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Non-ruminants

Nutritional plans of digestible phosphorus for growing-finishing barrows

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ABSTRACT - This study was conducted to evaluate nutritional plans of digestible phosphorus for barrows weighing between 30 and 100 kg. Eighty animals were distributed in a randomized block design with five nutritional plans containing 2.19-1.86-1.71, 2.57-2.23-2.09, 2.94-2.61-2.46, 3.32-2.99-2.84, and 3.70-3.36-3.32 g of digestible phosphorus kg^{-1} of diet, respectively, for the phases of 30 to 50 kg, 50 to 70 kg, and 70 to 100 kg, with eight replications and two barrows per experimental unit. The nutritional plans of digestible phosphorus had no effect on the final body weight, feed intake, daily weight gain, or feed conversion of barrows. The daily intake of digestible phosphorus increased with the dietary concentrations of digestible phosphorus. Of the carcass characteristics assessed, only muscle depth responded significantly to the highest concentration of digestible phosphorus, as assessed in barrows sequentially fed the 3.70-3.36-3.32 g kg^{-1} diet. The nutritional plans had no effect on backfat, rib eye area, or carcass lean tissue mass, percentage, and deposition. The nutritional plan containing 2.19-1.86-1.71 g kg^{-1} of digestible phosphorus meet the nutrient requirements for performance and carcass characteristics of barrows weighing from 30 to 100 kg.

Key Words: carcass characteristics, mineral requirements, nutrient requirement

Introduction

As an essential element for animal growth, phosphorus has been extensively studied since it was first discovered and isolated in Germany in 1669. Phosphorus plays important roles in numerous processes, including effective energy use and transfer, protein and amino acid synthesis, fatty acid transport, appetite control, and fertility maintenance, and is also a cell wall component (Saraiva et al., 2009; Lehninger et al., 2013).

Recent genetic advances have enabled the breeding of pigs with a high capacity for lean tissue deposition, albeit resulting in changes in dietary phosphorus requirements due to variations in the carcass muscle-to-fat ratio. However, metabolism, tissue synthesis, and feed intake differ considerably between growth stages, thereby also changing the pattern of dietary requirements of pigs during their growth stages (Kornegay and Harper, 1997).

Thus, because dietary requirements change, the dietary content of digestible phosphorus for swine must be constantly adjusted, and over the years, research studies have been conducted to identify the levels that best meet the nutrient requirements of swine. A wide range of information related to determining the requirements of total, available, and digestible phosphorus according to body weight group or production stage of pigs can be found in the literature. Among these studies, the tables of nutrient requirements, including the Dutch (CVB, 1998), French (INRA-AFZ, 2004), Brazilian (Rostagno et al., 2011), and American (NRC, 2012) tables are of particular note.

However, although in sequential feeding it is important to adjust the diets to more accurately meet the nutrient requirements of swine, there have been relatively few studies that assessed diets containing different concentrations of digestible phosphorus and their effects on swine production. Consequently, this study was conducted to evaluate the effects of nutritional plans of digestible phosphorus on the performance and carcass characteristics of barrows of 30 to 100 kg.

Material and Methods

The research took place on an experimental farm in Terenos, Mato Grosso do Sul, Brazil (latitude 20º26'32" S and longitude 54º51'37" W). Research on animals was conducted according to the institutional committee on animal use (case number 495/2013).

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Eighty commercial crossbred (Duroc/Pietran × Large Withe/Landrace) barrows with an initial mean age of 70 days and initial mean body weight ranging from 31.9±2.5 to 102.5±7.6 kg were used.

The animals were allotted to a randomized block design, with five nutritional plans containing 2.19-1.86-1.71, 2.57-2.23-2.09, 2.94-2.61-2.46, 3.32-2.99-2.84, and 3.70-3.36-3.32 g of digestible phosphorus kg^{-1} of diet, respectively, for the phases of 30 to 50, 50 to 70, and 70 to 100 kg, with eight replications and two barrows per experimental unit. The experimental unit was the pen, and the blocks were established based on the initial body weights of the barrows.

The barrows were housed in a brick shed containing forty 1.15-m wide × 2.86-m long pens, with 1.65 m^2 of available space per animal, equipped with water troughs, semi-automatic feeders, and bite drinkers. Dry bulb, wet bulb, and black globe temperatures and relative air humidity (%) were measured daily at 08.00 and 16.00 h, at nine points along the height of the backs of the barrows, using a portable digital thermometer. The wet-bulb globe temperature (WBGT) index was calculated using the equation proposed by Buffington et al. (1981).

The reference diets were formulated based on corn and soybean meal, according to the nutrient requirements of barrows, following the recommendations of Rostagno et al. (2011). The feed total phosphorus concentrations were assessed by laboratory tests. The concentrations of digestible phosphorus used to prepare the experimental diets were based on the digestibility coefficients established by Rostagno et al. (2011) for growing pigs (Table 1). Based on the reference diet (Table 2), the experimental diets were supplemented with dicalcium phosphate to prepare feeds with five concentrations of digestible phosphorus (30 to 50 kg phase: 2.19, 2.57, 2.94, 3.32, and 3.70 g kg^{-1}; 50 to 80 kg phase: 1.86, 2.23, 2.61, 2.99, and 3.36 g kg^{-1}; and 80 to 100 kg phase: 1.71, 2.09, 2.46, 2.84, and 3.32 g kg^{-1}). All diets were supplemented with limestone as a source of calcium to maintain the constant calcium digestible phosphorus ratio.

Feed was provided *ad libitum* to the animals during the experimental period. Feed wastes were collected daily from the floor, weighed weekly, and added to the leftovers at the end of each experimental phase to determine the average daily feed intake.

The barrows were weighed at the beginning (31.9±2.5 kg), (47.9±3.4 kg), and (82.8±6.3 kg), and end (102.0±7.6 kg) of the experimental period to calculate the weight gain and feed conversion. The digestible phosphorus intake was determined using the feed intake values [phosphorus concentration (%) × daily feed intake]/100.

At the end of the experimental period, the animals were subjected to fasting for 12 h. Thereafter, the barrows were weighed and transported to the slaughterhouse where they remained in resting pens for 4 h. After this period, they were slaughtered according to the management standards and slaughter procedures in force in Brazil, in accordance with the Ministry of Agriculture, Livestock and Food Supply (MAPA) legislation.

At the end of the slaughter line, the carcasses were halved longitudinally along the dorsal-lumbar spine, and both halves were weighed. The backfat and *Longissimus dorsi* muscle depth were then measured in the left half carcass at point P2 using a digital caliper.

The carcass lean tissue percentage was calculated using the following equation: Lean tissue (%) = 65.92 – [(0.685 × backfat, mm) + (0.094 × muscle depth, mm) – (0.026 × cold carcass weight, kg)], according to the method adopted by Oliveira et al. (2013); lean tissue mass (kg) = (hot carcass weight × lean tissue, %)/100; daily lean tissue deposition (g) = (final lean mean weight, kg – initial lean tissue weight, kg)/experimental period.

The data collected were subjected to analysis of variance considering the initial body weight of the barrows as a covariate. The assumptions of error normality and homoscedasticity were met in the statistical model regarding the study characteristics performance and carcass. Possible differences in study variables between diets were assessed using the Tukey test at 5% significance, and the tests were performed using SAS (Statistical Analysis System, version 9.1) statistical software.

Table 1 - Total values of calcium and phosphorus, digestibility coefficient, and digestible phosphorus of ingredients used in the experimental diets

Ingredient	Calcium (g kg^{-1})[1]	Total phosphorus (g kg^{-1})[1]	TPDC for pigs (%)[2]	Digestible phosphorus (g kg^{-1})
Corn	0.30	2.20	44.00	0.97
Soybean meal	2.40	5.70	45.70	2.60
Dicalcium phosphate	245.00	186.20	75.00	139.70
Limestone	377.00	-	-	-

[1] Analyzed values.
[2] True phosphorus digestibility coefficient for pigs (Rostagno et al., 2011).

Table 2 - Centesimal and nutritional composition of basal experimental diets

Ingredient	Phase		
	30-50 kg	50-80 kg	80-100 kg
	Digestible phosphorus (g kg^{-1})		
	2.19	1.86	1.71
Corn	735.10	755.00	771.30
Soybean meal	215.50	202.30	189.80
Inert (kaolin)	15.00	15.00	15.00
Soybean oil	8.70	6.06	4.70
Dicalcium phosphate	6.56	4.28	3.35
Limestone	5.24	4.43	4.08
Premix[1]	4.00	4.00	4.00
Salt	4.06	3.80	3.55
L-lysine HCl 78%	3.40	3.12	2.69
DL-methionine 99%	0.94	0.74	0.54
L-threonine 98%	0.93	0.73	0.64
L-tryptophan 98%	0.11	0.08	0.02
Bacitracin zinc	0.50	0.50	0.50
Crude protein (g kg^{-1})	160.00	155.00	150.00
Metabolizable energy (kcal kg^{-1})	3,230	3,230	3,230
Digestible lysine (g kg^{-1})	9.43	8.91	8.29
Digestible methionine + cysteine (g kg^{-1})	5.56	5.26	4.97
Digestible threonine (g kg^{-1})	6.13	5.79	5.55
Digestible tryptophan (g kg^{-1})	1.70	1.60	1.49
Digestible valine (g kg^{-1})	6.58	6.38	6.19
Digestible isoleucine (g kg^{-1})	5.79	5.58	5.58
Sodium (g kg^{-1})	1.80	1.70	1.60
Calcium (g kg^{-1})	4.32	3.43	3.05
Total phosphorus (g kg^{-1})	4.07	3.61	3.41
Digestible phosphorus (g kg^{-1})	2.19	1.86	1.71
Calcium:digestible phosphorus	1.97	1.84	1.78

[1] Content per kg of product: pantothenic acid, 9.2 mg; niacin, 18.0 mg; folic acid, 0.5 mg; copper, 15.0 mg; iron, 0.10 g; zinc, 0.13 g; iodine, 1.0 mg; selenium, 0.3 mg; manganese, 0.05 g; vitamin A, 5,000 IU; vitamin D3, 1,000 IU; vitamin E, 25.0 IU; vitamin K3, 3.0 mg; vitamin B1, 1.5 mg, vitamin B2, 4.0 mg; vitamin B6, 1.5 mg; vitamin B12, 18.0 mg; B.H.T. (butylated hydroxytoluene) and excipient q.s.p., 1,000 g.

Results

During the experimental period, the average values of mean, maximum, and minimum air temperatures; relative air humidity; and wet-bulb globe temperature (WBGT) index were 25.60±4.65 °C, 30.66±3.63 °C, and 19.31±3.48 °C; 65.34±18.00; and 76.60±5.5, respectively.

The nutritional plans of digestible phosphorus had no effect (P≥0.01) on the final weight, daily feed intake, daily weight gain, or feed conversion of the barrows (Table 3). The daily intake of digestible phosphorus increased (P≤0.05) according to the increase in the level of phosphorus in the diet.

The nutritional plans had no effect (P≥0.01) on carcass backfat, percentage, and mass, or on carcass lean tissue deposition (Table 4). Muscle depth was affected (P≤0.05) by the level of digestible phosphorus in the diet, in which the nutritional plan with 3.70-3.36-3.32 g of digestible phosphorus kg^{-1} presented greater depth in relation to the basal plan with 2.19-1.86-1.71 g kg^{-1}.

Discussion

The mean temperature recorded during the experimental period (25.62±4.65 °C) was higher than the upper critical temperature recommended by Huynh et al. (2005) and Leal and Nãas (1992). According to these authors, temperature values considered optimal for the welfare of growing-finishing pigs (from 30 to 100 kg) range from 18 to 12 °C.

The value for the WBGT e index obtained in the present study was higher than the mean calculated by Tinôco et al. (2007), when assessing swine at the same stages. The authors described this value as critical for swine because it provides strong evidence of heat stress. High temperature and WBGT predispose swine to unfavorable conditions of welfare, thereby affecting their performance.

The daily feed intakes reached by pigs fed the five diets were lower than the values reported in the literature (Rostagno et al., 2011): 1.960, 2.450, and 2.930 kg daily feed intake for 30-50, 50-70, and 70-100 kg swine,

respectively. However, although different from the findings of Rostagno et al. (2011), these values are similar to those observed in the swine industry.

In the present study, the animals consuming the nutritional plan containing the basal diets with 2.19-1.86-1.71 g of digestible phosphorus kg^{-1} had feed intake similar to that of barrows fed the nutritional plan with the highest concentration of digestible phosphorus (i.e., 3.70-3.36-3.32 g kg^{-1}), which indicates that the lowest concentration of the mineral had no adverse nutritional effect on the feed intake.

Similarly, Hastad et al. (2004) also observed no effect of available phosphorus concentration on the feed intake of pigs weighing from 88 to 109 kg randomly allotted to five dietary treatments containing 1.80, 2.20, 2.50, 2.90, or 3.20 g kg^{-1} available phosphorus. Conversely, Stahly et al. (2000) reported a positive effect ($P \leq 0.05$) of the dietary concentration of available phosphorus on daily feed intake, which ranged from 1.05 to 3.00 kg in the four study stages, in swine with body weights ranging from 9 to 119 kg.

The results of previously published studies show that phosphorus is involved in feed intake control because low phosphorus levels lower the basal metabolism, thereby decreasing appetite. According to Parmer et al. (1987), dietary phosphorus deficiency may adversely affect feed intake because of the decrease in growth and thyroid hormone synthesis and release, particularly triiodothyronine (T3). However, a decrease in effective intake will only occur in cases of extreme deficiency (Reinhart and Mahan, 1986).

In the present study, barrows fed the 2.19-1.86-1.71 g kg^{-1} diet had feed intake similar to that of barrows fed the 3.70-3.36-3.32 g kg^{-1} diet, showing that the decreased supply of digestible phosphorus caused no deficiency or decrease in voluntary intake. This finding may be explained by the probable change in nutrient requirements of swine that have been subjected to constant genetic breeding programs for improved nutrient uptake efficiency. Therefore, their requirements for this mineral could be lower than those currently recommended in the literature.

This context underlines the importance of studying diets for sequentially fed growing pigs because, according to the literature, these diets more efficiently meet the nutrient requirements, primarily through the metabolic effects that specific nutrients provided during growth may have on the subsequent growth stages (Kill et al., 2003; Main et al., 2008).

The barrows sequentially fed the 2.19-1.86-1.71 g kg^{-1} diet had a 30% lower intake of digestible phosphorus than animals subjected to the 2.94-3.61-2.46 g kg^{-1} dietary treatment, without any effect on their performance. Because no increase in daily feed intake was observed, the results suggest that the response is linked to the dietary concentration of digestible phosphorus.

Table 3 - Performance of barrows between 30 and 100 kg fed diets containing different nutritional plans of digestible phosphorus

Nutritional plan (g kg^{-1})	IW (kg)	FW (kg)	ADFI (kg)	DCDP (g)[1]	DWG (g)	FC
2.19-1.86-1.71	32.17	101.41	1.90	4.35a	0.900	2.12
2.57-2.23-2.09	31.93	101.84	1.89	5.28b	0.908	2.08
2.94-2.61-2.46	31.88	102.91	1.89	6.21c	0.922	2.05
3.32-2.99-2.84	31.87	101.03	1.92	7.01d	0.900	2.13
3.70-3.36-3.32	31.98	102.71	1.93	8.07e	0.919	2.11
CV (%)	-	5.52	7.01	7.68	8.03	6.12
P-value	-	0.955	0.963	<0.001	0.948	0.690

IW - initial weight; FW - final weight; ADFI - average daily feed intake; DCDP - daily consumption of digestible phosphorus; DWG - daily weight gain; FC - feed conversion; CV - coefficient of variation.
[1] Means followed by different letters in the column differ ($P<0.05$) by Tukey test.

Table 4 - Carcass characteristics of barrows fed diets containing different nutritional plans of digestible phosphorus

Nutritional plan (g kg^{-1})	CL (cm)	BF (mm)	LM (mm)[1]	PLM (%)	ALM (kg)	DLM (g)
2.19-1.86-1.71	92.68	11.99	62.23b	61.61	46.07	0.393
2.57-2.23-2.09	94.64	9.32	66.64ab	63.83	48.29	0.491
2.94-2.61-2.46	93.74	10.70	69.78ab	63.13	49.02	0.495
3.32-2.99-2.84	92.42	11.12	66.84ab	62.65	46.62	0.409
3.70-3.36-3.32	94.24	11.22	74.02a	63.18	48.96	0.470
CV (%)	12.22	28.85	14.26	3.95	7.776	22.15
P-value	0.722	0.852	<0.005	0.516	0.301	0.597

CL - carcass length; BF - backfat; LM - muscle depth; PLM - percentage of lean meat; ALM - amount of lean meat; DLM - deposition of lean meat per day; CV - coefficient of variation.
[1] Means followed by different letters in the column differ ($P<0.05$) by Tukey test.

However, the nutritional plan of digestible phosphorus used in the present study (2.19-1.86-1.71 g kg^{-1}) was lower than those reported by Rostagno et al. (2011), who recommended a daily intake of 5.97, 6.56, and 7.28 g digestible phosphorus for barrows weighing from 30 to 50, 50 to 70, and 70 to 100 kg, respectively, with a high potential for lean tissue deposition. Similarly, the NRC (2012) advocated daily intake values higher than those assessed in the present study, which are 4.59, 5.71, and 6.00 g kg^{-1} digestible phosphorus for barrows weighing 25 to 50, 50 to 75, and 75 to 100 kg, respectively.

The daily weight gain and feed conversion of barrows sequentially fed 2.19-1.86-1.71 g kg^{-1} digestible phosphorus were similar to those of the other dietary treatments, which suggests that the dietary concentrations of phosphorus at the three stages meet the nutrient requirements for performance. According to Stahly (2007), dietary phosphorus concentrations lower than the requirements of swine may change the carcass muscle-to-fat ratio, thereby increasing the body fat content, impairing weight gain, and decreasing feed efficiency and/or conversion. Studies conducted by Reinhard and Mahan (1986) showed that low dietary phosphorus concentrations adversely affect the weight gain and feed efficiency of growing pigs.

Similarly, studies conducted by O'Quinn et al. (1997) with pigs weighing from 25 to 50, 50 to 80, and 80 to 118 kg showed that the diets should not have concentrations of available phosphorus lower than 2.10, 1.90, and 1.60 g kg^{-1}, respectively.

Muscle depth increased with the dietary concentration of digestible phosphorus. The results of the present study corroborate the findings of Traylor et al. (2005), who assessed crossbred pigs weighing from 45 to 110 kg. However, according to studies by Arouca et al. (2010), a daily dose of 3.50 g kg^{-1} available phosphorus is recommended to meet the nutrient requirements of swine weighing from 60 to 95 kg.

Although the diet with the highest concentration of digestible phosphorus led to increased muscle depth, a positive effect on this variable alone is insufficient to recommend this dose because the barrows sequentially fed the 2.19-1.86-1.71 g kg^{-1} diet showed results for all performance variables and most carcass characteristics similar to those fed the diet with intermediate digestible phosphorus concentrations, which are close to the values recommended by Rostagno et al. (2011) and even similar to those fed the diets with the highest concentrations of digestible phosphorus tested (3.70-3.36-3.32 g kg^{-1}).

Although no significant difference was observed among treatments, the lean tissue deposition measured in the carcass of barrows sequentially fed the 2.19-1.86-1.71 g kg^{-1} diet in the phases of 30 to 50, 50 to 70, and 70 to 100 kg was similar to the mean value of 390.00 g recommended by the NSNG (2010) for barrows weighing from 20 to 110 kg with high genetic potential for lean tissue deposition.

Phosphorus concentrations suitable for growing-finishing pigs must meet the nutrient requirements for performance, maximize muscle tissue growth, yield carcasses with high allowance index, and lower production costs. Therefore, the findings of the present study suggest that, despite the effect of increased dietary concentration of digestible phosphorus on improved muscle depth, the basal nutritional plan containing 2.19-1.86-1.71 g kg^{-1} digestible phosphorus is best suited to meet the nutrient requirements for performance and carcass characteristics due to the decreased feed and mineral intake of barrows weighing from 30 to 100 kg with high genetic potential for lean tissue deposition.

Conclusions

The nutritional plan containing 2.19-1.86-1.71 g kg^{-1} of digestible phosphorus meet the nutrient requirements for performance and carcass characteristics of barrows weighing from 30 to 100 kg.

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