PHOSPHORUS IN PIG NUTRITION

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ABSTRACT

In order to reduce P excreted by pigs, P dietary supply should be better adjusted to the requirements and strategies to improve P availability should be implemented. The use of a feeding system relying on P apparent digestibility is recommended. This allows the reduction of safety margins when formulating pig diets, resulting in a decrease in P excretion. Low digestibility of P in feed ingredients remains the main problem for reducing P excretion. It can be alleviated by the use of highly digestible feed phosphates, such as monocalcium P, and the supplementation of diets with microbial phytase. Substantial reduction of P excretion can also be achieved through phase feeding. This requires a precise evaluation of P requirements. The bases for the factorial determination of apparent digestible P requirements by weaned piglets, fattening pigs and lactating and gestating sows according to their characteristics and performance are updated. A reduction of P supply to sows is still possible, but new experimental data regarding the management of bone stores throughout lactation and gestation are required.
Key words : pig, phosphorus, nutrition, phosphates, minerals

INTRODUCTION

For a sustainable pork production, emission of pollutants from pig herds and use of non-renewable resources should be decreased as far as possible. Through last decades, ways to reduce environmental impact of N, P and trace elements in pig production were investigated, because of the potential negative impact of these elements on ground and surface water, and on air quality. Besides, the use of diminishing phosphate world reserves should be limited.

In growing-finishing pigs fed a cereal-soybean meal diet, about 45% of P intake is absorbed, of which around 30% is retained, the remaining being excreted via urine (Poulsen *et al.*, 1999, Dourmad et al, 1999). Totally, 65-70% of P ingested is excreted by growing-finishing pigs. This value is lower in weaners (50-55%) and higher in sows (80%)

In order to reduce P losses, the nutritional approach has received great attention from researchers. This approach relies on improvements in our knowledge of dietary supply and in our knowledge of pig's requirement in order to achieve a better agreement of supply with requirement. The improvement of nutrient availability in feedstuffs is the second way to be investigated.

The aim of this paper is to give a review of the recent knowledge on P nutrition in pigs.

EVALUATING P VALUE OF FEEDSTUFFS AND DIETS

In the past, P value of feedstuffs and diets, and P requirements, were usually expressed as total phosphorus. But because P digestibility greatly differs between feedstuffs, new systems have been proposed for the formulation of pig diets. Apparent total tract digestibility (referred to as apparent digestibility) and relative bioavailability are the two major systems for assessing the P value of feedstuffs for pigs. In Western Europe, the concept of apparent digestibility is extensively used by nutritionists, who refer to published tabulated values (CVB, 2000; INRA-AFZ, 2004), whereas the bioavailability concept is more often used in North America (NRC, 1998). The use of these systems allows a reduction of the safety margin when formulating diets for pigs compared to the formulation of diets on a total P basis.

Some feedstuffs, such as wheat and wheat by-products, contain a significant amount of natural phytase (Pointillart, 1991). This results in the improvement of their P digestibility. However, plant phytase appears to be much less active than microbial phytase (Eeckhout and De Paepe, 1992; Zimmermann *et al.*, 2002) and highly sensitive to denaturation, especially in the case of a heat stress during the peletting process. In the INRA-AFZ (2004) tables two P digestibility values are given for phytase rich feedstuffs. The lower value is determined considering that the natural phytase is inactivated, whereas the higher value takes into account the improvement of digestibility resulting from the presence of phytase. For example, P digestibility and digestible P content of wheat amount to 45% and 1.40 g/kg, and 30% and 0.96 g/kg when the effect of natural phytase is considered or not, respectively. On a practical point of view, it can be recommended to use the low P digestibility value when diets are pelleted, and the high one when they are not pelleted. Moreover, because of the variable phytase activity encountered in a single feedstuff (Nys et al., 1996), we recommend not accounting for more than 500 units of plant phytase per kg diet in order to avoid any overestimation of its content in digestible P. This corresponds to a maximum of around 0.4 g digestible P released by plant phytase per kg diet.

Table 1. **Total and digestible P content of usual feedstuffs for pig diets[1]**

		Pelleted diet		**Flour diet**	
	P content (g/kg)	**P digest. (%)**	**Digestible P (g/kg)**	**P digest. (%)**	**Digestible P (g/kg)**
Wheat	**3.2 ±0.3**	**30**	**0.96**	**45**	**1.40**
Triticale	**3.5 ±0.4**	**30**	**1.05**	**48**	**1.70**
Wheat bran	**9.9 ±1.1**	**25**	**2.50**	**50**	**4.95**
Corn	**2.6 ±0.3**	**28**	**0.73**	**28**	**0.73**
Soybean-meal	**6.2 ±0.5**	**32**	**2.00**	**32**	**2.00**

[1]from INRA-AFZ (2004)

Despite the improvement resulting from the use of digestible and bio-available P compared to total P, the system still needs to be improved in the future to better take into account factors of variation related to the animals or the composition of the feedstuff. Moreover, further research is needed to better evaluate the relevance of the current tabulated P digestibility values for weaned piglets and sows.

IMPROVING DIETARY P DIGESTIBILITY

The use of highly digestible phosphates

Using highly digestible mineral P supplements is the first efficient way for decreasing total P content of diets and P excretion. Indeed, great differences exist among phosphate sources in their P digestibility. This is reported in table 2 for the main phosphates used in animal nutrition. In the INRA-AFZ (2004) tables biological value of phosphate (RBV) is expressed relatively to monosodium phosphate (food grade) which has a digestibility of about 90% in pigs. Thus digestible P can be calculated as 0.90 x RBV (table 2). Tricalcium and defluorinated phosphates have the lowest value, with only 55 and 60% digestibility, respectively. Digestibility of monocalcium P is much higher with a value of about 83%, whereas dicalcium P is intermediate.

Table 2. Relative biological value (RBV), P digestibility and digestible P content of different phosphate sources[1]

	P (g/kg)	RBV[2] (%)	P digest. (%)	dP[3] (g/kg)
Monosodium phosphate (food grade)[2]	*255*	*100*	*90*	*230*
Monocalcium phosphate	229	92	83	190
Mono-Dicalcium phosphate	219	83	75	164
Dicalcium phosphate hydrated	182	77	69	126
Dicalcium phosphate (a)	202	73	66	133
Dicalcium phosphate (b)	180	73	66	118
Defluorinated phosphate	180	67	60	109
Tricalcium phosphate	180	61	55	99

[1]from INRA-AFZ (2004) and Bleuks (2005)
[2]RBV is expressed relatively to monosodium phosphate (food grade) which is given a 100 value
[3]digestible P is calculated as RBV x digestibility of monosodium phosphate = RBV x 0.90

Supplementing diets with microbial phytase

In some countries, microbial phytase is introduced in diets for pigs, because of its positive effect on P digestibility. Total P supply may be decreased, resulting in less P excreted (Jongbloed and Lenis, 1992; Latimier *et al.*, 1994). For instance, in the study by Latimier *et al.* (1994), supplementing a low P basal diet with phytase resulted in similar growth performance and bone breaking strength but a P excretion reduced by nearly 50% compared to the same diet supplemented with mineral phosphorus.

Nevertheless, it is established that the response of digestible P to graded levels of microbial phytase is curvilinear and that the maximum P digestibility never exceeds 60-70%, even at high levels of phytase supplementation. Based on literature reviews, equivalency equations of digestible P for microbial phytase were established (Kornegay, 2001). However, the authors of all these literature reviews pointed out the variability of the response for a similar level of phytase supplementation. Several dietary factors may be responsible for this variability. First, depending on the commercial product used, different amounts of P are released *in vivo* for a similar phytase activity measured *in vitro*, irrespective of the class (3 or 6-phytase) (Augspurger *et al.*, 2003). The composition of the diet and the characteristics of phytates it contains may also influence the efficacy of phytase (Nys *et al.*, 1996). High levels of dietary Ca have a deleterious effect on the efficacy of microbial phytase (Qian *et al.*, 1996). More recently, Augspurger *et al.* (2004) pointed out the deleterious effect of zinc used at pharmacological levels on the efficacy of microbial phytase in improving P availability to weaned piglets.

As for digestibility values, the question arises whether the equivalency values of digestible P for microbial phytase can be used whatever the category of pigs. Rodehustcord *et al.* (1995) found a similar efficacy of 400 units of 3-phytase in pigs weighing 16 and 40 kg. However, Kemme *et al.* (1997) observed that the efficacy of a 3-phytase was higher in lactating sows and growing-finishing pigs than in piglets (1.0, 0.8 and 0.7 digestible P for 500 phytase units, respectively). With 0.32 g for 500 phytase units, the amount of digestible P released by phytase was by far the lowest in pregnant sows at mid pregnancy. Similarly, Jongbloed *et al.* (2004) reported that 750 units of a 6-phytase released 0.77, 0.33 and 0.42 g digestible P in lactating sows and gestating sows at days 70 and 100 of gestation, respectively. These results suggest that, for a given commercial additive, equivalency values should be adapted to the category of pig, but experimental data are still not numerous enough.

ESTIMATING PHOSPHORUS REQUIREMENTS

The factorial method, generally used to evaluate P requirements, is based on the measurement of the retention of P in the body, foetuses or milk, its obligatory losses and its digestibility (Guéguen and Pérez, 1981). The basic equations used for the factorial determination of P requirements of pigs are given in table 3 (Jondreville and Dourmad, 2005). Total requirement is calculated as the sum of requirements for maintenance, growth and production. Minimum urinary losses are calculated according to body weight, the same value of 10 mg/kg BW being used for al types of pigs (Guéguen and Pérez, 1981). Body P retention is calculated according to body weight using a curvilinear relationship evaluated form a literature review (table 3). P requirement for lactation is calculated from milk production, assuming a 1.55 g/kg P content in milk, the amount of milk being estimated according to litter growth rate and size (Noblet and Etienne, 1989). The requirement for pregnancy is calculated as the sum of the requirement for maternal growth, in the same way as for growing pigs, and the requirement for conceptus (Jongbloed, 1999). P retention in conceptus is obtained from protein retention assuming a P/protein ratio of 0.96%.

Level of Ca should be adapted to level of P because of its possible effect on P digestibility. When diets where formulated on total P an optimal ratio of 1.2-1.4 : 1 was recommended. Because insufficient data are available on Ca digestibility, Jongbloed et al. (1999) recommended to formulate diets on the basis of a total Ca : digestible P ratio, with values for this ratio of 2.9, 3.2 and 3.6 for growing animal, lactating sows and pregnant sow, respectively.

Table 3. Basis for the determination of digestible P requirement of pigs

	Growing pigs	
Maintenance	Endogenous losses, mg/d	10 x BW
Growth	Body P content[1], g	5.4199 x BW – 0.002857 x BW^2
	Lactation	
Maintenance	Endogenous losses, mg/d	10 x BW
	Milk P[1], g/d	[(0.0257 LWG + 0.42 LS) x 6.38 / 50] x 1.55
	Pregnancy	
Maintenance	Endogenous losses, mg/d	10 x BW
Conceptus	P in foetuses[3], g	Exp [4.591 - 6.389 x Exp (- 0.023998 * (d_g - 45)) + 0.0897 x LS]* W_{litter} * 6,25 / Exp [4.591 - 6.389 * Exp (- 0.023998 * (115 - 45)) + 0.0897 * LS]
	P in placenta, g	Exp [7.34264 - 1.40598 * Exp (- 0.06250 * (t - 45)) + 0.00759 * d_g + 0.06339 LS] * 0.0096 / 23.8

BW : Body weight (kg), LWG : Litter weight gain (g/d), LS : litter size, d_g : gestation stage (d).
[1]from literature review.
[2]calculated from N in milk (Noblet and Etienne, 1989) assuming 50 g protein and 1.55 g P / kg milk, respectively.
[3]from Jongbloed et al. 1999

Table 4. Digestible P[1] requirements of piglets and growing pigs

Body weight, kg	10	20	30	50	70	100	115
ADG, g/d	400	500	600	750	850	900	850
FCR, kg/kg	1.35	1.8	2.15	2.5	2.8	3.3	3.5
Digestible P							
g/d	2.2	2.9	3.4	4.4	5.0	5.4	5.2
g/kg diet	4.2	3.2	2.7	2.3	2.1	1.8	1.7

[1]calculated according to Jondreville and Dourmad (2005)

Growing pigs

Examples of calculations of digestible P requirement for growing pigs are presented in Table 4 (Jondreville and Dourmad, 2005). Digestible P requirement is estimated at 2.25 and 5.36 g/day in 10 kg-pigs with a feed conversion ratio of 1.35 and 100 kg-pigs with a feed conversion ratio of 3.30, respectively. Expressed as g/kg diet, the digestible P requirement decreases from 4.2 to 1.7 for these 10 and 100 kg-pigs, respectively. These values are similar to those calculated by Jongbloed et al. (1999) for “very lean” pigs.

Reproductive sows

In pregnant sows, for the first two thirds of gestation, P requirement corresponds mainly to maintenance and maternal growth. By the end of gestation, P requirement increases due to the growth of the products of conception and thus depends on prolificacy (Jondreville and Dourmad, 2005). For instance, digestible P requirements increase from about than 4.6 g/d during the beginning of pregnancy up to 6.5 and 7.4 g/d for sows producing 10 and 14 piglets weighing 1.4 kg at birth, respectively (table 5). This means that there is a potential for a better adaptation of the P supply according to gestation stage. However, a safety margin must be kept, in order to compensate for the possible bone demineralisation during the preceding gestation.

Table 5. Digestible P[1] requirements of pregnant sows

Gestation stage, d	beginning (0-90d)	end (90-114d)		
Nb piglets		10	12	14
Digestible P				
g/d	4.6	6.5	7.0	7.4
g/kg diet	1.6	2.3	2.4	2.6

[1]calculated according to Jondreville and Dourmad (2005)

Requirement for lactation is mainly affected by milk production which can be estimated from litter weight gain. For instance the requirement increases from 12.8 to 18.2 g/d digestible P for a litter daily gain of 2000 to 3000 g / day. At this physiological stage, loss of appetite may cause problems of insufficient digestible P provision and, in turn, excessive bone demineralisation. In these situations P concentration in the diet must be increased.

Table 6. Digestible P[1] requirement of lactating sows, effect of litter growth and sow feed intake

Litter growth rate, g/d	2000	2250	2500	2750	3000
Digestible P					
g/d	12.8	14.2	15.5	16.9	18.2
g/kg (4 kg FI/d)	3.2	3.6	3.9	4.2	4.6
g/kg (5 kg FI/d)	2.6	2.8	3.1	3.4	3.6
g/kg (6 kg FI/d)	2.1	2.4	2.6	2.8	3.0

[1]calculated according to Jondreville and Dourmad (2005)

CONCLUSION

During the recent years the questions related to P nutrition in pigs have been drastically renewed. In the past, the only objective was to maximise animal performance, whereas nowadays we also need to minimise P excretion. This requires a precise evaluation of P requirements of pigs as well as P availability in feed ingredients. This can be achieved with the use of a feeding system relying on P apparent digestibility, and the factorial determination of P requirements. Finally, this allows the reduction of safety margins when formulating pig diets, resulting in a decrease in P excretion. Low digestibility of P in feed ingredients remains another problem for reducing P excretion. It can be alleviated by the use of highly digestible feed phosphates, such as monocalcium P, and/or the supplementation of diets with microbial phytase.

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