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The determination of digestibility of phosphorus in various feed phosphates for pigs

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Abstract

Three balance periods of 7 days with 12 castrated males each in the life weight range from 35 kg to 60 kg were carried out to determine the P digestibility of 3 different feed phosphates according to the guidelines of GfE (1994). The phosphates were 2 Dicalcium phosphates and 1 Calcium Magnesium phosphate. Additional to the digestibility of P also the Ca digestibility and in the case of the Calcium Magnesium phosphate the digestibility of Mg were determined.

Differences were found in case of the P-digestibility between 72 % and 84 %. These differences clearly reflect differences in chemical composition (anhydrous vs. dihydrate). The digestibility of P was in all phosphates above the value of the DLG table (1999).

Keywords: P-digestibility, Feed Phosphates, Pig, Phosphorus, Calcium, Magnesium

Zusammenfassung

Die Bestimmung der Verdaulichkeit des Phosphors bei verschiedenen Futterphosphaten beim Schwein

In 3 Bilanzperioden zu je 7 Tagen mit 12 kastrierten männlichen Schweinen wurde im Lebendmasseabschnitt von 35 kg bis 60 kg die Verdaulichkeit des P von 3 verschiedenen Futterphosphaten nach den Vorgaben der GfE (1994) bestimmt. Dabei handelte es sich um zwei Dicalciumphosphate und ein Calcium Magnesium Phosphat. Neben der Verdaulichkeit des P wurde auch die des Ca und im Falle des Calcium Magnesium Phosphates die des Mg bestimmt.

Dabei wurden Unterschiede in der P-Verdaulichkeit der 3 Phosphate gefunden, die zwischen 72% und 84% lagen. Diese Differenzen sind in der chemischen Zusammensetzung der Phosphate begründet (Anhydrid bzw. Dihydrat). Die Verdaulichkeit des P aller 3 Phosphate lag über dem Tabellenwert der DLG (1999).

Schlüsselworte: P-Verdaulichkeit, Futterphosphate, Schwein, Phosphor, Calcium, Magnesium

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1 Introduction

The determination of the digestibility of any nutrients primarily is to evaluate the potential absorption rate in the digestive tract. In the case of phosphorus (P), the determination of digestibility can be complicated by secretion of P in the digestive tract which is influenced by dietary supply. P digestibility is thus more accurately described as "net absorption" (Rodehutscord et al., 1994). That is why the Society of Nutrition Physiology developed in 1994 (GfE, 1994) a method to determine the digestible P in feedstuffs for pigs.

To meet the recommended P requirement for pigs, supplementation of complete feed with P of mineral origin is usually necessary. The supply for growing finishing pigs is mostly in the form of monocalcium- (MCP) or dicalcium-phosphate (DCP). Mineral phosphates are produced by a technical process mainly to convert the phosphorus into the animal available form and to eliminate undesirable elements especially fluorine.

The aim of the trial was to evaluate the digestibility of P of two sources of DCP, which were manufactured using different processes as well as P from calcium-magnesium phosphate. Variations in P-digestibility of different feed phosphates normally originate from differences in chemical composition, with MCP having a higher P-digestibility than DCP (DLG-Information 1/1999). But also it is known from literature (CVB, 1990) that there are differences in digestible P-content of DCP dihydrate compared to DCP anhydrate. Up to now, however, no differentiation is made between the two chemically different products (DLG-Information 1/1999) and only one value for P-digestibility of 70% has been assigned to all DCP's. The calcium-magnesium phosphate was tested because no accurate P-digestibility figure exists for such a product. For the evaluation growing pigs were used according to the guidelines of the GfE (1994).

2 Material and methods

Base diet was a ground ration (GR) with a low P-content (less than 1 g calculated digestible P per kg DM). Phosphates were added to the base diet at a rate such that the total calculated digestible P did not exceed 2 g per kg DM (Table 1).

The calcium content was formulated to a level of 5.68 g/kg DM (GR) to 5.94 g/kg DM in the diets to exclude any affect of calcium on the P-digestibility. Magnesium in the form of magnesium oxide (MgO) was added to the phosphate diets that did not contain "Monomag" so that all the diets should contain the same level of Mg. Twelve castrated males (hybrids "BHZP") were used in the trial.

Table 1:
Composition of the mixed feeds (g/kg)

	GR	DCP 1	DCP 2	Ca-Mg-P
		"Italphos"	"Aliphos"	"Monomag"
Corn starch	635.0	635.0	635.0	635.0
Sugar beet pulp	150.0	146.0	145.5	144.5
Potato protein	85.0	85.0	85.0	85.0
Albumen protein	65.0	65.0	65.0	65.0
Cellulose	30.0	30.0	30.0	30.0
Soy oill	15.0	15.0	15.0	15.0
Vitamins/trace elements	5.0	5.0	5.0	5.0
$CaCO_3$	9.5	4.5	5.0	8.0
NaCl	3.0	3.0	3.0	3.0
Lysine-HCl	2.0	2.0	2.0	2.0
L-Tryptophane	0.5	0.5	0.5	0.5
MgO	-	1.5	1.5	-
Phosphate	-	7.5	7.5	7.0

Table 2:
Design of the trial

Day	Period	GR	"Italphos"	"Aliphos"	"Monomag"
1- 7	Pre period	Anim. 1 - 3	Anim. 4 - 6	Anim. 7 - 9	Anim. 10 - 12
8 - 14	Collection period	Anim. 1 - 3	Anim. 4 - 6	Anim. 7 - 9	Anim. 10 - 12
15 - 21	Pre period	Anim. 4 - 6	Anim. 7 - 9	Anim. 10 - 12	Anim. 1 - 3
22 - 28	Collection period	Anim. 4 - 6	Anim. 7 - 9	Anim. 10 - 12	Anim. 1 - 3
29 - 35	Pre period	Anim. 7 - 12	Anim. 1 - 3		Anim. 4 - 6
36 - 42	Collection period	Anim. 7 - 12	Anim. 1 - 3		Anim. 4 - 6

Three balance trials were carried out with these animals in the live weight (LW) range from 36.6±0.9 kg up to 61.6±1.2 kg in an incomplete Latin square arrangement. Thereby each of the animals was fed the GR once, 9 animals were fed the test feeds containing "Italphos" and "Monomag" respectively and because only 3 x 12 = 36 animals were available, 6 animals were fed the test feedstuff containing the phosphate "Aliphos" (Table 2).

Feedstuffs were analysed for crude nutrients and mineral elements. In faeces and urine N, P, Ca and Mg were analysed. The examination of the difference trials was carried out for the minerals P and Mg according to the guidelines of the GfE (1994) with the exception that the Mg level in the trial diets was not below the animal requirements.

The calculation of P digestibility (DP) is defined in the recommendations of GfE (1994) as:

$$DP_{\text{of test component}}\,(\%) = \frac{DP_{\text{of test feed}}\,(\%) - DP_{GR}\,(\%) \times (1-a)}{a}$$

Whereas

$$a = \frac{\text{Analysed P content of the test component (g/kg DM) x ratio of the test component in test feed (kg/kg)}}{\text{Analysed P content of the test feed (g/kg DM)}}$$

3 Feed phosphate production

There are several routes to produce feed phosphates, specifically Dicalcium phosphates (DCP), resulting in products with differing chemical compositions resulting in possible differences in phosphorus digestibility. The production method normally applied in West European countries, including "Italphos", starts with the production of phosphoric acid and follows the 'wet acid' route. Phosphate rock is dissolved in sulphuric acid to yield phosphoric acid. After filtration, purification and defluorination this acid is used for the production of DCP by reacting this "feed grade" phosphoric acid with a calcium source such as quicklime or limestone. Because of the exothermic process the resulting DCP is typically an anhydrous DCP or a mixture of anhydrous and hydrated DCP. The purity of the raw materials used in the process and the process conditions do have major consequences for the digestibility of such a product.

The "Aliphos" brand of dihydrated DCP or crystalline DCP, which includes two molecules of crystal water, starts with the dissolving of phosphate rock in hydrochloric acid. Following purification the dicalcium phosphate dihydrate crystals are precipitated by means of over saturating the solution with additional calcium. Dissolution is a gradual process, offering a number of advantages for the end product quality.

Calcium magnesium phosphate is produced by means of reacting a calcium source and a highly reactive magnesium oxide (MgO) with "feed grade" phosphoric acid. The resulting product is a homogeneous chemical complex of monocalcium phosphate and monomagnesium phosphate.

The three investigated phosphates were also analyzed according to the so-called XRD-analysis[1]. With this method the composition of the product can be estimated. The dihydrated dicalcium phosphate ("Aliphos") contained mainly dihydrate dicalcium phosphate ($CaHPO_4 . 2H_2O$) as well as traces of dicalcium phosphate anhydrate. In contrast to this the "Italphos" dicalcium phoshate is mainly a dicalcium phosphate anhydrate ($CaHPO_4$) together with $CaCO_3$, $Ca(OH)_2$ and traces of CaO. The product "Monomag" is composed of monocalcium phosphate $Ca(H_2PO_4)_2 \times H_20$ (both the hydrated and the anhydrous form) and monomagnesium phoshate $Mg(H_2PO_4)_2$ together with Magnesium oxide (MgO) and calcium carbonate ($CaCO_3$).

4 Results

The phosphates used in the experiment are characterised in Table 3.

The results of the analyses of mixed feeds are shown in Table 4.

The results for animal number 8 in the first balance period and number 9 in the second period were excluded because of unknown feed refusal. Therefore in case of the phosphates "Aliphos" and "Italphos" only the balances from 5 and 8 animals respectively were used for calculation.

The mean feed intake of all animals in the whole trial period was 1503 ± 83 g/day. The average LW was 48.5 ± 8.1 kg with an average live weight gain (LWG) of 590 ± 116 g/day. The mean calculated N-retention was 15 ± 2.6 g/day.

In case of the Ca supplementation to the feedstuffs, the first aim was an adequate supply to avoid an influence on

Table 3:
Mineral contents of phosphates

	"Italphos"	"Aliphos"	"Monomag"
DM (%)	98.2	96.8	95.2
P (g/kg DM)	182.5	184.0	197.0
Ca (g/kg DM)	290.0	245.0	101.0
Mg (g/kg DM)	n.a.	n.a.	114.0

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Table 4:
Results of analyses of mixed feeds

	GR	"Italphos"	"Aliphos"	"Monomag"
DM (%)	89.4	90.5	89.4	89.2
Ash (% DM)	3.4	3.2	3.8	3.6
Cr. Prot. (% DM)	15.8	15.7	15.3	15.6
Cr. Fat (% DM)	1.8	1.9	1.9	1.9
Cr. Fibre (% DM)	3.6	3.5	3.7	3.5
Starch (% DM)	57.8	57.9	60.6	61.1
Sugar (% DM)	2.0	3.0	3.0	3.0
Ca (g/kg DM)	5.59	5.52	6.15	5.61
P (g/kg DM)	0.76	1.99	2.01	1.91
Mg (g/kg DM)	0.53	1.10	1.23	1.12
ME (MJ/kg DM)	16.00	16.13	16.21	16.31

Table 5:
Ca, P and Mg intake and excretion per day

	n	Ca intake mg	Ca faeces mg	Ca urine	
				mg	% of intake
GR	12	7625±433	2657±369	2772±755	36
"Italphos"	8	7500±463	2672±733	2507±819	33
"Aliphos"	5	8030±301	2104±393	2090±350	26
"Monomag"	9	7500±433	2089±398	2156±551	29
		P intake mg	P faeces mg	P urine	
				mg	% of intake
GR	12	1036±59	854±116	20±3	2
"Italphos"	8	2700±167	1213±171	17±2	1
"Aliphos"	5	2628±99	1050±184	18±1	1
"Monomag"	9	2550±147	884±132	16±2	1
		Mg intake mg	Mg faeces mg	Mg urine	
				mg	% of intake
GR	12	717±41	319±52	437±52	61
"Italphos"	8	1500±93	845±127	707±173	34
"Aliphos"	5	1606±60	864±89	539±68	47
"Monomag"	9	1500±87	876±89	672±107	45

P-digestibility. Hence, the digestibility of Ca was calculated as the mean of all animals, independent of phosphate. This digestibility was 68 ± 8.5 %. The animals consumed a mean of 7.6 ± 0.4 g Ca/day and retention was 2.7 ± 0.9 g/day (36 ± 11 % of intake).

Table 6:
Digestibility of Ca, P and Mg from the experimental diets (in %)

	n	Ca	P	Mg
GR	12	65 ± 6	17 ± 13	55 ± 8
"Italphos"	8	64 ± 12	55 ± 7	43 ± 11
"Aliphos"	5	74 ± 5	60 ± 6	46 ± 5
"Monomag"	9	72 ± 6	65 ± 4	41 ± 8

The results of the balance trial are shown in Table 5.

The digestibility of P, Mg and Ca in the test feedstuffs and the GR is shown in Table 6. In the case of P digestibility the lowest value (17 %) was detected for the GR as well as the highest variance. This is an indication of a suboptimal supply.

The results for P- and Mg-digestibility were calculated according to the guidelines of the GfE (1994) for evaluation of P-digestibility in feedstuffs. So the mean values of the digestibility ratios of the particular animals of the GR and of the test feedstuffs, respectively, were the base of the calculations. In detail, for the calculation of P-digestibility of "Italphos" n = 8 values, of "Aliphos" n = 5 values and of "Monomag" n = 9 values were usable.

Table 7:
Digestibility of Ca, P and Mg of the mineral sources (feed phosphates and MgO)

	"Italphos"	"Aliphos"	"Monomag"
D-Ca (%)	62.0	94.6	(121.8)
D-P (%)	72.1	79.9	83.9
D-Mg (%)	38.3	41.1	35.7

Also n = 9 values were used to calculate the Mg-digestibility of "Monomag" (Table 7). The data of the digestibility of Ca are restricted in their interpretation because of an adequate supply in all feedstuffs including the GR. Additionally, the contribution of Ca in the test diets of phosphate origin are relatively low (12 % for "Monomag" up to 39 % for "Italphos") compared with the P contribution (66 % for "Aliphos" up to 69 % for "Monomag").

The digestibility of P from the GR was 17 ± 13 %. The P-digestibility of the test feedstuff (Table 6) based on phosphate "Italphos" showed a relatively high variation (minimal 44.3 % and maximal 63.3 %). That can be a sign of reduced homogeneity of this product compared to "Aliphos" (50.0 %, 66.0 %) or "Monomag" (59.8 %, 71.8 %).

In the case of this trial it is only possible to compare the digestibility of Mg from "Monomag" to the digestibility of Mg from MgO, supplemented to the test feeds of the other two phosphates (each with 1.5 g/kg, Table 1). Basis of this calculation was the mean of n = 13 values (5 "Aliphos" and 8 "Italphos"). The digestibility of Mg from MgO was 39.3 %. Animals are capable of adjusting mineral absorption if the levels are above the requirement. In this trial the level of Mg was clearly above the requirements for pigs which will certainly influence the results with respect to Mg digestibility. Therefore, no real conclusions can be drawn for Mg digestibility based on this trial protocol.

5 Discussion

The calculated content of digestible P should be less than 2 g/kg DM (GfE, 1994). Based on the analysed P contents (Table 4) and assuming a digestibility of P in the GR of 60 % (Düngelhoef et al., 1992; GfE, 1994; Rodehutscord et al., 1994) and in the phosphates of 90 % (Grimbergen et al., 1985; Düngelhoef et al., 1992; Berk and Schulz, 1993; Rodehutscord et al., 1994) results in expected contents of dP of 0,46 g/kg DM (GR), 1,56 g/kg DM "Italphos", 1,58 g/kg DM "Aliphos" and 1,49 g/kg DM "Monomag" respectively. This is clearly below the recommended content of not more than 2 g/kg DM (GfE, 1994).

So one can postulate that the result of digestibility is only due to the added P in phosphate form and not influenced by regulative excretion via faeces (Gütte et al., 1961; Vemmer, 1982; Jongbloed, 1987). This is documented by the low excretion of P in urine in case of all feedstuffs. The high excretion of Ca and Mg via urine in contrast to P is at least partly due to the high absorption rate in growing pigs and the low storage in tissues (GfE, 1987).

The P digestibility of the tested phosphates is between 72 % and 84 % (Table 7). This is the same range as described by some authors (Walz und Pallauf, 1992; Düngelhoef et al., 1992; Rodehutscord et al., 1994) but higher than results from other literature (Grimbergen et al., 1985; CVB, 1990; Berk and Schulz, 1993). The relatively higher digestibility in the present case seems to be the result of the suboptimal P supply compared to the results with a lower P digestibility.

The data of Ca and Mg digestibility are also available (Table 7). But due to the supply being greater than requirement in the case of Mg and, in the case of Ca, due to the wide range of Ca : P ratio these values do not represent real digestibility. This is clearly seen in the relatively high excretion in the urine of more then 25 % of intake, whereas the excretion of P is only 1% when the phosphates are added.

Conclusions

Differences were found between P-digestibility of the dicalcium phosphates "Italphos" and "Aliphos" as well as the calcium-magnesium phosphate "Monomag". While the digestibilities of P from DCP were 72% and 80 % respectively, the value from calcium-magnesium phosphate was 84 %.

A level of 72 % dP for "Italphos" is in accordance with the DLG value of 70 %. The level of 80 % for Aliphos is, however, clearly higher than the DLG value. These differences clearly reflect differences in chemical composition (anhydrous vs. dihydrate). A level of 84 % dP for "Monomag" is more or less what was to be expected of a product in which the greater part of the P is found in the form of MCP.

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