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Performance, body and carcass composition and bone characteristics of pigs fed rapeseed and soyabean meal-cereal diets supplemented with microbial phytase *

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ABSTRACT

Thirty-three female pigs from 25 to 70 kg body weight were fed isocaloric and isoprotein diets composed of rapeseed (RSM) or soyabean meal (SBM) and a wheat-barley mixture with high intrinsic phytase content (over 900 FTU/kg). Basal diets containing 0.19-0.20% of digestible P were unsupplemented or supplemented with either microbial phytase (1000 FTU/kg, Natuphos*) or dicalcium phosphate to the level of 0.25% recommended for growing pigs. Apparent digestibility of nutrients, growth performance, carcass value, physical properties of the femur, third metatarsal and metacarpal and chemical composition of the whole bodies of pigs were investigated.

Microbial phytase supplementation increased ($P<0.01$) the content of digestible P to a higher degree in the diet with RSM (0.78 g) than with SBM (0.48 g/kg), and in the empty body increased ash, calcium and phosphorus contents by 1.55, 0.58 and 0.34 g/kg, respectively. The phytase-supplemented pigs had similar Ca:P ratios as unsupplemented ones and higher ($P<0.01$) ratios of ash and phosphorus to protein in their bodies. Growth performance, carcass characteristics, protein and energy content in the body and physico-mechanical properties of the femur and metatarsal were not

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changed by phytase or dicalcium supplementation, except the strength value in the third metacarpal which was higher in pigs receiving the diet supplemented with inorganic P. Utilisation of digestible P was significantly higher (85-87%) in pigs fed basal diets than in animals fed diets supplemented with microbial phytase or dicalcium phosphate (67-73%).

Daily protein deposition in the body was not decreased by reducing the P content in the diet to 0.19%. RSM, as the high protein feed in the diet with barley and wheat, supplied a sufficient amount of P to cover the requirements of growing pigs. The results of the experiment indicated that cereal phytase has a beneficial effect on total phytic P utilisation.

KEY WORDS: phosphorus, phytase, body composition, bone strength, pigs

INTRODUCTION

In most protein-feeds of plant origin phosphorous is poorly available for pigs due to the proportion of phytate P in feedstuffs and the lack of intrinsic phytase (Düngelhoef et al., 1994; Rodehutscord et al., 1996). Numerous reports have shown that addition of microbial phytase to pig diets can release a significant portion of the bound P, improving phosphorus availability (Näsi et al., 1995; Helander et al., 1996; Kornegay and Qian, 1996). Microbial phytase supplementation was mainly effective in diets formulated with maize and soyabean meal, which have extremely low plant phytase contents (Jongbloed et al., 1996; Kornegay and Qian, 1996). However, concentrates for pigs are often based on other cereals such as wheat, barley, rye, and triticale which have markedly higher P availability than maize. This is attributed to the frequently very high intrinsic phytase activity in these cereals, as reviewed by Weremko et al. (1997). Supplementation of such feedstuffs with microbial phytase could further improve P digestibility by 7-14% (Düngehoef et al., 1994; Fandrejewski et al., 1997).

Until recently, not enough attention was paid to barley and wheat with high phytase contents in the formulation of practical diets for pigs. Some diets based on such cereals contain a large proportion of RSM, which is one of the richest sources of P of plant origin (Pointillart et al., 1985; Näsi et al., 1995), and covers the animal's needs for total phosphorus. However, the availability of P from such diets for growing pigs is almost unknown.

Current recommendations for P requirements of pigs vary due to the criteria of adequacy. Obviously, several criteria, not only one, should be taken into consideration in pig nutrition – this includes environmental pollution. Estimation of the chemical composition of the whole body of pigs seems to be one of the convenient methods of studying P balance in pigs (Rymarz et al., 1986).

The presented experiment was conducted to determine the response of growing pigs to a level of digestible P in the diet reduced to below a current recommendations, and to determine the effect of adding microbial phytase to cereal-RSM or

SBM-diets when the cereals contain high levels of intrinsic phytase. Digestibility of phosphorus, its deposition in the body as well as carcass and bone characteristics were studied on growing pigs kept in environmental conditions similar to practice.

MATERIAL AND METHODS

Diets

Rapeseed meal (RSM), soyabean meal (SBM), wheat and barley that contained 13.1, 6.1, 3.4 and 3.3 g P per kg dry matter were used. The concentration of phytate P as a proportion of total P was 0.67, 0.55, 0.66 and 0.71, respectively. Plant ingredients differed markedly due to phytase activity, which was extremely low in RSM and SBM (<60 FTU/kg), high in barley (795 FTU/kg), and the highest in wheat (1710 FTU/kg). The RSM contained 22 moles of glucosinolates per kg of fat-free dry matter.

Two basic diets (B) containing the RSM or SBM were formulated to meet requirements of pigs from 25 to 70 kg liveweight for metabolisable energy (12.5 MJ/kg) and crude protein (17.0%) (Table 1). The concentration of digestible P in both basal diets (1.8 g/kg) estimated from chemical analysis and digestive coefficient calculated from data given in Nutrient Requirements of Pigs (1993) was below present recommendations for growing pigs.

The RSM/B diet was composed from RSM, wheat and barley that were the only sources of phosphorus (0.57% total P). The RSM/M diet was supplemented with microbial phytase (1000 FTU/kg, Natuphos, BASF), whereas the RSM/D diet was supplemented with 0.58% dicalcium phosphate to the level of 2.5 g/kg digestible P, recommended by the Nutrient Requirements of Pigs (1993). The basal diet with the soyabean meal (SBM/B) was supplemented with inorganic P (0.04%) to maintain a level of digestible-P similar to the RSM/B diet. The SBM/M and SBM/D-diets were supplemented with either microbial phytase or dicalcium phytase.

The Ca:P-total ratio in all diets was maintained at 1.3:1 by addition of limestone and/or dicalcium phosphate. Vitamins and essential trace elements were added to the diets as a premix. L-lysine · HCl and DL-methionine were added to maintain the balance of essential amino acids.

Animals and procedures

The experiment was carried out on 5-6 growing pigs in a 3 x 2 factorial design. Landrace gilts, taken from a breeding farm, were closely related, often originated from the same litters. The pigs were allowed at least 1 week to adjust to the pen.

TABLE 1

Composition of the experimental diets

Protein source	RSM			SBM		
Phytase addition	-	+	-	-	+	-
Phosphate addition	-	-	+	-	-	+
Group	B	M	D	B	M	D
Ingredients, g/kg						
rapeseed meal	250	250	250	-	-	-
soyabean meal	-	-	-	205	205	205
barley	178	177.8	172.8	423.1	422.9	416.2
wheat	547	547	547	350	350	350
premix[1]	5	5	5	5	5	5
limestone	13.0	13.0	12.4	9.0	9.0	8.7
NaCl	3	3	3	3	3	3
L-lysine · HCl	4	4	4	2.4	2.4	2.4
DL-methionine	-	-	-	0.3	0.3	0.3
dicalcium phosphate[2]	-	-	5.8	2.2	2.2	9.4
Natuphos®	-	0.2	-	-	0.2	-
Chemical composition (89% DM), g/kg						
crude protein		170			172	
lysine		10.2			10.3	
crude fibre		55			45	
ether extract		26			19	
ash	45	45	50	38	38	44
Ca	7.4	7.4	8.7	5.5	5.5	7.2
P-total	5.7	5.7	6.7	4.2	4.2	5.5
P-phytate	3.8	3.8	3.8	2.4	2.4	2.4
Phytase, FTU[3]	803	1812	868	761	1718	752
Gross energy, MJ		16.7			16.6	

[1] amounts of vitamins and microelements supplied per kg of diet: vitamin A – 15000 IU, vitamin D3 – 2000 IU, vitamin E – 15 mg, vitamin K3 – 1.5 mg, vitamin B1 – 1.0 mg, vitamin B2 – 5 mg, vitamin B6 – 1.5 mg, vitamin B12 – 0.015 mg, biotin – 0.03 mg, folic acid – 0.5 mg, nicotinic acid – 15 mg, calcium pantothenate – 8 mg, choline chloride – 150 mg, Mn – 30 mg, Zn – 40 mg, Cu – 15 mg, Fe – 60 mg, J – 0.5 mg, Se – 0.15 mg, Co – 0.6 mg, virginiamycin (Stafac®) – 5 mg

[2] containing 267 g Ca and 180 g P

[3] native and microbial (determined in the middle of experiment)

The dietary treatments were then introduced over a 3 d period, when the pigs reached 25 kg liveweight (s.e.= 0.12 kg). Animals were kept in individual pens (1.3 x 2.6 m) on a non-slatted floor and fed twice daily, at 08:00 and 14:00 h. The diets were fed in mash form, and water was supplied *ad libitum* by nipple drinkers. Daily rations were calculated to 85% of voluntary feed intake, according to ARC (1981). At about 45 kg of body weight, nutrient digestibility was measured in all

pigs by an indirect method, with Cr_2O_3 as the indicator, over a 5-day collection period. Pigs were slaughtered at 70 kg liveweight using electric stunning. Additionally, 10 pigs weighing 25 kg were slaughtered to provide the initial body composition. The left half-carcasses and viscera were autoclaved for 8 h, ground and homogenized. Bristles were also quantitatively collected and dried. All materials were analyzed for protein, ether extract, water, ash, Ca, and P contents. Retention of nutrients in the body during growth from 25 to 70 kg was measured from the differences between the final and initial contents. The amount of phosphorus excreted (*via* faeces, urine and hair) was calculated as the difference between P consumed by pigs and P retained in their body.

The right half carcass was partially dissected into lean and fat. Additionally 3 bones (the femur, third metacarpal and third metatarsal) from the right half-carcass were taken for determination of physical and mechanical characteristics. Bones were stored at -28°C in plastic bags to maintain the original moisture content. After defrosting, adhering tissue was removed, the bones were weighed and measured (length of total bone, diameter of bone shaft and bone volume). Volume was determined by placing the whole bones into water and recording the quantity of water displaced. Bone density was calculated as the weight-to-volume ratio.

The mechanical properties of bones were determined by flexion testing with an Instron Universal Testing Machine. The bones were treated as beams supported at each end and a force was applied at midshaft. The force was applied at a constant rate of 6 mm/min with a recorder. The elastic deflection of bone to permanent damage was measured (with a tensiometer), and force required to break the bone was also determined.

Breaking force was used to estimate bending moment, which allows comparison of breaking strength of bones of different lengths. Bending moment (Mb) was expressed as N x m and was determined by the formula:

$$Mb = (\text{force} \times \text{length}) / 4$$

where:

- force (Newton) applied in the midpoint of the shaft until breaking
- length equals the distance between the two fulcra points that support the bone, and was 0.03 m (for the metacarpal and metatarsal) or 0.07 m (for the femur).

Analytical methods

Feeds, faeces, and samples of pig bodies were analyzed according to standard methods (AOAC, 1990). Gross energy of feeds was determined by combustion of samples in a bomb calorimeter. Phosphorus was determined photometrically using the vanado-molybdate method, Ca from ash solutions by atomic absorption spectrophotometry. Phytase activity of ingredients and feed mixtures was measured according to Eeckhout and De Paepe (1994), one unit (FTU) of phytase activity

being defined as the activity liberating 1mmole of inorganic phosphate per minute from 0.0015 mole of sodium phytate at 37°C and pH 5.5. Phytate was estimated according to Tangkongchitr et al. (1981) modified by Antoniewicz et al. (1992).

Statistical analysis

The data were subjected to a least squares analysis of variance using the Anova method. The significance of differences among means was tested with the Tukey least significance difference test. All calculations were performed using Statgraphics Plus, Version 7.0. Because no interaction between protein source and dietary additives was observed, besides for fat content in the body (Table 6), only the main effects of the dietary treatments are given in the Tables 2-7.

RESULTS

Effect of microbial phytase

Addition of microbial phytase to the RSM and SBM-basal diet did not influence growth performance (Table 3) and slaughter results (Table 4) but increased ($P<0.01$) digestibility of P by 14.0 and 11.6 percentage units, respectively (Table 2). Thus, the concentration of digestible P increased from 1.98 to 2.77 g/kg in the RSM diet, and from 1.93 to 2.41 g/kg in the SBM diet. As a further result, the breaking forces of the bones of pigs fed diets supplemented with microbial phytase were greater ($P>0.05$) than in control pigs (Table 5). The supplemented pigs contained on an average 1.55 g ash, 0.58 g Ca and 0.34 g P/kg more ($P<0.01$), and had higher ($P<0.01$) ratio of ash and phosphorus to protein in their empty body (Table 6). Also, daily ash, calcium and phosphorus deposition was significantly higher ($P<0.01$) by 1.9, 0.63 and 0.38 g in animals fed supplemented diets. In these pigs, however, utilisation of digestible P was 17 percentage units lower than in pigs given the basal diet (69 vs 86%; Table 7).

Effect of dicalcium phosphate

Inclusion of dicalcium phosphate into RSM-diet non-significantly decreased digestibility of energy by 1.3 percentage ($P>0.05$) and increased digestibility of P by 6.5 percentage units ($P<0.01$) and digestible P content by 0.78 g/kg of diet (Table 2). Pigs from the RSM/D group deposited significantly ($P<0.01$) more 2.6 g ash, 0.9 g Ca and 0.5 g P, and contained correspondingly more ash and Ca and P in the body than pigs from the RSM/B group. The ratios of ash and phosphorus to protein were also higher ($P<0.01$) than in pigs given the phosphate unsupplemen-

TABLE 2

Digestibility of nutrients, %

Protein source	RSM			SBM				ANOVA: effect of	
Treatment	B n=5	M n=5	D n=5	B n=6	M n=6	D n=6	SEM	protein source	treatment
Crude protein	75.0	77.6	75.3	82.6	79.2	80.2	0.684	<0.001	NS
Ether extract	33.3	44.3	36.0	29.5	32.0	29.9	1.906	NS	NS
Crude fibre	37.8	39.7	35.1	46.9	37.8	37.4	1.332	NS	NS
N-free extractives	91.8	91.4	89.7	94.4	93.7	93.1	0.178	<0.001	0.007
Energy	81.0	82.3	79.7	83.3	83.4	83.1	0.434	<0.001	NS
Ash	41.8	45.9	39.8	50.9	53.7	49.8	0.901	<0.001	NS
P	34.7	48.7	41.2	46.5	58.1	48.3	1.042	<0.001	<0.001
Digestible P, g/kg	1.98	2.77	2.76	1.93	2.41	2.58	-	-	

TABLE 3

Growth performance

Protein source	RSM			SBM				ANOVA: effect of	
Treatment	B n=5	M n=5	D n=5	B n=6	M n=6	D n=6	SEM	protein source	treatment
Initial body weight, kg	25.1	25.0	25.0	25.3	25.2	25.5	0.115	NS	NS
Final body weight, kg	69.7	70.3	69.9	70.1	69.5	69.9	0.155	NS	NS
Average daily gain, g	751	748	750	776	747	750	10.47	NS	NS
Feed conversion ratio, kg/kg	2.80	2.83	2.81	2.74	2.87	2.83	0.036	NS	NS

TABLE 4

Slaughter results

Protein source	RSM			SBM				ANOVA: effect of	
Treatment	B n=5	M n=5	D n=5	B n=6	M n=6	D n=6	SEM	protein source	treatment
Carcass yield, %	74.2	75.8	76.0	76.8	77.7	78.4	0.270	<0.001	NS
Carcass length, mm	905	896	892	876	890	906	4.888	NS	NS
Backfat thickness, mm	18.5	18.6	17.2	17.3	18.0	17.5	0.424	NS	NS
Longissimus dorsi area, cm^2	27.4	29.8	30.7	33.1	32.6	32.3	0.460	0.002	NS
Meat in ham, %	71.5	73.6	74.3	74.5	72.1	72.8	0.414	NS	NS
Bone in ham, %	9.0	8.2	8.2	8.5	9.2	9.4	0.159	NS	NS
Fat in loin, %	28.3	27.2	24.9	23.3	25.2	25.6	0.675	NS	NS
Fat trimmed primal cuts, kg	11.1	11.8	12.1	11.9	11.6	12.0	0.111	NS	NS

TABLE 5

Physical bone characteristics

Protein source	RSM			SBM				ANOVA: effect of	
Treatment	B n=5	M n=5	D n=5	B n=6	M n=6	D n=6	SEM	protein source	treatment
Bending moment, Nm									
femur	48.3	59.0	52.8	46.8	51.0	52.5	1.137	NS	NS
metacarpal	6.48	7.58	8.10	6.32	7.33	7.35	0.235	NS	NS
metatarsal	6.25	6.64	6.96	6.20	6.50	6.63	0.057	NS	0.003
Deflection, mm									
femur	2.66	2.66	2.75	2.62	2.65	2.83	0.029	NS	NS
metacarpal	5.35	5.56	5.61	5.26	5.44	5.50	0.052	NS	NS
metatarsal	5.14	4.62	4.66	5.69	5.04	5.07	0.129	NS	NS

ted diet (Table 6). However, utilisation of digestible P was lower in the RSM/D than in the RSM/B group (0.70 vs 0.87%).

Digestibility of P in the control SBM/B diet, containing some inorganic P was 46.5% (Table 2). Further inclusion of inorganic phosphorus (SBM/D) improved digestibility of P by 1.8 percentage units ($P>0.05$) and increased the digestible P content in the diet from 1.93 to 2.58 g/kg. The breaking force of bones, namely of the 3 metatarsal, was increased ($P<0.01$). The amounts of ash, Ca and P deposited in the body per day as well as the ratio of Ca and P to protein were significantly higher in the SBM/D than SBM/B group (Table 6). Similarly as in the RSM diet, supplementation of the SBM-basal diet with phosphate also reduced utilisation of digestible P from 0.85 to 0.73%.

Pigs reacted more distinctly to the addition of dicalcium phosphate than microbial phytase. However only P digestibility differed significantly between these groups. Pigs receiving the basal diet plus 1000 FTU/kg phytase digested P more efficiently by 8.7 percentage units than pigs fed the diet supplemented with dicalcium phosphate.

Effect of protein feeds

The digestibility of protein, energy, ash and phosphorus in diets containing SBM was higher than in the RSM diets. These differences equaled 4.7, 2.3, 9.0, and 9.5 percentage units, respectively. Pigs fed SBM diets deposited 10 g more protein daily ($P<0.05$) and 2 g more fat ($P>0.05$) than those fed the RSM diet (Table 6). Lower deposition of protein in the body of pigs fed the diet with RSM is presumably connected with lower ileal digestibility of amino acids in RSM than

TABLE 6

Chemical body composition

Protein source	RSM			SBM			SEM	ANOVA: effect of	
Treatment	B n=5	M n=5	D n=5	B n=6	M n=6	D n=6		protein source	treatment
EBW, kg	64.4	66.1	65.9	64.4	66.1	65.9	0.166	0.029	NS
Content in EBW,g/kg:									
protein	152	153	154	159	157	158	0.685	0.003	NS
fat*	197	181	181	178	192	194	2.973	NS	NS
water	623	637	635	637	624	620	2.509	NS	NS
ash	27.7	28.9	29.7	25.8	27.7	28.6	0.227	0.006	<0.001
Ca	8.46	8.89	9.18	7.74	8.47	8.77	0.084	0.008	<0.001
P	5.18	5.40	5.50	4.60	5.05	5.31	0.125	0.002	<0.001
ash/protein	0.182	0.188	0.193	0.162	0.177	0.181	0.002	0.002	<0.001
P/protein	0.034	0.035	0.036	0.029	0.032	0.034	0.036	<0.001	<0.001
Ca/P	1.63	1.65	1.67	1.68	1.68	1.65	0.014	NS	NS
Daily deposition (25-70 kg), g/d [1]									
energy, MJ	8.99	8.62	8.76	8.96	9.44	9.66	1.140	NS	NS
protein	106	109	110	121	117	119	1.805	0.012	NS
fat	171	151	164	153	167	171	3.330	NS	NS
ash	18.7	20.3	21.3	17.4	19.7	20.8	0.338	NS	0.017
Ca	6.0	6.5	6.9	5.5	6.2	6.6	0.133	NS	0.011
P	3.6	3.9	4.1	3.4	3.6	4.0	0.071	NS	0.013

* protein source x treatment interaction (P<0.05)

[1] initial content in the body (at 25.21±0.115 kg): 3.51 kg protein, 2.81 kg fat, 0.68 kg ash, 0.19 kg Ca and 0.12 kg P

SBM (Buraczewska et al., 1999). Animals given the SBM-diets contained less Ca and P in their bodies and had a lower ratio of ash to protein and P to Ca ($P<0.01$). They also excreted less P than their analogues given diets with RSM (Table 7). The carcass dressing percentage of pigs fed the SBM diet was 2.3 % higher ($P<0.01$) than of pigs given RSM-based rations (Table 4).

TABLE 7

Daily phosphorus balance

Protein source	RSM			SBM				ANOVA: effect of	
Treatment	B n=5	M n=5	D n=5	B n=6	M n=6	D n=6	SEM	protein source	treatment
Total P intake, g	11.87	11.98	14.04	8.60	8.87	11.33	0.070	<0.001	<0.001
Digestible P, g	4.13	5.82	5.78	4.00	5.16	5.47	0.112	NS	NS
P-retained, g	3.61	3.89	4.05	3.39	3.64	3.98	0.071	NS	0.013
P-excreted, g	8.26	8.09	9.99	5.21	5.23	7.35	0.096	<0.001	<0.001
P-retained/P-total	0.30	0.33	0.29	0.39	0.41	0.35	0.007	<0.001	0.026
P-retained/ P-digestible	0.87	0.67	0.70	0.85	0.71	0.73	0.021	NS	<0.001

DISCUSSION

The phytase activity in wheat and barley (1710 and 795 FTU/kg, respectively) was relatively high, but even two fold higher values have been found in the literature (Weremko et al., 1997). It is also important to point out that the cereals used in the present study were not artificially dried during or after harvesting in order to avoid possible inactivation of the enzyme, as high temperatures markedly reduce P digestibility in feedstuffs with phytase (Jongbloed and Kemme, 1990). Phytase activity in the feeds after storage for 40-50 d was about 10% lower than at the beginning of the experiment. However, such a decrease of enzyme activity did not depend on the type of feed or Natuphos supplementation. Loss of phytase activity during storage of cereal diets is reported also in other studies (Frapin, 1996). Under optimal conditions of cereal storage, a loss of 5% enzyme activity over 1 month is reported for both Natuphos (Günther, 1996) and intrinsic phytase in ground grains (Frapin, 1996).

Phosphorous digestibility in the basal diet containing RSM was 34.7% and was similar to the digestibility of P in wheat-RSM and barley-RSM mixtures obtained in a short-term study by Fandrejewski et al. (1997) and agreed with the results of Näsi et al. (1995) with barley-RSM diets. This is 5-8 percentage units higher than estimated according to Nutrient Requirements of Pigs (1993), suggesting a beneficial effect of plant phytase present in barley and wheat on digestibility of phytic P in the whole diet. Moreover, phytase added to diets containing RSM increased P

digestibility at a similar rate (by 14 units) in both earlier (Näsi et al., 1995; Fandrejewski et al., 1997) and the present studies. Based on the results of this experiment, 1000 FTU microbial phytase releases 0.78 g digestible P. This is in agreement with the study of Jongbloed et al. (1996), who found that 500 to 2000 FTU of microbial phytase releases between 0.8 and 1.0 g of digestible P. It should be added that a dose of 1000 FTU/kg of microbial phytase was not in excess, since in RSM-cereal diets the steady state in the increase of P digestibility due to microbial phytase was reached when phytase level was 30% higher then in the present study (Weremko, 1998).

Microbial phytase in the SBM-diet increased P digestibility to a similar degree as in the RSM diet, but released much less phosphorus (0.48 g P per 1000 FTU of Natuphos). This is also less than obtained with maize-soyabean diets as reported by Kornegay and Qian (1996). The present work clearly indicates that phosphorus liberated by phytase depends on the concentration of P chemically bound in phytate molecules and on the amount of microbial and plant phytases in the diet. Thus, a dose of 1000 FTU microbial phytase was in excess in the SBM, but not in the RSM diet, which contained more phytic P (3.8 vs 2.4 g/kg). Our results also suggest that in diets rich in phytic P the effect of both kinds of phytase is additive. However, it is not complete due to the different, broader pH spectrum of activity of this type of phytase, as found by Eeckhout and Paepe (1996).

In these studies pigs were fed diets differing by 40% in their digestible phosphorous contents (from 1.9 to 2.8 g/kg). The pigs receiving the largest amount of digestible P deposited about 4 g of P daily in their bodies. In the dry fat-free mass of these pigs the P concentration (about 30 g/kg) was similar to that found in growing gilts fed diets containing excess macroelements (Fandrejewski et al., 1986). It can, therefore, be concluded that the mineral requirements of these pigs were fully covered. On the other hand, both basal diets led to a decline in P deposition, which, however, did not lead to visible changes in the motoric behaviour of these animals. The performance of all of the animals was normal and no differences were found among the groups in carcass or bone quality, with the exception of the lower breaking strength of the 3 metacarpal, but bones vary widely in sensitivity to P deficit.

In contrast with literature data (Mroz et al., 1994; Näsi et al., 1995; Helander et al., 1996), in this study supplementation with microbial phytase did not improve digestibility and retention of other phytate-bound nutrients. Many authors have found that phytase improves the digestibility and retention of energy (Ketaren et al., 1993), protein (Mroz et al., 1994; Helander et al., 1996) or particular amino acids (Mroz et al., 1994). On the other hand, Näsi et al. (1995) failed to find increased N retention in pigs fed diets containing RSM. This may indicate that in these types of studies, the proprietary type of phytase used should be taken into account. For example, in previous studies (Fandrejewski et al., 1997) the addition

of Allzyme phytase significantly improved protein and energy digestibility in diets having similar compositions as those in this experiment in which Natuphos phytase was used.

The main differences were found in the chemical composition of the body, particularly in the amounts of Ca and P. Deposition of P and Ca was higher when phytase or inorganic phosphorous were added than in pigs fed the control diets. The average increase in P and Ca retention in response to phytase supplementation was in agreement with earlier studies (Lantzch et al., 1995; Jongbloed et al., 1996). Although deposition of these elements increased, the Ca:P ratio in the body did not change, hence the conclusions that there is no need to adjust the Ca content in the diet when using phytase (Qian et al., 1996). In the studies of Näsi et al. (1995) the addition of phytase, although without effect on Ca absorption, did increase its deposition, leading to a decrease in urinary excretion of Ca.

The dependence between the amount of P absorbed and deposited in the body was greater for digestible P ($r = 0.89$) than total P ($r = 0.79$), but these relationships were not linear, even for digestible P. The utilisation of digestible P was significantly better (85-87%) in pigs fed the control diet than in the remaining groups (67-73%). Increasing P retention by supplementing the diet with inorganic P or microbial phytase decreased its utilisation. Fernandez (1995) also found that net retention of P increased as the amount of absorbed P increased, but the ratio of deposited to absorbed P decreased gradually as absorption increased, which in effect caused a reduction in P utilization. The utilisation of digestible P in our study was 5-10% lower than reported in the literature (Lantzch et al., 1995; Näsi et al., 1995; Helander et al., 1996). This difference may be in part explained by the methods used to measure P balance (in metabolic cages or by comparative slaughter technique) which give different results (Jongbloed, 1987).

Although the amount of digestible P in diets affected P deposition, it had no effect on that of protein. In this study, lowering protein deposition from 4.1 to 3.4 g/day did not affect protein deposition, which remained at about 120 g/day.

It can, therefore, be concluded that the lower limit of P deposition (0.19%) necessary to sustain homeostasis is below 3.4 g P/ day. The lowest level of digestible P in the basic diet used in this study was 0.2-0.3 g/kg feed lower than given in the NRC standards (1998).

Most of the studies reported in the literature have been performed on soyabean and maize diets, while RSM has high levels of phytate, glucosinolate and other antinutritive factors. For this reason the efficacy of phytase treatments could be different from that in maize and SBM diets (Pointillart et al., 1985). In our study carcass dressing of pigs fed the SBM diet was 2.3 percentage points greater ($P<0.01$) than of pigs given RSM-based diets. This was presumably due to the hypertrophic influence of glucosinolates on internal organ weight, which is in agreement with the results of Bourdon and Aumaitre (1990).

The results of the present study indicate that diets formulated with wheat and barley and a high proportion of RSM (25%) may meet the requirement of growing pigs for P without the necessity of adding inorganic P. Although supplementation of such diets with inorganic P increases the safety margin for bone mineralization, large amounts of P are then excreted into the environment (Table 7). From the present study can also concluded that diets formulated with SBM and cereals rich in native phytase and further supplemented with microbial phytase are an appropriate feed for growing pigs, since feeding such a diet containing 0.19% of digestible P allows achieving good production results.

REFERENCES

Agricultural Research Council. Nutrient Requirements of Pigs, 1981. Commonwealth Agricultural Bureaux, Slough (UK)

Antoniewicz A., Dumańska K., Ombach A., 1992. Availability of phosphorus from field bean *(Vicia faba)* and lupin *(Lupinus albus)* seeds to broiler chickens. J. Anim. Feed Sci. 1, 127-137

AOAC, 1990. Official Methods of Analysis of the Association of Official Analytical Chemists. 15th Edition. Washington, DC

Bourdon D., Aumaitre A., 1990. Low-glucosinolate rapeseeds and rapeseed meals: effects of technological treatments on chemical composition, digestible energy content and feeding value for growing pigs. Anim. Feed Sci. Tech. 30, 175-191

Buraczewska L., Wasilewko J., Fandrejewski H., Żebrowska T., Han In K., 1999. Formulation of pig diets according to ileal digestible amino acids content. Livest. Prod. Sci. 59, 13-24

Düngelhoef M., Rodehutscord M., Spiekers H., Pfeffer E., 1994. Effects of supplemental microbial phytase on availability of phosphorus contained in maize, wheat and triticale to pigs. Anim. Feed Sci. Tech. 49, 1-10

Eeckhout W., De Paepe M., 1994. Total phosphorus, phytate-phosphorus and phytase activity in plant feedstuffs. Anim. Feed Sci. Tech. 47, 19-29

Eeckhout W., De Paepe M., 1996. In vitro and in vivo comparison of microbial and plant phytase. In: M.B. Coelho, E.T. Kornegay (Editors). Phytase in Animal Nutrition and Waste Management. BASF Corporation, pp. 237-240

Fandrejewski H., Raj St., Weremko D., Żebrowska T., Han In K., Kim J.H., Cho W.T., 1997. Apparent digestibility of phosphorus in experimental feed and the effect of commercial phytase. Asian-Austr. J. Anim. Sci. 10, 665-670

Fandrejewski H., Rymarz A., 1986. Effect of feeding level on Ca, P, K and Na content in the bodies of growing boars and gilts. Livest. Prod. Sci. 14, 211-215

Fernández José A., 1995. Calcium and phosphorus metabolism in growing pigs. III. A model resolution. Livest. Prod. Sci. 41, 255-261

Frapin D., 1996. Valorisation du phosphore phytique végétal chez l'oiseau: intérêt et mode d'action des phytases végétales et microbienne. These de Doctorat. 133. Ecole Nationale Supérieure Agronomique de Rennes; SRA, INRA, Centre de Tours (France)

Günther C., 1996. Stability of Natuphos phytase through feed processing. In: M.B. Coelho, E.T. Kornegay (Editors). Phytase in Animal Nutrition and Waste Management. BASF Corporation, pp. 655-666

Helander E., Näsi M., Partanen K., 1996. Effect of supplementary *Aspergillus niger* phytase on the availability of plant phosphorus, other minerals and nutrients in growing pigs fed on high-pea diets. J. Anim. Physiol. Anim. Nutr. 76, 66-76

Jongbloed A.W., 1987. Phosphorus in the feeding of pigs; effect of diet on the absorption and retention of phosphorus by growing pigs. Ph.D., Wageningen Agricultural University (The Netherlands)

Jongbloed A.W., Kemme P.A., 1990. Effect of pelleting mixed feeds on phytase activity and the apparent absorbability of phosphorus and calcium in pigs. Anim. Feed Sci. Tech. 28, 233-242

Jongbloed A.W., Kemme P.A., Mroz Z., 1996. Effectiveness of Natuphos phytase in improving the bioavailabilities of phosphorus and other nutrients for growing-finishing pigs. In: M.B. Coelho, E.T. Kornegay (Editors). Phytase in Animal Nutrition and Waste Management. BASF Corporation, pp. 259-274

Ketaren P.P., Batterham E.S., White E., Farrell D.J., Milthorpe B.K., 1993. Phosphorus studies in pigs. 3. Effect of phytase supplementation on the digestibility and availability of phosphorus in soya-bean meal for grower pigs. Brit. J. Nutr. 70, 289-311

Kornegay E.T., Qian H., 1996. Replacement of inorganic phosphorus by microbial phytase for young pigs fed on a maize-soyabean-meal diet. Brit. J. Nutr. 76, 563-578

Lantzch H.J., Wjst S., Drochner W., 1995. The effect of dietary calcium on the efficacy of microbial phytase in rations for growing pigs. J. Anim. Physiol. Anim. Nutr. 73, 19-26

Mroz Z., Jongbloed A.W., Kemme P.A., 1994. Apparent digestibility and retention of nutrients bound to phytate complex as influenced by microbial phytase and feeding regimen in pigs. J. Anim. Sci. 72, 126-132

National Research Council, 1998. Nutrient Requirements of Swine. 10th revised Edition. National Academy Press, Washington, DC

Näsi J.M., Helander E.H., Partanen K.H., 1995. Availability for growing pigs of minerals and protein of a high phytate barley-rapeseed meal diet treated with *Aspergillus niger* phytase or soaked with whey. Anim. Feed Sci. Tech. 56, 83-98

Nutrient Requirements of Pigs. Nutritive Value of Feeds (in Polish). 1993. The Kielanowski Institute of Animal Physiology and Nutrition (Editor). Jabłonna (Poland)

Pointillart A., Fontaine N., Thomasset M., Jay M.E., 1985. Phosphorus utilization, intestinal phosphatases and hormonal control of calcium metabolism in pigs fed phytic phosphorus: soyabean or rapeseed diets. Nutr. Rep. Int. 32, 155-167

Qian H., Kornegay E.T., Conner D. E. Jr., 1996. Adverse effects of calcium:phosphorus ratios on supplemental phytase efficacy for weanling pigs fed different dietary phosphorus levels. J. Anim. Sci. 74, 1288-1297

Rodehutscord M., Faust M., Lorenz H., 1996. Digestibility of phosphorus contained in soybean meal, barley, and different varieties of wheat, without and with supplemental phytase fed to pigs and additivity of digestibility in a wheat-soybean-meal diet. J. Anim. Physiol. Anim. Nutr. 75, 40-48

Rymarz A., 1986. Chemical body composition of growing pigs. Ca, P, K, Na and Mg contents in the body. Pig News Inf. 7, 177-181

Statgraphics Plus version 7.0 for DOS, 1993. Statistical Graphics System by Graphics Corporation

Tangkongchitr U., Seib P.A., Hoseney R.C., 1981. Phytic acid. I. Determination of three form of phosphorus in flour, dough and bread. Cereal Chem. 58, 226-272

Weremko D., 1998. Bioavailability of phosphorus in rapeseed meal for growing pigs (in Polish). Ph.D. Thesis. The Kielanowski Institute of Animal Physiology and Nutrition, Jabłonna (Poland)

Weremko D., Fandrejewski H., Żebrowska T., Han In K., Kim J.H., Cho W.T., 1997. Bioavailability of phosphorus in feeds of plant origin for pigs - review. Asian-Austr. J. Anim. Sci. 10, 551-566

STRESZCZENIE

Wyniki produkcyjne, skład ciała i tuszy oraz charakterystyka kości świń żywionych dawkami z udziałem poekstrakcyjnej śruty rzepakowej lub sojowej i ziarna zbóż z wysoką zawartością fitazy roślinnej, uzupełnionymi fitazą mikrobiologiczną lub fosforem nieorganicznym

Trzydzieści trzy loszki, o masie ciała 25-70 kg, żywiono mieszankami izoenergetycznymi i izobiałkowymi złożonymi z poekstrakcyjnej śruty rzepakowej (RSM) lub sojowej (SBM) oraz pszenicy i jęczmienia, zawierającymi fitazę roślinną powyżej 900 FTU/kg. Do paszy podstawowej zawierającej 0,19-0,20% strawnego fosforu dodano fitazę mikrobiologiczną (1000 FTU/kg, Natuphos®) lub dwufosforan wapnia, aby ilość P strawnego pokrywała zapotrzebowanie zgodnie z normami. Określono współczynniki strawności pozornej składników pokarmowych, przyrosty dzienne i wykorzystanie paszy, cechy fizyko-mechaniczne kości udowej, śródręcza i śródstopia oraz skład chemiczny ciała.

Dodatek fitazy mikrobiologicznej w większym stopniu zwiększył zawartość fosforu strawnego w mieszance ze śrutą rzepakową (o 0,78 g) niż sojową (o 0,48 g/kg), oraz średnio o 1,55; 0,58 i 0,34 g/kg zwiększył zawartość popiołu, wapnia i fosforu w ciele świń. Fitaza mikrobiologiczna zwiększyła proporcję P i Ca do białka, ale nie zmieniła proporcji Ca do P ani zawartości białka i energii w ciele, nie wpłynęła na wartość rzeźną tuszy i cechy fizyko-mechaniczne kości z wyjątkiem kości śródstopia, której wytrzymałość na złamanie była większa u świń żywionych mieszanką podstawową z dodatkiem fosforanu. Wykorzystanie P było istotnie lepsze przez świnie żywione paszą podstawową (85-87%) niż z dodatkiem fitazy lub fosforanu (67-73%).

Stwierdzono, że obniżenie w dawce zawartości fosforu strawnego do 0,19% nie pogarszało dobowego odłożenia białka w ciele. Śruta rzepakowa będąca jedynym składnikiem wysokobiałkowym w mieszance z jęczmieniem i pszenicą dostarczała wystarczającą ilość P do pokrycia potrzeb rosnących świń. Badania sugerują, że fitaza roślinna zawarta w zbożu wpływa korzystnie na wykorzystanie fosforu fitynowego całej dawki.