Effects of supplemental phytase on nutrient digestibility and performance of sows fed diets with high or low native phytase activity

E.R. Grela[1], J. Matras[1], A. Czech[2]

[1]Institute of Animal Nutrition and Bromatology, University of Life Sciences of Lublin, Poland
[2]Department of Biochemistry and Toxicology, University of Life Sciences of Lublin, Poland

ABSTRACT: Two experiments were conducted to examine the influence of addition of microbial phytase to diets differing in native phytase content, on the performance of sows and digestibility of nutrients. Barley and wheat grains relatively poor in native phytase used in Experiment 1 mixtures were replaced by triticale and rye (rich in this enzyme) in Experiment 2 diets. There were 3 groups in each experiment. Group I (control) received basal diets enriched with dicalcium phosphate (10 g/kg), group II (negative control) was fed basal diets without any additive, and group III (negative control) was supplemented with microbial phytase (500 PU/kg). Body weights of sows were monitored at mating, before parturition, immediately after parturition and at weaning. Apparent ileal and total tract digestibility of basal nutrients, detergent fibre fractions, Ca and P of the investigated diets from particular treatments was determined. Microbial phytase (Natuphos®, BASF AG, Ludwigshaven, Germany) supplemented at 500 PU/kg in pregnancy and lactation diets based on barley and wheat resulted in smaller body weight losses during lactation and higher weight gain over the whole cycle. Synergistic effects of microbial phytase and native phytase on body weight changes of sows, feed conversion ratio during pregnancy, and apparent (ileal and total tract) digestibility of both organic matter and minerals (total and phytic phosphorus and calcium) were found out.

Keywords: sows; intrinsic and microbial phytase; reproductive traits; digestibility

Cereal grains are relatively rich in phosphorus, however, the major portion of this mineral in plants occurs in a hardly soluble phytate form (Jacela et al., 2010). A phytase necessary for liberation of phosphorus from phytates in the animal digestive tract can originate from digested plants (native, i.e. intrinsic phytase) or it can be created by microorganisms. The concentration of native phytase depends on the grain species and it occurs in high quantities only in some grains. Rye and triticale are high in native phytase (Düngelhoef et al., 1994; Czech and Grela, 2004; Czech, 2007), whereas wheat and barley are not so rich in this enzyme. Maize and oil industry by-products are particularly poor in endogenous phytase (Selle et al., 2000). The role of microbial phytase secreted by the gut microflora of poultry and pigs is rather insignificant. In recent years, however, microbial phytase, obtained biotechnologically, has been introduced as an additive to the diets of these animals. Its inclusion in the diets for growing pigs increases the availability of phosphorus and some other minerals (Brady et al., 2002; Hanczakowska et al., 2009; Nitrayova et al., 2009; Jacela et al., 2010) and also the digestibility of organic nutrients (Johnston et al., 2004). It elevates protein and fat deposition as well (Sands et al., 2001; Shelton et al., 2003).

The trials carried out by Kemme et al. (1997), Baidoo et al. (2003) and Jongbloed et al. (2004) revealed a positive effect of this enzyme both on mineral availability and organic nutrient digestibility as well as on the performance of animals.

These studies were carried out with typical maize-soybean diets, which are poor in native phytase activity. Studies on the effectiveness of phytase supplementation of diets with high activity of native phytase are scarce, especially in sows. In our previous study (Czech and Grela, 2004), we reported the interaction between intrinsic phytase and phytase of microbial origin in the absorption of phosphorus and copper, affecting their contents in sow blood. We also noted a tendency of higher levels of blood enzymes when a diet with high phytase activity and microbial phytase was supplied. In these studies, we assumed that the effectiveness of microbial phytase in sow nutrition depended on the activity of intrinsic phytase contained in the basal components, i.e. in the grains.

The present study examined the influence of phytase supplementation on the apparent ileal and total tract digestibility of nutrients and the performance of sows fed diets with various levels of native phytase activity.

MATERIAL AND METHODS

Experimental diets

The studies comprised two nutritional experiments, carried out on multiparous (2^{nd} and 3^{rd} reproductive cycle) Polish Landrace × Polish Large White sows. The number of animals used in Experiment 1 was 104 while 74 sows were used in Experiment 2. Different grains were included in the diets of both experiments. Diets in Experiment 1 were based on grains (barley, wheat) with a lower level of native phytase activity, whereas Experiment 2 diets contained grains (triticale, rye) with a higher activity of this enzyme. The nutritional requirements of sows were met according to the NRC (1998). Lactation diets were additionally supplemented with soybean meal in comparison with pregnancy mixtures. There were 3 feeding groups (34–35 and 24–25 animals in Experiment 1 and 2, respectively) in each experiment. Group I (control) was fed the basal diets enriched with dicalcium phosphate (10 g/kg), group II (negative control) received basal diets without addition of dicalcium phosphate and group III – the negative control was supplemented with microbial phytase (Natuphos®, BASF AG, Ludwigshaven, Germany – 500 PU/g diet). During pregnancy the sows were kept in pens (4–5 animals per pen) and till the 96^{th} day of pregnancy they received 2.2 kg of the mixture and then until parturition 3.5 kg of the mixture a day. In lactation period (individual cages) they received their appropriate treatment mixtures, initially 2.5 kg a day, afterwards 1.5 kg of feed was added each subsequent day. From the 4^{th} day postpartum to weaning (day 28) the sows were fed *ad libitum*. They had free access to water.

Animal management

Body weight of sows was determined at mating, before and after parturition, as well as at weaning. Their backfat thickness was also evaluated three times: after mating, before parturition and at weaning. At the end of lactation twelve sows from each group in Experiment 1 and six ones in Experiment 2 were used for determination of coefficients of total tract apparent digestibility (CTTAD) of basal nutrients, detergent fibre fractions and some minerals (Ca and P). Their lactation diets contained chromic oxide (Cr_2O_3) as an indigestible marker (3.0 g/kg). Faecal samples were obtained by the rectal stimulation of sows. It was done twice a day (morning and evening) at the same time during the last five days of lactation.

After completion of the lactation period, five sows from each group were slaughtered 3 h after morning feeding. Their precaecal ileal contents were evacuated and samples were taken to determine the coefficients of apparent ileal digestibility (CAID) of basal nutrients, calcium, phosphorus and detergent fibre fractions, using chromic oxide (like at CTTAD determination) as an indicator.

Analytical procedures

The samples of faeces and digesta were stored at −20°C and afterwards thawed and homogenized. One part of the sample was used for nitrogen content determination and the other part was dried, ground and used in the other analyses of nutrients.

Diet and digesta samples were analysed, using the AOAC (2000) procedures. The diets were analysed for dry matter (DM), crude protein (CP – 976.06), ether extract (EE), ash, detergent fibre fractions (NDF and ADF – 973.18), Ca and P (968.08), phytic phosphorus content (Oberleas, 1971) and phytase activity (Engelen et al., 1994). The chromic oxide was determined according to Suzuki and Early (1991) method.

Apparent digestibility coefficients (ADC) were calculated using the following equation:

$$ADC = 100 - (100 \times \frac{a \times b}{c \times d}) \quad (\%)$$

where:
a = the chromium content in feed (%)
b = the nutrient content in digesta or faeces (%)
c = the chromium content in digesta or faeces (%)
d = the nutrient content in feed (%)

Statistical analysis

Statistical analysis was performed by Statistica software vers. 6.0. All experimental data were subjected to the analysis of variance according to the following model for a randomized block design:

$$Y_{ij} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + e_{ij}$$

where:
Y_{ij} = the independent variable
μ = overall mean
α_i = the effect of group (i = 1, 2, 3)
β_j = experimental effect – native phytase activity (j = 1, 2)
e_{ij} = error contribution with an average and variance δ^2

RESULTS

Diets composition

During pregnancy the average content of crude protein in sow diets of both experiments amounted to about 140 g. In lactation period it was about 190 g (Table 1). The standard diets for the pregnancy period given to the animals of group I contained about 6.0 g of total phosphorus per 1 kg DM in Experiment 1, whereas in the second experiment its level was slightly lower. Phosphorus contents of the standard diets for lactation in both experiments were about 6.40 g/kg and 6.01 g P/kg DM, respectively. In comparison with group I (control), the diets of experimental treatments (group II and III) contained by 30% less P (Table 1). The phytic phosphorus constituted about 40% of total P in control group diets (pregnancy and lactation) and about 60% in experimental diets (without any inorganic P supplement).

In Experiment 2 the activity of native phytase in the diets fed during pregnancy and in lactation was higher by about 700 PU/kg and 580 PU/kg, respectively, in comparison with the diets used in Experiment 1. In both experiments the phytase activity of the diets for group III (where total phytase activity was the sum of plant and microbial phytase) was higher, in accordance with the principles of the methods, by about 500 PU/kg than that of the diets for groups I and II (Table 1).

Performance of sows

Some parameters concerning the monitoring of body weight of sows during the reproduction cycle, as well as the data on feed intake and utilization in both experiments are shown in Table 2. The average body weight of sows at mating (188.9 kg in Experiment 1 and 185.7 kg in Experiment 2) was similar in the particular groups of both experiments. The sows receiving diets with the higher activity of native phytase showed higher gains (on average by 0.9 kg) during pregnancy but they had higher losses (by about 1.1 kg) at parturition. However, the losses of their body weight during 28-day lactation were lower ($P = 0.045$) by 1.8 kg. These sows were 1.9 kg heavier ($P = 0.037$) during the whole reproduction cycle. No significant differences in feed intake were noted according to the native phytase activity. However, the higher ($P = 0.041$) feed conversion ratio (FCR) was determined when they were fed the mixture with higher native phytase activity over the pregnancy period. At mating the sows of Experiment 1 had thicker backfat (32.1 mm) than those of Experiment 2 (30.8 mm). Backfat thickness was slightly reduced during lactation in the sows receiving diets with higher activity of native phytase (Experiment 2).

The withdrawal of dicalcium phosphate from group II diets caused increased losses of body weight during lactation and lower net weight gain of sows over the whole reproduction cycle (Table 2). These differences between groups I and II were significant only in Experiment 1. Microbial phytase (500 PU/kg, group III) allowed the sows to perform the standard of the positive control group.

Nutrient digestibility

The coefficients of apparent ileal digestibility (CAID) of nutrients to the end of the small in-

Table 1. Ingredients and chemical composition of the diets for lactating sows

Ingredients (g/kg)	Experiment 1			Experiment 2		
	I	II	III	I	II	III
Barley	291	296	296	–	–	–
Triticale	–	–	–	300	306	306
Oat	100	100	100	180	180	180
Rye	–	–	–	100	100	100
Wheat	300	300	300	–	–	–
RSM ‘00’, extracted	100	100	100	50	50	50
Garden pea	–	–	–	80	80	80
Soybean meal, extracted	120	120	120	200	200	200
Dried grass	50	50	50	50	50	50
Limestone	12	17	17	13	17	17
Dicalcium phosphate	10	–	–	10	–	–
Salt (NaCl)	4	4	4	4	4	4
Trace mineral–vitamin premix	10	10	10	10	10	10
Cr_2O_3	3	3	3	3	3	3
Microbial phytase[1]	–	–	+	–	–	+
Total	1000	1000	1000	1000	1000	1000
Analyzed in 1 kg of DM:						
Crude protein (N × 6.25) (g)	190.2	192.8	193.1	193.6	193.1	193.9
ADF (g)	85.9	87.2	86.9	97.8	98.1	97.9
Calcium (g)	8.42	8.23	8.26	8.56	8.29	8.30
Total phosphorus (g)	6.43	4.52	4.55	6.07	4.19	4.21
Phytic phosphorus (g)	2.77	2.84	2.83	2.50	2.52	2.51
Phytase activity (PU/kg)	420	440	940	1000	1020	1500
Chromium as Cr_2O_3 (g/kg)	2.94	2.92	2.94	2.96	2.97	2.96

[1]Natuphos®, 5000 PU/g

testine are shown in Table 3. These coefficients concerning all the analysed nutrients appeared to be higher for the diets with the higher activity of native phytase (Experiment 2) with OM, CP, total P, phytic P and Ca being statistically significant. In Experiment 1, phytase supplementation increased ($P \leq 0.05$) CAID of OM, CP, NDF, total phosphorus, phytic phosphorus and calcium in comparison with the other treatments. A similar effect, except for the CAID of OM and NDF, was found out in Experiment 2.

Similarly like CAID, the coefficients of apparent total tract digestibility (CATTD) of nutrients depended upon the diet. They were generally higher when the pigs were fed the rations with a higher content of native phytase (Table 4). In comparison with both control groups, the phytase addition tended to elevate not only the availability of phytic P ($P \leq 0.01$), total P and Ca ($P \leq 0.05$) but also the digestibility of organic nutrients. However, the statistically significant ($P \leq 0.05$) differences (about 3 percentage points) were noted only for CATTD of crude protein. A diet × phytase interaction was noted ($P \leq 0.05$) in total and phytic P and Ca availability. The availability of total P, phytic P and also Ca of microbial phytase diets in Experiment 1 was

Table 2. Performance, feed efficiency and backfat thickness of sows

Experiment	Groups	Body weight at mating (kg)	Body weight gain during pregnancy (kg)	Loss of body weight at parturition (kg)	Loss of body weight during lactation (kg)	Net body weight gain of sows over the whole cycle (kg)	Total feed intake during pregnancy (kg)	Total feed intake during lactation (kg)	Feed efficiency per 1 kg of weight gain during pregnancy (kg)	Average standardized backfat thickness (mm)		
										at mating	increasing at pregnancy	decreasing at lactation
1 – low native phytase activity	I	189.1	44.6	19.5^{b}	13.1^{a}	12.0^{a}	278.6	197.2	6.25	32.3	4.6^{ab}	–4.4
	II	188.9	43.5	18.6^{a}	14.2^{b}	10.7^{b}	278.1	198.1	6.39	32.1	4.1^{a}	–4.2
	III	188.7	44.5	19.8^{b}	12.9^{a}	11.8^{a}	278.3	197.3	6.25	31.9	4.8^{b}	–4.5
	Mean	188.9	44.2	19.3	13.4*	11.5*	278.3	197.5	6.30*	32.1	4.5	–4.4
	SEM	6.31	1.22	0.93	0.49	0.43	3.79	2.54	0.042	0.03	0.01	0.02
2 – high native phytase activity	I	186.4	45.2	20.2^{ab}	11.1^{a}	13.9	274.1	196.2	6.06	30.9	4.6	–3.9
	II	184.9	44.9	19.7^{a}	12.3^{b}	12.9	275.2	196.6	6.13	30.4	4.4	–4.1
	III	185.7	45.4	21.2^{b}	11.3^{ab}	13.4	273.9	197.1	6.03	31.0	4.8	–3.7
	Mean	185.7	45.1	20.4	11.6*	13.4*	274.4	196.6	6.07*	30.8	4.6	–3.9
	SEM	7.13	1.18	0.79	0.43	0.74	3.19	2.46	0.043	0.04	0.02	0.02
Diet (Group)			0.142	0.042	0.038	0.055	0.886	0.910	0.094	0.692	0.054	0.082
Phytase (Exp.)			0.102	0.061	0.045	0.037	0.764	0.669	0.041	0.882	0.067	0.535
Diet × phytase			0.047	0.066	0.078	0.048	0.887	0.839	0.089	0.624	0.204	0.089

[a,b]means within columns with different superscript letters are different ($P \leq 0.05$)

*means within columns between experiments with superscript are different at $P \leq 0.05$

SEM = least square means standard error within experiment.

higher by 7.5, 6.6 and 2.2 percentage points, respectively, in comparison with that of the negative control. In Experiment 2 these differences were slightly larger (9.3, 7.6 and 1.8 percentage points, respectively).

DISCUSSION

The present investigations documented the increased net weight gains of sows in the whole reproduction cycle and better feed utilization per 1 kg gain during pregnancy in the experimental treatments compared with the negative control. Similarly, beneficial productive effects of microbial phytase in the nutrition of sows were reported by Czech and Grela (2002) and Jongbloed et al. (2004) who examined diets containing microbial phytase applied to sows in the presence of formic acid. Dietary microbial phytase added to the diets without MCP appeared to be more effective in diets with the lower native phytase activity. Similar investigations are missing in the available literature. Apparent total tract digestibility (ATTD) coefficients are usually higher than coefficients of ileal apparent digestibility (Fan et al., 1995; Johnston et al., 2004). According to studies of Badaway et al. (1957) and Fell (1961), at a slaughter technique which was used in our investigation, these differences, dealing with especially nitrogenous compounds, may even be somewhat larger (shedding of mucosal cells into the intestinal lumen at death and physical manipulation of the intestine to remove the digesta). A positive influence of microbial phytase on both ileal and total tract digestibility of organic matter and crude protein was noted. Significant differences in OM digestibility, however, were found out only for CIAD in the treatment with low native phytase activity in the diet, whereas both ileal and total tract digestibility coefficients

Table 3. Coefficients of apparent ileal digestibility (%) of dietary nutrients of sows at the end of lactation (n = 5 in each group)

Experiment	Groups	Organic matter	Crude protein	Ether extract	ADF	NDF	Total phosphorus	Phytic phosphorus	Calcium
1 – low native phytase activity	I	68.8^{a}	68.5^{a}	48.9	16.3	42.4^{a}	42.8^{b}	23.9^{a}	40.2^{a}
	II	68.5^{a}	67.9^{a}	48.1	16.2	42.3^{a}	39.1^{a}	24.5^{a}	40.6^{a}
	III	71.1^{b}	70.6^{b}	49.3	16.4	46.1^{b}	47.2^{c}	33.7^{b}	43.4^{b}
	Mean	69.5*	69.0*	48.8	16.3	43.6	43.0*	27.4*	41.4*
	SEM	0.243	0.161	0.718	0.343	0.167	0.192	0.163	0.182
2 – high native phytase activity	I	71.5	70.4^{a}	49.6	16.7	44.5	48.4^{b}	26.8^{a}	44.8^{a}
	II	71.1	70.1^{a}	48.9	16.4	45.1	44.8^{a}	27.2^{a}	45.3^{a}
	III	72.7	73.3^{b}	50.2	17.3	46.2	52.1^{c}	41.1^{b}	49.2^{b}
	Mean	71.8*	71.2*	49.6	16.8	45.3	48.4*	31.7*	46.4*
	SEM	0.174	0.129	0.079	0.161	0.128	0.129	0.135	0.152
Diet (Group)		0.054	0.046	0.184	0.302	0.062	0.016	0.006	0.044
Phytase (Exp.)		0.042	0.044	0.412	0.282	0.098	0.021	0.018	0.028
Diet × phytase		0.043	0.082	0.208	0.456	0.387	0.044	0.028	0.038

^{a,b,c}means within columns with different superscript letters are different ($P \le 0.05$)
*means within columns between experiments with superscript are different at $P \le 0.05$
SEM = least square means standard error within experiment

Table 4. Coefficients of apparent total tract digestibility (%) of dietary nutrients of sows at the end of lactation (n = 6 in each group in Exp. 1 and Exp. 2, respectively)

Experiment	Groups	Organic matter	Crude protein	Ether extract	ADF	NDF	Total phosphorus	Phytic phosphorus	Calcium
1 – low native phytase activity	I	78.3	75.7^{a}	53.4	25.7	52.1	45.3^{ab}	31.9^{A}	51.3^{a}
	II	78.1	75.1^{a}	53.2	25.3	51.8	42.3^{a}	32.8^{A}	50.4^{a}
	III	79.5	78.2^{b}	53.9	26.5	53.2	49.7^{b}	39.3^{B}	52.6^{b}
	Mean	78.6*	76.3	53.5	25.8	52.4	45.8*	34.7*	51.4*
	SEM	0.243	0.168	0.438	0.312	0.163	0.179	0.212	0.121
2 – high native phytase activity	I	81.1	76.1^{a}	54.9	26.5	54.5	50.8^{b}	36.3^{A}	53.4^{a}
	II	80.7	77.0^{a}	54.2	26.9	54.8	47.1^{a}	37.6^{A}	54.1^{a}
	III	82.2	79.3^{b}	55.1	27.8	56.3	56.4^{c}	45.2^{B}	56.9^{b}
	Mean	81.3*	77.5	54.7	27.1	55.2	51.4*	39.7*	54.8*
	SEM	0.214	0.161	0.714	0.182	0.129	0.176	0.187	0.167
Diet (Group)		0.064	0.048	0.211	0.392	0.089	0.008	< 0.001	0.047
Phytase (Exp.)		0.042	0.041	0.107	0.132	0.102	0.009	0.004	0.023
Diet × phytase		0.056	0.089	0.102	0.341	0.307	0.044	0.019	0.038

^{a,b,c}means within columns with different superscript letters are different ($P \le 0.05$)
^{A,B}means within columns with different superscript letters are different ($P \le 0.01$)
*means within columns between experiments with superscript are different at $P \le 0.05$
SEM = least square means standard error within experiment

of crude protein were significantly higher in this treatment for diets with both low and high intrinsic phytase activity. Literature data on the efficacy of phytase supplementation on organic nutrient digestibility are equivocal. Investigations carried out by Baidoo et al. (2003) on lactating sows fed maize-soybean based diets revealed considerable both DM and CP increase of ATTD coefficients, whereas the Kemme et al. (1997) studies did not prove any influence of this enzyme on ATTD of organic matter. In both above-mentioned papers (Kemme et al., 1997; Baidoo et al., 2003) as well as in other studies (Jongbloed et al., 2004; Männer and Simon, 2006; Steiner et al., 2006), microbial phytase added to sow diets elevated the apparent total tract digestibility coefficients of minerals, especially of (total and phytic) phosphorus and calcium. Similar results were achieved in this study. The ATTD coefficients closely corresponded with the apparent ileal digestibility coefficients both for total and phytic phosphorus and calcium. Higher ileal and total tract digestibility coefficients of P and Ca were typical of the diets with higher intrinsic phytase activity.

The improved performance both in pregnancy and in lactation of sows fed diets with the higher native phytase activity as well as diets enriched with microbial phytase is a result of higher digestibility and availability of some organic nutrients as well as phosphorus and calcium. It was confirmed by the increased contents of some macro- and microminerals in sow blood immediately before piglet weaning in Czech and Grela (2004) studies.

CONCLUSIONS

The product microbial phytase (Natuphos®, BASF AG, Ludwigshaven, Germany) added at 500 PU/kg to pregnancy and lactation diets based on grains relatively poor in native phytase (barley, wheat) resulted in smaller losses of body weight of sows during lactation and higher weight gains over the whole cycle in comparison with sows fed diets containing grains with a higher native phytase activity (triticale, rye).

Synergistic effects of microbial phytase and native phytase on body weight changes, reproductive performance of sows and feed intake were found out.

Apparent (both ileal and total tract) digestibility of organic nutrients and the availability of phytic phosphorus and calcium of the diets based on grains with high native phytase activity were higher than in the diets with low native phytase. Irrespective of the activity of native phytase in grains, the addition of microbial phytase to pig diets increased the availability not only of the investigated minerals (phosphorus and calcium) but also of crude protein (N).

REFERENCES

AOAC (2000): Official Methods of Analysis. 17th Ed. Association of Official Analytical Chemists, Washington, DC, USA, 1094 pp.

Badaway A.M., Campbell R.M., Cuthbertson D.P., Fell B.F. (1957): Changes in the intestinal mucosa of the sheep following death by humane killer. Nature, 180, 756–757.

Baidoo S.K., Yang Q.M., Walker R.D. (2003): Effects of phytase on apparent digestibility of organic phosphorus and nutrients in maize-soya bean meal based diets for sows. Animal Feed Science and Technology, 104, 133–141.

Brady S.M., Callan J.J., Cowan D., McGrane M., O'Doherty J.V. (2002): Effect of phytase inclusion and calcium/phosphorus ratio on the performance and nutrient retention of grower-finisher pigs fed barley/wheat/soya bean meal-based diets. Journal of the Science of Food and Agriculture, 82, 1780–1790.

Czech A. (2007): The effectiveness of phytase in animal diets. Medycyna Weterynaryjna, 63, 1034–1039. (in Polish)

Czech A., Grela E.R. (2002): Effect of microbial phytase and formic acid supplementation to sow diets on performance and hematological parameters of blood. Annals of Animal Science, E201–E205.

Czech A., Grela E.R. (2004): Biochemical and haematological blood parameters of sows during pregnancy and lactation fed the diet with different source and activity of phytase. Animal Feed Science and Technology, 116, 211–223.

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. Animal Feed Science and Technology, 49, 1–10.

Engelen A.J., van der Heeft F.C., Randsdorp P.H.G., Smit E.L.C. (1994): Simple and rapid determination of phytase activity. AOAC International, 77, 760–765.

Fan M.Z., Sauer W.C., De Lange C.F.M. (1995): Amino acid digestibility in soya bean meal, extruded soybean and full-fat canola for early-weaned pigs. Animal Feed Science and Technology, 52, 189–203.

Fell B.F. (1961): Cell shedding in the epithelium of the intestinal mucosa: fact and artefact. Journal of Pathology and Bacteriology, 81, 251–254.

Hanczakowska E., Swiatkiewicz M., Kühn I. (2009): Effect of microbial phytase supplement feed for sows on apparent digestibility of P, Ca and crude protein and reproductive parameters in two consecutive reproduction cycles. Medycyna Weterynaryjna, 65, 250–254. (in Polish)

Jacela J.Y., DeRouchey J.M., Tokach M.D., Goodband R. D., Nelssen J.L., Renter D.G., Dritz S.S. (2010): Feed additives for swine: Fact sheets – high dietary levels of copper and zinc for young pigs, and phytase. Journal of Swine Health and Production, 18, 87–91.

Johnston S.L., Williams S.B., Southern L.L., Bidner T.D., Bunting L.D., Matthews J.O., Olcott B.M. (2004): Effect of phytase addition and dietary calcium and phosphorus levels on plasma metabolites and ileal and total-tract nutrient digestibility in pigs. Journal of Animal Science, 82, 705–714.

Jongbloed A.W., van Diepen J.Th.M., Kemme P.A., Broz J. (2004): Efficacy of microbial phytase on mineral digestibility in diets for gestating and lactating sows. Livectock Production Science, 91, 143–155.

Kemme P.A., Jongbloed A.W., Mroz Z., Beynen A.C. (1997): The efficacy of *Aspergillus niger* phytase in rendering phytate phosphorus available for absorption in pigs is influenced by pig physiological status. Journal of Animal Science, 75, 2129–2138.

Männer K., Simon O. (2006): Effectiveness of microbial phytases in diets of sows during gestation and lactation. Journal of Animal and Feed Science, 15, 199–211.

NRC (1998): National Research Council. Minerals. In: Nutrient Requirements of Swine. 10th Ed. National Academy Press, Washington, DC, USA, 156 pp.

Nitrayová S., Patráš P., Brestenský M., Zelenka J., Brož J., Heger J. (2009): Effect of microbial phytase and diet fermentation on ileal and total tract digestibility of nutrients and energy in growing pigs. Czech Journal of Animal Science, 54, 163–174.

Oberleas D. (1971): The determination of phytate and inositol phosphates. In: Glick D. (ed.): Methods of Biochemical Analysis. John Wiley & Sons, New York, USA, 87–101.

Sands J.S., Ragland D., Baxter C., Joern B.C., Sauber T.E., Adeola O. (2001): Phosphorus bioavailability, growth performance, and nutrient balance in pigs fed high available phosphorus corn and phytase. Journal of Animal Science, 79, 2134–2142.

Selle P.H., Ravindran V., Caldwell R.A., Bryden W.L., Selle P. (2000): Phytate and phytase: consequences for protein utilization. Nutrition Research Reviews, 13, 255–278.

Shelton J.L., Southern L.L., Bidner T.D., Persica M.A., Braun J., Cousins B., McKnigh F. (2003): Effect of microbial phytase on energy availability, and lipid and protein deposition in growing swine. Journal of Animal Science, 81, 2053–2062.

Steiner T., Mosentin R., Fundis A., Jakob S. (2006): In-fluence of feeding level on apparent total tract digestibility of phosphorus and calcium in pigs fed low-phosphorus diets supplemented with microbial or wheat phytase. Livestock Science, 102, 1–10.

Suzuki E.Y., Early R.J. (1991): Analysis of chromic oxide in small samples of feds and feces using chlorine bleach. Canadian Journal of Animal Science, 71, 931–934.

Received: 2010–11–23
Accepted after corrections: 2011–03–21

Corresponding Author

Prof. Dr. Eugeniusz R. Grela, Institute of Animal Nutrition and Bromatology, University of Life Sciences of Lublin, Akademicka 13, 20-934 Lublin, Poland
Tel. 48 81 445 67 18, fax 48 81 533 35 45, e-mail: ergrela@interia.pl