

Nutritional plans of net energy with a constant calorie:nutrient ratio on the performance of piglets from 7 to 30 kg

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ABSTRACT - This study was conducted to evaluate different nutritional plans of net energy (NE) with a constant calorie:nutrient ratio on the performance of piglets from 7 to 30 kg. Sixty barrows with an initial weight of 7.11 ± 0.89 kg were distributed among five nutritional plans: two NE-decreasing plans (A and B, starting from NE concentrations of 2.47 and 2.52 Mcal kg⁻¹, respectively, and ending both at 2.37 Mcal kg⁻¹) and three NE-constant plans (C, 2.37 Mcal kg⁻¹; D, 2.42 Mcal kg⁻¹; and E, 2.47 Mcal kg⁻¹). The nutritional plans were composed of two decreasing plans: A, 2.47-2.42-2.37-2.37-2.37 Mcal of NE kg⁻¹ of feed; B, 2.52-2.47-2.42-2.37-2.37 Mcal of NE kg⁻¹ of feed; and three constant plans: C, 2.37 Mcal of NE kg⁻¹ of feed; D, 2.42 Mcal of NE kg⁻¹ of feed; E, 2.47 Mcal of NE kg⁻¹ of feed, from 7 to 10, 10 to 15, 15 to 20, 20 to 25, and 25 to 30 kg, respectively, with six replicates per treatment and two animals per experimental unit. Animal performance was evaluated through the following measurements: average daily feed intake (ADFI), NE intake, standardized ileal digestible lysine intake (SID Lys intake), average daily gain (ADG), feed:gain ratio (F:G), final weight (FW), feed cost per kg of weight gain (CWG), economic efficiency index (EEI), and fecal score. Piglets' final weight was 32.95 ± 3.30 kg. Considering the total experimental period, there was no effect of the nutritional plan on ADG, F:G, CWG, and EEI. The final weight of piglets under plan D was higher than that recorded for those allocated to plan C, not differing from the other nutritional plans. Piglets fed under nutritional plans A and D presented higher ADFI compared with those subjected to other plans. Net energy and SID Lys intakes were significantly higher in piglets subjected to plans A, D, and E compared with those under plans B and C. Net energy nutritional plans did not influence the fecal score and the occurrence of diarrhea of the piglets. Based on our analysis, a nutritional plan containing a constant NE level of 2.42 Mcal kg⁻¹ of feed may be recommended for piglets from 7 to 30 kg.

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1. Introduction

Owing to the economic importance of the energy component in diet of pigs (Noblet, 2007), effects in performance, and carcass (Quiniou and Noblet, 2012), numerous studies have been carried out to find

out the ideal level of energy that maximizes performance of pigs (Beaulieu et al., 2006; Oresanya et al., 2008; Arnaiz et al., 2009; Pereira et al., 2011; Vieira et al., 2015; Ribeiro et al., 2016; Marçal et al., 2018a; Marçal et al., 2018b; Marçal et al., 2019; Silva et al., 2020). One of the strategies that can be used to formulate feeding regimes of animals is based on the net energy (NE) amount. This system allows the elaboration of more precise diets, able to meet the nutritional requirements of the animals considering the differences in nutrient metabolism, since it describes more accurately the real content of the diet (Sakomura and Rostagno, 2016).

In the Brazilian Tables for Poultry and Swine, it is recommended a decrease in the NE levels of piglet diet according to the weight range, with 2.52, 2.48, and 2.47 Mcal kg⁻¹ for the ranges of 5.5 to 9.0, 9.3 to 15, and 15 to 30 kg, respectively (Rostagno et al., 2017). On the other hand, in the Nutrient Requirements of Swine from the National Research Council (NRC, 2012), lower NE levels are recommended, and a lower decreasing rate is also proposed: 2.448, 2.448, and 2.412 Mcal kg⁻¹ for 5 to 7, 7 to 11, and 11 to 25 kg, respectively.

Owing to the inefficiency of the digestive function of piglets in the initial stages of their life cycle (Santos et al., 2016), it has been hypothesized that supplying lower and fixed levels of energy as they gain body mass from 7 up to 30 kg may be a useful nutritional strategy to maximize performance while reducing production costs. However, energy intake may be the main limiting factor in the piglet growth, regardless of the energy concentration of the diet, since no regulation of energy intake happens in pigs weighing less than 20 kg (Black et al., 1986).

Up to date, nutritional plans of piglets with decreasing NE levels have not been compared to those providing constant NE levels. In this work, we evaluated how different NE nutritional plans affect the performance of pigs as they gain body mass from 7 to 30 kg, aiming at establishing the nutritional strategy that provides the best profitability.

2. Material and Methods

The research was carried out in Terenos, Mato Grosso do Sul, Brazil (latitude 20°26'32" S, longitude 54°51'37" W). Research was approved by the Institucional Committee on Animal Use (case no. 957/2018).

Sixty genetically similar (Duroc/Pietrain × Large White/Landrace) 21-day-old barrows with an initial weight of 7.11±0.89 kg were housed in a nursery room, equipped with suspended cages, semi-automatic feeders, a nipple-type drinking fountain, and artificial heating. The animals were distributed following a complete block design among five nutritional plans, which comprised two NE-decreasing plans (in accordance with weight progression of animals through five weight ranges) and three NE-constant plans with different NE levels according to the weight ranges (Table 1), with six replicates and two animals per experimental unit. The initial weight was adopted as a criterion for block formation.

Table 1 - Nutritional plans of net energy (NE) in diets of piglets from 7 to 30 kg¹

Body weight (kg)	Nutritional plan (NE, Mcal kg ⁻¹ of feed) ²				
	A	B	C	D	E
7 to 10	2.47	2.52	2.37	2.42	2.47
10 to 15	2.42	2.47	2.37	2.42	2.47
15 to 20	2.37	2.42	2.37	2.42	2.47
20 to 25	2.37	2.37	2.37	2.42	2.47
25 to 30	2.37	2.37	2.37	2.42	2.47

¹ A total of sixty 21-day-old barrows (Duroc/Pietrain × Large White/Landrace) with an initial weight of 7.11±0.89 kg were used from 7 to 30 kg trial with two piglets per cage and six replicates per treatment.

² Nutritional plans = A: 2.47-2.42-2.37-2.37-2.37 Mcal of NE kg⁻¹ of feed, B: 2.52-2.47-2.42-2.37-2.37 Mcal of NE kg⁻¹ of feed, C: 2.37-2.37-2.37-2.37-2.37 Mcal of NE kg⁻¹ of feed, D: 2.42-2.42-2.42-2.42-2.42 Mcal of NE kg⁻¹ of feed, E: 2.47-2.47-2.47-2.47-2.47 Mcal of NE kg⁻¹ of feed.

Experimental diets (Tables 2, 3, 4, 5, and 6) were formulated based on the ideal protein concept to meet the nutritional requirements of piglets of high genetic potential (Rostagno et al., 2017). The increase in NE concentration to obtain the different nutritional plans was achieved by the inclusion of soybean oil substituting kaolin. The calorie:nutrient ratio (calorie:crude protein; digestible lysine, methionine + cystine, threonine, and tryptophan; calcium; and digestible phosphorus) at each weight phase (0.174, 0.183, 0.197, 0.197, and 0.197 NE:SID Lys) was maintained constant in all diets by the inclusion of amino acids, limestone, and dicalcium phosphate replacing kaolin. Feed and water were provided *ad libitum* during the experimental period.

The environmental conditions inside the nursery room were monitored by a maximum and minimum thermometer and a portable digital thermometer (model ITWTG 2000). Dry bulb, wet bulb, and black globe temperatures, as well as the relative air humidity (%), were recorded daily at 8:00 and 16:00 h, at six points in the nursery room. The wet-bulb globe temperature index (WBGTI) was calculated using the equation proposed by Buffington et al. (1981).

Pigs and feeders were weighed at the beginning and at the end of each phase to calculate average daily feed intake (ADFI), average daily weight gain (ADWG), and feed conversion ratio (F:G). Net energy intake and standardized ileal digestible lysine (SID Lys) intake were determined by multiplying the total feed intake by the NE or the SID Lys content of each diet, and subsequently dividing by the number

Table 2 - Composition of experimental diets for piglets from 7 to 10 kg

Item	NE, Mcal kg ⁻¹ of feed
	2.37 - 2.42 - 2.47 - 2.52
Ingredient (g kg ⁻¹)	
Corn (7.88%)	568.73
Soybean meal (46.5%)	211.60
Whole whey powder	100.00
Blood plasma	50.00
Kaolin	24.00 - 15.90 - 7.81 - 0.00
Soybean oil	5.14 - 11.62 - 18.10 - 24.31
Dicalcium phosphate	20.09 - 20.81 - 21.53 - 22.25
Limestone	8.94 - 9.06 - 9.15 - 9.24
L-Lysine HCl	4.10 - 4.46 - 4.83 - 5.21
L-Threonine	1.86 - 2.06 - 2.27 - 2.48
DL-Methionine	1.72 - 1.88 - 2.04 - 2.20
L-Tryptophan	0.32 - 0.37 - 0.43 - 0.48
Vitamin premix ¹	1.00
Halquinol	1.00
Probiotic	1.00
Mineral premix ²	0.50
Nutritional composition (g kg ⁻¹ as fed) ³	
Metabolizable energy (Mcal kg ⁻¹)	3.20 - 3.26 - 3.32 - 3.37
Net energy (NE; Mcal kg ⁻¹)	2.37 - 2.42 - 2.47 - 2.52
Crude protein	197.5 - 198.1 - 198.7 - 199.4
SID Lysine	13.65 - 13.93 - 14.22 - 14.51
SID Methionine + cystine	7.65 - 7.81 - 7.97 - 8.13
SID Threonine	9.14 - 9.33 - 9.53 - 9.72
SID Tryptophan	2.60 - 2.65 - 2.71 - 2.76
Digestible phosphorus	4.81 - 4.91 - 5.01 - 5.11
Calcium	10.04 - 10.26 - 10.47 - 10.68
Sodium	2.51
Lactose	48.80

¹ Guaranteed level per kilogram of product: vitamin A, 1,250,000 IU; vitamin D₃, 250,000 IU; vitamin E, 6250 IU; vitamin K₃, 750 mg; vitamin B₁, 375 mg; vitamin B₂, 1000 mg; vitamin B₆, 375 mg; vitamin B₁₂, 4500 mg; pantothenic acid, 2300 mg; folic acid, 125 mg.

² Guaranteed level per kilogram of product: iron, 25 mg; copper, 3750 mg; manganese, 12.5 g; zinc, 31.25 g; iodine, 250 mg; selenium, 75 mg; and vehicle.

³ Calculated values based on the nutritional composition of the ingredients according to Rostagno et al. (2017).

of days in each phase. The average NE (ANE) was calculated considering the NE of diets in each period evaluated.

Additionally, an economic analysis of the diets was carried out using the equation adapted from Bellaver et al. (1985): $CWG_i = (Q_i \times P_i)/G_i$, in which CWG_i = cost of feed per kilogram of weight gain in the i -th treatment, P_i = price per kilogram of feed used in the i -th treatment, Q_i = amount of feed intake in the i -th treatment, and G_i = piglet's weight gain in the i -th treatment. The economic efficiency index (EEI) was calculated according to the equation adapted from Fialho et al. (1992): $EEI = (MCE_i/CTE_i) \times 100$, in which MCE_i = lower feed cost per kilogram gain and CTE_i = cost of treatment considered. The calculations for feed cost were based on the acquisition value of the ingredients used in experimental diets.

Pig fecal score was determined twice daily (in the morning and afternoon) by visual evaluation, assigning scores from 0 to 3 for each animal based on the following criteria: 0 = solid feces, 2 = liquid/pasty feces, 3 = liquid feces. Scores 2 and 3 indicated the occurrence of diarrhea. During the experimental period, all piglets diagnosed with diarrhea were medicated with antimicrobial agents based on amoxicillin, sulfadoxine, and trimethoprim.

Table 3 - Composition of experimental diets for piglets from 10 to 15 kg

Item	NE, Mcal kg ⁻¹ of feed
	2.37 - 2.42 - 2.47
Ingredient (g kg ⁻¹)	
Corn (7.88%)	601.28
Soybean meal (46.5%)	251.6
Whole whey powder	50.0
Blood plasma	30.0
Kaolin	26.86 - 18.85 - 10.85
Soybean oil	0.00 - 6.49 - 12.98
Dicalcium phosphate	19.72 - 20.44 - 21.09
Limestone	7.97 - 8.00 - 8.11
L-Lysine HCl	3.65 - 4.00 - 4.35
L-Threonine	1.70 - 1.90 - 2.09
DL-Methionine	1.39 - 1.56 - 1.71
L-Tryptophan	0.20 - 0.26 - 0.32
Vitamin premix ¹	1.00
Halquinol	1.00
Probiotic	1.00
Mineral premix ²	0.50
Salt	2.13
Nutritional composition (g kg ⁻¹ as fed) ³	
Metabolizable energy (Mcal kg ⁻¹)	3.19 - 3.25 - 3.30
Net energy (NE; Mcal kg ⁻¹)	2.37 - 2.42 - 2.47
Crude protein	200.0 - 200.6 - 201.2
SID Lysine	12.92 - 13.19 - 13.46
SID Methionine + cystine	7.23 - 7.39 - 7.54
SID Threonine	8.65 - 8.84 - 9.02
SID Tryptophan	2.45 - 2.51 - 2.56
Digestible phosphorus	4.47 - 4.57 - 4.66
Calcium	9.34 - 9.53 - 9.73
Sodium	2.19
Lactose	24.40

¹ Guaranteed level per kilogram of product: vitamin A, 1,250,000 IU; vitamin D₃, 250,000 IU; vitamin E, 6250 IU; vitamin K₃, 750 mg; vitamin B₁, 375 mg; vitamin B₂, 1000 mg; vitamin B₆, 375 mg; vitamin B₁₂, 4500 mg; pantothenic acid, 2300 mg; folic acid, 125 mg.

² Guaranteed level per kilogram of product: iron, 25 mg; copper, 3750 mg; manganese, 12.5 g; zinc, 31.25 g; iodine, 250 mg; selenium, 75 mg; and vehicle.

³ Calculated values based on the nutritional composition of the ingredients according to Rostagno et al. (2017).

Table 4 - Composition of experimental diets for piglets from 15 to 20 kg

Item	NE, Mcal kg ⁻¹ of feed
	2.37 - 2.42 - 2.47
Ingredient (g kg ⁻¹)	
Corn (7.88%)	696.54
Soybean meal (46.5%)	211.60
Blood plasma	20.00
Kaolin	29.86 - 21.92 - 14.01
Soybean oil	0.00 - 6.49 - 13.01
Dicalcium phosphate	18.84 - 19.41 - 20.06
Limestone	7.51 - 7.61 - 7.67
L-Lysine HCl	5.20 - 5.53 - 5.85
L-Threonine	2.09 - 2.27 - 2.43
DL-Methionine	1.78 - 1.93 - 2.07
L-Tryptophan	0.45 - 0.50 - 0.55
Vitamin premix ¹	1.00
Halquinol	1.00
Probiotic	0.50
Mineral premix ²	0.50
Salt	3.13
Nutritional composition (g kg ⁻¹ as fed) ³	
Metabolizable energy (Mcal kg ⁻¹)	3.15 - 3.20 - 3.26
Net energy (NE; Mcal kg ⁻¹)	2.37 - 2.42 - 2.47
Crude protein	175.0 - 175.6 - 176.1
SID Lysine	12.00 - 12.26 - 12.51
SID Methionine + cystine	6.84 - 6.99 - 7.13
SID Threonine	7.80 - 7.97 - 8.13
SID Tryptophan	2.28 - 2.33 - 2.38
Digestible phosphorus	4.04 - 4.12 - 4.21
Calcium	8.43 - 8.61 - 8.79
Sodium	2.05

¹ Guaranteed level per kilogram of product: vitamin A, 1,250,000 IU; vitamin D₃, 250,000 IU; vitamin E, 6250 IU; vitamin K₃, 750 mg; vitamin B₁, 375 mg; vitamin B₂, 1000 mg; vitamin B₆, 375 mg; vitamin B₁₂, 4500 mg; pantothenic acid, 2300 mg; folic acid, 125 mg.

² Guaranteed level per kilogram of product: iron, 25 mg; copper, 3,750 mg; manganese, 12.5 g; zinc, 31.25 g; iodine, 250 mg; selenium, 75 mg; and vehicle.

³ Calculated values based on the nutritional composition of the ingredients according to Rostagno et al. (2017).

The performance data were analyzed as a completely randomized block design using the general linear model procedure with SAS (Statistical Analysis System, version 9.4). The following statistical model was used:

$$Y_{ijk} = \mu + T_i + B_j + \varepsilon_{ijk}$$

in which Y_{ijk} is the quantitative response variable, μ is the overall mean, T is the effect of i -th nutritional plan, B is the effect j -th block, and ε is the random error. The initial body weight was used as a covariate in the model. A contrast analysis comparing nutritional plans with decreasing (A and B) versus constant (C, D, and E) NE levels was performed, and the Student-Newman-Keuls test was used for comparison of the means. The statistical program BioStat (version 5.3) was used to analyze the fecal scores, based on the non-parametric Kruskal-Wallis test. Significance was set at $P < 0.05$.

3. Results

The mean temperature during the experimental period was 26.5 ± 2.7 °C, with relative humidity of $77.9 \pm 12.8\%$, black globe temperature of 26.4 ± 2.8 °C, and WBGT of 76.0 ± 3.8 .

According to the contrast analysis performed, there were no differences between the NE-decreasing nutritional plans (A and B) versus the NE-constant nutritional plans (C, D, and E) for the variables analyzed.

In the initial phase of 7 to 10 kg, there were no differences for FW, ADG, ADFI, NE intake, and SID Lys intake. However, the F:G ratio in piglets of nutritional plan C was higher ($P < 0.05$) compared with that obtained in animals under nutritional plan B (Table 7). There was no difference in animal performance during the cumulative 7 to 15 kg period.

When considering the cumulative phase of 7 to 20 kg, there was no effect of the nutritional plan in terms of FW, ADG, ADFI, F:G, and SID Lys intake. However, NE intake varied among treatments. Piglets subjected to plan D presented higher ($P < 0.05$) NE intake than those subjected to the other nutritional plans, following the numerical tendency of ADFI. For the cumulative phase from 7 to 25 kg, nutritional plan D resulted in higher ($P < 0.05$) ADFI compared with plans B, C, and E, but without difference in respect to plan A.

The ADFI influenced NE intake and SID Lys intake to a greater extent than ANE of each nutritional plan itself. We detected that the lower ADFI of piglets subjected to plans B and C resulted in lower NE intake and SID Lys intake compared with plan D. Despite resulting in a lower ADFI, nutritional plan E was

Table 5 - Composition of experimental diets for piglets from 20 to 25 kg

Item	NE, Mcal kg ⁻¹ of feed
	2.37 - 2.42 - 2.47
Ingredient (g kg ⁻¹)	
Corn (7.88%)	689.10
Soybean meal (46.5%)	241.40
Kaolin	24.77 - 16.87 - 8.96
Soybean oil	0.00 - 6.51 - 13.03
Dicalcium phosphate	18.92 - 19.50 - 20.15
Limestone	7.27 - 7.38 - 7.43
L-Lysine HCl	5.82 - 6.15 - 6.47
L-Threonine	2.48 - 2.66 - 2.83
DL-Methionine	2.02 - 2.18 - 2.32
L-Tryptophan	0.52 - 0.57 - 0.62
Vitamin premix ¹	1.00
Halquinol	1.00
Probiotic	0.50
Mineral premix ²	0.50
Salt	4.70
Nutritional composition (g kg ⁻¹ as fed) ³	
Metabolizable energy (Mcal kg ⁻¹)	3.15 - 3.21 - 3.26
Net energy (NE; Mcal kg ⁻¹)	2.37 - 2.42 - 2.47
Crude protein	175.0 - 175.6 - 176.1
SID Lysine	12.00 - 12.26 - 12.51
SID Methionine + cystine	6.84 - 6.99 - 7.13
SID Threonine	7.80 - 7.97 - 8.13
SID Tryptophan	2.28 - 2.33 - 2.38
Digestible phosphorus	4.04 - 4.12 - 4.21
Calcium	8.43 - 8.61 - 8.79
Sodium	2.05

¹ Guaranteed level per kilogram of product: vitamin A, 1,250,000 IU; vitamin D3, 250,000 IU; vitamin E, 6250 IU; vitamin K₃, 750 mg; vitamin B₁, 375 mg; vitamin B₂, 1000 mg; vitamin B₆, 375 mg; vitamin B₁₂, 4500 mg; pantothenic acid, 2300 mg; folic acid, 125 mg.

² Guaranteed level per kilogram of product: iron, 25 mg; copper, 3,750 mg; manganese, 12.5 g; zinc, 31.25 g; iodine, 250 mg; selenium, 75 mg; and vehicle.

³ Calculated values based on the nutritional composition of the ingredients according to Rostagno et al. (2017).

associated to intermediate values for NE intake and SID Lys intake due to its higher ANE, not differing from the other plans. Piglets allocated to nutritional plan A showed a similar response.

Considering the total experimental period (7 to 30 kg), there was no effect of nutritional plan on ADG, F:G, CWG, and EEI. At the end of the experiment, the average weight of piglets was 32.95 ± 3.30 kg, and FW of piglets fed under nutritional plan D was higher than those under plan C, while FW of piglets allocated to plans A, B, and E showed no difference compared with that recorded for animals under plans D or C. These results can be explained considering the NE intake and SID Lys intake, considering that piglets fed nutritional plan D presented the greatest value of NE and SID Lys intake, while piglets under nutritional plan C presented the lowest value for these variables in the present study.

The NE intake of the piglets subjected to nutritional plans A, D, and E was higher than that of piglets subjected to plans B and C. Similar results were obtained for the ADFI: the plans with intermediate ANE levels (A and D) led to higher ADFI values compared with the plans with the lowest (C) and the highest (B and E) ANE levels. Despite the low ADFI detected for plan E, NE and SID Lys intakes were among the highest due to high ANE supply throughout the total experimental period.

There was no effect of diet on fecal scores recorded. For the total experimental period, the average fecal scores were 1.23, 1.18, 1.02, 1.25, and 0.92 for nutritional plans A, B, C, D, and E, respectively.

Table 6 - Composition of experimental diets for piglets from 25 to 30 kg

Item	NE, Mcal kg ⁻¹ of feed
	2.37 - 2.42 - 2.47
Ingredient (g kg ⁻¹)	
Corn (7.88%)	689.1
Soybean meal (46.5%)	241.4
Kaolin	24.77 - 16.87 - 8.96
Soybean oil	0.00 - 6.51 - 13.03
Dicalcium phosphate	18.92 - 19.50 - 20.15
Limestone	7.27 - 7.38 - 7.43
L-Lysine HCl	5.82 - 6.15 - 6.47
L-Threonine	2.48 - 2.66 - 2.83
DL-Methionine	2.02 - 2.18 - 2.32
L-Tryptophan	0.52 - 0.57 - 0.62
Vitamin premix ¹	1.00
Halquinol	1.00
Probiotic	0.50
Mineral premix ²	0.50
Salt	4.70
Nutritional composition (g kg ⁻¹ as fed) ³	
Metabolizable energy (Mcal kg ⁻¹)	3.15 - 3.21 - 3.26
Net energy (NE; Mcal kg ⁻¹)	2.37 - 2.42 - 2.47
Crude protein	175.0 - 175.6 - 176.1
SID Lysine	12.00 - 12.26 - 12.51
SID Methionine + cystine	6.84 - 6.99 - 7.13
SID Threonine	7.80 - 7.97 - 8.13
SID Tryptophan	2.28 - 2.33 - 2.38
Digestible phosphorus	4.04 - 4.12 - 4.21
Calcium	8.43 - 8.61 - 8.79
Sodium	2.05

¹ Guaranteed level per kilogram of product: vitamin A, 1,250,000 IU; vitamin D₃, 250,000 IU; vitamin E, 6250 IU; vitamin K₃, 750 mg; vitamin B₁, 375 mg; vitamin B₂, 1000 mg; vitamin B₆, 375 mg; vitamin B₁₂, 4500 mg; pantothenic acid, 2300 mg; folic acid, 125 mg.

² Guaranteed level per kilogram of product: iron, 25 mg; copper, 3,750 mg; manganese, 12.5 g; zinc, 31.25 g; iodine, 250 mg; selenium, 75 mg; and vehicle.

³ Calculated values based on the nutritional composition of the ingredients according to Rostagno et al. (2017).

Table 7 - Performance of piglets under nutritional plans of NE (Mcal kg⁻¹ of feed) from 7 to 30 kg¹

Variable	Nutritional plan of net energy ²					CV (%)	P-value
	A	B	C	D	E		
	7 to 10 kg						
ANE (Mcal kg ⁻¹)	2.47	2.52	2.37	2.42	2.47	-	-
IW (kg)	7.11	7.03	7.07	7.12	7.04	6.87	0.336
FW (kg)	9.98	9.79	10.17	10.14	10.10	8.00	0.484
ADG (kg)	0.270	0.260	0.302	0.287	0.293	16.26	0.672
ADFI (kg)	0.345	0.347	0.360	0.382	0.380	12.64	0.223
F:G	1.295ab	1.367b	1.204a	1.317ab	1.300ab	6.88	0.013
NE intake (Mcal kg ⁻¹)	0.848	0.874	0.853	0.919	0.932	12.58	0.232
SID Lys intake (g day ⁻¹)	4.881	5.035	4.912	5.293	5.368	12.60	0.233
	7 to 15 kg						
ANE (Mcal kg ⁻¹)	2.45	2.50	2.37	2.42	2.47	-	-
FW (kg)	14.72	14.23	14.66	14.77	14.60	7.54	0.335
ADG (kg)	0.39	0.37	0.405	0.405	0.402	10.82	0.669
ADFI (kg)	0.512	0.484	0.500	0.513	0.503	9.19	0.347
F:G	1.315	1.308	1.235	1.272	1.268	4.63	0.286
NE intake (Mcal kg ⁻¹)	1.249	1.206	1.185	1.242	1.243	9.22	0.279
SID Lys intake (g day ⁻¹)	6.949	6.718	6.605	6.927	6.932	9.27	0.289
	7 to 20 kg						
ANE (Mcal kg ⁻¹)	2.42	2.47	2.37	2.42	2.47	-	-
FW (kg)	19.64	19.30	20.10	20.56	19.95	6.92	0.321
ADG (kg)	0.437	0.426	0.445	0.461	0.443	8.10	0.383
ADFI (kg)	0.636	0.614	0.636	0.663	0.616	7.13	0.065
F:G	1.461	1.444	1.426	1.432	1.396	4.01	0.251
NE intake (Mcal kg ⁻¹)	1.532b	1.508b	1.507b	1.605a	1.521b	7.13	0.049
SID Lys intake (g day ⁻¹)	7.844	7.709	7.650	8.150	7.768	7.23	0.060
	7 to 25 kg						
ANE (Mcal kg ⁻¹)	2.41	2.45	2.37	2.42	2.47	-	-
FW (kg)	24.62	24.20	24.34	25.04	24.61	5.56	0.226
ADG (kg)	0.481	0.473	0.483	0.499	0.490	6.05	0.304
ADFI (kg)	0.724ab	0.698b	0.711b	0.755a	0.710b	6.52	0.029
F:G	1.506	1.478	1.466	1.506	1.448	3.61	0.124
NE intake (Mcal kg ⁻¹)	1.734ab	1.697b	1.686b	1.827a	1.753ab	6.47	0.012
SID Lys intake (g day ⁻¹)	8.846ab	8.643b	8.546b	9.267a	8.922ab	6.50	0.013
	7 to 30 kg						
ANE (Mcal kg ⁻¹)	2.40	2.43	2.37	2.42	2.47	-	-
FW (kg)	32.43ab	32.33ab	31.49b	32.75a	32.35ab	2.83	0.013
ADG (kg)	0.566	0.544	0.548	0.566	0.560	4.77	0.069
ADFI (kg)	0.901a	0.853b	0.852b	0.892a	0.863b	5.90	0.020
F:G	1.593	1.571	1.554	1.571	1.543	3.49	0.353
NE intake (Mcal kg ⁻¹)	2.149a	2.054b	2.020b	2.159a	2.132a	5.85	0.011
SID Lys intake (g day ⁻¹)	10.930a	10.437b	10.230b	10.940a	10.829a	5.85	0.011
CWG (R\$)	0.869	0.873	0.869	0.856	0.861	5.55	0.596
EEl (%)	91.60	91.27	91.55	92.73	92.01	5.50	0.615

ANE - average net energy; IW - initial weight; FW - final weight; ADG - average daily gain; ADFI - average daily feed intake; F:G - feed to gain ratio; NE - net energy; SID Lys - standardized ileal digestible lysine; CWG - feed cost per kilogram of piglet weight gain; EEl - economic efficiency index; CV - coefficient of variation.

¹ A total of sixty 21-day-old barrows (Duroc/Pietrain × Large White/Landrace) with an initial weight of 7.11±0.89 kg were used from 7 to 30 kg trial with two piglets per cage and six replicates per treatment.

² Nutritional plans = A: 2.47-2.42-2.37-2.37-2.37 Mcal of NE kg⁻¹ of feed, B: 2.52-2.47-2.42-2.37-2.37 Mcal of NE kg⁻¹ of feed, C: 2.37-2.37-2.37-2.37-2.37 Mcal of NE kg⁻¹ of feed, D: 2.42-2.42-2.42-2.42-2.42 Mcal of NE kg⁻¹ of feed, E: 2.47-2.47-2.47-2.47-2.47 Mcal of NE kg⁻¹ of feed. Means followed by distinct letters on the same row differ from each other by the SNK test (P<0.05).

4. Discussion

The results observed for the environmental thermal variables in the present study indicate that temperatures remained close to the temperature range (22 to 26 °C) considered ideal (Kummer et al., 2009) and temperatures (22 to 25 °C) considered as thermal comfort for this category of piglets (Le Dividich, 1991).

According to the results of this study, the best nutritional plan to be recommended for growing piglets, 7 to 30 kg, is the one containing an intermediate and constant energy density, such as that of our nutritional plan D. This recommendation is based on the highest final weight achieved by the animals and also on economic issues including CWG and EEI, even though these economic variables did not differ statistically among the nutritional plans considered.

The literature reports that during the early growth stages, piglets are not able to efficiently regulate their feed intake as a function of the dietary energy concentration because of the reduced physical capacity of the gastrointestinal tract (Black et al., 1986). This concept is in line with the lack of effect of the nutritional plan in most of the performance variables assessed in piglets up to 25 kg.

The increase in oil level from 0.514% (nutritional plan C) to 2.431% (nutritional plan B) may have affected the F:G ratio of piglets due to lower activity of pancreatic lipase enzyme in the post-weaning phase, as documented by Jensen et al. (1997), resulting in an unfavorable F:G ratio in piglets allocated to a higher energy density plan (B, NE = from 2.52 to 2.37 Mcal kg⁻¹) compared with a lower energy density plan (C, NE = constant value of 2.37 Mcal kg⁻¹). On the other hand, we highlight the fact that piglets subjected to different NE diets had all average fecal scores close to 1, demonstrating that soybean oil inclusions were not enough to cause diarrhea.

It was reported that in piglets weighing more than 20 kg, the regulation process of feed intake is a function of the dietary energy concentration (Black et al., 1986), which would explain why in our study superior ANE levels resulted in lower ADFI values compared with intermediate ANE levels. This hypothesis was corroborated in previous studies such as that of Beaulieu et al. (2006), Pereira et al. (2011), and Quiniou and Noblet (2012), who found that an increased energy concentration in the diet promoted a reduction in feed intake of piglets.

While older pigs have the ability to regulate feed intake according to their energy requirement (Noblet et al., 2001), there is evidence that weaned piglets do not have this control capacity yet, since studies have found that increasing the energy concentration of the diet can stimulate intake (Adebowale et al., 2019; Silva et al., 2020). There is also the hypothesis that for weaned piglets, due to their limited stomach capacity, the increased concentration of energy in the diet stimulates energy intake and increases weight gain (Oresanya et al., 2008). Thus, nutritional plans with lower ANE levels may have negatively affected ADFI when compared with ANE-intermediate plans.

The higher FW observed in piglets subjected to nutritional plan D may be ascribed to their increased NE intake and SID Lys intake. Given the adjustment of the calorie:nutrient ratio in the diets, the increase in NE intake was accompanied by an increase in digestible lysine intake. This may have resulted in positive effects on final weight, as previously reported (Marçal et al., 2019), because piglets fed under this nutritional plan had greater energy and amino acids input for protein synthesis. On the other hand, piglets subjected to plan C showed lower FW, probably owing to the lower NE and SID Lys intake.

Numerous studies have been carried out to define the energy level of the diet that provides better performance to growing piglets. However, most of them are based on metabolizable energy (ME) contents and present variable results. For instance, ME levels of 3.40, 3.60, and 3.80 Mcal kg⁻¹ did not affect growth, FW, ADFI, ADG, and F:G in early-weaned piglets (Vieira et al., 2015). Likewise, changes in the ME levels of piglets' diet during the initial growth stage in the range of 3.25, 3.40, 3.55, and 3.70 Mcal kg⁻¹ did not result in improved ADFI, ADG, or F:G ratios (Ribeiro et al., 2016).

On the other hand, it was reported that the use of a nutritional plan consisting of 3.40, 3.35, 3.30, and 3.25 Mcal ME kg⁻¹ for piglets from 7 to 10 kg, 10 to 15 kg, 15 to 20 kg, and 20 to 30 kg, respectively,

increased ADFI, ADG, and FW, and also improved feed conversion when compared with nutritional plans with lower ME levels (Silva et al., 2020).

According to the results obtained in the present study, nutritional plan D (NE constant level of 2.42 Mcal kg⁻¹) can be considered ideal for piglets gaining body mass from 7 to 30 kg. This suggests that the ideal net energy levels may be below those previously recommended, including the sequential regimes of 2.52, 2.48, and 2.47 Mcal kg⁻¹ for piglets from 7 to 30 kg, proposed by Rostagno et al. (2017), and the plan of 2.47 and 2.46 Mcal kg⁻¹ for piglets from 7 to 22 kg suggested in the FEDNA guidelines (FEDNA, 2013). However, ideal NE levels seem to be closer to those of the NRC (2012) guidelines, which recommend NE levels of 2.45 and 2.41 Mcal kg⁻¹ for piglets from 5 to 25 kg.

5. Conclusions

A nutritional regime providing a constant net energy supply of 2.42 Mcal kg⁻¹ of feed is adequate and cost-effective and can be, therefore, recommended for piglets from 7 to 30 kg.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

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