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Available phosphorus levels in diets for swine from 15 to 30 kg genetically selected for meat deposition[1]

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ABSTRACT - With the objective to evaluate available phosphorus levels in diets for swine genetically selected for meat deposition, sixty commercial hybrid pigs were used, being 30 castrate males and 30 females, with initial weight of 15.00 ± 0.41 kg, distributed in a completely randomized experimental design, with six treatments, five replications and two animals (1 male and 1 female) per experimental unit. The treatments were composed of a basal diet and other five diets obtained through basal diet supplementation with dicalcium phosphate to obtain six AP levels (0.114; 0.221; 0.328; 0.435; 0.542 and 0.649%). The available phosphorus levels promoted a linear increase in the daily feed intake. Daily weight gain and feed conversion showed a quadratic behavior according to AP levels, with the maximum response at 0.509 and 0.477% of AP in the diet, respectively. Bone strength and bone calcium and phosphorus contents also presented a quadratic behavior according to AP levels, with maximum response at 0.529; 0.619 and 0.596% of AP levels in the diet, respectively. There was no effect of the AP levels in the diets on the bone ash content. The best weight gain and feed conversion observe for castrated male and female pigs from 15 to 30 kg, genetically selected for meat deposition, is provided by 0.509 and 0.477% of available phosphorus levels, respectively, corresponding to daily intakes of 6.39 and 5.93 grams of available phosphorus.

Key Words: genotype, minerals, nutrition, requirement

Níveis de fósforo disponível em rações para suínos selecionados geneticamente para deposição de carne dos 15 aos 30 kg

RESUMO - Com o objetivo de avaliar níveis de fósforo disponível (PD) em rações para suínos selecionados geneticamente para deposição de carne, utilizaram-se 60 leitões híbridos comerciais (30 machos castrados e 30 fêmeas) com peso inicial de 15,00 ± 0,41 kg, distribuídos em delineamento experimental inteiramente casualizado, com seis rações, cinco repetições e dois animais (um macho e uma fêmea) por unidade experimental. Avaliaram-se uma ração basal e outras cinco rações, obtidas pela suplementação da ração basal com fosfato bicálcico, totalizando seis níveis de fósforo disponível (0,114; 0,221; 0,328; 0,435; 0,542 e 0,649%). Os níveis de fósforo disponível promoveram aumento linear no consumo diário da ração. O ganho de peso diário e a conversão alimentar variou de forma quadrática de acordo com os níveis de PD, com valores máximos de 0,509 e 0,477% de PD na ração, respectivamente. A resistência óssea e os teores de cálcio e fósforo no osso também aumentaram de forma quadrática de acordo com os níveis de PD, com valores máximos de 0,529; 0,619 e 0,596% de PD na ração, respectivamente. Não houve efeito dos níveis de PD nas rações sobre o teor de cinza óssea. Os melhores resultados de ganho de peso e conversão alimentar de suínos, machos castrados e fêmeas, na fase dos 15 aos 30 kg, selecionados geneticamente para deposição de carne, são proporcionados pelos níveis de fósforo disponível de 0,509 e 0,477%, respectivamente, correspondentes a consumos diários de 6,39 e 5,93 g de fósforo disponível.

Palavras-chave: exigência, genótipo, minerais, nutrição

Introduction

In a feeding program, nutritional requirement values close to the demands of animals should be considered in order to avoid excess and deficiency of nutrients. Thus, genetic selection and market introduction of new pig strains with high potential for meat deposition are causes for concern among nutritionists, since the nutritional

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requirements change, depending on the genetic potential of the animal. According to Stahly et al. (1991) and Friesen et al. (1994), the feeding strategies must be specific for each genotype.

The achievement of satisfactory production rates, as well as animal welfare, depends on the adequate supply of energy and nutrients in the diet. Among these nutrients, phosphorus has required special attention because of its role in the synthesis of body protein. According to Frederick & Sthaly (1998) and Sthaly (2007), the phosphorus concentration in the muscle tissue is significantly high compared to that of fat tissue.

Phosphorus is the second most abundant mineral in the animal body, because, together with calcium, serves in the formation and maintenance of the bone structure of the skeleton (Underwood & Suttle, 1999). Approximately 80% of the phosphorus is present in bones and teeth, and the rest is widely distributed in soft tissues, red blood cells, nucleic acids, cell membranes, muscle and nerve tissue. Besides the formation and maintenance of the bone system and teeth, phosphorous plays a role in the energy use, storage and transfer, composes the structure of nucleic acids, serves on the acid-base balance and in maintaining the osmotic pressure, and in many enzymatic systems (Lehninger et al., 2002).

Diets for pigs are formulated based on corn and soybean meal, which have inadequate levels of available phosphorus to meet the nutritional requirements of animals. Therefore, it is necessary to supplement phosphorus in diets through the addition of dicalcium phosphate as the main source of inorganic phosphorus.

Considering the environmental pollution caused by the excretion of nutrients in regions of intensive swine production and the increasing availability of new genetic strains in the market, the redefinition of the phosphorus requirements for pigs is a constant need, since the deficiency of this mineral affect the growth of animals. The excess in the diet, on the other hand, can contribute to the increase in the excretion of this mineral in the environment.

This research was carried out to assess the effects of different available phosphorus levels in diets for swine from15 to 30 kg genetically selected for meat deposition.

Material and Methods

The experiment was conducted in the Swine Sector of the Department of Animal Sciences, Viçosa Federal University (UFV), municipality of Viçosa, Minas Gerais, Brazil.

Sixty commercial hybrid pigs were used, being 30 castrate males and 30 females, with initial weight of 15.00 ± 0.41 kg, distributed in a completely randomized design with six diets (available phosphorus levels), five replications and two animals, one of each sex, per experimental unit. The experimental unit was represented by the cage.

The animals were housed in suspended metal cages, with wired mash floor and sides, equipped with semi-automatic feeders and nipple drinkers, located in concrete building with concrete floor and lowered wooden roof. The temperature inside the room was daily measured, once a day (at 8 pm), by means of a maximum and minimum thermometer.

The experimental diets (Table 1) were formulated based on corn and soybean meal and supplemented with vitamins and minerals to meet the requirements of animals, according to Rostagno et al. (2005), except for the available phosphorus. A basal diet and five other diets were evaluated, obtained by supplementing the basal diet with dicalcium phosphate, replacing the washed sand, resulting in experimental diets with 0.114, 0.221, 0.328, 0.435, 0.542 and 0.649% of AP. The industrial amino acids were added keeping up with digestible lysine ratios recommended by Rostagno et al. (2000), according to the concept of ideal protein.

Diets and water were *ad libitum* fed to animals. Diets, orts and waste products were weekly weighted and the animals were weighted at the beginning and end of the experimental period, which lasted 25 days, to determine the consumption of diet and available phosphorus, the weight gain and feed conversion.

At the end of the experimental period, after fasting for 12-hour, an animal of each experimental unit, weighting around 30.0 kg was slaughtered by stunning for collection of the front right leg.

The collected legs were placed in aluminum container containing water and boiled to soften the skin and meat that involve the bones for the removal of the third metacarpal bone.

The metacarpal bones were kept in air forced oven at 65ºC for a period of 72 hours and then submitted to a breaking bending force (shear failure), indicator of bone strength, using the apparatus Instron Corporation IX Automated Materials Testing System - Model 4204, which belongs to the Cellulose and Paper Laboratory of the Department of Forestry Engineering, Universidade Federal Viçosa.

After broken, the bones were defatted in Soxhlet extractor and kept in air force oven at 65ºC for 24 hours. Then, they were crushed in a ball mill.

Table 1 - Composition in ingredient and nutritional of experimental diets

Item	Available phosphorus level (%)					
	0.103	0.210	0.317	0.424	0.531	0.638
Ingredient						
Corn	63.136	63.136	63.136	63.136	63.136	63.136
Soybean meal	29.583	29.583	29.583	29.583	29.583	29.583
Soybean oil	2.371	2.371	2.371	2.371	2.371	2.371
Dicalcium phosphate	0.000	0.577	1.156	1.735	2.314	2.890
Limestone	1.849	1.477	1.103	0.729	0.355	0.00
Washed sand	1.540	1.335	1.130	0.925	0.720	0.499
L-lysine HCL	0.170	0.170	0.170	0.170	0.170	0.170
DL-methionine	0.056	0.056	0.056	0.056	0.056	0.056
L-threonine	0.028	0.028	0.028	0.028	0.028	0.028
Salt	0.457	0.457	0.457	0.457	0.457	0.457
Mineral mix[1]	0.200	0.200	0.200	0.200	0.200	0.200
Vitamin mix[2]	0.400	0.400	0.400	0.400	0.400	0.400
Growth promoter[3]	0.200	0.200	0.200	0.200	0.200	0.200
BHT	0.010	0.010	0.010	0.010	0.010	0.010
Nutritional (Calculated)						
EM (kgcal/kg)	3.250	3.250	3.250	3.250	3.250	3.250
Crude protein (%)[4]	18.84	18.84	18.84	18.84	18.84	18.84
Digestible lysine (%)[4]	1.000	1.000	1.000	1.000	1.000	1.000
Digestible Met. + Cyst. (%)[4]	0.600	0.600	0.600	0.600	0.600	0.600
Digestible threonine (%)[4]	0.650	0.650	0.650	0.650	0.650	0.650
Na (%)	0.200	0.200	0.200	0.200	0.200	0.200
Ca (%)	0.800	0.800	0.800	0.800	0.800	0.800
Ca (analyzed) (%)	0.688	0.688	0.688	0.688	0.688	0.688
Total P (analyzed) (%)	0.314	0.421	0.528	0.635	0.742	0.849
Available P (%)	0.114	0.221	0.328	0.435	0.542	0.649

[1] Content/kg of product: vit. A - 3,000,000 IU; vit. D3 - 1,200,000 IU; vit. E - 7500 mg; vit. K3 - 1250 mg; vit. B12 - 7,000 mg; vit. B2 - 2300 mg; biotin - 50 mg; calcium pantothenate - 6,000 mg; niacin - 10,000 mg; choline - 125 g; growth promoter - 50 g; antioxidant - 5,000 mg; vit. B1 -500 g; vit. B6 - 1,000 mg; folic acid - 150 mg and q.s.p. vehicle - 1,000 g.
[2] Content/kg of product: Fe - 45,000 mg, Cu - 37,000 mg; Mn - 25,000 mg; zinc - 35,000 mg; Co - 300 mg; I - 800 mg; If - 120 mg and q.s.p. vehicle - 1,000 g.
[3] Active Principle: colistin.
[4] Values estimated based on the digestibility of amino acid ingredients, according to Rostagno et al. (2005).

The determination of the calcium and phosphorus levels of the experimental diets, as well as the concentrations of calcium, phosphorus and ash in bones, was performed at the *Rodes Química Cajati LTDA* Laboratory, in the municipality of Cajati - Sao Paulo, Brazil.

The performance characteristics and bone parameters were analyzed using the procedures for analysis of variance and regression in the System for Genetic and Statistic Analysis (SAEG), developed at the Universidade Federal Viçosa (UFV, 2000), version 8.0. The available phosphorus requirements were determined through linear and quadratic regression analysis.

Results and Discussion

During the experimental period, the minimum and maximum temperatures inside the room were maintained, respectively, at 19.5 ± 1.2ºC and 28.3 ± 1.5ºC, with variation within the ideal range from 18 to 28 º C, according to Coffey et al. (2000), for this category of animal.

The available phosphorus levels affected ($P < 0.01$) the daily feed intake, which increased in a linear behavior, according to the equation: $\hat{Y} = 1061.58 + 380.173AP$ ($r^2 = 0.70$) (Table 2). Similar results were obtained by Eeckhout et al. (1995), who evaluated AP levels from 0.11 to 0.17% in the diet for pigs from 37 to 61 kg and also observed a linear effect of increasing available phosphorus levels on diet consumption.

Variation in daily diet consumption of growing pigs with the increase in available phosphorus level in the diet was also observed by Sthaly et al. (2000) and Ekpe et al. (2002). It was evidenced in this study that the linear response of feed intake was caused by significant low feed intake in animals that was fed diet with the lowest available phosphorus level. With these results, it could be inferred that low available phosphorus levels can compromise the voluntary consumption of feed for pigs at the initial growth stage.

Effect of the available phosphorus levels ($P<0.01$) was observed on daily weight gain, which increased in a quadratic

Table 2 - Performance and bone parameters of pigs from 15 to 30 kg fed with diets with different available phosphorus levels

Item	Available phosphorus level (%)						CV (%)
	0.114	0.221	0.328	0.435	0.542	0.649	
Average final weight (kg)	28.19	30.86	31.55	34.35	33.58	33.00	-
Diet consumption (g/day)[1]	1059	1197	1158	1299	1253	1272	9.07
AP consumption (g/day)[1]	1.21	2.64	3.80	5.65	6.79	8.25	10.42
Weight gain (g/day)[2]	527	630	675	772	738	721	8.99
Feed Conversion[2]	2.01	1.90	1.72	1.69	1.70	1.77	3.81
Bone strength (N)[3]	234.20	327.80	373.33	578.66	572.30	446.28	15.80
Bone phosphorus (g/kg)[3]	71.96	76.10	84.09	86.93	89.19	88.14	6.12
Bone calcium (g/kg)[3]	140.25	152.00	162.00	165.40	167.30	171.20	4.24
Bone ash content (%)	51.83	49.53	50.80	50.91	50.04	49.13	10.15

[1] Linear effect (P<0.01).
[2, 3] Quadratic effect (P<0.01) and (P<0.05), respectively.

behavior up to 0.509% maximum response (Figure 1). This result was consistent with those obtained by Sthaly & Cook (1996) and Sthaly et al. (2000), who observed improvements in the daily weight gain of pigs up to 37 kg in function of the increase in the available phosphorus level of the diet up to of 0.40 and 0.48% of available phosphorus levels, respectively.

Despite the similarity of results in relation to the positive effects of the available phosphorus levels on the daily weight gain of pigs, levels that promoted the best results differ from work to work. This fact is probably associated, among other factors, to the possible genetic difference of animals in relation to the meat deposition potential. Assessing the total content of minerals in loin and ham of pigs from two distinct genotypes, Wiseman et al. (2007) observed that the calcium and phosphorus concentrations were higher in strains with higher meat deposition potential. These results show that the phosphorus requirements may vary according to the potential of pigs for growing of lean tissue.

The lowest weig ht gain observed in animals that received the diet with lower available phosphorus levels (0.114, 0.221 and 0.328%) in this study may be related to the high calcium/phosphorus ratio.

Evaluating the effect of calcium levels of diets on the phosphorus requirement in growing pig, Eeckout et al. (1995) found that high calcium/phosphorus ratios have negative effects on weight gain of animals only when the phosphorus level was below the requirements. According to Liu et al. (2000), high calcium/phosphorus ratio in the diet can reduce the phosphorus absorption and performance of animals, even when adequate phosphorus levels are provided.

The available phosphorus levels in the ration influenced (P<0.01) the feed conversion, which reduced in a quadratic

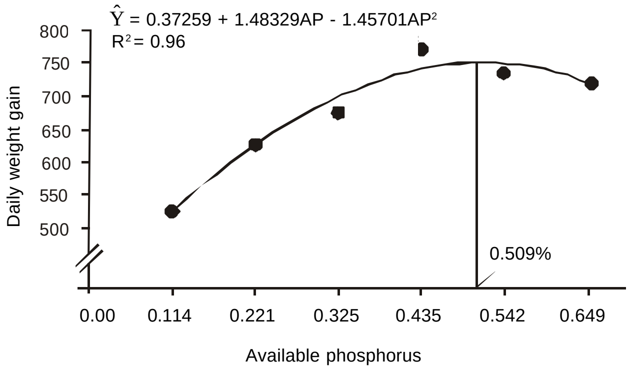

Figure 1 - Daily weight gain of pigs from 15 to 30 kg fed diets with different available phosphorus levels.

behavior up to 0.477% maximum response (Figure 2). Similarly, Stahly et al. (2000) worked with pigs from 9 to 37 kg and found that the feed efficiency of animals improved in a quadratic behavior up to 0.26% AP level in the diet.

Moreover, the feed conversion results obtained in this study differ from those found by Kegley et al. (2001) and Stahly & Cook (1996), who did not observe any effect of the AP levels on the feed conversion, respectively, of pigs from 6 to 18 kg and from 6 to 31 kg.

The difference in results among the studies may be related, in addition to genetic variation, to differences in the immune challenge level of animals used in experiments.

This suggestion is based on results obtained by Sthaly & Cook (1997), who assessed available phosphorus levels in pigs from 6 to 30 kg and found that the best feed conversion response of animals with moderate exposure to antigen occurred in the level of 0.70%, while animals with high exposure occurred in the level of 0.40% of available phosphorus.

Considering that in this study was observed an increase in the diet consumption and daily weight gain, the improvement in feed conversion up to 0.477% maximum response of available phosphorus may be evidence of a variation in the weight gain composition of animals among the AP levels. Thus, animals fed with diets with highest available phosphorus levels deposited more protein and less fat tissue. This suggestion is in accordance with results from Cromwell et al. (1970), who found significant fat deposition and lower loin-eye-area in pigs fed with diets with low phosphorus levels. According to Marinho et al. (2007), the increase in the protein deposition was one of the main factors justifying the increase in weight gain, combined with improved feed conversion.

Phosphorus is needed for the growth of muscle tissue for being involved in the energy metabolism (storage and transfer via ATP), in the synthesis of nucleic acids and structure of cell membranes (phospholipids).

According to Frederick & Stahly (1998) and Stahly (2007), the muscle tissue contains high amounts of phosphorus, while the concentration of this mineral is significantly low in adipose tissue. Thus, the increases in AP requirements of pigs selected for increased weight gain can be attributed to the high phosphorus requirements for the synthesis of muscle protein.

With the available phosphorus level of 0.509%, corresponding to a daily intake of 6.39 grams of available phosphorus, which provided the best weight gain result, it is clear that AP levels of 0.32 and 0.40%, respectively, recommended by the NRC (1998) and by Rostagno et al. (2005) may not be sufficient to meet the requirements of pigs from the current genotypes available on market at the initial growth stage (15 to 30 kg).

The available phosphorus levels influenced ($P<0.05$) the bone strength, which increased in a quadratic behavior up to 0.529% maximum response (Figure 1a). Similar typical response standard of bone strength of pigs to the AP level

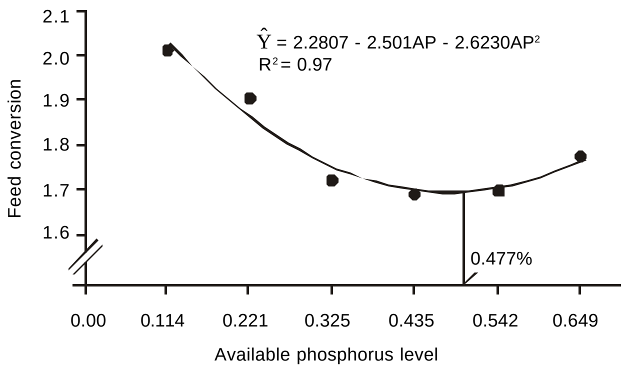

Figure 2 - Feed conversion of pigs from 15 to 30 kg fed diets with different available phosphorus levels.

of diet was also observed by O'Quinn et al. (1997). However, Hastad et al. (2004) did not observe any effect of the AP levels of diet on bone strength in the third and fourth metacarpal bones of pigs from 33 to 55 kg.

According to Crenshaw et al. (1981), variation in results among phosphorus requirement among works based on bone strength was related to the type of bone and type of equipment used in measuring the physical characteristics of bones as well as changes in procedures used to preparing bones for testing.

The fact that the available phosphorus level (0.529%) that provided the highest bone strength value was higher than the level that resulted in better daily weight gain (0.509%) corroborates the reports from Crenshaw et al. (1986) and Combs et al. (1990), in which the available phosphorus level required to improve bone strength was greater than that required for maximum weight gain.

The lowest bone mineralization degree, confirmed by the lowest bone strength values in animals that consumed diets with lower available phosphorus levels (0.114, 0.221, 0.328 and 0.435%) can also be a result of the high Ca:P ratio of diets, which, according to Eeckout et al. (1995), not only decreases the weight gain and feed efficiency, but also impairs the bone mineralization.

The amounts of calcium (CaO) and phosphorus in bones were influenced ($P<0.05$) in a quadratic behavior by the available phosphorus levels in the diet and increased up to 0.619% (Figure 1 b) and 0.596% (Figure 1 c) maximum response, respectively, These results was in accordance with reports from Reinhard & Mahan (1986) that high phosphorus levels in the diet can have negative effects on bone parameters of pigs. However, this finding contradicts the reports from Cromwell et al. (1970) that negative effects are not observed when the dietary phosphorus levels are higher than those required for maximum weight gain, suggesting that the relation between calcium and phosphorus may be more critical that high phosphorus levels.

Studying the influence of available phosphorus levels of diet on the bone phosphorus content of pigs from 13 to 37 kg, Gomes et al. (1989) also observed the effect of the available phosphorus levels on the bone phosphorus content, which increased in a quadratic behavior with increasing available phosphorus levels in the diet.

Otherwise, Huertas (1992), in a study with sows at 95 days of gestation, assessed the total phosphorus levels and observed no difference in the calcium and phosphorus contents in the caudal vertebrae of these animals.

The lowest bone calcium and phosphorus contents in animals that consumed diets with lower available phosphorus levels indicate less mineralization of the skeleton, probably due to insufficient quantity of phosphorous in diets.

The bone ash percentage (BA) was not affected (P>0.05) by the available phosphorus levels in the diet. Similar results were obtained by Hastad et al. (2004), in a study with pigs from 33 to 55 kg, who did not observe any variation in the ash percentage determined in the third metacarpal bone related to the increasing available phosphorus levels in diets. However, these authors found a linear increase in the bone calcium percentage when determined in the fourth metacarpal bone and in the fifth, sixth and seventh ribs.

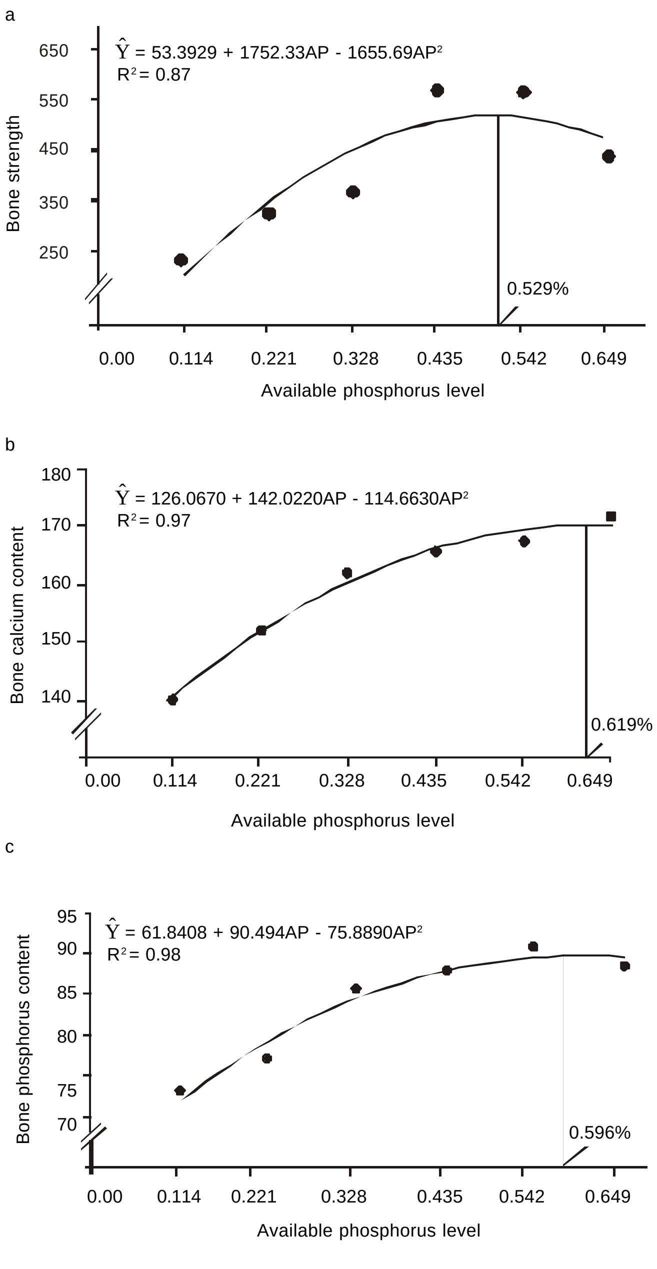

Figure 3 - Bone strength (a), bone calcium content (b) and bone phosphorus content (c) of pigs from 15 to 30 kg fed diets with different available phosphorus levels.

Variation in the bone calcium levels from work to work were probably due to the types of bones used. Cromwell et al. (1970) found reduction of 22% in the bone ash content of the nasal turbinate compared to a reduction of only 6% of the metacarpal of growing pigs when the phosphorus level was reduced from 0.50 to 0.38%. These results suggest that the bone of the nasal turbinate was more sensitive to phosphorus in comparison to other types of bones; therefore, it is more suitable for use in estimating the available phosphorus requirements for pigs, based on bone parameters.

Conclusions

The best weight gain and feed conversion observed for castrated male and female pigs from 15 to 30 kg, genetically selected for meat deposition, is provided by 0.509 and 0.477% of available phosphorus levels, respectively, corresponding to daily intakes of 6.39 and 5.93 g of available phosphorus.

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