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ANIMAL NUTRITION

Vitamin D, Total Calcium and Digestible Phosphorus in Swine Nutrition: Nutritional Recommendations

Vitamina D, Calcio Total y Fósforo Digestible en la Nutrición Porcina: Recomendaciones Nutricionales

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Resumen

La vitamina D, calcio y fósforo son nutrientes esenciales necesarios para una mineralización ósea, inmuno-modulación y reproducción eficiente. La vitamina D se sintetiza en el organismo tras la exposición a la luz solar, además puede ser aportado a través de la dieta en sus formas D2 y D3. En los últimos años se ha utilizado la forma *25-OH-D3* en la alimentación animal con mejores resultados que la forma D3 debido a su mayor biodisponibilidad. Su deficiencia produce alteraciones en el desarrollo del sistema óseo conocido como raquitismo y osteomalacia en cerdos jóvenes y adultos, respectivamente. Existe un gran avance en el conocimiento de los requerimientos nutricionales de vitamina D, calcio y fósforo para la especie porcina, razón por la cual se han publicado varios artículos de investigación, revisión y guías nutricionales. Dentro de estas últimas destacan *NRC, NSNG, Tablas Brasileñas, FEDNA* y otras desarrolladas por la industria proveedora de aditivos y genética porcina de reconocido prestigio mundial. Los valores sugeridos varían entre las diferentes fuentes de información relacionadas en gran parte a las condiciones en las cuales fueron desarrolladas (experimentales, comerciales o tipo campo). Sin embargo, es el nutricionista quien debe estar en la capacidad de adaptar estos valores a sus condiciones y objetivos de producción. El propósito de este manuscrito es presentar de manera resumida las recomendaciones nutricionales de vitamina D, calcio y fósforo proporcionando un contenido valioso para el nutricionista dedicado a la alimentación y formulación de dietas para cerdos.
Palabras clave: Alimentación, micronutrientes, vitaminas, minerales, cerdos.

Abstract

Vitamin D, calcium and phosphorus are essential nutrients necessary for efficient bone mineralization, immuno-modulation and reproduction. Vitamin D is synthesized in the body after exposure to sunlight, and it can also be provided through the diet in its D2 and D3 forms. In recent years, the *25-OH-D3* form has been used in animal feed with better results than the D3 form due to its greater bioavailability. Its deficiency produces alterations in the development of the bone system known as rickets and osteomalacia in young and adult pigs, respectively. There is great

advance in the knowledge of the nutritional requirements of vitamin D, calcium and phosphorus for the swine species, causing that research articles, reviews and nutritional guides have been published. Among the latter are *NRC, NSNG, Brazilian Tables, FEDNA* and others developed by the supplier industry of additives and genetics of swine of recognized world prestige. The suggested vales vary among the different sources of information related largely to the conditions in which they were developed (experimental, commercial or field type). However, it is the nutritionist who must be able to adapt these values to their production conditions and objectives. The purpose of this manuscript is to present in a summarized way the nutritional recommendations of vitamin D, calcium and phosphorus providing a valuable content for the nutritionist dedicated to the feeding and formulation of diets for pigs.
Keywords: Food, micronutrients, vitamins, minerals, pigs.

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1 Introduction

Vitamin D is a fat-soluble vitamin that participates in bone mineralization (Endo et al., 2003) and is lately related to immuno-modulation processes (Bikle, 2008; Yuk et al., 2009; Baeke et al., 2010a,b; Sun, 2010; Zhao et al., 2014; Tian et al., 2016) and antioxidants (Lahucky et al., 2007). This vitamin accumulates in the adipose tissue of rats, pigs and humans (Brouwer et al., 1998; Jakobsen et al., 2007; Didriksen et al., 2015), and it is a steroid molecule that could be considered as a hormone instead of a vitamin because of its action mechanism.

Vitamin D is synthesized in the skin, specifically in the epithelial cells from 7-dehydrocholesterol with ultraviolet light intervention (Larson-Meyer et al., 2017). The activation of this vitamin requires two hydroxylations at the hepatic and renal level, in positions $C-25$ and $C-1$, respectively, to form an active compound *1-25-*$(OH)_2$*-vitamin D* (Hollis, 2005). The activation regulation at the renal level is controlled by the action of Parathormone *(PTH)* (Crenshaw et al., 2011; Dittmer and Thompson, 2011). The reduction in the calcium serum level stimulates the secretion of *PTH*, thus synthetizing active vitamin D and causing an increase in the plasma level of calcium (Cunningham, 2014). This effect is achieved since vitamin D increases the absorption of Ca and P at the intestinal level, promotes greater bone resorption and reduces renal excretion of calcium and phosphate *Guyton2011*. Additionally, vitamin D can be ingested in the diet in its forms D2 or D3; fish oils naturally contain large amounts of D3, whereas D2 is present in certain plants in the form of ergosterol, being transformed to the D2 by action of the ultraviolet light (DeLuca, 2004).

Confined swine production limits exposure to sunlight, causing an increased risk of vitamin D deficiency even when supplemented through the diet (Alexander et al., 2017), coupled with the rapid growth of pork and early weaning. Vitamin D deficiency produces rickets, delayed skeletal and muscular development in growing pigs (Holick, 2006), while in adult pigs this deficiency produces osteomalacia (Pepper et al., 1978; Horst and Littledike, 1982; Fox et al., 1985; Thompson and Robinson, 1989; Dittmer and Thompson, 2011; NRC, 2012). For several years, a new form of vitamin D supplementation has been introduced to the market, the 25*OHD*3 which when used in sows it improves the body status of vitamin D when compared to the form D3 (Fritts and Waldroup, 2003; Lauridsen et al., 2010; Coffey et al., 2012; Lauridsen, 2014), and it is associated with better bioavailability (Bar et al., 1980).

In fattening pigs, productive performance and meat quality are improved when the source of vitamin D is 25*OHD*3, largely related to its best bioavailability (Jakobsen et al., 2007; Burild et al., 2016; Duffy et al., 2018). However, excessively high doses may decrease food intake (Flohr et al., 2014b), and dietary supplementation of vitamin D3 in sows during gestation has long-term effects on growth, integrity and bone mineralization of their piglets. Some of these alterations may be present from the birth and others may take longer (3-8 weeks of age) to show (Amundson et al., 2016). Supplementation of high concentrations of vitamin D3 in sows increases the level of *25(OH)D3* in the serum of pigs and piglets, as well as the concentration of vitamin D3 in milk and the tissue concentration of the neonate (Flohr et al., 2014a). Because of the latter, it is important to know the correct levels of vitamin D, calcium and phosphorus in sows feeding supplementation to maintain an adequate health and ensure maximum productive performance.

There are currently several sources of information where can be found the nutritional requirements for pigs, some are academic-experimental and others are created by the industry in order to achieve the maximum productive potential. In the first group is the nutritional guide of the National Research Council (NRC, 2012), *the Brazilian Tables for Birds and Pigs* (Rostagno et al., 2017), The United States National Nutritional Guide *(NSNG)* (U.S. Pork Center of Excellence, 2010), and the recommendations of the Spanish Foundation for the Development of Animal Nutrition *(FEDNA)* (FEDNA, 2013). The second group highlights the DSM Vitamin Supplementation Guide of 2016 for Animal Nutrition (DSM, 2016) and the PIC Nutrient Specification Manual (PIC, 2016). The aim of this manuscript is to summarize the nutritional recommendations of vitamin D, calcium and phosphorus conducted by different organizations of recognized world prestige, providing valuable content for the nutritionist dedicated to the feeding and formulation of diets for pigs in their different physiological states.

2 Source of information

Table 1 presents the main nutritional guide and the different characteristics used to elaborate this manuscript.

3 Requirements of vitamin D, total calcium (total Ca) and disgestible phosphorum (P dig) for fattening pigs

Requirements of vitamin D are expressed in international units (UI) per kilogram of food, while total Ca and P dig. are expressed in terms of composition percentage $(\%)$ (Tables 2 and 3). The total phosphorus value was not included since it was not included in several of the guides used. In Figure 1, trend lines of the needs of vitamin D3 (vertical axis) are plotted considering the weight of the pig (horizontal axis).

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Table 1. Nutritional guides.

Nutritional guide	Characteristics	Country of origin	Year of publication
National Research Council (NRC)	Minimum nutritional requirements. Carried out by different Universities under experimental conditions	United States of America	2012
Brazilian Tables	Requirements for a cheaper production of pigs. Conducted by Brazilian Universities	Brazil	2017
The United States National Nutritional Guide (NSNG)	Provides margins for a standard productive yield	United States of America	2010
Spanish Foundation for the Development of Animal Nutrition (FEDNA)	Practical recommendations in field conditions to obtain standard production levels	Spain	2013
DSM (Commercial 1)*	Recommendations to reach a maximum productive potential in pigs. Information obtained at the University and Industrial levels	Switzerland	2016
PIC (Commercial 2)*	Recommendations to reach a máximum productive potential in pigs	United States of America	2016

* Commercial 1 and 2 were used in this manuscript to refer to the nutritional guides of the enterprises DSM and PIC, respectively.

According to the NRC (2012), the needs of vitamin D are the lowest of all nutritional guidelines $150 - 220\ IU/Kg$, since they include the minimum amount needed to prevent the emergence of clinical signs related to deficit problems. It opposed to the suggested levels by *Commercial 2*, $2233 - 3883\ IU/Kg$ which is the highest and corresponds to approximately 14 to 17 times above what was reported by the *NRC*, seeking to achieve the greatest productive performance of the pig, providing the necessary amount to cover losses due to stress in animals, variations in environmental temperature, presence of infectious diseases, parasitic infections among other problems that may impair the optimum performance of the animal.

The U.S. Pork Center of Excellence (2010) suggests a level that is 3 times higher than the *NRC*, with its range between $330 - 660\ IU/Kg$ of food. The *Brazilian tables (2017)*, *FEDNA (2013)* and *Commercial 1 (2016)* have closer values to each other, with a range between $1000 - 2700\ IU/Kg$ but higher than the NRC (2012) and lower than those reported by *Commercial 2*. In all cases the contribution is always higher in the initial stages of the pig (pre and post-weaning stage) because the consumption of food is lower, having to be more concentrated the contribution of this vitamin, thus achieving the required level. Whereas, in the growth and completion stages, $30 - 60Kg$ and $60 - 120Kg$, respectively, decrease the contribution of vitamin D per Kg of food but increase the consumption of food by the animal, except for the case of *NSNG* in which increases the level of vitamin D in the finishing or completion stage when ractopamine is included in order to have a higher lean performance in pigs.

In a study carried out in piglets with an initial weight of $6{,}6Kg$ (28 days of age) and a duration of 14 days, it was found that there was no significant difference in the productive yield (food consumption, daily weight gain, food conversion) or in the bone mineralization when vitamin D3 is supplemented to levels of 1378 (control) or 13780 IU/Kg of food. However, when supplementation was performed at a level of 44100 IU/Kg (200 times higher than the *NRC*), food consumption decreased significantly (Flohr et al., 2014b).

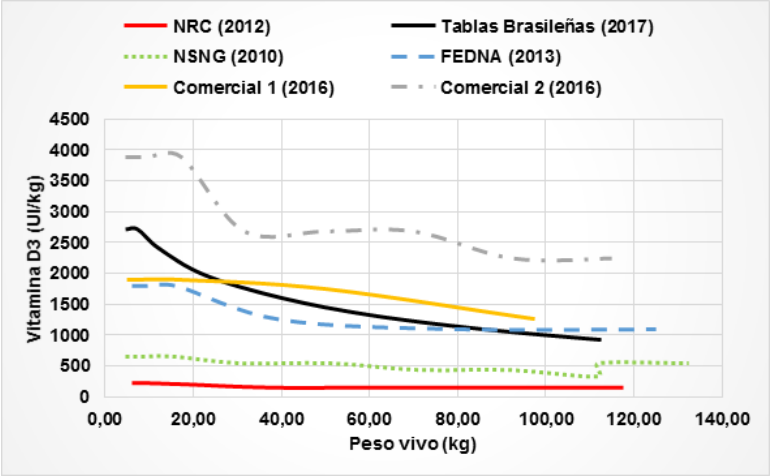

Figure 1. Requirement of vitamin D3 during the pig's growth.

Table 2. Nutritional recommendations of vitamin D3, Total Ca, P. dig, and total Ca-P dig relation for NRC, Brazilian Tables and NSNG.

Nutritional guide	Rank of alive weight (Kg)	Vitamin D3 (UI/Kg)	Total Ca (%)	Digestible P (%)	Total Ca-P dig. relation
NRC (2012)	5 - 7	220	0.85	0.7	1.21
	7 - 11	220	0.8	0.65	1.23
	11 -25	200	0.7	0.6	1.17
	25 - 50	150	0.66	0.56	1.18
	50 - 75	150	0.59	0.52	1.13
	75 - 100	150	0.52	0.47	1.11
	100 - 135	150	0.46	0.43	1.07
Brazilian tables (2017)	3.5 - 5.5	2707	0.888	0.5	1.78
	5.5 - 9	2707	1.068	0.51	2.09
	9 - 15	2405	0.973	0.47	2.09
	15 - 30	1969	0.794	0.38	2.09
	30 - 50	1599	0.655	0.31	2.09
	50 -70	1324	0.524	0.25	2.06
	70 -100	1101	0.454	0.22	2.06
	100 - 125	924	0.406	0.197	2.06
NSNG (2010)	4 - 5	660	0.9	0.57	1.58
	5 - 7	660	0.85	0.53	1.6
	7 - 11	660	0.85	0.4	2.13
	11 - 20	660	0.75	0.33	2.27
	20 - 41	550	0.71	0.29	2.45
	41 - 61	550	0.61 - 0.65	0.24 - 0.25	2.57
	61 - 81	440	0.56 - 0.61	0.2 - 0.22	2.79
	81 - 102	440	0.52 - 0.57	0.17 - 0.19	3.03
	102 - 122	330	0.49 - 0.53	0.14 - 0.15	3.52
	102 - 122*	550	0.51 - 0.55	0.19 - 0.20	2.72
	122 - 143*	550	0.48 - 0.52	0.15 - 0.17	3.13

* Inclusion of ractopamine.

These results agreed with those reported in another study conducted by the same author, in which vitamin D3 supplementation at levels of 1800 or 18000 IU/Kg during 35 days after weaning (day 21 age) did not generate significant differences in the productive variables (Flohr et al., 2014a). Additionally, vitamin D3 supplementation at a level of 3500 IU/Kg in piglets of 6-7 Kg weight (18 days of age) causes an immuno-modulatory impact by significantly increasing the number of leukocytes in the blood and its phagocytic capacity (Konowalchuk et al., 2013). Vitamin D3 supplementation at supranutritional levels of 40000 or 80000 IU per Kg of food for at least 44 days prior to slaughter improves meat color and increases pH without affecting muscle calcium concentrations (Wilborn et al., 2004). On the other hand, Wiegand et al. (2002) found that supplementation of elevated levels of vitamin D3 ($250000 - 500000$ IU/day) in completion pigs in 3 days prior to slaughter results in high plasma concentrations of calcium without improving the quality of the meat.

Table 3. Nutritional recommendations of vitamin D3, Total Ca, P. dig and total Ca-P dig. relation for FEDNA, Commercial 1 and 2.

Nutritional guide	Rank of alive weight (kg)	D3 Vitamin (UI/Kg)	Total Ca (%)	Digestible P (%)	Total Ca -P dig. relation
FEDNA (2013)	5 - 7	1800	0.65 - 0.75	0.41	1.71
	7 - 12	1800	0.70 - 0.80	0.38	1.97
	12 - 20	1800	0.73 - 0.81	0.33	2.33
	20 - 60	1250	0.67 - 0.80	0.28	2.63
	60 - 100	1100	0.65 - 0.80	0.25	2.9
	>100	1100	0.59 - 0.80	0.23	3.02
Commercial 1 (2016)	<5	1800 - 2000	-	-	-
	5 - 30	1800 - 2000	-	-	-
	30 - 70	1500 - 2000	-	-	-
	70 - mercado	1000 - 1500	-	-	-
Commercial 2 (2016)	3.5 - 5.5	3883	0.85	0.57	1.49
	5.5 - 7.5	3883	0.85	0.57	1.49
	7.5 - 11.5	3883	0.79	0.44	1.8
	11.5 - 23	3883	0.71	0.39	1.82
	23 - 40	2673	0.70 - 0.71	0.33	2.14
	40 - 60	2673	0.64 - 0.65	0.3	2.15
	60 - 80	2673	0.58 - 0.6	0.27 - 0.28	2.15
	80 - 105	2233	0.53 - 0.55	0.25 - 0.26	2.12
	105 - mercado	2233	0.48 - 0.5	0.24	2.04
	105 - market (<21 days)*	2233	0.63 - 0.64	0.29 - 0.30	2.15
	105 - market (>21 days)*	2233	0.60 - 0.63	0.28 - 0.29	2.16

* Inclusion of ractopamine.

4 Total Ca relation (%)−digestible P (%) in fattening pigs

The total Ca −P dig. relation (Tables 2 and 3) results in dividing the value of the total Ca column and the value of the P dig. Column, and it was considered as a reference variable to be able to compare between the different sources of information; in addition, it the relationship considering the requirements as the pig grows was graphed (Figure 2). The first *NRC* has a sustained line along the growth of the pig with values higher than 1 ($1{,}07 - 1{,}21$), without significant variations until reaching the weight of slaughter. The *Brazilian Tables* and *Commercial 2* also present a sustained line but their values are very close to 2; $1{,}78 - 2{,}09$ and $1{,}49 - 2{,}16$, respectively. On the other hand, U.S. Pork Center of Excellence (2010) and FEDNA (2013) present a tendency to increase as the pig grows, reaching a relationship of 3 or more. Higher values of the total Ca ratio − digestible P result from a large rank bet-

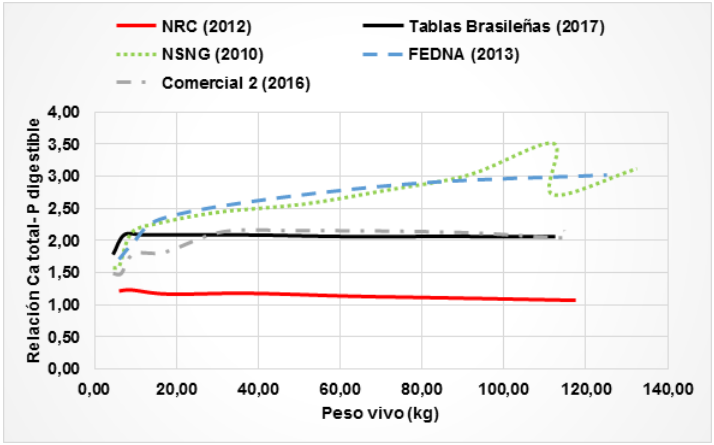

Figure 2. Total $Ca - P$ digestible relation during the pigs growth.

ween suggested CA levels and P requirements, specifically high CA and lower P requirements. It was not possible to present the trend of *Commercial 1* as this guide only makes recommendations of vitamins.

5 Nutritional recommendations of vitamin D3, total calcium and digestible phosphorus for pigs in reproductive stage

Recommendations of vitamin D for pigs in reproductive-stage are shown in Table 4 and are graphed in Figure 3 for their best understanding. The lowest values are those suggested by the *NRC* in replacement sows (nulliparous or future mothers) and boars (sexually active males) being of 200 IU/Kg for both cases, whereas for pigs the lowest values was presented in *NSNG* with 660 IU/Kg. The highest levels in all reproductive categories are given by *Commercial 2* 1985, 1985 and 2000 UI/Kg for replacement, sows and boars, respectively; proving to be 10 times higher than the *NRC* recommendations and agreeing with being the highest level of this guide as well as fattening pigs. Following the values of*Commercial 2* are those of *Commercial 1*, 1900, 1750 and 1750 IU/Kg of food. Intermediate values in the general comparison and very similar to each other are those described by the *Brazilian Tables* and *FEDNA* with a range between $1200 - 1600$ IU/Kg; being 8 times higher than the recommendations of the *NRC* for replacement and boars and double in the category of sows.

Supplementation of *25OHD3* (500 $IU\ D3/Kg$ of food 50g $25OHD3/Kg$ of food) in first-serve sows before and during gestation improves the status of vitamin D in the mother and fetuses, the conception rate and litter size without affecting the average live weight of piglets compared to sows that only received vitamin D3 (2500 $IUD3/Kg$ food) (Coffey et al., 2012). In a similar study, *25OHD3* supplemented at the same levels of the previous study in pregnant sows was found to have a positive impact on fetal skeletal muscle development as well as in mioblastic activity (Hines et al., 2013; Zhou et al., 2016). The latter is because the *25OHD3* form has greater bioavailability compared to the form D3 (Sitrin et al., 1982; Bischoff-Ferrari et al., 2012); however, regardless the form and dose of vitamin D the transfer of this vitamin to progeny is scarce via transplacental (Lauridsen et al., 2010) but not through breast milk (Flohr et al., 2016a,b).
Additionally, in a study carried out in sows in supplemented with *25OHD3* at a level of 2000 IU/Kg during the gestation and lactation it was observed that the status of this vitamin improved in sows, as well as the skeletal mineralization in piglets (Witschi et al., 2011); but in another study it was determined that the supplementation of *25OHD3* at a level of 2000 IU/Kg significantly increased the birth and weaning weight when compared to the form D3 (Weber et al., 2014). On the other hand, the supplementation of vitamin D3 at a level of 2000 IU/Kg in boars improved the quality of the spermatozoa, which is related to an increase in the hormonal synthesis and to changes in the composition of the seminal plasma and to the genetic expression in the spermatozoa; statistically there was no difference between 2000 IU supplementation with 4000 IU of vitamin D3 per Kg of food (Lin et al., 2017).

Table 4. Nutritional recommendations of vitamin D3, total Ca and P dig. in pigs under breeding stage.

Nutritional guide	Phase	D Vitamin (UI/Kg)	Total Ca (%)	Digestible P (%)	Total Ca -P dig. relation
NRC (2012)	Reemplacement	200	0,49 - 0,61	0,27 - 0,30	1,93
	Sows	800	0,43 - 0,83	0,19 - 0,36	2,29
	Boar	200	0,57 - 0,64	0,23 - 0,28	2,37
Brazilian tables (2017)	Reemplacement	1560	0,705 - 0,847	0,333 - 0,405	2,1
	Sows	1560	0,705 - 0,847	0,333 - 0,405	2,1
	Boar	1560	0,705 - 0,847	0,333 - 0,405	2,1
NSNG (2010)	Reemplacement	660	0,65 - 0,81	0,26 - 0,35	2,39
	Sows	660	0,85 - 0,90	0,35 - 0,39	2,36
	Boar	660	0,68 - 0,86	0,29 - 0,45	2,08
FEDNA (2013)	Reemplacement	1600	0,85 - 1,05	0,30 - 0,32	3,06
	Sows	1600	0,81 - 1,05	0,29 - 0,32	3,05
	Boar	1200	0,85 - 1	0,31	2,98
Commercial 1 (2016)	Reemplacement	1900	-	-	-
	Sows	1750	-	-	-
	Boar	1750	-	-	-
Commercial 2 (2016)	Reemplacement	1985	0,7	0,35	2
	Sows	1985	0,85	0,44	1,93
	Boar	2000	0,8	0,4	2

6 Total Calcium−digestible phosphorous relation in pigs during the reproductive phase

Total calcium − digestible phosphorus relation is shown in Figure 4. The highest values are those calculated for *FEDNA* being of 3.06; 3.05 and 2.98 in replacement, sows and boars, respectively. The other nutritional guidelines (*NRC, Brazilian Tables, NSNG, commercial 2*) have similar values that oscillate between 1.93-2.39; 1.93-2.36 and 2-2.37 for replacement, sows and boars, respectively. The values of *Commercial 1* are not presented since the guide only includes recommendations of vitamins.

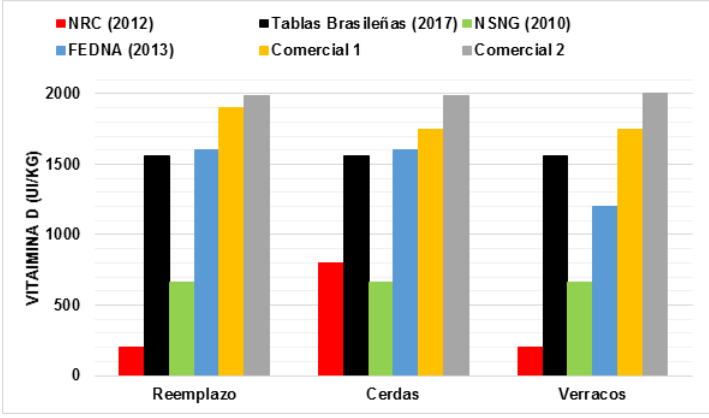

Figure 3. Requirements of vitamin D3 on pigs during the reproductive phase.

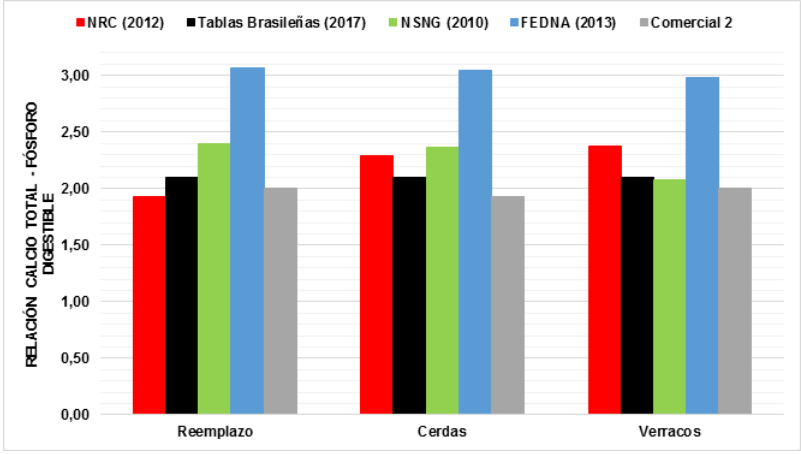

Figure 4. Total *Ca*− digestible P relation for pigs during the reproductive phase.

7 Conclusions

There are several information sources (nutritional guidelines) from which can be obtained nutritional recommendations for pigs in productive (fattening) and reproductive stages. The variation existing among the suggestions of vitamin D, total calcium and digestible phosphorus is really wide among the different references, the nutritionist and/or pig production specialist, who must be able to adapt the suggested nutrient levels to the production conditions, looking to achieve the objectives of the farm.

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