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EFFECT OF NEW FEED PHOSPHATE ON BALANCE AND APPARENT ABSORPTION OF CALCIUM AND PHOSPHORUS IN FATTENING PIGS*

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Abstract

New dicalcium phosphate (CNP), produced using energy-efficient and environment-friendly chemical technology was compared to monocalcium phosphate (MCP) and calcium-sodium phosphate (CNP) in a digestibility and balance trial with fattening pigs. Phosphorus from these phosphates accounted for 30% of the pig requirement for total P in complete starter and grower diets. The new phosphate (n-DCP) significantly (p<0.05) improved the utilization of phosphorus and calcium from these diets compared to MCP and/or CNP. These data may indirectly indicate that the new dicalcium phosphate is of good quality and is highly suitable as a feed material.

Key words: phosphates, fattening pigs, minerals, apparent absorption, balance

Pig nutrition is based on cereal grains, which are a major source of phosphorus. Phosphorus found in cereal grains is in the form of phytates, which are largely unavailable to animals. A well-known method of increasing the availability of phosphorus from phytate compounds is to supplement the diets with preparations containing exogenous microbial phytase (Czech and Grela, 2004; Revy et al., 2004; Zacharias et al., 2003).

The amount of phosphorus available in feed materials of plant origin does not meet the needs of fast-growing pigs even with microbial phytase supplements and it is necessary to supplement the ration with mineral phosphorus at 30–50% of the requirement (Orda et al., 1998).

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Phosphates available on the feed market include mono-, di- and tricalcium phosphates as well as calcium-sodium, sodium-calcium-magnesium, and ammonium phosphates. The apparent digestibility of phosphorus in these phosphates may vary from 65 to 90% depending on production technology and quality of the phosphorus materials used (Eeckhout and Paepe, 1997). The highest apparent digestibility of phosphorus in pigs was obtained for mono- or disodium phosphate (91%), and the lowest when using defluorinated phosphate (50%) (Jongbloed et al., 2002).

The feed market is deficient in phosphorus, which has to date been produced mainly from apatite and phosphorite materials. Therefore, it was appropriate to undertake research on new technologies for obtaining phosphates with increased phosphorus availability (Hoffmann and Hoffmann, 2009).

The objective of the study was to determine the feeding value of new dicalcium phosphate manufactured in Poland and to compare it with recognized phosphates such as monocalcium and calcium-sodium phosphates. The suitability of this phosphate as a feed material was determined based on its chemical analysis and digestibility of macro- and microelements in fattening pigs.

Material and methods

Dietary phosphates

The new dicalcium phosphate (n-DCP) was produced by the Gdańsk Phosphatic Fertilizer Plant "Fosfory" Ltd. based on the authors' own technology developed jointly with the Institute of Inorganic Technology and Mineral Fertilizers of the Wrocław University of Technology, and filed for patent protection (patent application no. P-369805).

This phosphate is made from concentrated phosphoric acid as a source of phosphorus and from calcium oxide and calcium carbonate. The product, obtained by direct chemical reaction between phosphoric acid and calcium, is a salt of phosphoric acid with the chemical formula of $CaHPO_4 \times 2H_2O$. It is known as dicalcium phosphate (n-DCP).

The production technology is environment-friendly, waste-free, sewage-free, and autothermal (uses reaction heat for drying the product). Because no direct gas drying is applied, the final product contains no harmful organic and inorganic substances (Hoffmann and Hoffmann, 2009).

The experimentally produced phosphate was compared to monocalcium phosphate (MCP) and dicalcium phosphate (CNP), which are registered and authorized for marketing in Europe.

Chemical analysis of these phosphates determined the content of Ca, total P, P soluble in 2% citric acid and undesirable substances such as Pb, Cd, As and Hg. These analyses were performed at the Laboratory of the Institute of Inorganic Technology and Mineral Fertilizers of the Wrocław University of Technology, using current procedures (AOAC, 1995; Górecka and Górecki, 2000).

Experimental animals and diets

The experimental fattening was carried out at the Experimental Animal Feeding Station in Gorzyń (Poznań University of Life Sciences). Subjects were 24 weaners: [(Polish Large White × Polish Landrace sow) × (Hampshire × Pietrain) boar] with average initial weight of 20 kg. Animals were assigned to 3 groups with 8 animals per group.

The allocation of weaners to 3 feeding groups was dependent on the proportion of phosphates in the complete starter and grower diets.

Group I – experimental, mixtures with n-DCP ($CaHPO_4 \times 2H_2O$),

Group II – positive control, mixtures with MCP ($Ca(H_2PO_4)_2$),

Group III – control, mixtures with CNP ($Na_2Ca_5PO_4$).

The proportion of individual phosphates resulted from the optimization of P in the complete mixtures. It was assumed that mineral phosphorus from the analysed phosphates will form 30% of the requirement for total phosphorus.

Two types of mixtures (starter and grower) adjusted for age and meatiness of the fattening pigs were used to ensure optimal protein and phosphorus utilization by the young animals. The dietary level of protein, amino acids, energy, minerals and vitamins was adjusted to the level recommended by Polish standards (Normy Żywienia Świń, 1993).

The mixtures were manufactured based on ground barley and ground wheat. Deficient protein was supplemented by adding appropriate amounts of soybean meal. The amino acids optimized in the mixtures, such as lysine, methionine, threonine and tryptophan were added in crystalline form to reach the levels recommended in the feeding standards. The minerals and vitamins were supplemented with a 4.0 and 3.0% vitamin-mineral (starter and grower) mixture (MPU) produced by LNB Poland Ltd. in Kiszkowo using the set formula. The level of calcium and all microelements and vitamins in the mixtures was the same for each group.

All the mixtures were supplemented with microbial phytase (500 FTU/kg^{-1}) and an enzyme preparation containing xylanase and glucanase. The starter and grower mixtures were supplemented with a feed acidifier at 0.5 and 0.3%, respectively (Table 2).

The components used in the production of complete mixtures were subjected to chemical analysis at the Laboratory of the Department of Animal Nutrition and Feed Science of the Wrocław University of Environmental and Life Sciences, according to current standards (AOAC, 1995). The results of these analyses were used to determine the content of basic nutrients and minerals in the complete mixtures. The energy value was calculated based on the authors' own analyses of the components and digestibility coefficients according to the formulae in Polish (Normy żywienia świń, 1993) and Dutch standards (CVB, 2004).

Feeding and sample collections

The complete starter diets were given to weaners for 26 days and grower diets for the next 21 days. The digestibility and balance test was started when the pigs weighed around 65 kg.

Selected pigs were placed in individual digestibility-balance cages and fed the same feeds as previously. The amount of the diet was similar for all animals (2 kg per day). All the feed offered was consumed. The first 3 days were treated as the pretreatment period after the change of housing conditions. The next 4 days were the collection period and the amounts of feed consumed and faeces and urine excreted were recorded each day. Urine was collected into special plastic containers placed under the cages. Each day, 10 ml of 10% sulphuric acid was poured into the containers to bind ammonia. Faeces excreted by the pigs were collected over a plastic net under the slats. On each of the 4 days, excreted faeces and urine were collected and weighed at the same hour. About 20% of the daily faecal and urine excretion was collected and placed in special jars with ground-in stoppers (urine) and in plastic bags (faeces). The samples were stored in a refrigerator at 3–4ºC. The faeces collected over 4 days were thoroughly mixed and 1 kg faecal and 1 l urine samples were collected. So prepared average samples from the 4-day collection were taken for chemical analysis at the Laboratory of the Department of Animal Nutrition and Feed Science of the Wrocław University of Environmental and Life Sciences. The samples of dried faeces and urine were assayed for Ca and P. The analytical procedures were appropriate for this type of analysis (AOAC, 1995).

Statistical analysis

The results were analysed statistically by analysis of variance using Statistica ver. 6.0. The effect of the phosphate on the level of analysed traits in different groups was determined using Duncan's multiple range test. One level of significance was used (P<0.05).

Results

The results of chemical analyses of the three phosphate types are consistent with the values declared by the manufacturer in terms of phosphorus, calcium and sodium content. The content of undesirable substances such as fluorine, lead, cadmium arsenic and mercury did not exceed the values permitted by Polish and EU legislation. Phosphorus solubility in 2% citric acid was the highest for MCP (99%) compared to 98% for both n-DCP and CNP (Table 1).

During the digestibility and balance test, each day pigs received 2 kg of grower diet, which provided 13.6 g Ca and 10.0 g P to all animals. The apparent absorption values and the balance of the analysed macroelements are listed in Table 3.

Pigs from all the groups excreted similar amounts of Ca in faeces (4.57–4.91 g), which constituted 34–36% of Ca intake. The urinary excretion of Ca was only 0.74 –1.19 g, which formed 5–8% of dietary Ca intake. Pigs from group III (CNP) had a significantly higher excretion compared to groups I and II (P<0.05). Ultimately, Ca retention in group I (60.9%) was significantly higher than in groups II and III (P<0.05). The apparent absorption of Ca did not differ significantly between the individual groups.

Table 1. Chemical analyses of feed phosphate (in 1 kg dry matter)

Item	Dicalcium	Monocalcium	Calcium-sodium
Chemical formula	(n-DCP) $Ca\ HPO_4 \times 2H_2O$	(MCP) $Ca\ (H_2PO_4)_2$	(CNP) $Na_2Ca_5\ (PO_4)$
Total phosphorus (P) (g)	185	227	180
Relative solubility of P in 2% citric acid (%)	98	99	98
Calcium (Ca) (g)	250	177	310
Sodium (Na) (g)			49
Undesirable substances:			
Fluorine (F) (mg)	350	450	800
Lead (Pb) (mg)	1.4	5	5
Cadmium (Cd) (mg)	2.3	5	0.5
Arsenic (As) (mg)	0.7	8	2
Mercury (Hg) (mg)	0.008	0.02	0.02

Table 2. Percentage composition and feeding value of mixtures for fatteners

Ingredients	Units	Type of mixture	
		starter	grower
1	2	3	4
Ground wheat	%	35.0	40.0
Ground barley	%	41.7	43.4
Soybean oil meal	%	15.5	11.5
Soybean oil	%	3.3	1.8
Acidifier	%	0.5	0.3
Supplementary starter feed	%	4.0	
Supplementary grower feed	%		3.0
Total	%	100.00	100.00
In 1 kg of mixture:			
net energy	Kcal	2340	2280
metabolizable energy	MJ	13.60	13.25
dry matter	%	87.3	87.2
crude protein	%	17.4	15.7
crude fibre	%	3.0	2.8
crude fat	%	5.0	3.1
crude ash	%	5.1	4.3
N-free extractives	%	56.8	61.3
Lysine	%	1.17	0.93
Methionine	%	0.39	0.29
Methionine + Cystine	%	0.71	0.60
Threonine	%	0.75	0.59
Tryptophan	%	0.23	0.20
Isoleucine	%	0.66	0.59

table 2 – contd.

1	2	3	4
Ca	%	0.73	0.68
P total	%	0.55	0.50
Mineral P*	%	0.16	0.15
Digestible P	%	0.34	0.30
Phytase	FTU	500	510
Na	%	0.20	0.20
Fe	mg	198	183
Mn	mg	91	82
Cu	mg	167	25
Zn	mg	157	148
I	mg	1.66	1.49
Co	mg	0.88	0.81
Se	mg	0.49	0.48

* – Source of mineral phosphate: Group I – Dicalcium phosphate (new product), Group II – Monocalcium phosphate, Group III – Calcium-sodium phosphate.

** – Added to 1 kg mixture:

Vitamin A – 12 000 IU, vitamin D_3 – 1998 IU, vitamin E – 124 mg, vitamin K_3 – 1.8 mg, vitamin B_1 – 1.8 mg, vitamin B_2 – 4.8 mg, nicotinic acid – 24 mg, pantothenic acid – 12 mg, vitamin B_6 – 3.6 mg, vitamin B_{12} – 30 µg, biotin – 120 µg, choline chloride – 288 mg, vitamin C – 102 mg, folic acid – 2.4 mg, Fe – 120 mg, Mn – 60 mg, Cu – 19 mg, Zn – 120 mg, I – 1.4 mg, Co – 0.7 mg, Se – 0.3 mg.

Table 3. Balance and apparent absorption of calcium and phosphorus

Item	Phosphate		
	I Dicalcium	II Monocalcium	III Calcium-sodium
	Calcium balance		
Ca intake (g)	13.60	13.60	13.60
Ca excreted (g) in:			
faeces:	4.57±0.73	4.91±0.43	4.86±1.12
urine:	0.74 a±0.20	0.85 a±0.11	1.19 b±0.41
Ca retention (g)	8.29±0.73	7.84±0.51	7.55±1.10
Ca retention (%)	60.9 a±5.4	57.6 b±3.7	55.5 b±8.1
Ca absorption (%)	66.4±5.4	63.9±3.1	64.3±8.7
	Phosphorus balance		
P intake (g)	10.00	10.00	10.00
P excreted (g) in:			
faeces:	2.32 b±0.29	2.66 a±0.29	2.56±0.42
urine:	0.06±0.02	0.05±0.01	00.8±0.05
P retention (g)	7.62±0.31	7.29±0.32	7.36±0.42
P retention (%)	76.2 a±3.1	72.9 b±3.2	73.6±4.3
P absorption (%)	76.8 a±2.9	73.5 b±2.9	74.4±4.2

Means with different letters (a, b) differ significantly (P<0.05).

Phosphorus was mainly excreted with faeces and pigs from group I excreted significantly lower amounts of it compared to group II (P<0.05). Daily retention of this macroelement in group I was 7.62 g, with apparent absorption of 76.8%, which is significantly greater than in group II (MCP).

Discussion

It is apparent from the results obtained that the new dicalcium phosphate (n-DCP) was characterized by lower P and higher Ca content compared to MCP. Ca was most abundant in CNP. These values are higher than or comparable to those reported by Plumlee et al. (1958), who evaluated the chemical composition of 7 major sources of phosphorus for animals. In addition to content, the most important characteristics of macroelements are solubility, availability, and effect on the digestibility of other nutrients.

The new phosphate (n-DCP) was characterized by very good solubility of 2% in citric acid, which was comparable to that of MCP. Gajda-Janiak (2007) collected 132 samples of monocalcium phosphates and 89 samples of dicalcium phosphates from 9 Polish producers to assess phosphorus solubility in 2% citric acid. The average solubility (% of P_2O_5 in relation to total P_2O_5 content) ranged from 96.6 to 98.3% for monocalcium phosphates and from 50.9 to 98.5% for dicalcium phosphates.

Overall, the new phosphate had a positive effect on reducing the excretion of the main macroelements (Ca and P) and significantly increased the retention and absorption of these important bioelements compared to the other groups (MCP and/or DNP). This physiological and biochemical phenomenon is difficult to explain. Probably, n-DCP digestion was better and the calcium and phosphorus ions released in the digestive tract were more available, as evidenced by the significantly higher Ca and P content in the femurs of these pigs (group I vs. groups II and III), which was documented by Dobrzański et al. (2010).

Meanwhile, Hoffmann et al. (2008) found on the basis of scanning microscopy analysis that there was a much higher content of Ca on the surface of n-DCP compared to the other two phosphates (MCP and CNP) and of phosphorus in relation to CNP. This may be the reason for the better retention and apparent absorption of Ca and P in pigs receiving the new phosphate.

There are many reports on Ca and P availability in fattening pigs, but it is difficult to relate them to our findings because of the differences in diet composition or animal age, sex and breed (Fernandez, 1995; Nieto et al., 2008; Stein et al., 2008).

It is worthy of note that the three phosphates in the grower diets were also analysed for their effects on digestibility of dry matter, crude protein, crude fat, crude fibre, crude ash and nitrogen-free extractives. No statistically significant differences were found between the groups receiving n-DCP, MCP and CNP. These results will be the subject of a separate publication.

It is concluded from the present study that the new dicalcium phosphate (n-DCP), produced using energy-efficient and environment-friendly chemical technology significantly improved the utilization of phosphorus and calcium from the complete mixtures compared to MCP and/or CNP. This shows that the new dicalcium phosphate is of good quality and is highly suitable as a feed material.

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Wpływ nowego fosforanu paszowego na bilans i absorpcję pozorną wapnia i fosforu u tuczników

STRESZCZENIE

Nowy fosforan dwuwapniowy (n-DCP) uzyskany według energooszczędnej, proekologicznej technologii chemicznej porównano do fosforanu jednowapniowego (MCP) oraz fosforanu wapniowo-sodowego (CNP) w badaniach strawnościowo-bilansowych na tucznikach. Fosfor z tych fosforanów stanowił 30% zapotrzebowania tuczników na P ogólny w mieszankach pełnoporcjowych typu „Starter" i „Grower". Nowy fosforan (n-DCP) wpłynął na istotnie ($P<0,05$) lepsze wykorzystanie z pełnoporcjowych mieszanek fosforu i wapnia w porównaniu do MCP i/lub CNP. Dane te mogą pośrednio dowodzić o dobrej jakości nowego fosforanu dwuwapniowego i jego pełnej przydatności do celów paszowych.