DIETARY PHOSPHORUS LEVELS AND CALCIUM:AVAILABLE PHOSPHORUS RATIO FOR GROWING PIGS

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SUMMARY

The effect of four levels of available phosphorus (0.1-0.4%) and four calcium:available phosphorus ratios (1.7-2.9) on growth performance and bone characteristics of growing pigs from 20-50 kg live weight were evaluated. Levels of available phosphorus did not significantly affect growth respose, regardless of the calcium:available phosphorus ratio in the diet. However, carcass daily gain was reduced, and feed conversion ratio significantly ($P < 0.05$) increased when pigs were fed a dietary calcium:available phosphorus ratio greater than 2.5: 1 .0. Bone dry matter, percent bone ash and bone bending moment were significantly ($P < 0.01$) increased as the available phosphorus level in the diet increased but were unaffected by the ratio of calcium:available phosphorus. Percent bone ash of the coxae, tibia/ fibula and radius/ulna had better responses to the dietary available phosphorus than other bones or growth response.

The results indicate that, for growth, a dietary level of 0.1% available phosphorus was adequate. However, 0.3% available phosphorus was needed for adequate bone development, using percent bone ash as the criterion of response.

INTRODUCTION

Current recommendations for available phosphorus for growing pigs from different countries vary from 0.21 to 0.46%, with an average of 0.30% (Agricultural Research Council, 1981; Jongbloed, 1987). The reasons for this variation are likely due to environmental and genetic differences, rate of feeding, major ingredients used in the diets to determine the levels of available phosphorus and criteria of adequacy.

In Australia, total phosphorus recommendations are based on those of the Agricultural Research Council (ARC) (1981) (Standing Committee on Agriculture (SCA), 1987). Their recommendation for growing pigs is 0.60 total phosphorus, which corresponds to a calculated 0.46% available phosphorus. These levels are higher than the recent recommendations of the National Research Council (NRC) (1988) of 0.50% total and 0.23% available phosphorus for growing pigs,.

Available phosphorus in plant materials varies considerably depending on species and processing technique. The concentration of available phosphorus in a diet is considered to be a more precise measure for defining phosphorus requirements than total phosphorus. Hence, expression of calcium:available phosphorus ratio is more preferable than calcium: total phosphorus ratio.

The objective of this experiment was to evaluate the effects of various dietary available phosphorus levels and calcium:available phosphorus ratios on growth and bone development in growing pigs.

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MATERIALS AND METHODS

The basal diet consisted of raw sugar and soyabean meal (Table 1).

Table 1. Composition (% air-dry basis) of the basal diet

Components	
Soya-bean meal	43.5
Sugar	54.1
Soyabean oil	1.3
DL-methionine	0.14
L-valine	0.18
Vitamins and minerals	0.50
Limestone	0.14
Sodium tripolyphosphate	0.11
Composition*	
Crude protein (N x 6.25)	19.8
Digestible energy (MJ/kg)	15.7
Lysine	1.17
Calcium	0.17
Total Phosphorus	0.32
Available phosphorus (estimated)	0.10
Calcium:avail.phosphorus ratio	1.7

* calculated

Four levels of calculated available phosphorus (0.1, 0.2, 0.3 and 0.4%) and four calcium:available phosphorus ratios (1.7, 2.1, 2.5 and 2.9) were formulated by substituting the required amounts of limestone and sodium tripolyphosphate for sugar. The levels of available phosphorus and calcium:available phosphorus ratio in this experiment are maintained within the range of the ARC (1981) and NRC (1988) recommendat ions for growing pigs.

The diets were offered ad *libitum* to 96 pigs (4 males and 4 females per diet) over the 20 to 50 kg growth phase. The pigs were then slaughtered and carcass and bone characteristics assessed.

RESULTS

Growth performance

Dietary available phosphorus level from 0.1 to 0.4% did not significantly affect feed intake, weight gain, feed conversion ratio, carcass gain, carcass feed conversion ratio, dressing percentage or backfat thickness (Table 2). On the other hand, the widest calcium:available phosphorus ratio (2.9:1.0) significantly ($P < 0.01$) reduced daily carcass gain and increased feed conversion ratio and carcass feed conversion ratio .

The R2 and % variation values were generally low indicating dietary available phosphorus levels had little influence on the growth performance of the pigs.

Dry matter of bones

The dry matter of the bones varied from 44-67% (Table 3) with the lowest value in the sternum and the highest in the fourth metatarsal bone. The dry matter of the bones was significantly ($P<0.01$) affected by dietary phosphorus level. Available phosphorus increased the dry matter of the bones linearly and quadratically ($P < 0.01$). The maximum bone dry matter was generally obtained by feeding the pigs the diet containing 0.3% available phosphorus.

Table 2. Effect of dietary available phosphorus level and calcium:available phosphorus ratio on the performance of growing pigs

	Available phosphorus (%)				Calcium:available phosphorus ratio				Statistics		
	0.1	0.2	0.3	0.4	1.7	2.1	2.5	2.9	SEM	R^2	% variation (linear effect of P)**
Feed intake (g/d)	2052	2106	2118	2031	2034	2101	2068	2103	35	0.28	0.1
Weight gain (g/d)	915	946	955	916	946	943	943	900	15	0.16	0.0
Feed conversion ratio	2.24	2.23	2.23	2.22	2.15	2.23	2.20	2.34	0.03*	0.32	0.3
Carcass gain (g/d)	739	762	758	733	761	757	760	714	11*	0.25	0.3
Carcass feed conversion ratio	2.78	2.78	2.80	2.77	2.67	2.78	2.73	2.95	0.04*	0.30	0.0
Dressing percentage	78	78	77	78	78	78	78	77	0.34	0.13	2.1
Backfat thickness (P_2 mm)	17.7	18.7	18.3	17.5	17.6	18.3	17.9	18.5	0.51	0.14	0.2

* Linear response to Ca:available P ratio significant (P < 0.01)

** Percent variation explained by the linear effect of available phosphorus excluding other variables

Table 3. Effect of dietary available phosphorus level and calcium available phosphorus ratio on percent dry matter (%) of various bones of growing pigs

Bones	Available phosphorus (%)				Calcium:available phosphorus ratio				Statistics		
	0.1	0.2	0.3	0.4	1.7	2.1	2.5	2.9	SEM	R^2	% variation (linear effect of P)
Scapula	48.5	53.7	55.8	57.4	53.8	55.0	52.4	54.3	0.76**	0.64	55
Humerus	52.3	56.4	57.5	59.1	56.0	57.0	54.9	57.4	0.81*	0.53	38
Radius/ulna	54.6	60.5	61.0	62.7	59.2	60.1	58.5	61.0	0.80**	0.59	45
First-fourth thoracic vertebra	50.6	55.9	57.1	58.7	55.3	56.7	53.9	56.4	0.63**	0.70	59
First-fourth ribs	49.9	54.4	57.1	57.2	54.1	55.5	53.6	55.3	0.73**	0.61	49
Sternum	44.6	48.8	50.4	50.7	48.1	49.4	46.6	50.4	1.07**	0.41	23
Coxae	50.5	55.2	57.1	58.3	54.9	56.2	53.8	56.1	0.66**	0.65	55
Femur	50.7	55.9	56.7	57.5	54.7	55.0	54.5	56.6	0.87**	0.46	33
Tibia/fibula	54.5	58.7	58.9	61.2	57.0	58.8	57.7	59.9	0.70*+	0.55	41
Fourth metatarsal	62.1	66.2	66.6	67.4	65.0	65.5	65.0	66.7	0.67**	0.56	34

* Linear response to available P significant ($P < 0.01$)
** Linear and quadratic response to available P significant ($P < 0.01$)
\+ Linear response to Ca:available P ratio significant ($P < 0.01$)

The largest effect on bone dry matter was between 0.1 and 0.2% available phosphorus and declined with the other consecutive levels. On the other hand, dry matter of bones was generally not influenced by the calcium:available phosphorus ratio used in this experiment. R2 and % variation values for bone dry matter were higher than for growth. The highest values were found in the first-fourth thoracic vertebrae, followed by the scapula and coxae bones.

<u>Percent bone ash</u>

Percent bone ash of all bones was significantly ($P<0.01$) increased when the available phosphorus level increased in the diets (Table 4). These responses were significantly ($P<0.01$) linear and quadratic. With most bones, the optimum percent bone ash was obtained when pigs were fed diets containing 0.3% available phosphorus or lower. Humerus, sternum and fourth metatarsal bones reached the optimum percent bone ash when the diets contained 0.2% available phosphorus. The lowest percent bone ash was found in the sternum and the highest in the radius/ulna and scapula bones.

Generally, the values of R2 and % variation were higher than for previous values. The values ranged from 0.40-0.75, with the lowest in the sternum and the highest in the coxae, followed by radius/ulna and femur bones.

Percent bone ash did not respond consistently to the calcium:available phosphorus ratio in the diet. As shown in Table 4, percent bone ash of the scapula, ribs, coxae, tibia/fibula and femur were influenced by the ratio but others were not.

<u>Bone bending moment</u>

Bone bending moment of the fourth metacarpal and metatarsal bones were significantly ($P< 0.01$) increased as the level of phosphorus in the diet increased (Table 4) Both bones responded linearly to the available phosphorus level but the metacarpal' bone bending moment responded quadratically as well as linearly; it reached the optimum bone bending moment when the pigs were fed the diet containing 0.3% available phosphorus. The greatest effect on bone bending moment was found between 0.1 and 0.2 % available phosphorus compared to the other levels. The data also showed that the bone bending moments of the metacarpals were higher than metatarsal values.

Ratio of calcium:available phosphorus did not significantly alter the bone bending moment of the metacarpal or metatarsal bones.

The values of R2 and % variation were generally lower than the values for percent bone ash. However, feeding the pigs diets containing available phosphorus levels between 0.1-0.4% and calcium:available phosphorus ratios between 1.7-2.9 did not result in any visual symptoms of bone disorder or gait difficulty in the growing pigs

DISCUSSION

The results of this experiment have provided various response criteria to the dietary available phosphorus levels and calcium:available phosphorus ratios for growing pigs. Pig performance criteria are important measures in the pig industry. On these criteria, this experiment indicates that at 0.1% dietary available phosphorus (= 0.32% total phosphorus in this experiment) was sufficient to support growth of pigs provided calcium:available phosphorus was between 1.7-2.5: 1.0. This indicates that growing pigs require approximately 2.1 g of available phosphorus per kg weight gain. Theoretically this level can be achieved by formulating diets of 65% wheat /barley and 30% soybean meal without any phosphorus supplement. This level is in agreement with Koch and Mahan (1985) who found that 0.31% total phosphorus was sufficient for the growth of pigs. However, this is slightly lower than current NRC (1988) recommendations or the level suggested by Cera and Mahan (1988), and much

Table 4. Effect of dietary available phosphorus level and **calcium:available** phosphorus ratio on percent bone ash or bone bending moment (kg/cm) of various bones of growing pigs

Bones	Available phosphorus (%)				Calcium:available phosphorus ratio				Statistics		
	0.1	0.2	0.3	0.4	1.7	2.1	2.5	2.9	SEM	R^2	% variation (linear effect of P)
Percent bone ash											
Scapula	48.8	52.5	53.8	54.5	52.5	53.3	51.6	52.2	0.47**	0.63	57
Humerus	48.3	51.8	53.3	53.3	51.4	52.0	51.0	52.3	0.49**	0.59	49
Radius/ulna	48.6	52.8	53.6	54.5	52.4	52.9	51.9	52.3	0.39**	0.74	66
First-fourth thoracic vertebra	48.7	52.3	53.4	54.0	52.3	52.9	51.5	51.7	0.49**	0.62	51
First-fourth rib	47.6	51.4	53.2	53.8	51.6	52.3	50.3	51.6	0.46**	0.71	62
Sternum	39.0	42.0	44.4	44.6	42.1	42.8	41.3	43.7	0.97*	0.40	25
Coxae	45.6	50.1	52.2	52.6	50.4	51.0	48.7	50.4	0.45**	0.75	68
Femur	45.5	49.3	51.9	52.1	49.6	50.4	48.6	50.1	0.47**	0.74	65
Tibia/fibula	47.5	51.3	52.5	52.9	51.0	51.8	50.1	51.5	0.44**	0.68	57
Fourth metatarsal	49.9	51.0	52.5	51.9	52.0	51.4	50.9	51.0	0.68**	0.53	50
Bone bending moment											
Metacarpal	28.6	37.2	42.5	45.0	36.5	37.5	40.5	38.8	1.42**	0.51	47
Metatarsal	24.0	33.6	37.7	43.2	33.0	35.0	35.8	34.8	1.28*	0.62	58

* Linear response to available P significant ($P < 0.01$)
** Linear and quadratic response to available P significant ($P < 0.01$)

lower than ARC (1981) recommendations; it is probable that their recommendations are to achieve both maximum growth and adequate bone development.

Calcium:available phosphorus ratios between 1.7-2.5: 1.0 did not adversely affect the pig performance. These ratios were very close to the calcium: phosphorus ratios in the whole body and the bone of pigs which have ratios of 1.6:1.0 and 2.2:1.0 respectively (Hays, 197 6). Widening the dietary calcium: available phosphorus ratio to 2.9: 1.0 decreased carcass gain, increased feed conversion ratio and carcass feed conversion ratio. It seems that high dietary calcium in this ratio depressed food utilization. Batterham (1969) and Pointillart et al. (1987) also found that excessive dietary calcium reduced weight gain and feed efficiency of growing pigs. Koch and Mahan (1985) also reported that feed conversion ratio of growing pigs was increased when fed diets containing 0.12-0.50% total phosphorus with calcium:total phosphorus ratio between 1.5: 1 .0 to 3 .0: 1 .0. In relation to the detrimental effect of excess dietary calcium, Vipperman et al. (1974) reported that nitrogen retention was reduced when calcium levels increased without increasing dietary phosphorus at the same time.

All types of bones, for all criteria measured, significantly responded to dietary available phosphorus. The increase in available phosphorus in the diet increased bone dry matter, percent bone ash, and bone bending moment of the metatarpals and metatarsals. These responses may well be explained by the report of McLean and Wrist (1968) who stated that, in bone mineralization, water in the bone matrix is being continually replaced by crystals of bone mineral until there is no more space available for further expansion, where maximum mineralization is achieved. Thus, by increasing phosphorus level in the diet, bone dry matter is increased as bone water is replaced by mineral crystals.

The increase of dietary available phosphorus was also followed by the increase in percent bone ash. This again may have been associated with the mineralisation process reported by McLean and Wrist (1968) as previously mentioned. Koch and Mahan (1985) also found that the increase in dietary phosphorus increased bone component weight in growing pigs.

The largest effect on all response criteria was found between 0.1 to 0.2% available phosphorus compared to other consecutive levels. This indicates that the first 0.1% increase in available dietary phosphorus had a greater influence on all bones compared to other higher available phosphorus levels. Based on R2 and % variation values, percent bone ash was more sensitive than other criteria in responding to a change in dietary available phosphorus levels. This suggests that bone ash may well be used as response criteria in assessing phosphorus adequacy or availability phosphorus in feed ingredients.

The data in Table 4 show that all bones tested reached the optimum percent bone ash when the pigs were fed a diet containing 0.3% available phosphorus or equal to approximately 6.3 g available phosphorus per day (= 6.7 g available phosphorus per kg weight gain).

All type of bones based on bone ash criteria significantly ($P < 0.01$) responded to the dietary available phosphorus, regardless of the calcium: available phosphorus ratio. This is in agreement with Crenshaw et al. (1981) who reported that all bones responded to the dietary phosphorus when fed to three month old pigs. However, among the bones tested in this experiment as shown in Table 4, coxae, femur and radius/ulna bones had higher R2 and % variation values compared to other bones. This suggests that these bones were more sensitive to the change in dietary available phosphorus. Thus, when determining the phosphorus adequacy or availability in growing pigs, those bones can be selected as bone samples when bone ash is taken as the response criterion.

Although the bone bending moment of metacarpal and metatarsal bones were both increased significantly ($P < .01$) with the increase in dietary available phosphorus level, the increase in bone bending moment of the metatarsal associated with available phosphorus level was higher compared to the metacarpal. This indicates that the metatarsal is preferable as a bone sample if bone bending moment is to be taken as the response criteria for assessing phosphorus adequacy or availability in growing pigs. The increase in bone bending moment as the result of increasing available phosphorus level in the diet is in agreement with reports of Crenshaw (1986), Crenshaw et al. (1981), Reinhart and Mahan (1986) and Cera and Mahan (1988). The increase in bone bending moment may have been related to the increase in bone dry matter of the metatarsal. Sedlin and Hirsch (1966) also reported that bone strength was increased after exposing the bone in air for ten minutes or longer.

CONCLUSIONS

1. Feeding growing pigs diets containing 0.1-0.4% available phosphorus with calcium:available phosphorus ratio of between 1.7-2.5: 1.0 did not significantly influence feed intake, growth rate or feed conversion ratio.

2. The available phosphorus requirement for growth is 0.1% or 2.1 g per day or 2.3 g per kg weight gain.

3. The available phosphorus requirement for optimum percent bone ash is 0.3%, which is equivalent to 6.3 g per day or 6.7 g per kg weight gain.

4. In assessing adequacy or availability of phosphorus for growing pigs, coxae, femur and radius/ulna are sensitive bones when percent bone ash is taken as the response criteria.

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