	0.55[2]				0.47[2]			
G:F	0.55[2]				0.47[2]			

[1] IC = immunological castrate; PC = physical castrate.
[2] If the one-slope broken line regression produced a Hessian is singular statement, then the quadratic plateau model was not tested.
[3] For the Lys titration, performance was measured 2 wk post the start of the phase 3 (d 63) diet change which corresponded to 2 wk post second anti-gonadotropin releasing factor injection (Improvest, Zoetis Inc., Florham Park, NJ).

Table 9. Standardized ileal digestible (SID) Lys requirements for immunologically castrated and physically castrated pigs based on averaging the ADG and G:F requirements of the one slope broken line regression model

	Sex[1]	
	IC	PC
Item		
Phase 1 (~ 30 to 65 kg BW)		
g SID Lys/d	20.2	20.7
mg SID Lys/g PD[2]	115.4	133.5
g SID Lys/Mcal ME	3.04	2.60
g SID Lys/Mcal NE	4.05	3.45
mg SID Lys/g gain	20.2	19.7
Phase 2 (~65 to 100 kg BW)		
g SID Lys/d	22.7	20.2
mg SID Lys/g PD	129.6	144.3
g SID Lys/Mcal ME	2.40	1.79
g SID Lys/Mcal NE	3.16	2.34
mg SID Lys/g gain	19.4	18.5
Phase 3[3] (~ 115 to 140 kg BW)		
g SID Lys/d	19.8	14.9
mg SID Lys/g PD	123.8	99.3
g SID Lys/Mcal ME	1.63	1.40
g SID Lys/Mcal NE	2.13	1.82
mg SID Lys/g gain	19.9	19.6

[1] IC = immunological castrate; PC = physical castrate.
[2] PD = protein deposited. The estimates of PD were obtained by entering in values for feed intake, initial and final BW, and days into the NRC modeling program. The PD value was adjusted so that the model's predicted values closely matched the observed ones from a previous experiment (Elsbernd et al., 2015).
[3] For the Lys titration, performance was measured 2 wk post the start of the phase 3 (d 63); diet change which corresponded to 2 wk post second anti-gonadotrophin releasing factor injection (Improvest, Zoetis Inc., Florham Park, NJ).

Table 10. Effects of sex on ADFI 1 wk before and 4 wk post second anti-gonadotropin releasing factor injection

Item	Sex[1]		SEM	P-value	% IC of PC
	IC ADFI	PC ADFI			
No. of pens	30	29	-	-	-
Day in relation to second injection					
-7 (wk before)[2]	2.91[b]	3.52[a]	0.045	<0.001	83
1-2	2.83[b]	3.36[a]	0.044	<0.001	84
3-4	2.89[b]	3.50[a]	0.049	<0.001	83
5-6	2.97[b]	3.46[a]	0.077	<0.001	86
7-8	3.01[b]	3.21[a]	0.050	0.009	94
9-10	3.36	3.46	0.059	0.193	97
11-12	3.66	3.52	0.075	0.193	104
13-14	3.55[a]	3.31[b]	0.061	0.007	107
15-21	3.74[a]	3.39[b]	0.047	<0.001	110
22-28	3.86[a]	3.37[b]	0.047	<0.001	115

[ab] Within a row, means without a common superscript differ ($P < 0.05$).

[1] IC = immunological castrate; PC = physical castrate.

[2] BW was not significantly different between sexes ($P > 0.05$).

Table 11. Effects of standardized ileal digestible Lys level on apparent total tract digestibility (ATTD)[1] of GE and gross and digestible energy of diets fed to immunologically castrated pigs by dietary phase (DM basis)

	Lys percent of NRC (2012) model estimated requirement						*P*-value		
Item	80%	90%	100%	110%	120%	SEM	linear	quadratic	cubic
No. of pens	6	6	6	6	6	-	-	-	-
Phase 1[2]									
ATTD, %									
GE	81.0	80.7	80.8	83.0	83.0	0.55	0.002	0.231	0.127
Energy, Mcal/kg DM									
GE	4.35	4.37	4.41	4.46	4.46	-	-	-	
DE	3.53	3.53	3.56	3.70	3.71	0.024	< 0.001	0.275	0.055
Phase 2[3]									
ATTD, %									
GE	82.8	84.9	83.6	85.1	85.0	0.44	0.005	0.336	0.188
Energy, Mcal/kg DM									
GE	4.32	4.35	4.37	4.41	4.43	-	-	-	
DE	3.58	3.70	3.66	3.75	3.77	0.019	< 0.001	0.393	0.163
Phase 3[4]									
ATTD, %									
GE	86.8	87.2	86.7	87.8	88.2	0.33	0.003	0.181	0.948
Energy, Mcal/kg DM									
GE	4.30	4.38	4.37	4.43	4.44	-	-	-	
DE	3.74	3.82	3.79	3.89	3.92	0.015	< 0.001	0.798	0.291

[1] ATTD (%) = 100 – [(100 × diet concentration of TiO_2 × fecal concentration of component) / (fecal concentration of TiO_2 × feed concentration of component)] (Oresanya et al., 2007).
[2] Feces collected on d 23 to 25 during phase 1.
[3] Feces collected on d 51 to 53 during phase 2.
[4] Feces collected on d 93 to 95 during phase 3; collection started 30 d post second anti-gonadotropin releasing factor injection (Improvest, Zoetis Inc., Florham Park, NJ).

Table 12. Effects of standardized ileal digestible Lys level on apparent total tract digestibility (ATTD)[1] of GE and gross and digestible energy of diets fed to physically castrated pigs by dietary phase (DM basis)

	Lys percent of NRC (2012) model estimated requirement						*P*-value		
Item	80%	90%	100%	110%	120%	SEM	linear	quadratic	cubic
No. of pens	5	6	6	6	6	-	-	-	
Phase 1[2]									
ATTD, %									
GE	82.1	80.7	80.9	82.1	80.5	0.69	0.383	0.745	0.058
Energy, Mcal/kg DM									
GE	4.30	4.33	4.36	4.39	4.40	-	-		
DE	3.54	3.50	3.53	3.58	3.53	0.030	0.460	0.913	0.073
Phase 2[3]									
ATTD, %									
GE	84.3	83.4	83.3	84.4	84.8	0.65	0.383	0.137	0.519
Energy, Mcal/kg DM									
GE	4.29	4.30	4.38	4.40	4.42	-	-		
DE	3.61	3.58	3.64	3.71	3.75	0.028	<0.001	0.218	0.191
Phase 3[4]									
ATTD, %									
GE[5]	87.4	87.7	89.0	87.4	86.6	0.48	0.262	0.012	0.866
Energy, Mcal/kg DM									
GE	4.29	4.32	4.33	4.36	4.46	-	-		
DE	3.75	3.79	3.85	3.82	3.87	0.021	0.002	0.350	0.328

[1] ATTD (%) = 100 – [(100 × diet concentration of TiO_2 × fecal concentration of component) / (fecal concentration of TiO_2 × feed concentration of component)] (Oresanya et al., 2007).
[2] Feces collected on d 23 to 25 during phase 1.
[3] Feces collected on d 52 to 53 during phase 2.
[4] Feces collected on d 93 to 95 during phase 3.