Standardized Total Tract Digestibility (STTD) of Phosphorus

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SUMMARY

The standardized total tract digestibility of P can be calculated by correcting values for the apparent total tract digestibility P for the basal endogenous losses of P. Basal endogenous losses of P have been determined in a number of experiments and average approximately 200 mg per kg dry matter intake. Unlike values for the apparent total tract digestibility of P, values for the standardized total tract digestibility of P, are not dependent on the inclusion rate of P in the diet and these values are, therefore, believed to be additive in mixed diets. The fecal excretion of P can also be calculated from these values, which will make it possible to predict P-excretion from animals fed diets that were formulated on the basis of standardized total tract digestibility of P. The quantity of standardized total tract digestible P will most accurately reflect the quantities of P in mixed diets that pigs can utilize and practical diet formulation should, therefore, be based on values for the standardized total tract digestibility of P.

INTRODUCTION

The quantity of P that is available to pigs in a feed ingredient is often determined by the relative bioavailability of P in the ingredient. To determine this value, several diets containing graded levels of the ingredient need to be formulated, animals are fed the diets for 4 to 6 weeks and then sacrificed, bones are extracted from the front feet, and the P in the bones is determined. This procedure is relatively expensive and labor intensive, and results obtained for individual feed ingredients are not always additive in mixed diets. As an alternative, the apparent total tract digestibility (**ATTD**) of P in a feed ingredient may be determined using a diet that contains this ingredient as the sole source of P. The diet is fed to individually housed pigs and the feces from the pigs that are fed the diet are collected and analyzed for P. Pigs are not sacrificed, and only one diet per ingredient is needed. This procedure is, therefore, less expensive and much faster than the procedure used to determine the relative bioavailability of P. It has, however, been demonstrated that the values for the ATTD of P that are obtained depend on the concentration of P in the diet (Fan et al., 2001). The reason for this observation is that the endogenous losses of P contribute a greater proportion of total P output if P is included in diets at low inclusion rates than if P is included at a greater concentration. To solve this problem, values for the ATTD of P may be corrected for the endogenous losses, which will result in calculation of values for the digestibility of P that are independent of the concentration of P in the diet. These values are, therefore, believed to be additive among feed ingredients when mixed into a common diet.

DETERMINATION OF ENDOGENOUS LOSSES

There are 2 forms of endogenous losses that may be used to correct values for the ATTD of P. These are the basal endogenous losses and the total endogenous losses. Total endogenous losses may be determined using the regression procedure (Fan et al., 2001), which requires that graded levels of a feed ingredient are fed to animals, thus providing graded levels of P intake. By regressing P intake for each diet on the output of P and extrapolating this regression line back to zero P intake, the Y intercept of the regression line is considered the total endogenous loss of P. Alternatively, the total endogenous loss of P may also be determined using diets containing radioactive labeled P (von Lantzsch et al., 1965). However, there appears to be great difficulty in determining the endogenous loss of P accurately using these procedures and values for total endogenous losses between 8 mg/kg dry matter intake (Akinmusire and Adeola, 2009) and 670 mg/kg dry matter intake (Shen et al., 2002) have been reported..

Total endogenous losses consist of basal endogenous losses and diet specific endogenous losses. The basal endogenous losses are secreted in response to the intake of dry matter and are not related to the diet that is fed. Values for the total endogenous losses of P can be determined by feeding a P-free diet to the animals (Table 1) and collecting feces during a 4 or 5-day period (Petersen and Stein, 2006; Bünzen, 2009). This procedure is relatively simple and much easier and less time consuming than the procedures required for determining total endogenous losses. More importantly, data for basal endogenous losses determined using this procedure are much less variable than values obtained for the total endogenous losses and an average value for basal endogenous losses of approximately 200 mg per kg dry matter intake have been reported. This value is relatively constant among experiments.

CALCULATION OF STANDARDIZED TOTAL TRACT DIGESTIBILITY OF P

By correcting values for the ATTD of P by the basal endogenous losses of P, values for the standardized total tract digestibility (STTD) of P are calculated. It is, therefore, necessary to first calculated the ATTD of P, and then make the correction for the basal endogenous losses. Values for the ATTD of P can be calculated using equation 1 (Almeida and Stein, 2010):

ATTD of P (%) = [(P intake – P output)/P intake] × 100 **[1]**

Values for STTD of P are calculated by subtracting the basal endogenous losses for P from the output of P before output is subtracted from P intake according to equation 2 (Almeida and Stein, 2010):

STTD of P (%) = [(P intake – (P output - basal endogenous loss))/P intake] × 100 **[2]**

where P intake, P output, and basal endogenous losses are expressed as gram per day or as gram for the entire collection period.

It follows from the above equations that values for STTD of P can be calculated only if a value for the basal endogenous loss of P is available. As mentioned, this value is determined using a P-free diet, but because the variability among experiments in the determined endogenous loss of P is relatively small, it is not necessary to determine the basal endogenous P in every experiment where the digestibility of P is determined. Thus, it is necessary only to determine the ATTD of P, and by using the average value for basal endogenous losses (200 mg per kg dry matter intake), values for the STTD of P can be calculated.

PRACTICAL DIET FORMULATION

The main disadvantage of using data for ATTD of P is that ATTD values are not always additive in mixed diets because of the influenced of the dietary P level in diets used to determine the ATTD of P.

If a constant value for the basal EPL of pigs is assumed, it is possible to calculate values for STTD of P from experiments that were conducted to determine effects of dietary P on ATTD of P. As an example, in the experiment by Fan et al. (2001), different inclusion rates of soybean meal resulted in diets containing 0.11, 0.21, 0.32, and 0.43% P and the ATTD of P in these diets was 18.8, 37.6, 38.5, and 45.2%, respectively (Table 2). If the ATTD values are corrected for basal endogenous loss of P and if it is assumed that the basal endogenous loss of P is 200 mg/kg dry matter intake, values for the STTD of P can be calculated at 43.4, 48.4, 44.7, and 48.1% for the 4 diets. It is, therefore, apparent that the differences in STTD values among diets are much less than the differences in ATTD values and the effects of the level of dietary P is removed when values for STTD are used. A similar conclusion was reached in a recent experiment (Kim et al., 2010) in which the ATTD and STTD of P in whey powder and 2 sources of whey permeate (Perlac 850 and Variolac 960) were determined. Diets containing whey powder or Perlac 850 contained 0.20% P whereas the diet containing Variolac 960 contained only 0.04% P. The ATTD of P in whey powder and Perlac 850 (84.3 and 86.1%, respectively) were greater ($P < 0.05$) than in Variolac 960 (55.9%), but for STTD, no differences among the 3 ingredients were calculated (91.2, 93.1, and 91.8%, respectively). Data from both of these experiments, therefore, clearly illustrate that by using values for the STTD of P, effects of dietary P-level are removed. Diets may, therefore, be more accurately formulated if P digestibility values are based on the STTD of P rather than the ATTD of P and values for the STTD of P should be used in practical diet formulation. These principals are equivalent to those previously reported for amino acids, where it was shown that values for standardized ileal digestibility of amino acids are more additive in mixed diets than values for apparent ileal digestibility (Stein et al., 2005). Diets are, therefore, most accurately formulated if values for standardized ileal digestibility of amino acids and values for the standardized total tract digestibility of P are used.

CONCLUSIONS

When practical diets for pigs are formulated, values for the STTD of P in all feed ingredients should be used. These values are calculated by correcting values for the ATTD of P for the basal endogenous loss of P, which average 200 mg per kg dry matter intake. It is, therefore, possible to calculate STTD values for all feed ingredients for which ATTD values exist. By using STTD values in diet formulation, values that are additive in mixed diets are used, which will result in the most accurate prediction of the dietary concentration of digestible P. In addition, the fecal excretion of P can also be calculated, which in turn allows for estimation of P output in the manure of pigs.

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Table 1. Example of P-free diets used to calculate the basal endogenous loss of P

Ingredient, %	Weanling pigs	Growing-finishing pigs
Gelatin	20.00	20.00
Soybean oil	4.00	4.00
Solka floc	4.00	4.00
Ground limestone	0.80	0.80
Sucrose	20.00	20.00
Lactose	20.00	-
Cornstarch	29.22	49.22
Amino acid mixture[1]	0.78	0.78
Sodium chloride	0.40	0.40
Vitamin mineral premix	0.30	0.30
Potassium carbonate	0.40	0.40
Magnesium oxide	0.10	0.10
Total	100.00	100.00

[1]Contain the following AA (%, as-is basis): DL-methionine, 0.27; L-threonine, 0.08; L-tryptophan, 0.14; L-histidine, 0.08; L-isoleucine, 0.16; and L-valine, 0.05.

Table 2. Effect of dietary P concentration on values for apparent (ATTD) and standardized (STTD) total tract digestibility of P [1]

Item	Dietary soybean meal, %			
	13.6	27.3	40.8	54.6
P, g/kg diet DM	1.1	2.1	3.2	4.3
ATTD, %	18.8	37.6	38.5	45.2
STTD[2], %	43.4	48.4	44.7	48.1

[1]Values from Fan et al. (2001). n = 4.

[2]Values for STTD of P were calculated by correcting ATTD values for basal endogenous losses of P. The basal endogenous losses of P were assumed to be 200 mg/kg DMI.

Table 3. Differences in values for apparent total tract digestibility (ATTD) and standardized total tract digestibility (STTD) of P in whey products fed to weanling pigs[1, 2]

Item	Milk product			SEM	*P*-value
	Whey powder	Perlac 850	Variolac 960		
P in diet, %	0.203	0.202	0.040	-	-
ATTD of P	84.3[a]	86.1[a]	55.9[b]	2.08	< 0.001
STTD of P[3]	91.2	93.1	91.8	2.08	0.813

[a,b] Values within a row lacking a common superscript letter are different ($P < 0.05$).

[1]Values from Kim et al. (2010).

[2]Each least squares mean represents 8 observations.

[3]Values for STTD of P were calculated by correcting ATTD values for basal endogenous losses of P. The basal endogenous losses of P were determined at 153 ± 11.2 mg/kg DMI in pigs fed the P-free diet.