Chapter 13
Establishing a digestible calcium requirement for pigs

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Abstract

The standardized total tract digestibility (STTD) of calcium (Ca) in most feed ingredients used in diets fed to pigs has been determined, and the effect of microbial phytase on STTD of Ca has also been determined. This has made it possible to formulate diets based on values for STTD of Ca and attempts to determine requirements for STTD of Ca for 11 to 25, 25 to 50, and 100 to 130 kg pigs have been made. Results of these experiments have indicated that STTD Ca provided in excess of the requirement is detrimental to pig growth performance. This is particularly true if dietary STTD phosphorus (P) is marginal, whereas the negative effects of excess Ca is mitigated if STTD P is provided in excess of the requirement. As a consequence, effects of microbial phytase on the STTD of Ca need to be accounted for in diet formulation. Based on currently available information, it is recommended that diets for pigs less than 50 kg are formulated to have a STTD Ca:STTD P ratio between 1:1 and 1.35:1, whereas diets for pigs greater than 100 kg should have a STTD Ca:STTD P ratio that does not exceed 1.1:1.

Keywords: digestibility, minerals, phosphorus, pigs

13.1 Introduction

Historically, requirements for calcium (Ca) in diets fed to pigs have been expressed on the basis of total Ca and all feed requirement tables include values for the requirement for total Ca by different categories of pigs. This is in contrast to values for phosphorus (P) where requirements are usually expressed as values for either apparent total tract digestible (ATTD) P or standardized total tract digestible (STTD) P. In the current version of 'Nutrient Requirements of Swine' requirements for total Ca were calculated by multiplying requirements for STTD P by 2.15 (NRC, 2012). However, the committee that developed 'Nutrient Requirements of Swine' acknowledged that this approach was used simply because no data for the digestibility of Ca in feed ingredients were available and the committee specifically stated that 'A preferred ratio would have been a ratio between digestible Ca and digestible P, but again, because of lack of data the ratios between total Ca and STTD P are used' (NRC, 2012). Thus, the lack of data for digestibility of Ca in feed ingredients prevented the committee from estimating requirements for STTD of Ca.

C.L. Walk *et al.* (ed.) **Phytate destruction – consequences for precision animal nutrition**
DOI 10.3920/978-90-8686-836-0_13, © Wageningen Academic Publishers 2016

However, during the last few years, values for the digestibility of Ca in most Ca containing feed ingredients have been determined, and it has, therefore, been possible to initiate work to estimate requirements for digestible Ca in diets fed to different categories of pigs. It is the objective of the current contribution to present currently available data for digestibility of Ca in feed ingredients and preliminary data for the requirement for STTD Ca by growing-finishing pigs.

Nutrient requirements are determined by factorial calculations or empirical measurements. Because the factorial technique accounts for several factors such as availability, obligatory losses of the nutrient in the body, and retention of nutrients, it is believed that requirements obtained using this approach is more precise (Weremko *et al.*, 1997). However, empirical measurements, which use one or several response criteria to determine the nutrient requirement, have been most commonly used (NRC, 2012; Weremko *et al.*, 1997). However, factors such as sex and age may influence the requirement values (NRC, 2012).

Muscle and bones grow independently, therefore, deposition of Ca and P in lean tissue and skeletal tissue are not directly proportional (Crenshaw, 2001). Thus, the ratio between Ca and P in the body ranges between 1.20:1 and 1.60:1 for a 25 kg pig, and between 1.25:1 and 1.70:1 for a 50 kg pig (Hendriks and Moughan, 1993; Mahan and Shields, 1998; Pettey *et al.*, 2015; Rymarz *et al.*, 1982; Wiseman *et al.*, 2009). However, because 96 to 99% of Ca is believed to be present in skeletal tissue (Crenshaw, 2001), it is expected that requirements of STTD Ca to maximize bone ash are close to requirements to maximize Ca retention in the body.

13.2 Digestibility of calcium in feed ingredients

Preliminary work to determine the digestibility of Ca in feed ingredients fed to pigs indicated that the basal endogenous loss of Ca from pigs is between 150 and 400 mg per kg dry matter intake (Gonzalez-Vega *et al.*, 2013). As a consequence, values for ATTD of Ca are influenced by the inclusion level of Ca in the diets because the endogenous Ca contributes a greater proportion of Ca to the faecal output of Ca at low levels of Ca intake compared with greater levels of intake. Values for the ATTD of Ca are, therefore, not additive in mixed diets and as a consequence, digestibility values for Ca need to be corrected for the basal endogenous losses and expressed as values for the STTD of Ca.

A number of experiments have been conducted in recent years to determine the STTD of Ca in feed ingredients fed to pigs (Table 13.1). In general, the greatest STTD values have been obtained in feed ingredients of animal origin whereas the STTD of Ca in most inorganic sources of Ca has been observed to be less than in most animal proteins. Cereal grains and most cereal co-products contain very little or no Ca, whereas oilseed meals provide some Ca to the diets with canola meal having the greatest concentration of Ca among oilseed meals. However, as is the case for P, a proportion of the Ca in oilseed meals is bound to phytate with a reduced digestibility as a consequence. Therefore, inclusion of microbial phytase to diets that contain oilseed meals will result in an increased STTD of Ca (Gonzalez-Vega *et al.*, 2013). It has, however, been demonstrated that the increase

Table 13.1. *Standardized total tract digestibility (STTD) of calcium (Ca) in feed ingredients (%).[1]*

Ingredient	STTD of Ca without phytase	STTD of Ca with phytase
Mineral supplements		
Monocalcium phosphate[1]	77	80
Dicalcium phosphate[1]	73	75
Calcium carbonate[1]	64	71
Plant feed ingredients		
Canola meal[2]	42	-
Soybean meal[2]	78	-
Animal feed ingredients		
Meat and bone meal[3]	77	82
Meat meal[3]	77	86
Fish meal[4]	76	87
Poultry meal[3]	82	76
Poultry by product meal[3]	88	87
Skim milk powder[2]	93	97
Whey powder[2]	96	93
Whey permeate[2]	58	71

[1] Gonzalez-Vega *et al.*, 2015a.

[2] Unpublished data from the University of Illinois.

[3] Merriman *et al.*, 2016b.

[4] Gonzalez-Vega *et al.*, 2015b.

in digestibility of Ca that is observed in response to microbial phytase in diets based on corn and soybean meal is greater than what can be explained by the release of Ca bound to phytate in soybean meal (Almeida and Stein, 2013), and it was, therefore, hypothesized that other dietary Ca from mineral supplements may be bound to phytate in corn-soybean meal diets. Indeed, working with corn-based diets, it was subsequently demonstrated that the STTD of Ca in calcium carbonate, but not in monocalcium phosphate or dicalcium phosphate, is increased if microbial phytase is added to the diet (Gonzalez-Vega *et al.*, 2015a). Likewise, the STTD of Ca in fish meal included in a corn-based diet is increased by microbial phytase (Gonzalez-Vega *et al.*, 2015b), but for other animal proteins such as meat and bone meals and poultry meals, effects of microbial phytase have been less clear (Merriman *et al.*, 2016b). The STTD of Ca in whey permeate is also increased by microbial phytase, but that is not the case for skim milk powder and whey powder (unpublished data). There is, however, no impact of particle size of calcium carbonate on the STTD of Ca, and growth performance of pigs is not affected by the particle size of the calcium carbonate in the diets (Merriman and Stein, in press).

The reason the STTD of Ca in calcium carbonate and some animal proteins is increased if microbial phytase is used is most likely that the phytate from the plant ingredients may chelate the Ca from non-plant feed ingredients in the stomach of the pigs, which prevents absorption, but if microbial phytase reduces the chelating abilities of phytate, less Ca will be bound to phytate, which will result in increased digestibility of Ca. However, because excess dietary Ca will reduce the digestibility of P and thereby increase P excretion in the faeces (Stein *et al.*, 2011) and reduce growth performance of pigs (Gonzalez-Vega *et al.*, in press, 2016; Merriman *et al.*, 2016a), it is important to take the increased digestibility of Ca that is a result of microbial phytase into account in the formulation of diets fed to growing pigs.

13.3 Calcium absorption

In pigs, Ca may be absorbed via passive or via active transport (Bronner, 2003). Active absorption is the primary route if pigs are supplied low levels of dietary Ca, whereas passive absorption is the primary route if dietary Ca supply is at or above the requirement. However, combined, the two sources of absorption results in a near constant rate of absorption, regardless of the concentration of Ca in the diet, and there is only limited regulation of Ca absorption at the intestinal level (Stein *et al.*, 2011). In the kidneys, Ca can also be absorbed into the bloodstream form the distal tubule, but in this case, only active transport is used, which means that Ca is absorbed only if there is a low concentration of plasma Ca. As a consequence, if plasma concentrations of Ca are adequate, less Ca will be absorbed from the kidney tubules, and more will be excreted in the urine. Thus the main regulatory site of Ca homeostasis in pigs is the kidneys (Gonzalez-Vega *et al.*, in press).

13.4 Requirements for digestible calcium by growing pigs

Three experiments were conducted to determine the requirements for digestible Ca by growing pigs. In the first experiment, six diets that contained 0.36% STTD P and six levels of digestible Ca from 0.32 to 0.72% were used (Gonzalez-Vega *et al.*, in press). Two additional diets containing 0.72% Ca and either 0.33 or 0.40% STTD P were also formulated. The eight diets were fed for 22 days to pigs that were 11.39±1.21 kg at the start of the experiment with four pigs per pen and eight replicate pens per treatment. Individual pig weights were recorded at the beginning and at the conclusion of the experiment and on the last day of the experiment, one pig per pen was sacrificed and the right femur was removed. Data for average daily gain (ADG), average daily feed intake (ADFI) and average gain to feed (G:F) ratios were calculated at the end of the experiment and the femurs from the sacrificed pigs were ashed and analysed for Ca and P. Diets were also fed to 80 pigs that were placed individually in metabolism crates with 10 replicate pigs per diet. Faeces and urine were collected from all pigs and balances for Ca and P were calculated.

In the second experiment, a total of 20 diets were used. Diets contained 0.15, 0.31, 0.39, or 0.47% STTD P and 0.13, 0.27, 0.42, 0.57, or 0.72% STTD Ca. Thus, diets were formulated in a 4×5 factorial design. A total of 240 pigs (initial BW: 24.70±1.27 kg) were allotted to the 20 diets with two pigs per pen and six pen replicates per diet (Gonzalez-Vega *et al.*, 2016). Pigs were fed experimental diets for 28 days and on the last day of the experiment, one pig per pen was sacrificed and the right femur was removed. Diets were also fed to 120 pigs that were placed individually in metabolism crates. All measurements in this experiment were similar to those in Exp. 1.

In the third Experiment, 90 growing pigs (initial BW: 99.89±3.34 kg) were housed individually and randomly allotted to 15 diets with six pigs per diet (Merriman *et al.*, 2016a). Experimental diets were formulated as a 3×5 factorial with three dietary concentrations of STTD P (0.11, 0.21, or 0.31%) and five concentrations of STTD Ca (0.08, 0.18, 0.29, 0.38, or 0.49%). Pigs were fed experimental diets for 28 days. Initial and final BW were recorded and daily feed allotments were recorded as well for calculation of ADG, ADFI, and average G:F for each treatment group. All pigs were sacrificed at the conclusion of the experiment and the right femur was collected from each pig and bone ash, bone Ca and bone P were measured.

Results from Exp. 1 indicated that there were no negative effects of reducing the concentration of STTD Ca in the diets, but adding more than 0.54 or 0.50% STTD Ca to the diets resulted in a negative response to ADG and G:F, respectively (Figures 13.1 and 13.2). In contrast, bone ash increased as the concentration of STTD Ca increased in the diet and the optimum amount of bone ash was achieved if STTD Ca was 0.48% (Figure 13.3). Concentrations of bone P and bone Ca were maximized at dietary concentrations of STTD Ca of 0.56 and 0.50%, respectively. Likewise, the retention of Ca and P in the body was maximized at concentrations of STTD Ca of 0.60 and 0.49%, respectively. Results of this experiment indicated that under the condition of the experiment, there were no negative effects of reducing dietary Ca to well below the expected requirement, but adding excess Ca to the diets is detrimental to ADG and G:F. Because bone ash and bone Ca were maximized at 0.48 to 0.50% STTD Ca in the diets, and because ADG and G:F declined

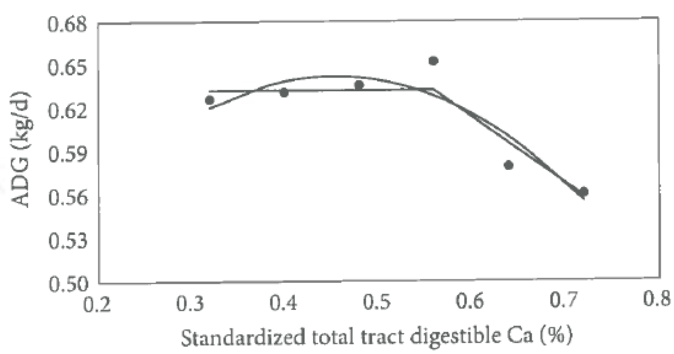

Figure 13.1. *Fitted broken line of ADG (kg/d, d 1 to 22) as a function of standardized total tract digestible Ca (STTD Ca; Exp. 1). The mean of each diet (●) represents the mean of 8 replicated pens per diet. The breakpoint was 0.56±0.10% STTD Ca if the broken line analysis was used (plateau = 0.63 kg/d ADG). The maximum ADG determined from the quadratic analysis was at 0.45±0.04% STTD Ca. The intersections between the broken line and quadratic analysis were 0.36 and 0.54% STTD Ca (adapted from Gonzalez-Vega* et al., *in press).*

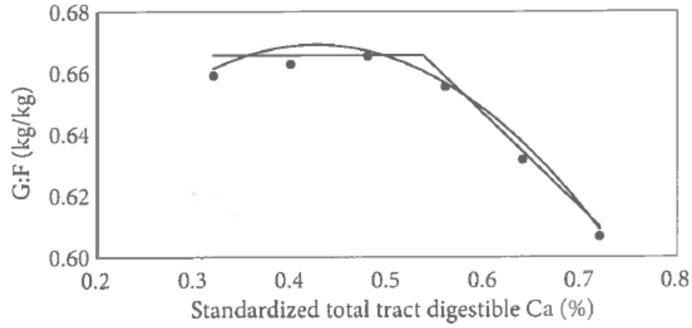

Figure 13.2. *Fitted broken line of G:F (kg/kg, d 1 to 22) as a function of standardized total tract digestible Ca (STTD Ca; Exp. 1). The mean of each diet (●) represents the mean of 8 replicated pens per diet. The break point for G:F was at 0.54±0.04% STTD Ca (plateau = 0.67 kg/kg G:F). The maximum G:F determined from the quadratic analysis was at 0.43±0.04% STTD Ca. The intersections between the broken line and quadratic analysis were 0.35 and 0.50% STTD Ca (adapted from Gonzalez-Vega* et al., *in press).*

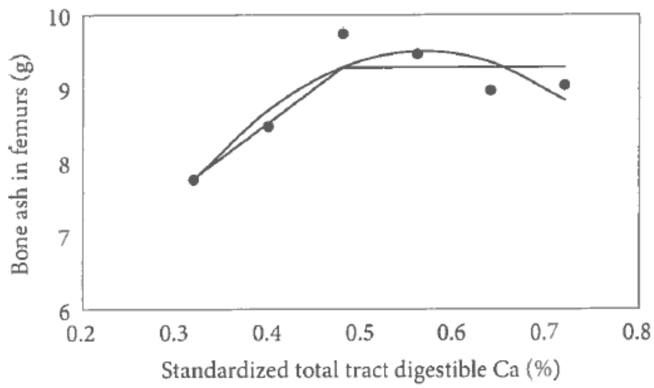

Figure 13.3. *Fitted broken line of bone ash in femurs (g) as a function of standardized total tract digestible Ca (STTD Ca; Exp. 1). The mean of each diet (●) represents the mean of 8 replicated pens per diet. The break point for g bone ash was at 0.48±0.11% STTD Ca if the broken line analysis was used (plateau = 9.30 g bone ash). The maximum concentration of bone ash determined from the quadratic analysis was 0.57±0.03% STTD Ca. The intersections between the broken line and quadratic analysis were 0.48 and 0.66% STTD Ca (adapted from Gonzalez-Vega* et al., *in press).*

at greater dietary concentrations of Ca, these levels should be considered the maximum levels of Ca that can be used in diets fed to pigs from 11 to 25 kg. These levels correspond to a ratio between STTD Ca and STTD P of approximately 1.35:1 and it appears that the best growth performance and bone ash concentrations in 11 to 25 kg pigs are obtained if the ratio between STTD Ca and STTD P is between 1:1 and 1.35:1, with the latter value being the absolute maximum that should be used.

Results of Exp. 2 confirmed that excess dietary Ca is detrimental to pig growth performance. This is particularly the case if dietary P is marginal or below the requirement (Table 13.2). However, results also confirmed that low dietary concentrations of Ca do not reduce growth performance of pigs. In contrast, bone ash, bone Ca, and bone P, and retention of Ca and P in the body are improved if diet concentrations of STTD Ca and STTD P are increased. However, it was observed that the concentration of Ca that is needed to maximize Ca retention is much greater than the concentration needed to maximize Ca in bone ash, which contradicts the expectation that 96 to 99% of all Ca in the body is stored in bones (Crenshaw, 2001). Overall, results of experiment 2 indicated that ADG, G:F, and bone ash were optimized if diets were formulated to a STTD Ca to STTD P ratio between 1.16:1 and 1.43:1. Formulating diets at a greater ratio between STTD Ca and STTD P will result in reduced growth performance of pigs.

Results of Exp. 3 confirmed the negative effects of excess Ca in the diets and indicated that both ADFI and ADG is reduced as dietary Ca increases, whereas dietary STTD P concentrations had no impact on ADG and ADFI (Table 13.3). However, there were no consistent impacts of dietary Ca or P on G:F in this experiment. The model to describe maximum ADG was negatively impacted by STTD Ca in the diet, but not by STTD P. However, bone ash linearly increased as STTD Ca or STTD P in the diets increased and the model to describe the response on bone ash was impacted by STTD Ca as well as STTD P (Figure 13.4).

Table 13.2. *Predicted values for average daily gain (ADG), gain to feed (G:F), bone ash, and calcium (Ca) retention of pigs fed diets containing 0.15, 0.31, 0.39, or 0.47% standardized total tract digestible (STTD) P and 0.13, 0.27, 0.42, 0.57, or 0.72% STTD Ca, Exp. 2 (adapted from Gonzalez-Vega* et al., *2016).*[1]

Item	Dietary STTD P			
	0.15	**0.31**	**0.39**	**0.47**
ADG (kg)	0.76 (0.12)	0.87 (0.36)	0.90 (0.47)	0.92 (0.59)
G:F	0.43 (0.09)	0.46 (0.38)	0.48 (0.52)	0.50 (0.67)
Bone ash (g)	14.3 (0.43)	21.3 (0.56)	23.2 (0.63)	24.0 (0.69)
Ca retention (g/d)	4.8 (0.76)	7.1 (0.93)	8.4 (1.02)	9.9 (1.11)

[1] The first value in each cell is the maximum response obtained at the STTD P concentration indicated, and the value in parenthesis is the % STTD Ca that will result in this response.

Table 13.3. *Growth performance of pigs fed experimental diets with varying concentrations of standardized total tract digestible (STTD) Ca and P for 28 d (adapted from Merriman* et al., *2016a).*

Item	Total Ca (STTD Ca) (%)				
STTD Ca (%)	0.12 (0.08)	0.29 (0.18)	0.46 (0.29)	0.61 (0.38)	0.78 (0.49)
Initial BW, kg					
0.11% STTD P	98.83	100.28	101.75	97.62	99.23
0.21% STTD P	99.42	98.38	101.07	98.47	100.45
0.31% STTD P	101.13	99.15	99.25	102.60	100.72
ADG, kg[1,2]					
0.11% STTD P	1.21	1.14	1.17	0.89	0.83
0.21% STTD P	1.16	1.20	1.17	1.15	0.96
0.31% STTD P	1.11	1.10	1.08	1.00	1.10
ADFI, kg[3,4]					
0.11% STTD P	3.70	3.29	3.27	3.16	2.88
0.21% STTD P	3.72	3.58	3.31	3.32	3.16
0.31% STTD P	3.46	3.32	3.27	3.16	3.16
G:F, d1-28[5,6]					
0.11% STTD P	0.33	0.35	0.37	0.28	0.29
0.21% STTD P	0.32	0.34	0.36	0.35	0.31
0.31% STTD P	0.33	0.33	0.34	0.32	0.35
Final BW, kg[7,8]					
0.11% STTD P	132.68	132.33	134.48	122.42	122.52
0.21% STTD P	132.02	131.85	133.75	130.77	127.32
0.31% STTD P	132.33	129.90	129.62	130.57	131.47

[1] Results indicated that ADG from d 1 to 28 at different combinations of STTD Ca and STTD P can be described by the following model: 1.2141 – 0.6230 × STTD Ca (P=0.008).

[2] Standard error of the within treatment least squares means = 0.09.

[3] Results indicated that ADFI from d 1 to 28 at different concentrations of STTD Ca can be described by the following model: 3.6782 – 1.2722 × STTD Ca (P=0.001).

[4] Standard error of the within treatment least squares means = 0.23.

[5] Results indicated that G:F from d 1 to 28 could not be predicted using STTD Ca or STTD P.

[6] Standard error of the within treatment least squares means = 0.02.

[7] Results indicated that final BW at different combinations of STTD Ca and STTD P can be described by the following model: 140.4729 – 42.9212 × STTD Ca – 30.3919 × STTD P + 140.2884 STTD Ca × STTD P (P=0.006).

[8] Standard error of the within treatment least squares means = 2.87.

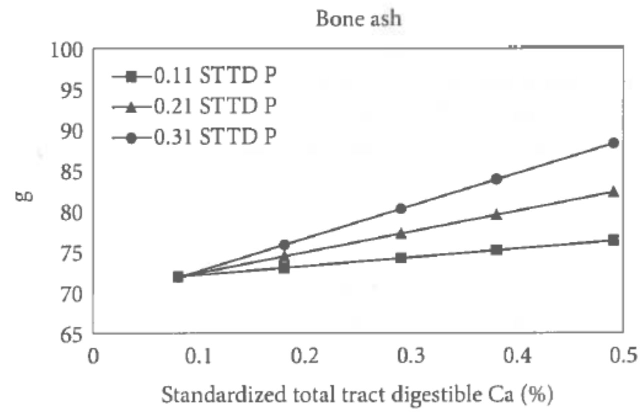

Figure 13.4. *Predicted values, based on the interaction between STTD Ca and STTD P (P=0.049), for bone ash (g) in pigs fed diets containing from 0.08 to 0.49% standardized total tract digestible (STTD) Ca and from 0.11 to 0.31% STTD P. All responses were linear, therefore, no maximum values were estimated (adapted from Merriman* et al., *2016a).*

13.5 Conclusions

1. Results of three experiments with 11 to 25 kg pigs, 25 to 50 kg pigs, and 100 to 130 kg pigs indicate that during short term experiments, it is not possible to reduce growth performance of pigs by reducing the concentration of STTD Ca in the diets.
2. In contrast, inclusion of excess STTD Ca in the diet will reduce ADG and G:F and this effect is more pronounced if dietary STTD P is marginal or below the requirement.
3. It is also clear that the amount of STTD Ca needed to maximize bone ash, bone Ca, bone P, or retention of Ca and P in the body is much greater than the amount needed to maximize growth performance.
4. Based on these results it is recommended that the STTD Ca to STTD P ratio for pigs less than 50 kg should be between 1:1 and 1.35:1, whereas diets fed to pigs above 100 kg should have a STTD Ca to STTD P ratio that does not exceed 1.1:1.
5. Because the STTD of Ca is increased in diets containing microbial phytase, it is important that the effect of phytase on STTD of Ca is taken into account in diet formulation.

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