Digestible Calcium and Digestible Phosphorus in Swine Diets

The CFM DE LANGE Lecture in Pig Nutrition

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ABSTRACT

Values for digestible Ca are believed to be additive in a complete diet. Therefore, use of digestible Ca may result in the most accurate diet formulations for pigs. The standardized total tract digestibility (**STTD**) of Ca in Ca-containing feed ingredients have been reported in recent years. Supplementation of exogenous phytase to swine diets increases not only P digestibility but also Ca digestibility. Therefore, the STTD values without or with phytase are also available. Values for the STTD of Ca and P by sows in mid-gestation are less than by growing pigs, which indicates that formulating diets for gestating sows using STTD values that were obtained in growing pigs may result in inaccuracies. Several experiments were conducted to determine the requirement for STTD Ca by growing pigs and the STTD Ca values in feed ingredients that have been evaluated were used to formulate diets. Results demonstrated that feed intake and average daily gain are reduced if excess Ca is included in diets. The negative effects of excess dietary Ca on growth performance are ameliorated by increasing dietary P above the requirement. As a consequence, the ratio between STTD Ca and STTD P appears to be more important than the actual inclusion rates. The estimated STTD Ca:STTD P ratios to maximize growth performance of pigs decrease from 1.40:1 to 1.10:1, as BW of pigs increases from 11 to 130 kg, whereas the STTD Ca:STTD P ratios to maximize bone ash increase from 1.70:1 to 2.30:1, as the pig grows. It appears that less dietary Ca is needed to optimize growth of pigs compared with optimizing bone ash. Therefore, greater STTD Ca:STTD P should be used if pigs are destined for the breeding herd than for terminal pigs.

Keywords: Calcium, Digestibility, Pig, Requirement

INTRODUCTION

With monosodium phosphate or monocalcium phosphate as standards, relative bioavailability of P in feed ingredients for pigs had been used (NRC, 1998). Only limited data for the relative bioavailability of Ca in feed ingredients were published, but the availability of Ca in most Ca supplements was believed to be close to 100% (Ross et al., 1984; Kuznetsov et al., 1987). However, values for the relative bioavailability vary among standard phosphates (Petersen et al., 2011), which makes values for the bioavailability of P difficult to compare from study to study. Therefore, the standardized total tract digestibility of P has been measured and is now used to estimate requirements of P for pigs (NRC, 2012).

Unlike P, Ca requirements for pigs have been expressed as total Ca because there has been scarce information about the digestible Ca in feed ingredients. If information on digestible Ca is available, therefore, the requirement for Ca by pigs also can be expressed on a digestible Ca basis.

DIGESTIBILITY OF CALCIUM

Apparent total tract digestibility (**ATTD**) values (%) can be calculated as previously outlined (Almeida and Stein, 2010) using Eq. [1]:

$$\text{ATTD} = \frac{\text{intake - output}}{\text{intake}} \times 100, \qquad [1]$$

where intake and output of Ca in feces are expressed as g per d.

The values for ATTD are often underestimated because endogenous loss of Ca contributes to the fecal Ca excretion. The endogenous loss of Ca from pigs is composed of basal endogenous loss of Ca and diet specific endogenous loss of Ca. The basal endogenous loss of Ca is an inevitable loss from the body that is related to dry matter intake (**DMI**) and the diet specific endogenous loss is related to diet-specific components (Stein et al., 2007). Therefore, the standardized total tract digestibility (**STTD**) can be calculated by correcting the ATTD values for the basal endogenous loss, and true total tract digestibility (**TTTD**) can be calculated by correcting the ATTD values for total endogenous loss, which includes both basal and specific endogenous losses. Because STTD and TTTD values are not affected by the level of nutrients in the ingredient, the values are additive in mixed diets (Zhang and Adeola, 2017; She et al., 2018).

Basal endogenous loss of Ca has been measured by feeding a Ca-free diet to pigs (González-Vega et al., 2015a) and are calculated as previously outlined (adapted from Almeida and Stein, 2010) using Eq. [2]:

$$\text{Basal endogenous loss} = \frac{\text{output of Ca}}{\text{DMI}} \times 1{,}000, \qquad [2]$$

where basal endogenous loss is expressed in mg/kg of DMI, DMI in kg of DMI/d and the fecal output of Ca in g/d.

The STTD values (%) can be calculated from the following Eq. [3] (adapted from Almeida and Stein, 2010):

$$\text{STTD} = \frac{\text{intake - (output - daily basal endogenous loss)}}{\text{intake}} \times 100, \qquad [3]$$

where intake, output, and daily basal endogenous loss are in g/d.

Unlike the basal endogenous loss of P, which has a relatively constant value of around 190 mg/kg DMI among studies (NRC, 2012), the basal endogenous loss of Ca varied from 123 (González-Vega et al., 2015b) to 550 mg/kg DMI (Merriman, 2016). Values for the basal endogenous loss of Ca and the ATTD of Ca were lower if pigs were fed cornstarch-based diets compared with corn-based diets (González-Vega et al., 2015a). The increase in values for basal endogenous loss of Ca and ATTD of Ca by pigs fed corn-based diets may be because of the presence of fiber in corn, which prevents precipitation of Ca in the intestine.

The total endogenous loss of Ca can be estimated by using a regression method (González-Vega et al., 2013). The TTTD values (%) can also be calculated as previously outlined (Petersen and Stein, 2006) using Eq. [4]:

$$\text{TTTD} = \frac{\text{intake - (output - daily total endogenous loss)}}{\text{intake}} \times 100, \qquad [4]$$

where intake, output, and daily total endogenous loss are in g/d. The negative y-intercept represents the total endogenous loss and the slope represents the TTTD of Ca in the regression, which regressed absorbed Ca against intake of Ca. The total endogenous loss of Ca that have been published varies from 160 mg/kg DMI (González-Vega et al., 2013) to 314 mg/kg DMI (Zhang and Adeola, 2017), depending on the feed ingredients in diets.

DIGESTIBILITY VALUES FOR CALCIUM IN FEED INGREDIENTS

Most digestible Ca in diets for pigs originate from mineral supplements including Ca phosphates and Ca carbonate, but animal and plant origin ingredients may also provide Ca. Calcium from feed ingredients is not always fully digested and absorbed by pigs and previous data indicated that digestibility of Ca decreased by increasing dietary phytate (Almaguer et al., 2014). Phytate is a primary form for P in plant feed ingredients and pigs usually cannot utilize phytate-bound P due to the absence of phytase secreted from the body. In addition, phytate can chelate Ca ions and form Ca-phytate compounds (Selle et al., 2009). Because corn is a primary source for swine diets, phytate from corn can bind to Ca ions from Ca carbonate or other feed ingredients (González-Vega et al., 2015b; Merriman et al., 2016b). Therefore, supplemental phytase increases both P and Ca digestibility (Almeida et al., 2013; Rodríguez et al., 2013; González-Vega et al., 2015b). The digestibility of Ca in Ca phosphates appears not to be affected by use of exogenous phytase because Ca from monocalcium phosphate or dicalcium phosphate already is bound to phosphoric acid (Walk, 2016). The ATTD, STTD, and TTTD of Ca in feed ingredients without or with supplemental phytase have been determined in recent years (Table 1).

DIGESTIBILITY VALUES FOR CALCIUM BY GESTATING SOWS

Values for STTD of Ca and P that were determined in growing pigs have been published in recent years (NRC, 2012; Stein et al., 2016), but values for the ATTD of Ca and P were less in sows in mid-gestation compared with growing pigs (Kemme et al., 1997; Lee et al., 2018a). The difference in feed intake was not the main reason for the difference in digestibility of Ca and P because level of feed intake appears not to affect digestibility of Ca and P (Lee et al., 2018a). Greater quantities of endogenous losses from gestating sows compared with growing pigs may affect the ATTD values, because the basal endogenous losses of Ca and P from mid-gestating sows were more than 3 times greater than from growing pigs (Lee et al., 2018b). However, even if correcting the ATTD values for the greater basal endogenous losses, sows in mid-gestation had lower values for STTD of Ca and P compared with growing pigs. Therefore, differences in feed intake and basal endogenous losses were not the main reason for the differences in digestibility values. The digestibility of Ca and P also differed among gestating sows in different trimesters and sows in late-gestation had greater STTD of Ca and P than sows in early- or mid-gestation. (Lee et al., 2019). This difference may be related to the different requirement for Ca and P by sows in different gestation periods. Therefore, it is not always accurate to formulate diets for gestating sows using digestibility values for Ca and P that were obtained in growing pigs or in sows in a certain period of gestation.

Table 1. Apparent total tract digestibility (ATTD), standardized total tract digestibility (STTD), and true total tract digestibility (TTTD) of Ca in feed ingredients without and with phytase added to the diet fed to growing pigs

Item, %	ATTD of Ca		STTD of Ca		TTTD of Ca	
Supplementation of phytase[1]:	-	+	-	+	-	+
Mineral supplements						
Calcium carbonate[2, 3, 4, 5, 6, 7, 8, 9]	68	74	71	77	70	-
Calcium carbonate without fat source[6]	52	-	-	-	-	-
Dicalcium phosphate[2, 3]	73	76	77	79	76	-
Lithothamnium calcareum[2]	63	66	65	69	-	-
Monocalcium phosphate[2]	83	83	86	86	-	-
Plant feed ingredients						
Canola meal[7, 8, 10]	41	-	45	70	47	70
Soybean meal[7, 8, 11]	53	-	78	-	-	-
Sugar beet co-product[2]	66	63	68	65	-	-
Sunflower meal[8]	22	-	-	-	-	-
Animal feed ingredients						
Meat and bone meal[12]	75	-	77	82	-	-
Meat meal[12]	75	-	77	86	-	-
Fish meal[13]	62	71	65	73	-	-
Poultry meal[12]	85	74	82	76	-	-
Poultry by product meal[12]	81	84	88	87	-	-
Skim milk powder[7]	95	-	97	-	-	-
Whey powder[7]	97	-	99	-	-	-
Whey permeate[7]	61	-	63	-	-	-

[1]Phytase level varies from 500 to 1,500 phytase units/kg diet.
[2]González-Vega et al. (2015b); [3]Zhang and Adeola (2017); [4]Blavi et al. (2017); [5]Merriman and Stein (2016); [6]Merriman et al. (2016a); [7]Unpublished data from the University of Illinois; [8]Zhang et al. (2016); [9]Kwon and Kim (2017); [10]González-Vega et al. (2013); [11]Bohlke et al. (2005); [12]Merriman et al. (2016b); [13]González-Vega et al. (2015a).

REQUIREMENTS FOR CALCIUM BY GROWING PIGS

Supplementation of phytase, genetics of animals, energy concentrations in diets, and management strategies may affect Ca requirements by pigs (Suttle, 2010). Other factors including ratio between dietary Ca and P (Veum, 2010), concentration of vitamin D in the diet (Crenshaw, 2001), and the age of the animal (NRC, 2012) also can affect the requirement for Ca by pigs.

REQUIREMENTS FOR TOTAL CALCIUM

Because of a lack of data for the digestibility of Ca in feed ingredients fed to pigs, Ca requirements have been expressed based on total Ca. Although factorial calculations are believed to be more accurate to estimate nutrient requirements compared with empirical measurements, the empirical method has been more frequently used for determination of Ca requirements by pigs (Crenshaw, 2001). The most common response criteria for the empirical method are growth performance and bone development, but other parameters including blood composition and carcass measurements have also been used (Cromwell et al., 1970; Stockland and Blaylock, 1973). Most previous experiments had a fixed ratio between dietary Ca and P or had varied Ca levels with a fixed concentration of P in the diets. It has been demonstrated that greater quantities of Ca and P are required to maximize bone development than to maximize growth.

The reason requirements for Ca by pigs have been expressed on the basis of total Ca rather than as digestible Ca is that there has been a lack of data for the digestibility of Ca in feed ingredients. Therefore, the requirement for total Ca by growing pigs was estimated by NRC (2012) by multiplying the STTD P requirement by 2.15. A modelling approach was used to estimate the requirements for STTD P by growing pigs and the model was based on several assumptions: 1) 85% of the P requirement to maximize bone ash is enough to maximize growth performance, 2) there is a linear relationship between body P mass and body protein mass, 3) the efficiency of STTD P utilization for P retention is 77%, 4) the basal endogenous loss of P is 190 mg/kg DMI, and 5) there is a daily minimum urinary loss of P of 7 mg/kg BW. The following equation [5] was used to estimate the STTD P requirement (%):

$$\text{STTD P requirement} = 0.85 \times [\text{maximum whole-body P retention} / 0.77 + 0.19 \times \text{DMI} + 0.007 \times \text{BW}], \quad [5]$$

REQUIREMENTS FOR DIGESTIBLE CALCIUM

Although requirements for Ca are expressed as total Ca because of a lack of the data for the digestibility of Ca in feed ingredients, it was indicated that Ca and P requirements are more accurate if expressed as a ratio between digestible Ca and digestible P (NRC, 2012). Therefore, the STTD of Ca in different Ca-containing feed ingredients was determined, which allowed the formulation of diets based on STTD Ca and the estimation of STTD Ca requirements for growing pigs. Five experiments have been conducted to estimate the requirement for STTD Ca and the optimum ratio between STTD Ca and STTD P by growing pigs in different phases that were between 11 and 130 kg of BW.

The first study was conducted for 22 days using pigs from 11 to 25 kg and 6 dietary treatments (González-Vega et al., 2016a). Diets consisted of 6 levels of STTD Ca and a fixed concentration of STTD P. The response variables were growth performance, bone mineralization, and retention of Ca. Results indicated that bone ash (grams per femur) and Ca retention were maximized if the STTD Ca concentrations were at or above 0.48% and 0.60%, respectively. However, due to a reduction in ADG and G:F at STTD Ca concentrations above 0.50%, the STTD Ca that maximized growth performance could not be estimated. Therefore, in the following studies different concentrations of STTD P that were below, at, or above the requirement were used to estimate the requirement for STTD Ca and the optimal STTD Ca:STTD P ratio.

The subsequent studies were designed to have 5 levels of STTD Ca (from 30% to 170% of the estimated requirement for Ca) and 3 (Merriman et al., 2017; Lagos et al., 2019a) or 4 (González-Vega et al., 2016b; Lagos et al., 2019b) concentrations of STTD P (from 50% to 150% of the estimated requirement for P). A total of 15 or 20 different diets and STTD Ca:STTD P ratios were thus tested in each experiment.

In the study conducted by González-Vega et al. (2016b), pigs from 25 to 50 kg were fed 20 experimental diets for 28 days. Results supported the previous observation of detrimental effects of excess dietary Ca on growth performance, and also demonstrated that the severity is greater if STTD P is at or below the requirement than if the concentration of P is above the requirement. This observation highlights the importance of using STTD Ca:STTD P ratios in the formulation of diets for growing pigs. It was then concluded that growth performance, bone ash, and Ca retention is maximized at STTD Ca:STTD P ratios of 1.16:1 to 1.43:1, 1.55:1 to 1.77:1, and 2.45:1 to 3.10: 1, respectively.

The following 2 studies were conducted to estimate requirements for STTD Ca in growing-finishing pigs using 15 different STTD Ca:STTD P ratios (5 STTD Ca levels and 3 STTD P levels). Pigs from 100 to 130 kg (Merriman et al., 2017) or from 50 to 85 kg (Lagos et al., 2019a) were fed experimental diets for 30 and 28 days, respectively. Because results of previous studies demonstrated that Ca requirements for Ca retention are greater than for bone ash, in these studies the response variables were only growth performance and bone mineralization. Again, results demonstrated the negative effects of excess dietary Ca on growth performance and this impact could be ameliorated by supplying P above the requirement for P. Results also indicated that if P is at the requirement, STTD Ca:STTD P ratios below 1.10:1 and above 2.30:1 are needed to maximize growth performance and bone ash, respectively. Results of the study with 50- to 85-kg pigs indicated that to maximize growth performance of pigs, a STTD Ca:STTD P ratio of 1.23:1 is needed if P is at the requirement, whereas bone ash is maximized if the STTD Ca:STTD P ratio is greater than 1.59:1.

The last study was conducted using pigs from 11 to 25 kg and 20 dietary treatments (5 STTD Ca levels × 4 STTD P levels) to estimate STTD Ca requirements to maximize growth performance and bone ash (Lagos et al., 2019b). Results from this study concurred with data from heavier pigs and indicated that excess dietary Ca is detrimental to growth performance if P is supplied at or below the requirement. In this experiment it was observed that an STTD Ca:STTD P ratio that is below 1:40:1 is needed to maximize growth performance of pigs, whereas a ratio of 1.66:1 is needed to maximize bone ash.

CONCLUSIONS

The total tract digestibility method has been used to measure digestibility of Ca and values for STTD of Ca in feed ingredients for pigs have been determined in recent years. Diets for growing and finishing pigs should be formulated based on a ratio between STTD Ca and STTD P because growth performance of pigs decreases by increasing STTD Ca if P is at or below the requirement. Calcium and P requirements for maximizing bone ash are greater than requirements to maximize growth performance, which indicates that after requirements for growth performance are met, pigs utilize Ca and P for bone tissue synthesis. Data from 4 recent studies indicate that the STTD Ca:STTD P ratio to maximize growth performance decreases as pigs grow, whereas the STTD Ca:STTD P ratio to maximize bone mineralization increases as the weight of the pigs increases (Table 2). Results also indicate that less dietary Ca is needed to optimize growth performance of pigs than to maximize bone ash. It is likely, therefore, that pigs that are destined for the breeding herd need diets with a greater STTD Ca:STTD P ratio than terminal pigs.

Table 2. Requirements for Ca to maximize growth performance and bone ash expressed as a ratio between standardized total tract digestible (STTD) Ca and STTD P for growing and finishing pigs fed diets that met the STTD P requirement[1]

	Body weight range, kg			
Item	11 to 25	25 to 50	50 to 85	100 to 130
Growth performance	< 1.40:1	< 1.35:1	< 1.25:1	< 1.10:1
Bone ash	1.70:1	1.80:1	2.00:1	2.30:1

[1]STTD P requirement estimates are based on NRC (2012).

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