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Evaluation of the standardized ileal digestible lysine requirement of nursery pigs from 28 to 63 d of age in a three-phase feeding program

Avaliação da exigência de lisina digestível de leitões na fase de creche dos 28 a 63 dias de idade em programa de alimentação trifásico

Diego de Ávila Martins Braga[1*]; Juarez Lopes Donzele[2]; Rita Flávia Miranda de Oliveira Donzele[2]; Matheus Faria de Sousa[3]; Evandro Ferreira Cardoso[4]; Igor de Freitas Donzeles[5]; João Paulo de Oliveira[1]; Jessica Mansur Siqueira Furtado[1]

Abstract

The objective of this study was to determine the standardized ileal digestible lysine (SID Lys) requirement of nursery pigs from 28 to 63 d of age fed a multi-phase feeding (PF) program and its possible adaptation to SID Lys-deficient diets. Ninety-six commercial hybrid piglets (Topigs Norsvin, 46 castrated males and 50 females) that had been weaned at 28 d of age with an initial body weight of 8.82 ± 0.28 kg were distributed in a randomized block design composed of four treatments, with eight replicates per treatment and three animals per replicate. The treatments were as follows: PF1, SID Lys levels of 1.05, 0.95, and 0.85%; PF 2, SID Lys levels of 1.15, 1.05, and 0.95%; PF 3, SID Lys levels of 1.25, 1.15, and 1.05%; and PF 4, SID Lys levels of 1.35, 1.25, and 1.15% from 28 to 35, 36 to 49, and 50 to 63 d of age, respectively. From 28 to 63 d of age, the average daily feed intake (ADFI) and average daily gain (ADG) were not affected by the SID Lys levels tested; however, final body weight (fBW) was affected, with PF1 having the lowest fBW. The SID Lys levels tested had a significant effect on the feed conversion ratio (FCR), which varied linearly from 28 to 35 d of age. In the period from 28 to 63 d of age, pigs fed PF4 had the highest FCR results. The protein deposition ratio (PDR) was also affected by the SID Lys levels tested, with PF3 and PF4 having the highest PDR results. Therefore, the optimal SID Lys requirement for nursery pigs from 28 to 35 d of age that provided better performance results was 1.25%, corresponding to a daily Lys intake of 4.13 g/d. PF3 provided the best performance and PDR results for piglets from 28 to 63 days of age.

Key words: Amino acid. Compensatory growth. Nutritional requirement. Tissue deposition.

Resumo

O objetivo deste estudo foi determinar a exigência de lisina digestível (LD) de leitões na fase de creche dos 28 aos 63 dias de idade alimentados com plano nutricional (PN) multifásico e sua possível adaptação às dietas deficientes em LD. Para este propósito, um total de noventa e seis leitões híbridos

[1] Drs. em Zootecnia, Programa de Pós-Graduação em Zootecnia, Universidade Federal de Viçosa, UFV, Viçosa, MG, Brasil. E-mail: dmartins2110@gmail.com; jpzooufv@hotmail.com; jessicasiq@gmail.com

[2] Profs. Drs., UFV, Departamento de Zootecnia, Viçosa, MG, Brasil. E-mail: donzele@ufv.br; flavia@ufv.br

[3] Drs., Proteinorte Alimentos S.A., Linhares, ES, Brasil. E-mail: matheus.souza@proteinorte.com.br

[4] Prof. Dr., Instituto Federal de Educação, Ciência e Tecnologia Baiano, Campus Itaberaba, Itaberaba, BA, Brasil. E-mail: evandro.cardoso@ifbaiano.edu.br

[5] M.e em Zootecnia, Programa de Pós-Graduação em Zootecnia, UFV, Viçosa, MG, Brasil. E-mail: igor.donzeles@gmail.com

[*] Author for correspondence

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comerciais (Topigs Norsvin), quarenta e seis machos castrados e cinquenta fêmeas, desmamados aos 28 dias de idade, com peso corporal inicial de 8,82 ± 0,28 kg, foram distribuídos em um delineamento em blocos ao acaso composto por quatro tratamentos (Trt), com oito repetições por Trt, e três animais por repetição. Os Trts foram: PN1. Níveis de LD de 1,05; 0,95; e 0,85%, PN2. Níveis de LD de 1,15; 1,05; e 0,95%, PN3. Níveis de LD de 1,25; 1,15; e 1,05%, e PN4. Níveis de LD de 1,35; 1,25; e 1,15%, respectivamente, para as fases compreendidas de 28 a 35, 36 a 49, e 50 a 63 dias de idade. De 28 a 63 dias de idade, a ingestão diária média de alimento (IDMA) e o ganho médio diário (GMD) não foram afetados pelos níveis testados de LD o peso corporal final (PCF) dos leitões foi afetado, PN1 apresentando o menor PCF. Os níveis de LD testados apresentaram um efeito significativo sobre a conversão alimentar (CA), que variou linearmente de 28 a 35 dias de idade. No período de 28 a 63 dias de idade, os leitões alimentados com PN4 apresentaram os maiores resultados de CA. A taxa de deposição de proteína (TDP) também foi afetada pelos níveis de LD testados, com PN3 e PN4 apresentando os maiores resultados para TDP. Portanto, a exigência de LD para leitões na fase de creche dos 28 aos 35 dias de idade que proporcionou os melhores resultados de desempenho foi de 1,25%, correspondendo ao consumo diário de lisina de 4,13 g. PN3 forneceu os melhores resultados de desempenho e TDP para leitões dos 28 aos 63 dias de idade.
Palavras-chave: Aminoácidos. Deposição tecidual. Exigência nutricional. Ganho compensatório.

Introduction

Lysine is the first limiting amino acid in corn-soybean meal-based diets for pigs during the post-weaning period (ROSTAGNO et al., 2011; NRC, 2012), and is commonly used as a reference when estimating the nutritional requirement for other essential amino acids (NEMECHEK et al., 2012). The standardized ileal digestible lysine (SID Lys) requirement of pigs is affected by several factors, such as genotype (TAYLOR et al., 2012), the environmental and sanitary conditions of the production system (KORNEGAY et al., 1993; MANNO et al., 2005), the dietary protein level (KERR and EASTER, 1995; RENAUDEAU; NOBLET, 2001), and the piglets' age at weaning (TRINDADE NETO et al., 2002). Therefore, as piglets' dietary SID Lys requirements vary, their levels should be monitored continuously, sequentially and independently of the feedstuff lysine added to the diet.

The SID Lys levels estimated by Rostagno et al. (2017) for piglets are 1.35, 1.25, and 1.13% from 28 to 35, 35 to 49, and 49 to 63 d of age, respectively. Taylor et al. (2012) stated that few studies have estimated high-performance-piglets' SID Lys requirements immediately after weaning, and the SID Lys levels recommended by Rostagno et al. (2011, 2017) for modern lines may be inadequate for maximizing post-weaned piglets' productive performance.

Many studies have reported increased lysine metabolism efficiency for growth when pigs are subjected to a period of moderate lysine restriction during the grower phase (CHIBA et al., 2002; FABIAN et al., 2002); however, few studies have evaluated moderate SID Lys restriction during the early post-weaning phase (NEMECHEK et al., 2012).

Several studies have investigated lysine requirements during specific phases (FONTES et al., 2005; HILL et al., 2007; SCHNEIDER et al., 2010; NEMECHEK et al., 2012; KAHINDI et al., 2017), however little information exists regarding SID Lys requirements in multi-phase feeding (PF) programs, or possible adaptation to lysine-deficient diets.

Therefore, in order to better understand post-weaned piglet nutrition, this study was designed to evaluate the effects of different SID Lys levels on the performance and carcass composition of weaned piglets fed a three-phase feeding program from 28 to 63 d of age.

Material and Methods

The protocol used in this study was reviewed and approved by the Animal Care and Use Committee of the Universidade Federal Viçosa (36/2012), and complied with the ethical principles of animal experimentation defined by the Colégio Brasileiro de Experimentação Animal (COBEA, 1991). The trial was conducted in the swine experimental facility at the Universidade Federal de Viçosa, Viçosa, Minas Gerais, Brazil.

Ninety-six commercial hybrid piglets (Topigs Norsvin, 46 castrated males and 50 females) that had been weaned at 28 d of age with an initial body weight of 8.82 ± 0.28 kg were allotted in suspended cages (1.6 x 1.02 x 1.1 m) based on their initial body weights. The experimental unit was each suspended cage, and in the block-formation the piglets' initial body weight was considered as criterion. Three weaned piglets were housed in each suspended cage, which was equipped with water nipples and semi-automatic feeders. All of the animals' were considered for growth-performance.

The animals were distributed in a randomized block design composed of four treatments, with eight replicates of three animals each. Each treatment consisted of a standard three-phase feeding (PF) program, including pre-starter I (28 to 35 d), pre-starter II (35 to 49 d), and starter (49 to 63 d) phases. The treatments were as follows: PF 1, SID Lys levels of 1.05, 0.95, and 0.85%; PF 2, SID Lys levels of 1.15, 1.05, and 0.95%; PF 3, SID Lys levels of 1.25, 1.15, and 1.05%; and PF 4, SID Lys levels of 1.35, 1.25, and 1.15% from 28 to 35, 35 to 49, and 49 to 63 d of age, respectively (Table 1, 2, and 3).

The experimental diets were corn-soybean meal-based, and were supplemented with minerals, vitamins, and synthetic amino acids in order to meet or exceed the nutritional requirement of high genetic potential for lean-meat-deposition piglets (7 to 30 kg) according to Rostagno et al. (2011) recommendations, except for SID Lys. For each phase, a basal diet was mixed, and lysine hydrochloride was added, replacing the inert, in order to achieve the desired SID Lys concentrations in the final diets.

The ratio of each essential amino acid to lysine was verified in all the experimental diets, and amino acids were added to the diets in place of inert, whenever necessary to ensure that no essential amino acids were limiting. When choosing the amino acid ratios, we followed the recommendations of Rostagno et al. (2011). Food and water were provided *ad libitum* throughout the experimental period.

The environmental conditions (temperature and relative air humidity) inside the heated nursery were monitored three times daily (7 am, 12 am, and 5 pm) using dry bulb, wet bulb, and black globe thermometers (Incoterm Ind. de Thermometers Ltda., Porto Alegre, Rio Grande do Sul, Brazil) that had been placed in an empty suspended cage located in the center of the piglet shed, at half the height of the animals' bodies. The data obtained were converted into the black globe temperature and humidity (BGTH) index, as proposed by Buffington et al. (1981), in order to characterize the thermal environment to which the animals were exposed. Thermal variations were also measured daily (7:00 am) using maximum-minimum thermometers (Incoterm Ind. de Thermometers Ltda., Porto Alegre, Rio Grande do Sul, Brazil).

All piglets were weighed at the beginning of the experimental period (day 28), day 35, day 49, and at the end of the experimental period (day 63) to determine average daily gain (ADG). Average daily feed intake (ADFI) during the different periods was calculated as the difference between the total feed supplied, orts and wastes collected from the floor. The feed conversion ratio (FCR) was calculated based on the ADFI and ADG.

At the end of the experimental period, the animals were fasted for 12 h and then weighed. One animal from each experimental unit weighting closest to the pen average was slaughtered according to Brazilian legislation (BRASIL, 2000). Whole carcasses, including feet and heads, were weighed and sectioned in half. The right half of each carcass was weighed and stored in a freezer (Metalfrio DA420) at -12 ºC.

Table 1. Ingredients and nutritional composition of experimental diets fed to piglets from 28 to 35 d of age.

Ingredient, %	SID Lys level[A], %			
	1.05	1.15	1.25	1.35
Corn, 7.8% CP	54.239	54.239	54.239	54.239
Soybean meal, 45% CP	20.000	20.000	20.000	20.000
Soybean oil	0.857	0.857	0.857	0.857
Micronized soybean	6.266	6.266	6.266	6.266
Whey powder[B]	11.111	11.111	11.111	11.111
Spray-dried plasma[C]	4.000	4.000	4.000	4.000
Dicalcium phosphate	1.226	1.226	1.226	1.226
Limestone	0.757	0.757	0.757	0.757
Salt	0.123	0.123	0.123	0.123
Growth promoter[D]	0.125	0.125	0.125	0.125
Zinc oxide	0.340	0.340	0.340	0.340
L-Lysine HCl, 78%	-	0.128	0.256	0.385
DL-Methionine, 99%	-	0.046	0.104	0.149
L-Threonine, 98.5%	-	0.007	0.071	0.135
L-Tryptophan, 99%	-	-	0.002	0.020
L-Isoleucine, 99%	-	-	-	0.005
L-Valine, 96.5%	-	-	-	0.052
Vitamin premix[E]	0.100	0.100	0.100	0.100
Mineral premix[F]	0.100	0.100	0.100	0.100
Inert[G]	0.746	0.565	0.313	0.000
Antioxidant[H]	0.010	0.010	0.010	0.010
Calculated nutritional composition[I]				
ME, Mcal/kg	3,391	3,393	3,396	3,400
Crude protein	20.06	20.20	20.40	20.64
SID lysine	1.05	1.15	1.25	1.35
Digestible tryptophan	0.22	0.22	0.23	0.24
Digestible threonine	0.72	0.72	0.79	0.85
Digestible Met + Cys	0.60	0.64	0.70	0.75
Digestible isoleucine	0.73	0.73	0.73	0.74
Digestible valine	0.88	0.88	0.88	0.93
Lactose	8.00	8.00	8.00	8.00
Calcium	0.750	0.750	0.750	0.750

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Non-phytate phosphorus	0.410	0.410	0.410	0.410
Sodium	0.230	0.230	0.230	0.230

[A] SID Lys, standardized ileal digestible lysine.
[B] Prius L71 (Auster Nutrição Animal Ltda., Hortolândia, SP, Brazil). Supplied per kg of product: lactose, 71.5%.
[C] AP301 (APC do Brasil Ltda., Chapecó, SC, Brazil).
[D] Tilosin S (MCassab Ltda., São Paulo, SP, Brazil). Supplied per kg of product: tylosin phosphate, 100 g; sulfadimidine, 100 g.
[E] Provides per kg of the complete diet: folic acid, 3 mg; pantothenic acid, 10 mg; biotin, 0.2 mg; niacin, 30 mg; selenium, 0.3 mg; retinyl acetate, 10,000 IU; cyanocobalamin, 30 mg; cholecalciferol, 2,000 IU; DL-α-tocopheryl acetate, 50 IU; menadione sodium bisulfite, 2 mg; thiamin, 2 mg; riboflavin, 6 mg; pyridoxine, 3 mg; and antioxidant, 5 mg.
[F] Provides per kg of the complete diet: 160.68 mg of Ca (as $Ca(HCO_2)_2$); 1 mg of Co (as $CoSO_4.7H_2O$); 10 mg of Cu (as $CuSO_4$); 100 mg of Fe (as $FeSO_4$); 1.5 mg of I (as $Ca(IO_3)_2$); 40 mg of Mn (as $MnSO_4$); and 100 mg of Zn (as $ZnSO_4$).
[G] Corn starch (Maizena®) (Unilever Bestfoods, Mogi Guaçu, SP, Brazil).
[H] Butylated hydroxytoluene (BHT) (EMFAL Especialidades Químicas, Betim, MG, Brazil). Supplied per kg of diet: butylated hydroxytoluene, 99 mg (as $C_{15}H_{24}O$).
[I] According to Rostagno et al. (2011).

Table 2. Ingredients and nutritional composition of experimental diets fed to piglets from 35 to 49 d of age.

Ingredient, %	SID Lys level[A], %			
	0.95	1.05	1.15	1.25
Corn, 7.8% CP	59.738	59.738	59.738	59.738
Soybean meal, 45% CP	25.000	25.000	25.000	25.000
Soybean oil	0.625	0.625	0.625	0.625
Micronized soybean	2.067	2.067	2.067	2.067
Whey powder[B]	6.944	6.944	6.944	6.944
Spray-dried plasma[C]	2.000	2.000	2.000	2.000
Dicalcium phosphate	1.395	1.395	1.395	1.395
Limestone	0.724	0.724	0.724	0.724
Salt	0.303	0.303	0.303	0.303
Growth promoter[D]	0.090	0.090	0.090	0.090
Zinc oxide	0.200	0.200	0.200	0.200
L-Lysine HCl, 78%	-	0.128	0.256	0.385
DL-Methionine, 99%	-	0.025	0.083	0.140
L-Threonine, 98.5%	-	-	0.059	0.123
L-Tryptophan, 99%	-	-	-	0.016
L-Valine, 96.5%	-	-	-	0.040
Vitamin premix[E]	0.100	0.100	0.100	0.100
Mineral premix[F]	0.100	0,100	0.100	0,100
Inert[G]	0,704	0,551	0,306	0,000
Antioxidant[H]	0.010	0.010	0.010	0.010
Calculated nutritional composition[I]				
ME, Mcal/kg	3,292	3,294	3,296	3,300

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Crude protein	19.11	19.24	19.42	19.66
SID lysine	0.95	1.05	1.15	1.25
Digestible tryptophan	0.21	0.21	0.21	0.23
Digestible threonine	0.67	0.67	0.72	0.79
Digestible Met + Cys	0.56	0.59	0.64	0.70
Digestible isoleucine	0.71	0.71	0.71	0.71
Digestible valine	0.82	0.82	0.82	0.86
Lactose	5.00	5.00	5.00	5.00
Calcium	0.750	0.750	0.750	0.750
Non-phytate phosphorus	0.410	0.410	0.410	0.410
Sodium	0.230	0.230	0.230	0.230

[A] SID Lys, standardized ileal digestible lysine.
[B] Prius L71 (Auster Nutrição Animal Ltda., Hortolândia, SP, Brazil). Supplied per kg of product: lactose, 71.5%.
[C] AP301 (APC do Brasil Ltda., Chapecó, SC, Brazil).
[D] Tilosin S (MCassab Ltda., São Paulo, SP, Brazil). Supplied per kg of product: tylosin phosphate, 100 g; sulfadimidine, 100 g.
[E] Provides per kg of the complete diet: folic acid, 3 mg; pantothenic acid, 10 mg; biotin, 0.2 mg; niacin, 30 mg; selenium, 0.3 mg; retinyl acetate, 10,000 IU; cyanocobalamin, 30 mg; cholecalciferol, 2,000 IU; DL-α-tocopheryl acetate, 50 IU; menadione sodium bisulfite, 2 mg; thiamin, 2 mg; riboflavin, 6 mg; pyridoxine, 3 mg; and antioxidant, 5 mg.
[F] Provides per kg of the complete diet: 160.68 mg of Ca (as $Ca(HCO_2)_2$); 1 mg of Co (as $CoSO_4.7H_2O$); 10 mg of Cu (as $CuSO_4$); 100 mg of Fe (as $FeSO_4$); 1.5 mg of I (as $Ca(IO_3)_2$); 40 mg of Mn (as $MnSO_4$); and 100 mg of Zn (as $ZnSO_4$).
[G] Corn starch (Maizena®) (Unilever Bestfoods, Mogi Guaçu, SP, Brazil).
[H] Butylated hydroxytoluene (BHT) (EMFAL Especialidades Químicas, Betim, MG, Brazil). Supplied per kg of diet: butylated hydroxytoluene, 99 mg (as $C_{15}H_{24}O$).
[I] According to Rostagno et al. (2011).

Table 3. Ingredients and nutritional composition of experimental diets fed to piglets from 49 to 63 d of age.

Ingredient, %	SID Lys level[A], %			
	0.85	0.95	1.05	1.15
Corn, 7.8% CP	66.603	66.603	66.603	66.603
Soybean meal, 45% CP	28.747	28.747	28.747	28.747
Soybean oil	0.844	0.844	0.844	0.844
Dicalcium phosphate	1.658	1.658	1.658	1.658
Limestone	0.676	0.676	0.676	0.676
Salt	0.531	0.531	0.531	0.531
Growth promoter[B]	0.090	0.090	0.090	0.090
L-Lysine HCl, 78%	-	0.128	0.256	0.385
DL-Methionine, 99%	-	0.006	0.063	0.120
L-Threonine, 98.5%	-	-	0.044	0.108
L-Tryptophan, 99%	-	-	-	0.010
L-Valine, 96.5%	-	-	-	0.018

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Vitamin premix[C]	0.100	0.100	0.100	0.100
Mineral premix[D]	0.100	0.100	0.100	0.100
Inert[E]	0.704	0.551	0.306	0.000
Antioxidant[F]	0.010	0.010	0.010	0.010
Calculated nutritional composition[G]				
ME, Mcal/kg	3,223	3,224	3,226	3,230
Crude protein	18.29	18.36	18.54	18.75
SID lysine	0.85	0.95	1.05	1.15
Digestible tryptophan	0.20	0.20	0.20	0.21
Digestible threonine	0.62	0.62	0.66	0.72
Digestible Met + Cys	0.53	0.53	0.59	0.64
Digestible isoleucine	0.70	0.70	0.70	0.70
Digestible valine	0.78	0.78	0.78	0.79
Calcium	0.750	0.750	0.750	0.750
Non-phytate phosphorus	0.41	0.41	0.41	0.41
Sodium	0.230	0.230	0.230	0.230

[A] SID Lys, standardized ileal digestible lysine.
[B] Tilosin S (MCassab Ltda., São Paulo, SP, Brazil). Supplied per kg of product: tylosin phosphate, 100 g; sulfadimidine, 100 g.
[C] Provides per kg of the complete diet: folic acid, 3 mg; pantothenic acid, 10 mg; biotin, 0.2 mg; niacin, 30 mg; selenium, 0.3 mg; retinyl acetate, 10,000 IU; cyanocobalamin, 30 mg; cholecalciferol, 2,000 IU; DL-α-tocopheryl acetate, 50 IU; menadione sodium bisulfite, 2 mg; thiamin, 2 mg; riboflavin, 6 mg; pyridoxine, 3 mg; and antioxidant, 5 mg.
[D] Provides per kg of the complete diet: 160.68 mg of Ca (as $Ca(HCO_2)_2$); 1 mg of Co (as $CoSO_4.7H_2O$); 10 mg of Cu (as $CuSO_4$); 100 mg of Fe (as $FeSO_4$); 1.5 mg of I (as $Ca(IO_3)_2$); 40 mg of Mn (as $MnSO_4$); and 100 mg of Zn (as $ZnSO_4$).
[E] Corn starch (Maizena®) (Unilever Bestfoods, Mogi Guaçu, SP, Brazil).
[F] Butylated hydroxytoluene (BHT) (EMFAL Especialidades Químicas, Betim, MG, Brazil). Supplied per kg of diet: butylated hydroxytoluene, 99 mg (as $C_{15}H_{24}O$).
[G] According to Rostagno et al. (2011).

Six animals at 28 d of age with similar initial body weight of the experimental units were also slaughtered to evaluate body composition at the beginning of the experimental period, before being frozen for subsequent processing and analyses.

The right-half-carcasses were individually ground in a commercial meat grinder after defrosting. The ground material was then homogenized, and samples were pre-dried at 60 °C in a drying oven for 72 hours, pre-degreased in a Soxhlet apparatus for 4 h, dried again at 60 °C for 1 hour, and finally ground in a ball mill. Protein analyses were conducted using the 955.04 method (AOAC, 2000) and lipid levels were determined using the 960.39 method (AOAC, 2000) at the Laboratory of Animal Nutrition, Department of Animal Science, Universidade Federal de Viçosa. Protein and fat deposition were calculated as the difference between the carcass composition values obtained at 28 and 63 d of age.

Performance and carcass composition data from 28 to 63 d of age were analyzed in a randomized block design using the Proc GLM procedure in SAS (SAS Institute Inc., Cary, NC, USA). Treatment means were compared by Tukey's test. For 28 to 35 d of age, the data were analyzed using the Proc REG procedure in SAS (SAS Institute Inc., Cary, NC, USA). Significance was declared at $P < 0.05$.

Results and Discussion

During the experimental period, the temperature and relative air humidity were 25.9 ± 1.96 °C and 69 ± 9.1%, respectively, and the maximum and minimum temperatures and BGTH index were 27.0 ± 1.65 °C, 25.3 ± 1.55 °C, and 75.1 ± 2.3, respectively. Close and Stanier (1984) stated that an air temperature ranging from 23 to 28 °C is ideal for piglets from 28 to 63 d of age, and Alebrante et al. (2011) stated that a BGTH index value of 74.3 ± 1.79 characterize thermoneutrality for pigs from 15 to 30 kg, so we can infer that, in the present study, the animals were kept in a thermoneutral environment conditions.

The ADFI of weaned piglets fed a three-PF program was not significantly affected ($P > 0.05$) by the SID Lys levels tested, regardless of the phase analyzed (Table 4). Similar ADFI results were obtained by Kendall et al. (2008), Yang et al. (2009), Schneider et al. (2010), and Kim et al. (2001) while working with post-weaned piglets. However, Taylor et al. (2012) reported a significant voluntary FI reduction when piglets were fed the highest dietary lysine level tested (1.60%). This may be explained by the higher lysine level used by those authors, which was above the highest level used in the present study. According to Edmonds et al. (1987), excess protein, and, consequently, amino acids, in the diet may negatively affect FI in pigs.

The dietary energy level is the main factor that affects voluntary FI in pigs (YANG et al., 2009), so the absence of any ADFI variation in the present study may have been because the experimental diets were isoenergetic.

Consistent results obtained by a number of studies indicate that, from 28 to 63 d of age, piglet FI is little-affected by dietary nutritional composition. Stress during weaning causes functional and structural alterations in small intestine mucosa (SPREEUWENBERG et al., 2001; BOUDRY et al., 2004), induces mucosal inflammatory reactions (MCCRACKEN et al., 1999), and promotes an imbalance in the intestinal microflora (CASTILLO et al., 2007; BAUER et al., 2011), so we can also infer that it plays a major role in defining the piglet FI pattern in the first weeks post-weaning by making pigs less sensitive to nutritional variations, except for those associated with excess protein and amino acids. In addition, the thermal environment also affects the voluntary FI of pigs (COLLIN et al., 2001); however, in the present study, the thermal environment was characterized as thermoneutral, so it should not have affected the piglet FI pattern.

The average daily lysine intake (ADLI) significantly increased ($P < 0.05$) linearly from 28 to 35 d, and weaned piglets fed diets containing the highest lysine levels, consequently, ingested larger quantities of this amino acid (Table 4). These results are in accordance with those obtained by Kim et al. (2001), Taylor et al. (2012), and Nemechek et al. (2012).

The SID Lys levels tested had no significant effect on the piglets' ADG ($P > 0.05$), regardless of the phase analyzed (Table 4). Despite not varying significantly, a gradual numeric increase was detected in absolute ADG between PF1 and PF3, being PF3 31.60, 13.40, and 9.50% higher from 28 to 35, 28 to 49, and 28 to 63 d of age, respectively. For the pre-starter I phase (28 to 35 d), the absence of a significant effect, despite the higher ADG variation, can be explained by the high coefficient of variation obtained (25.14%).

An improved growth rate in post-weaned piglets caused by an increased lysine concentration in the diet has also been reported by Yi et al. (2006), Kendall et al. (2008), Yang et al. (2009), and Kim et al. (2001). Although their results are qualitatively similar, the lysine levels estimated for obtaining a high ADG varied among studies due to several reasons, such as genotype (SCHNEIDER et al., 2010), facility sanitary status (GANDRA et al., 2012), thermal environment (CLOSE; STANIER, 1984), and the animals' social interactions (PLUSKE et al., 2003), which may compromise the expression of piglets genetic potential for growth.

Although the ADG did not vary significantly among the PF programs tested (P > 0.05), the PF1 animals had a significantly lower fBW than those in the other treatments at 63 d of age (P < 0.05). Considering the results obtained by Mahan and Lepine (1991) and Mahan et al. (1998), who reported a direct connection between body weight at weaning and at the end of the nursery phase with the body weight at 150 d of age, we can infer that the subsequent performance of animals fed PF1 could be compromised.

From 28 to 35 d of age, the dietary SID Lys level significantly affected piglets FCR (P < 0.05), which increased linearly, but no significant difference was found between the two highest SID Lys levels tested (1.25 and 1.35%), demonstrating that 1.25% SID Lys meets weaned piglets' requirements for body weight gain (Table 4). A positive effect of dietary SID Lys levels on the FCR of post-weaned piglets was also reported by Nemechek et al. (2012) and Taylor et al. (2012).

From 28 to 49 d of age, despite no significant FCR variation (P > 0.05), PF3 FCR was 6.34% improved when compared to PF1. No significant differences in the FCR were found between animals fed PF3 and PF4.

During the entire experimental period (28 to 63 d of age), PF4 piglets had a significantly higher FCR than PF1 and PF2 piglets (P < 0.05), but not PF3 piglets (P > 0.05). A positive effect of SID Lys levels on piglet FCR during the nursery phase was also reported by Yi et al. (2006), Kendall et al. (2008), Yang et al. (2009), and Kim et al. (2001).

The improvement in the FCR observed in this study indicates that although piglet ADG did not significantly differ among the PF programs investigated, the gain composition may have changed, with an increase in the carcass protein deposited. Protein deposition carries a high amount of water, because it is closely associated with the protein present in lean tissue and visceral organs, so in general, protein deposition positively affects feed efficiency for body weight gain (DE LANGE et al., 2003).

The protein deposition rate (PDR) significantly differed among the PF programs tested (P < 0.05), with the highest values obtained in pigs fed PF3 and PF4, which were similar (P > 0.05) (Table 4). Similarly, Fontes et al. (2005) and Oliveira et al. (2006), when evaluating females and castrated males from 15 to 30 kg, observed a linear PDR increase due to increase in the SID Lys level concentration (0.90 to 1.36%).

However, the fat deposition rate (FDR) did not significantly differ among the PF programs tested (P>0.05), which contradicts the results obtained by Taylor et al. (2012). According to those authors, post-weaned piglets fed lysine-deficient diets would have a suboptimal PDR and, consequently, more energy available for FDR (TAYLOR et al., 2012).

Table 4. Effects of different standardized ileal digestible lysine (SID Lys) levels and phase-feeding (PF) programs on performance and carcass composition of piglets from 28 to 63 d of age.

Variable	Phase-feeding program				CV %	P-value
	PF1 1.05-0.95-0.85	PF2 1.15-1.05-0.95	PF3 1.25-1.15-1.05	PF4 1.35-1.25-1.15		
28 to 35 d						
iBW, kg	8.85	8.81	8.80	8.80	1.10	0.644
fBW, kg	10.49	10.56	10.96	10.72	3.64	0.106
ADFI, g/day	292	294	330	297	17.33	0.437
ADLI[1], g/day	3.06	3.39	4.13	4.00	17.43	<0.01
ADG, g/day	234	249	308	274	25.14	0.073
FCR[1]	1.30	1.18	1.09	1.08	13.49	<0.01
28 to 49 d						
fBW, kg	18.09	18.56	19.28	19.04	4.95	0.080
ADFI, g/day	625	643	663	647	9.97	0.693
ADG, g/day	440	464	499	488	9.30	0.062
FCR	1.42	1.38	1.33	1.33	5.18	0.053
28 to 63 d						
fBW, kg	27.90[b*]	28.40[b]	29.69[a]	29.61[a]	4.79	0.040
ADFI, g/day	843	873	871	845	8.33	0.751
ADG, g/day	544	572	596	594	7.23	0.070
FCR	1.55a	1.52a	1.46ab	1.41b	5.17	<0.01
Tissue deposition rate g/day						
PDR	61.15[b]	62.02[b]	70.52[a]	70.69[a]	11.66	<0.01
FDR	58.58	59.33	61.67	57.27	15.08	0.560

[*] Values followed by different letters in the same row were significantly different according to a Tukey's test ($P < 0.05$).
CV, coefficient of variation; iBW, initial body weight; fBW, final body weight; ADFI, average daily feed intake; ADLI, average daily lysine intake; ADG, average daily gain; FCR, feed conversion ratio; PD, protein deposition; FD, fat deposition.
[1]Linear effect ($P < 0.05$): $\hat{Y}_{ADLI} = 2.755 + 0.356X$ ($R^2 = 0.82$); $\hat{Y}_{FCR} = 2.069 – 0.756X$ ($R^2 = 0.88$).

Conclusion

From 28 to 35 d of age, a 1.25% SID Lys level, which corresponds to an estimated ADLI of 4.13 g/d, meets the requirements for better performance in post-weaned piglets. The PF3 treatment, corresponding to SID Lys levels of 1.25, 1.15, and 1.05% from 28 to 35, 35 to 49, and 49 to 63 d of age, respectively, provided the best performance and PDR results of post-weaned piglets from 28 to 63 d of age.

References

ALEBRANTE, L.; DONZELE, J. L.; Oliveira, R. F. M.; SARAIVA, A.; GUIMARÃES, S. E. F.; FERREIRA, A. S. Níveis de fósforo disponível em rações para suínos de alto potencial genético para deposição de carne magra mantidos em ambiente de termoneutro dos 15 aos 30 kg. *Revista Brasileira de Zootecnia*, Viçosa, v. 40, n. 2, p. 323-330, 2011.

ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS - AOAC. Official Methods of Analysis of AOAC International. 17th ed. AOAC International, USA, 2000.

BAUER, E.; METZLER-ZEBELI, B. U.; VERSTEGEN, M. W. A.; MOSENTHIN, R. Intestinal gene expression in pigs: effects of reduced feed intake during weaning and potential impact of dietary components. *Nutrition Research Reviews*, Bethesda, v. 24, n. 2, p. 155-175, 2011.

BOUDRY, G.; PÉRON, V.; LE HUEROU-LURON, I.; LALLÈS, J. P.; SÈVE, B. Weaning induces both transient and long-lasting modifications of absorptive, secretory and barrier properties of piglet intestine. *Journal of Nutrition*, Rockville, v. 134, n. 9, p. 2256-2262, 2004.

BRASIL. Ministério da Agricultura. Instrução Normativa no. 3, de 17 de janeiro de 2000. Regulamento técnico de métodos de insensibilização para o abate humanitário de animais de açougue. *Diário Oficial [da] União*, Brasília, 2000. p. 14-16.

BUFFINGTON, D. E.; COLLAZO-AROCHO, A.; CANTON, G. H. Black globe humidity index (BGHI) as comfort equation for dairy cows. *Transaction of American Society of Agricultural Engineering*, Saint Joseph, v. 24, n. 3, p. 711-714, 1981.

CASTILLO, M.; MARTÍN-ORÚE, S. M.; NOFRARÍAS, M.; MANZANILLA, E. G.; GASA, J. Changes in caecal microbiota and mucosal morphology of weaned pigs. *Veterinary Microbiology*, Geneva, v. 124, n. 3-4, p. 239-247, 2007.

CHIBA, L. I.; KUHLERS, D. L; FROBISH, L. T. Effect of dietary restrictions on growth performance and carcass quality of pigs selected for lean growth efficiency. *Livestock Production Science*, Amsterdam, v. 74, n. 1, p. 93-102, 2002.

CLOSE, W. H.; STANIER, M. W. Effects of plane of nutrition and environmental temperature on the growth and development of the early-weaned piglet. 1. Growth and body composition. *Animal Production*, Central Java, v. 38, n. 2, p. 211-220, 1984.

COLÉGIO BRASILEIRO DE EXPERIMENTAÇÃO ANIMAL - COBEA. Princípios éticos na experimentação animal. São Paulo: Congresso do Colégio Brasileiro de Experimentação Animal, 1991. 1 p.

COLLIN, A.; VAN MILGEN, J.; DUBOIS, S.; NOBLET, J. Effect of high temperature on feeding behaviour and heat production in group-housed pigs. *British Journal of Nutrition*, Rockville, v. 86, n. 1, p. 63-70, 2001.

DE LANGE, C. F. M.; MOREL, P. C. H.; BIRKETT, S. H. Modeling chemical and physical body composition of the growing pig. *Journal of Animal Science*, Champaign, v. 81, n. 14, p. E159-E165, 2003.

EDMONDS, M. S.; GONYOU, H. W.; BAKER, D. H. Effect of excess levels of methionine, tryptophan, arginine, lysine or threonine on growth and dietary choice in the pig. *Journal of Animal Science*, Champaign, v. 65, n. 1, p. 179-185, 1987.

FABIAN, J.; CHIBA, L. I.; KUHLERS, D. I.; FROBISH, L. T.; NADARAJAH, K.; KERTH, C. R.; MCELHENNEY, W. H.; LEWIS, A. J. Degree of amino acid restrictions during the grower phase and compensatory growth in pigs selected for lean growth efficiency. *Journal of Animal Science*, Champaign, v. 80, n. 10, p. 2610-2618, 2002.

FONTES, D. O.; DONZELE, J. L.; OLIVEIRA, R. F. M.; SILVA, F. C. O.; LOPES, D. C. Níveis de lisina para leitoas selecionadas geneticamente para deposição de carne magra na carcaça dos 15 aos 30 kg. *Revista Brasileira de Zootecnia*, Viçosa, v. 34, n. 1, p. 90-97, 2005.

GANDRA, E. R.; TRINDADE NETO, M. A.; BERTO, D. A.; BUDINO, F. E. L.; GANDRA, J. R.; SCHAMMASS, E.A. Digestible lysine levels in diets for pigs from 24 to 50 kg under sanitary segregation. *Revista Brasileira de Zootecnia*, Viçosa, v. 41, n. 9, p. 2039-2047, 2012.

HILL, G. M.; BAIDO, S. K.; CROMWELL, G. L.; MAHAN, D. C.; NELSSEN, J. L.; STEIN, H. H. Evaluation of sex and lysine during the nursery period. *Journal of Animal Science*, Champaign, v. 85, n. 6, p. 1453-1458, 2007.

KAHINDI, R. K.; HTOO, J. K.; NYACHOTI, C. M. Dietary lysine requirement for 7-16 kg pigs fed wheat-corn-soybean meal-based diets. *Journal of Animal Physiology and Animal Nutrition*, Berlin, v. 101, n. 1, p. 22-29, 2017.

KENDALL, D. C.; GAINES, A. M.; ALLEE, G. L. Commercial validation of the true ileal digestible lysine requirement for eleven- to twenty-seven-kilogram pigs. *Journal of Animal Science*, Champaign, v. 86, n. 2, p. 324-332, 2008.

KERR, B. J.; EASTER, R. A. Effect of feeding reduced protein, amino acid supplemented diets on nitrogen and energy balance in grower pigs. *Journal of Animal Science*, Champaign, v. 73, n. 10, p. 3000-3008, 1995.

KIM, S. W.; BAKER, D. H.; EASTER, R. A. Dynamic ideal protein and limiting amino acids for lactating sows: the impact of amino acid mobilization. *Journal of Animal Science*, Champaign, v. 79, n. 9, p. 2356-2366, 2001.

KORNEGAY, E. T.; LINDEMANN, M. D.; RAVINDRAN, V. Effects of dietary lysine levels on performance and immune response of weanling pigs housed at two floor space allowances. *Journal of Animal Science*, Champaign, v. 71, n. 3, p. 552-556, 1993.

MAHAN, D. C.; CROMWELL, G. L.; EWAN, R. C.; HAMILTON, C. R.; YEN, J. T. Evaluation of the feeding duration of a phase 1 nursery diet to three-week-old pigs of two weaning weights. *Journal of Animal Science*, Champaign, v. 76, n. 2, p. 578-583, 1998.

MAHAN, D. C.; LEPINE, A. J. Effect of pig weaning weight and associated nursery feeding programs on subsequent performance to 105 kilograms body weight. *Journal of Animal Science*, Champaign, v. 69, n. 4, p. 1370-1378, 1991.

MANNO, M. C.; OLIVEIRA, R. F. M.; DONZELE, J. L.; FERREIRA, A. S.; OLIVEIRA, W. P.; LIMA, K. R. S.; VAZ, R. G. M. V. Effect of thermal environment on performance of growing pigs from 15 to 30 kg. *Revista Brasileira de Zootecnia*, Viçosa, v. 34, n. 6, p. 1963-1970, 2005.

MCCRACKEN, B. A.; SPURLOCK, M. E.; ROOS, M. A.; ZUCKERMANN, F. A.; GASKINS, H. R. Weaning anorexia may contribute to local inflammation in the piglet small intestine. *Journal of Nutrition*, Rockville, v. 129, n. 3, p. 613-619, 1999.

NATIONAL RESEARCH COUNCIL - NRC. Nutrient requirements of swine. 11. ed. National Academy Press, Washington DC, USA, 2012.

NEMECHEK, J. E.; GAINES, A. M.; TOKACH, M. D. Evaluation of standardized ileal digestible lysine requirement of nursery pigs from seven to fourteen kilograms. *Journal of Animal Science*, Champaign, v. 90, n. 12, p. 4380-4390, 2012.

OLIVEIRA, A. L. S.; DONZELE, J. L.; OLIVEIRA, R. F. M.; ABREU, M. L. T.; FERREIRA, A. S.; SILVA, F. C. O.; HAESE, D. Dietary digestible lysine requirement of barrows with high genetic potential for lean gain in the carcass from 15 to 30 kg. *Revista Brasileira de Zootecnia*, Viçosa, v. 35, n. 6, p. 2338-2343, 2006.

PLUSKE, J. R.; LE DIVIDICH, J.; VERSTEGEN, M. W. A. *Weaning the pig*: concepts and consequences. (Ed.). The Netherlands: Wageningen Academic Publishers, 2003. 432 p.

RENAUDEAU, D.; NOBLET, J. Effects of exposure to high ambient temperature and dietary protein level on sow milk production and performance of piglets. *Journal of Animal Science*, Champaign, v. 79, n. 6, p. 1540-1548, 2001.

ROSTAGNO, H. S.; ALBINO, L. F. T.; DONZELE, J. L.; GOMES, P. C.; OLIVEIRA, R. F.; LOPES, D. C.; FERREIRA, A. S.; BARRETO, S. L. T.; EUCLIDES, R. F. *Tabelas brasileira para aves e suínos*: composição de alimentos e exigências nutricionais. 3. ed. Editora UFV, Viçosa, MG, Brasil, 2011. 252 p.

______. *Tabelas brasileira para aves e suínos*: composição de alimentos e exigências nutricionais. 4. ed. Editora UFV, Viçosa, MG, Brazil, 2017. 488 p.

SCHNEIDER, J. D.; TOKACH, M. D.; DRITZ, S. S; NELSSEN, J. L.; DEROUCHEY, J. M.; GOODBANG, R. D. Determining the effect of lysine:calorie ratio on growth performance of ten- to twenty-kilogram of body weight nursery pigs of two genotypes. *Journal of Animal Science*, Champaign, v. 88, n. 1, p. 137-146, 2010.

SPREEUWENBERG, M. A. M.; VERDONK, J. M. A. J.; GASKINS, H. R.; VERSTEGEN, M. W. A. Small intestine epithelial barrier function is compromised in pigs with low feed intake at weaning. *Journal of Nutrition*, Rockville, v. 131, n. 5, p. 1520-1527, 2001.

TAYLOR, A. E.; TOPLIS, P.; WELLOCK, I. J.; MILLER, H. M. The effects of genotype and dietary lysine concentration on the production of weaner pigs. *Livestock Science*, Amsterdam, v. 149, n. 1-2, p. 180-184, 2012.

TRINDADE NETO, M. A.; BARBOSA, H. P.; PETELINCAR, I. M. Dietas para leitões nas fases de creche e diferentes idades ao desmame**.** *Revista Brasileira de Zootecnia*, Viçosa, v. 31, n. 2, p. 687-695, 2002.

YANG, Y. X.; GUO, J.; JIN, Z.; YOON, S. Y.; CHOI, J. Y.; WANG, M. H.; PIAO, X. S.; KIM, B. W.; CHAE, B. J. Lysine restriction and realimentation affected growth, blood profiles and expression of genes related to protein and fat metabolism in weaned pigs. *Journal of Animal Physiology and Animal Nutrition*, Berlin, v. 93, n. 6, p. 732-743, 2009.

YI, G. F.; GAINES, A. M.; RATLIFF, B. W. Estimation of the true ileal digestible lysine and sulfur amino acid requirement and comparison of the bioefficacy of 2-hydroxy-4-(methylthio)butanoic acid and DL-methionine in eleven- to twenty-six-kilogram nursery pigs. *Journal of Animal Science*, Champaign, v. 84, n. 7, p. 1709-1721, 2006.