EFFECT OF DIETARY CALCIUM ON GROWTH PERFORMANCE OF GROWING PIGS

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1.- INTRODUCTION

Relative bioavailability of P has been used to evaluate the available P in inorganic P supplements and values have usually been determined relative to the availability of P in monosodium phosphate or monocalcium phosphate [1]. However, only limited data for the bioavailability of Ca in inorganic supplements have been reported [2], but it is believed that the availability of Ca in most Ca supplements is high [3,4]. Values for relative bioavailability of P are variable among sources of P [5], and the relative bioavailability of P is often greater than digestibility values [6]. Therefore, use of values for the digestibility of Ca and P has been suggested as a more accurate way of assessing the digestibility and requirement of Ca and P by pigs [2,7].

2.- DIGESTIBILITY OF CA AND P BY GROWING PIGS

The digestibility of a nutrient represents the amount of that nutrient that disappears from the intestinal tract and it is assumed that this amount is also available for metabolism after absorption [8]. Total tract digestibility is used to determine the digestibility of Ca and

P because there is no net absorption or secretion of Ca and P into the large intestine [7,9]. Apparent total tract digestibility (**ATTD**) values (%) can be calculated as previously outlined [10] using eq. [1]:

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

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

The values for ATTD are usually influenced by dietary nutrient levels because not only dietary nutrients that have not been digested and absorbed, but also nutrients of endogenous origin are excreted in the fecal output, which may result in an underestimation of ATTD values [11,12]. The endogenous loss of nutrients from pigs consist of the basal endogenous loss that is considered an inevitable loss from the body that is related to dry matter intake (**DMI**) and a diet specific endogenous loss that is influenced by dietary components [13]. The ATTD values can be corrected for either basal endogenous loss or total endogenous loss to calculate standardized total tract digestibility (**STTD**) or true total tract digestibility (**TTTD**), respectively. Because the STTD or TTTD values are not affected by the level of nutrients in the diet, the STTD and TTTD of Ca and P are believed to be additive in mixed diets [14,15].

Basal endogenous losses of Ca and P have been measured by feeding a Ca-free or P-free diet to pigs [16,17] and are calculated as previously outlined (adapted from [10]) using eq. [2]:

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

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

The STTD values (%) can be calculated from the following eq. [3] (adapted from [10]):

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

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

Values for the basal endogenous loss of P that are estimated using a P-free diets are relatively constant regardless of BW and an average of a number of experiments indicated that a value of 190 mg/kg DMI is representative of the basal endogenous loss of P [2,18]. However, the basal endogenous loss of Ca that is estimated from pigs fed corn-based or cornstarch-based diets appears to be more variable and values ranging from 123 to 550 mg/kg DMI have been reported (Table 1). Relatively lower values for the basal endogenous loss of Ca and the ATTD of Ca have been observed in pigs fed cornstarch-based diets compared with pigs fed corn-based diets [16].

Table 1.- Estimates of basal endogenous loss and total endogenous loss of Ca by growing pigs

Reference	Initial BW, kg	Endogenous loss of Ca, mg/kg DMI	Main ingredients
Ca-free diet (basal endogenous loss)			
González-Vega et al. [16]	19.2	220	Cornstarch
González-Vega et al. [16]	19.4	396	Corn
González-Vega et al. [29]	17.7	123	Cornstarch
Merriman, Stein [34]	15.4	329	Corn
Merriman [47]	14.9	550	Corn
Blavi et al. [31]	15.4	430	Corn
Santana et al. [48]	20.5	140	Corn, soybean meal (1.25% soybean meal)
Lee et al. [27]	19.8	430	Corn
Regression method (total endogenous loss)			
Zhang, Adeola [15]	20.0	207	Corn, corn gluten meal, limestone
Zhang, Adeola [15]	20.0	316	Corn, corn gluten meal, dicalcium phosphate
Zhang, Adeola [15]	20.0	264	Corn, corn gluten meal, limestone, dicalcium phosphate
González-Vega et al. [33]	16.7	160	Canola meal
González-Vega et al. [33]	16.7	189 (with phytase)	Canola meal

2.1.- Absorption of Ca

The mechanism of Ca absorption is modified based on the quantity of Ca in the diet [19]. Transcellular transport is the primary route under low dietary Ca conditions whereas paracellular transport through the tight junctions is the preferred route of absorption if dietary Ca is at adequate or high levels [19]. This is because of the hormonal regulation of Ca in plasma by the active form of vitamin D (1,25-dihydroxycholecalciferol; calcitriol) and calcitonin [20]. Vitamin D is activated in the kidney by the parathyroid hormone (PTH) which is released as a result of low concentration of Ca in plasma, which increases the transcellular intestinal absorption of Ca and the reabsorption of Ca from the renal tubules and bones [20]. Intestinal and renal Ca absorption is increased by increasing the expression of apical membrane channels (transient receptor potential vanilloid; TRPV), which allow Ca to enter the cell, Ca binding proteins (calbindin), which transport Ca through the cell , and basolateral membrane channels (Ca-ATPase), which allow Ca to exit the cell [21]. Calcitonin, by contrast, is released in response to high concentrations of plasma Ca and increases the excretion of Ca in urine and preventing the resorption of Ca from bones [20].

2.2.- Sources of Ca and P

Most dietary Ca is supplied by mineral supplements, but animal and plant ingredients also provide Ca. Mineral supplements mainly include calcium carbonate and calcium phosphates, and the concentrations of Ca range from 15 to 40% [2]. Cereal grains and co-products of cereal grains, and oilseed meals can also provide dietary Ca, although most of the plant ingredients are low in Ca (range = 0.02 to 1.17%; [2]). Animal feed ingredients including milk products and animal byproducts contain relatively greater concentrations of Ca (between 0.20 and 8.28%) than plant feed ingredients [2]. The ATTD and STTD of Ca in feed ingredients have been evaluated in recent years and summarized values are presented in Table 2.

Table 2.- 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						
Monocalcium phosphate[2]	83	83	86	86	-	-
Dicalcium phosphate[2, 3]	73	76	77	79	76	-
Calcium carbonate[2, 3, 4, 5, 6, 7, 8, 9]	68	74	71	77	70	-
Calcium carbonate without fat source[6]	52	-	-	-	-	-
Lithothamnium calcareum[2]	63	66	65	69	-	-
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. [29]; [3]Zhang, Adeola [15]; [4]Blavi et al. [31]; [5]Merriman, Stein [34]; [6]Merriman et al. [37]; [7]Unpublished data from the University of Illinois; [8]Zhang et al. [49]; [9]Kwon, Kim [50]; [10]González-Vega et al. [33]; [11]Bohlke et al. [9]; [12]Merriman et al. [51]; [13]González-Vega et al. [16].

2.3.- Comparative digestibility values for Ca and P by gestating sows and growing pigs.

The digestibility of energy and some nutrients is affected by the physiological state of the animal and sows usually have greater digestibility values than growing pigs [22,23]. Absorption and retention of Ca and P also increases during pregnancy in humans and rats compared with non-pregnant periods because of an increased need for maternal body and fetus Ca and P [24]. However, pig data have demonstrated that ATTD of Ca and P in growing pigs are greater than in sows [25,26]. Difference in feed intake of gestating sows and growing pigs may affect the ATTD values, but it is not likely that the difference in feed intake is the main reason for the difference because feed intake of sows does not affect digestibility of Ca and P [26]. Greater endogenous losses from gestating sows than from growing pigs may also affect the ATTD values. Basal endogenous loss of Ca from gestating sows fed a Ca-free diet was 1,580 mg/kg DMI, whereas it was 430 mg/kg DMI for growing pigs (Table 3; [27]). However, gestating sows had reduced values for STTD of Ca and P compared with growing pigs indicating that the differences in endogenous losses were not the main reason for the differences in digestibility between growing pigs and sows. Considering the fact that retention of Ca and P is low in gestating sows, it is possible that gestating sows have a requirement for Ca and P that is close to the maintenance requirement, whereas growing pigs have a requirement for growth and bone development in addition to the requirement for maintenance, but additional research is needed to address this hypothesis.

Table 3.- Apparent total tract digestibility (ATTD) of DM and standardized total tract digestibility (STTD) of Ca and P by sows in mid-gestation and growing pigs fed diets containing different levels of phytate[1]

Item	Physiological state	Gestating sows		Growing pigs	
Dietary phytate (%)		**0.98**	**2.94**	**0.98**	**2.94**
ATTD of DM		90.1	81.6	90.2	80.9
STTD of Ca[2]		25.6	26.2	78.3	44.8
STTD of P[3]		27.8	11.8	63.0	27.3

[1] Derived from [27].

[2] The values for STTD of Ca were calculated by correcting ATTD of Ca for basal endogenous loss of Ca; basal endogenous loss of Ca from gestating sows = 1,580 mg/kg DM intake; basal endogenous loss of Ca from growing pigs = 430 mg/kg DM intake.

[3] The values for STTD of P were calculated by correcting ATTD of P for basal endogenous loss of P; basal endogenous loss of P from gestating sows = 780 mg/kg DM intake; basal endogenous loss of P from growing pigs = 160 mg/kg DM intake.

2.4.- Dietary factors affecting digestibility of Ca in pigs

Factors such as phytate [28] and fiber [16] as well as inclusion of phytase [29,30] or Zn [31] in the diet affect the digestibility of Ca. By contrast, factors such as dietary Ca level [7,32,33], particle size of Ca supplements [4,34], and concentration of P [35,36] do not appear to affect the digestibility of Ca. The effect of different sources of fat in diets on the digestibility of Ca is not clear although most fat sources increase Ca digestibility [37].

3.- REQUIREMENTS FOR CALCIUM BY GROWING PIGS

The concentration of dietary Ca and P as well as the Ca:P ratio [21], the concentration of vitamin D in the diet [20], and the age of the animal [2] may affect the requirement for Ca by growing pigs. Inclusion of phytase and other additives, animal genetics, concentration of energy in the diet, and management strategies can also influence the requirement for Ca [38].

3.1.- Requirements for Total Ca

Empirical measurements and factorial calculations have been used to determine requirements for total Ca by pigs [20] and although factorial calculations are believed to be more accurate for establishing nutrient requirements, empirical measurements are more often used [39]. Growth performance and bone development are the most common response criteria for the empirical method, however, blood composition and carcass characteristics have also been used [40,41]. In these type of experiments a constant concentration of P and different concentrations of Ca or a constant Ca:P ratio may be used. Results have demonstrated that the quantities of Ca and P needed to maximize bone development are greater than what is needed to maximize growth performance.

Because of the interest in reducing P excretion in the manure, maximizing P retention, and maximizing growth performance of pigs, values for STTD P are used in diet formulation [2]. However, requirements for Ca have been expressed on the basis of total Ca due to a lack of data about the digestibility of Ca in Ca containing feed ingredients [2]. A factorial approach was used to calculate the requirement for both STTD P and total Ca, thus, the STTD P requirement was based on maximizing whole-body P retention and the requirement for total Ca was calculated by multiplying the STTD P requirement by 2.15 [2]. However, the basis for this value is unclear. The STTD P requirement (%) was obtained using eq. [5]:

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

where it was assumed that 1) 85% of P requirement for maximum P retention will maximize growth performance; 2) P body mass is directly related to body protein mass; 3) 77% of the STTD P intake is used for P retention; 4) 190 mg/kg DMI are estimated as endogenous losses of P; and 5) 7 mg/kg BW are considered the minimum P urine losses. The body P mass (g) was obtained by using eq. [6]:

$$\text{Body P mass} = 1.1613 + 26.012 \times \text{body protein mass} + 0.2299 \times (\text{body protein mass})^2, \quad [6]$$

3.2.- Requirements for Digestible Ca

Requirements for Ca by pigs will be more accurately estimated using a ratio between STTD Ca and STTD P. Therefore, studies have been conducted to generate values for the STTD of Ca in most Ca containing feed ingredients [42], which allowed for determining the requirements for STTD Ca by growing pigs. Thus, a number of studies have been conducted to establish the requirement for STTD Ca expressed as a ratio between STTD Ca and STTD P.

In a 22-d study, a fixed concentration of STTD P, and 6 concentrations of STTD Ca were used to determine the amount of STTD Ca required to maximize growth performance, bone ash, and Ca retention in 11- to 25-kg pigs [43]. Results indicated that bone ash and Ca retention are maximized at STTD Ca concentrations of minimum 0.48% and 0.60%, respectively. However, a negative effect of STTD Ca above 0.50% on ADG and G:F prevented the estimation of a STTD Ca concentration that maximized growth performance. Therefore, the following studies were conducted using different concentrations of STTD P that were below, at, and above the requirement to estimate STTD Ca requirements an optimal STTD Ca:STTD P ratios at different concentrations of STTD P.

Four experiments have been conducted using 5 levels of STTD Ca and 3 or 4 levels of STTD P [44-46], for a total of 15 or 20 different STTD Ca:STTD P ratios. In the first experiment, the requirement for STTD Ca by 25- to 50-kg pigs was estimated by using 5 and 4 dietary concentrations of STTD Ca and STTD P, respectively. Results indicated a negative effect of increasing dietary concentrations of STTD Ca on growth performance and demonstrated that the impact is more evident if STTD P is at or below the requirement than if P is above the requirement [44], which demonstrates the importance of formulating diets based on a ratio between STTD Ca and STTD P. Growth performance and bone ash were maximized at STTD Ca:STTD P ratios of 1.16:1 to 1.43:1 and 1.55:1 to 1.77:1, respectively.

Two experiments were conducted to determine the requirement for STTD Ca by 100- to 130-kg and 50- to 85-kg pigs [45,46] using a total of 15 different STTD Ca:STTD P ratios. These experiments confirmed that excess concentrations of STTD Ca are detrimental to growth performance but that the negative effect may be ameliorated if dietary STTD P is included above the requirement. Linear responses in the 100- to 130-kg pigs study prevented estimation of maximum responses, however, data indicated greater values for growth performance and bone ash at a ratio between STTD Ca and STTD P below 1.10:1 and above 2.30:1, respectively, if STTD P was at the requirement [45]. For the 50- to 85-kg pigs study, bone ash was maximized at a ratio between STTD Ca and STTD P that ranged from 1.59:1 to 2.03:1, whereas growth performance was maximized at a ratio below 1.25:1, if STTD P was at the requirement [46].

Five levels of STTD Ca and 4 levels of STTD P were used to determine the STTD Ca requirement of 11- to 25-kg pigs (unpublished data). Results were in agreement with the previous experiments and indicated that maximizing growth performance requires an STTD Ca:STTD P ratio below 1.40:1, if STTD P was at the requirement. At the same STTD P level, bone ash was maximized at a ratio between STTD Ca and STTD P of 1.66:1.

4.- CONCLUSIONS

Growth performance of pigs is negatively affected by increasing dietary concentrations of STTD Ca if dietary P is at or below the requirement. However, the effect is ameliorated if P is above the requirement, indicating that diets should be formulated based on a ratio between STTD Ca and STTD P. Results confirmed that Ca and P requirements for bone ash are greater than for growth performance, which indicates that after the requirement for growth performance is met, pigs are able to utilize Ca and P for bone synthesis. It was also demonstrated that the requirement for Ca expressed as STTD Ca:STTD P that maximizes bone development increases as pig body weight increases, whereas the STTD Ca:STTD P ratio that maximizes growth performance is reduced as the weight of the pig increases (Table 4).

Table 4.- 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

Item	Body weight range, kg			
	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

5.- ABSTRACT

Values for standardized total tract digestibility (STTD) are believed to be additive in a complete diet. Therefore, use of values for STTD of Ca and P results in the most accurate diet formulations and values for the STTD of Ca in Ca supplements and feed ingredients have been reported. By supplementing exogenous phytase to swine diets, the STTD of Ca in feed ingredients may increase and, therefore, the STTD values without or with phytase are also available. Values for the STTD of Ca and P by sows are reduced compared with growing pigs, indicating that formulating diets for sows using the STTD values that were obtained using growing pigs may result in inaccuracies. Based on the STTD Ca values obtained from growing pigs, experiments have been conducted to determine the requirement for STTD Ca by growing pigs in recent years. Results of the experiments have demonstrated that increasing concentrations of dietary Ca reduces feed intake and, therefore, reduces average daily gain of pigs. The negative effects of excess Ca

on growth performance is more pronounced in diets with marginal P, but it may be ameliorated by increasing dietary P above the requirement. Therefore, it was concluded that the ratio between STTD Ca and STTD P is very important to optimize growth performance of pigs. The estimated ratios between STTD Ca and STTD P at different weight groups of pigs indicated that the STTD Ca:STTD P ratio to maximize growth performance decreases from 1.40:1 to 1.10:1, as pig body weight increases from 11 to 130 kg, whereas the STTD Ca:STTD P ratio to maximize bone ash increases from 1.70:1 to 2.30:1, as the weight of the pig increases. Results also demonstrated that to optimize growth performance of pigs, less quantities of dietary Ca are needed compared to what is needed to maximize bone ash. It is, therefore, likely that pigs that are destined for the breeding herd have greater requirements for dietary Ca and dietary P than terminal pigs.

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