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Utilisation of feed phosphates: Fact or confusion?

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1. Introduction

Feedstuffs of plant origin do not contain enough digestible phosphorus to meet the requirements for animal production. For this reason additional inorganic P is added to animal diets. Feedstuffs of plant and animal origin as well as inorganic phosphate sources contain various amounts of phosphate that is available for biochemical functions. Therefore most Nutritionists include a safety factor to ensure that production and production related characteristics are not impaired. These practices can easily lead to over formulation of phosphorus that is costly and lead to excessive phosphorus being excreted to the environment.

In order to formulate optimal diets for monogastrics, adequate knowledge of the utilisation of P in all feedstuffs as well as the corresponding requirements at any production stage need to be known. The dilemma for the Nutritionist is that in literature the concepts of P-utilisation (bioavailability, digestibility and their derivatives) are used freely and often lead to confusion. Nutritionists, not familiar with the way in which these values were determined can mistakenly formulate feeds on the wrong assumptions. The perceived discrepancies in the utilisation of inorganic feed phosphate sources must be emphasised in order to attempt to clarify the concepts involved.

2. Measure of P utilisation.

No element is ever completely absorbed and utilised. A fraction is inevitably lost in the normal digestive and metabolic processes. Different research techniques are used to determine as close as possible, the part that the animal will be able to utilise. From these methods an array of terminology is used to quantify the “utilisation” or “bioavailability” of phosphorus (includes “bio-availability; apparent digestibility; true digestibility; retention” and others). “Bioavailability” and “digestibility” are most often used. These terminologies are often used out of the context as suggested by the researchers and *should not be confused with one another.*

Definitions

Bioavailability. That proportion of a nutrient that can be absorbed and/or utilised by the animal *to meet its net requirements*. Or that proportion of a mineral that is retained in the body

Apparent digestibility: The amount of Phosphorus ingested minus the amount voided in the faeces, including endogenous losses.

Earlier trials were mainly carried out on chicks using bone parameters (tibia ash percentage or toe ash percentage to reflect relative biological value (RBV). This seems to be the most appropriate technique to determine bioavalability because of the fact that more than 80% of the phosphorus is transferred to the skeleton (Zwart, 1999). The phosphorus level in the feed must however be below the phosphorus requirement of the animal (Potter *et al*., 1995).

Although this technique seems ideal, it is worth noting that these P bioavailability studies does not measure true bioavailability but generally compare P sources on a relative basis (as shown in Table 1). The performance of test phosphates is compared to that of a reference standard phosphate (Waldroup, 1999). The RBV can be 100% or greater, depending on the reference phosphorus source.

Often, in plant feed sources, available P are defined as “total-P minus phytate-P” because it is assumed that phytate Phosphorus is not digestible and non-phytate Phosphorus is fully digested. In most feed tables this concept is used to determine the value of P to the animal. It was however clearly demonstrated by Van der Klis and Versteegh (1996), that the absorbability of P from plant feedstuffs was higher than "total-P minus phytate-P", while the absorbability of non-phytate-P varied from 55 to 92%. Many feed tables consider inorganic phosphates as of a non-phytate source and thus completely available to the animal, that is not the case. This illustrates the necessity for the evaluation of the P absorbability from all feedstuffs (inorganic, plant and animal origin)

Apparent tract digestibility of P is also frequently determined (Tables 2 and 3). Dellaert *et al*. (1990) concluded that the apparent total tract digestibility of P is the most efficient criterion to evaluate the nutritional value of various feed phosphates in pigs, compensating for potential confounding factors. The main factors are the endogenous P portion present in the faeces and the P content of the urine fraction. Compensation for these fractions (true digestibility) is considered to be a very good reflection of P bioavailability. These effects can be minimised by keeping the P content of the experimental diets below the recommended P requirement of the animals (Jongbloed *et al*., 1999). This can be verified if the results from urine analysis showed values below or near to the detection limit (<25 mg/ L). In balanced diets the concentration of P in the urine of piglets fed above the P requirement oscillates between 150 and 400 mg/L (Mulder and Jongbloed, 1985). In Poultry an adequate ileal sampling method is available for chyme sampling (Van der Klis, 1993). This implicates that the urinary P excretion does not interfere with the analyses at ileal level.

Apparent digestibility is a valuable measurement of the potential of the P in feedstuffs, with the precondition that the P content of the experimental diets is below the recommended P requirement of the animals. This is most likely the most practical way to express the value of the P component in a feedstuff.

3. How do these techniques reflect on inorganic phosphorus sources?

Over the years, many studies on the utilisation of inorganic feed phosphate supplements by animals were done. These studies showed distinct differences in utilisation between different generic sources as well as within broadly defined sources of the same description. In spite of these results, related research where inorganic phosphates were used (phytase enzyme work, digestible requirement determinations etc.), differences in the utilisation of different inorganic P sources are seldom accounted for. In many of these studies DCP sources are used without a description of the source itself (i.e. hydrated or anhydrated or to the digestibility of it). It is postulated that much of the variation between studies of the same kind can be partly attributed to these factors. The dilemma, that the Nutritionist is confronted with, is to assign the correct available/digestible value of a P source in order to formulate on.

Results of a trial reported by Waibel *et al*. (1984) show the determination of bioavailability by tibia ash relative to a MDCP reference source (Table 1). Two noteworthy conclusions from the data are:

- Relative available values is a handy way of ranking feed phosphates in order to determine nutritive value relative to a reference source (in this case MDCP). As shown these values are dependent on the reference source used. It is therefore possible to obtain values greater than 100 % and difficult if not impossible to compare results of different studies with each other.
- Variation in bioavailability within sources with the same generic description can be enormous. This is emphasised by the 32; 31 and 18-percentage units difference respectively between the lowest and highest values for MDCP; DCP and DFP in Table 1. To use average bioavailability values for generic described products without knowledge about the specific product can lead to large errors. Although it shows on average that there are about a 5 % difference in bioavailability between a MDCP and a DCP source, this could be misleading if accepted as a generic difference.

Table 1: Bioavailability of phosphates for turkeys (from Waibel *et al*., 1984)

Source	Reference source	Number of Samples (n)	Relative bioavalability[1]	
			Variation	Average
Mono dicalcium phosphate (MDCP)	MDCP	8	76.7-108.5	95.8
Dicalcium phosphate (DCP)	MDCP	20	75.1-106.3	90.3
Defluorinated phosphate (DFP)	MDCP	9	67.6-85.2	78.6

[1] Using tibia ash

Results on trials where apparent digestibility (reflected as bioavailability) of feed phosphates were determined are shown in Tables 2 and 3. The work reported by Van der Klis & Versteeg (1996), show the same ranking as with the relative bioavailable values shown in Table 1 for MDCP and DCP. However, these values are lower than the values in Table 1 due to the quantitative way it was measured. Digestibility values determined by this method could help the Nutritionist to give a practical value to the different sources. Part of the variation as shown in Table 1, where feed sources were described as MDCP; DCP or DFP, can be explained from the values in Table 2. The difference between a DCP (anhydrous) and DCP (hydrous) resulted in a 22-percentage unit difference in available P. It is also postulated that part of the variation in the MDCP figures can be because of the same phenomena.

Table 2: Phosphorus availability (digestibility) of inorganic phosphate sources measured with broilers (from Van der Klis & Versteegh, 1996)

Source of P	Total P (%)	Digestible P (% of total)
Calcium Sodium phosphate	18.0	59
Dicalcium phosphate (DCP) (anhydrous)	19.7	55
Dicalcium phosphate (DCP) (hydrous)	18.1	77
Monocalcium phosphate (MCP)	22.6	84
Mono-dicalcium phosphate (hydrous) (MDCP)	21.3	79
Monosodium phosphate	22.4	92

Table 3: Digestibility coefficients of P in pigs (Kemme *et al.*, 2001)

P source[1]	Average[2]
MCP 1 (European produced source – ***Bolifor 18***)	89.3c
MCP 2 (European produced source - ***Bolifor MCP-F***)	90.8c
MDCP (South African produced source – ***Kynofos 21***)	89.2bc
MDCP (United States produced source)	83.6ab
DCP (hydrous) (South African produced source – ***Kynofos 18***)	78.6a
MSP	92.3c

[1] MCP = Mono calcium phosphate; MDCP = Mono-dicalcium phosphate; DCP = Dicalcium phosphate; MSP = Mono sodium phosphate

[2] abc - Values with different superscripts are significantly different at $P < 0.05$

To categorise inorganic feed phosphates within a generic group more accurately, a number of factors can be monitored within reason. These differences (type of product) are mainly dependent on the chemical reaction and the factors influencing this reaction. The dynamics of these reactions dictate that all end products are chemical mixtures of different phosphates. That means that any conventional inorganic feed phosphate is a mixture of different compounds (i.e. a commercial MCP source will always contain some DCP as well).

3.1. DCP

The controls over the production process (temperature, control of the chemical reaction etc.) determine differences in DCP composition. Too high temperatures (uncontrolled reaction) can result in the evaporation of the water of crystallisation to form an anhydrate product. As shown in Table 2 this can have a detrimental effect on digestibility/bioavailability. Ways for the Nutritionist to determine if a product is an anhydrate product is firstly to look at the P value. The loss of water of crystallisation would "concentrate" the product to result in elevated P values. Typical, a dihydrate DCP would contain about 18 % P, while an anhydrate DCP can contain up to 20 % P. Another way is to do moisture analysis. A dihydrate would loose more moisture when dried at temperatures exceeding 100 ^{o}C than an anhydrate product. Another method would be to analyse the product by X-ray defraction (Kemme *et al*., 2001), which will distinguish between the different chemical properties of the source. The most accurate, however would be if a manufacturer can provide digestibility (bioavailability) figures for their specific product tested *in vivo* at a reputable institution employing sound techniques.

3.2. MCP/MDCP

MCP/MDCP products are a chemical mixture of MCP and DCP. Products are classified as a MCP if the P derived from the MCP fraction constitutes more than 80% of the product with DCP making up the rest. The data in Table 3 shows that ***Kynofos 21*** can compete favourably with the best in the world.

As for DCP, MDCP can differ substantially in composition and bioavailability as shown in Table 1. The MCP to DCP ratio can vary from lower than 50 % P from MCP up to 80 % P from MCP. The differences in bioavailability between MCP and DCP for pigs (Table 3) of about 12 percentage units shows that the characteristics of a MDCP is crucial to assign a realistic value to the product. The specific MDCP (***Kynofos 21***) referred to in Table 3 has a known ratio of P from MCP of 75 % and P from DCP of 25 %. This is most probably the reason that bioavailable values do not differ significantly ($P < 0.05$) from the MCP described samples (80 % P or higher from MCP). The lower bioavailability value obtained for the USA produced MDCP is most likely because of a different ratio of MCP to DCP in the product. As for DCP, a MDCP can be produced as an anhydrated product (di- and monohydrated product for the DCP and MCP fractions).

To be practical, two procedures could be followed to determine the MCP to DCP ratio in a MDCP source.

- The P in a pure MCP is fully water soluble (100%) and the P in a pure DCP is insoluble (0%) in water (CEFIC 1999). By the determination of the water soluble P in a product (or as provided by a manufacturer), the ratio of MCP to DCP can be determined. I.e. water-soluble P content of

75 % would indicate a product of which 75 % of the P content is derived from MCP and 25 % derived from DCP.

- As the DCP component in an MDCP raises, so would the total Ca content (DCP is higher in Ca than MCP – typical 24 % versus 16 %). A Ca to P ratio of about 0.8 could indicate a product of which 70 % plus of the P is obtained from MCP, while a ratio of higher than 0.9 Ca to P could indicate a product of which about 50 % of the P were obtained from MCP. These ratios can help the Nutritionist to characterise the type of product in question and adapt availability values accordingly.

As for DCP, the most accurate determinant would be when a manufacturer can provide bioavailability figures for their specific product tested *in vivo* at a reputable institution employing sound techniques.

4. General remarks

The Nutritionist must be fully aware of the pitfalls in the quest to determine and quantify the nutritional value of the phosphorus in feed sources. Several methods are used to test the digestibility of phosphorus sources. The test results are expressed either as digestibility or as a relative bioavailability (expressed as relative biological value RBV). These should not be confused with one another. The digestibility is given as a digestibility coefficient < 100%, that can be used when calculating dietary digestible P. Relative bioavailability obtained from performance parameters (toe ash and other response parameters) ranks feedstuffs relative to a reference source, which makes it difficult to use it in quantitative terms. The RBV can be 100% or greater, depending on the reference phosphorus source.

Available P in plant feed sources, defined as "total-P minus phytate-P" could lead to the under or over estimation of a feedstuffs potential since not all non-phytate P sources are equally available. It must also be remembered that phosphate from animal origin and inorganic P sources are not part of such a system and need to be evaluated differently.

Apparent digestibility is a valuable measurement of the potential of the P in feedstuffs, but with the precondition that the P content of the experimental diets is below the recommended P requirement of the animals. This is most likely the most practical way to express the value of the P component in a feedstuff.

The value of an inorganic feed phosphate for animals can **not** only be certified by its generic name (MDCP or DCP). Within these descriptive classes, huge differences in composition and utilisation by animals exist. These include differences such as hydrated versus anhydrated products as well as the ratio of MCP to DCP in a product. For the Nutritionist to know what bioavailability value can be assigned to a product of a specific manufacturer, a number of chemical characteristics can aid in the decision. This will not only lead to more accurate feed formulation, but also help to determine the value of a specific product.

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