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Prediction of calcium and phosphorus requirements for pigs in different bodyweight ranges using a meta-analysis

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Abstract

Several studies have focused on Ca and P requirements for pigs. These requirements are estimated from their retention and bone formation. However, modern pig breeds have different responses to dietary Ca and P than traditional breeds, and their requirements are expected to change on an annual basis. Besides individual Ca and P needs, the Ca to P ratio (Ca/P) is an important factor in determining requirements. This study aimed to implement a linear and quadratic regression analysis to estimate Ca and P requirements based on average daily gain (ADG), apparent total tract digestibility (ATTD) of Ca (ATTD-Ca), ATTD of P (ATTD-P), and crude protein (CP) digestibility. Results show that Ca/P had linear and quadratic effects on ADG in the phytase-supplemented (PS) group in both the 6–11 kg and 11–25 kg categories. In the latter category, the CP digestibility was linearly increased in response to increasing Ca/P in the without-phytase (WP) group. In the 25–50 kg category, there was a linear response of ADG and linear and quadratic responses of CP digestibility to Ca/P in the PS group, while a linear and quadratic increase in CP digestibility and a quadratic effect on ATTD-Ca were observed in the WP group. In the 50–75 kg category, Ca/P had significant quadratic effects on ADG in the PS and WP groups, along with significant linear and quadratic effects on ATTD-Ca. In addition, Ca/P had significant quadratic effects on ATTD-P and led to a significant linear and quadratic increase in the CP digestibility in the WP group. In the 75–100 kg category, analysis showed a significant decrease in ATTD-Ca and ATTD-P in the PS and WP groups; in the latter, ATTD-P and ATTD-Ca were linearly decreased by increasing Ca/P. In conclusion, our equations predicted a higher Ca/P in the 6–25 kg bodyweight categories and a lower Ca/P in the 50-100 kg category than that recommended in the literature.

Keywords: Phytase, Weanling, Growing, Crude protein, Digestibility, Meta-analysis

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The project underwent proper ethical standards and the experiments (KW-170519-1) were approved by the Institutional Animal Care and Use Committee of Kangwon National University, Chuncheon, Korea.

INTRODUCTION

In recent decades, the growth performance of commercial pigs has increased. This may suggest that higher levels of Ca and P supplements are being provided in diets than are currently recommended [1,2] for optimization of skeletal integrity and growth performance [3,4]. Calcium and P are the first limiting minerals in commercial swine nutrition and are commonly supplemented in all diets apart from those tailored to the growth stage. In recent decades, there has been a controversial discussion regarding the effects of the dietary content of Ca and P, and their relative ratio, on biological efficiency, growth performance, and bone mineralization [5,6]. In diets with inadequate levels of P, low bone mineralization and energy metabolism can become growth-limiting factors [7,8] and therefore, high P levels are common in pig diets. However, the dietary requirement of P for pigs has not been well studied.

It is well known that high dietary Ca improves bone formation and bone ash content [1,8,9]; however, increased Ca in the diet has also been associated with decreased growth performance due to interactions with other absorbed minerals [10,11]. Ca interacts with inorganic P and phytate and decreases the activity of exogenous phytase [12]. Limestone, an important Ca source, has high acid-binding capacity, which can decrease the solubility of protein and P, subsequently reducing N and P digestibility [7,13]. Therefore, there is a negative correlation between dietary Ca levels and P utilization. Moreover, high doses of dietary Ca decrease the digestibility of food by forming soap with free saturated fatty acids [8,14]. High Ca and P dietary supplementation has increased environmental problems linked to the excessive excretion of manure in intensive pig production. In recent years, supplementation with phytase enzymes has been one of the most commonly used strategies to control environmental contamination and increase P utilization in farm animals. This meta-analysis aimed at developing a new feeding strategy based on the Ca to P ratio (Ca/P) and phytase enzyme supplementation through evaluating their effects on average daily gain (ADG), apparent total tract digestibility (ATTD) of Ca (ATTD-Ca), ATTD of P (ATTD-P), and crude protein (CP) digestibility in pigs from different bodyweight (BW) ranges.

MATERIALS AND METHODS

Literature search and database recording

For the meta-analysis, data sets were collected from the literature (ISI Web of Science and PubMed) by searching keywords. Recent papers published between 2010 and 2021 were considered for data analysis. Keywords selected were as follows: pigs, calcium, phosphate, feed, phytase, CP, and digestibility. Papers were screened for suitability before performing statistical analysis. First, research papers relating to gilt, sows, and cannula experiments were excluded, as were conference proceedings without clear results. Then, screened research papers that included information regarding dietary Ca and P contents, presence of phytase, and growth performance, were selected to set up the database. The results of literature screening are presented in Table 1. In total, 76 research papers with 296 to 372 data points per trait were selected. The BW range of the database was set to 6–100 kg. This range was divided into the following five BW categories: 6–11 kg, 11–25 kg, 25–50 kg, 50–75 kg, and 75–100 kg. All BW categories were then classified by the presence or absence of phytase in diets.

Statistical analysis

All statistical analyses were performed using SAS software (SAS ver. 9.0, SAS Institute, Cary, NC, USA). In order to determine the optimal dietary Ca/P for each of the five BW categories (with and

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Table 1. Descriptive statistics in the databases

Weight (kg)	Variable	With phytase					Without phytase				
		N	Mean	SD	Min	Max	N	Mean	SD	Min	Max
7–11	Ca/P ratio	80	1.24	0.17	0.92	1.63	135	1.30	0.18	0.94	1.67
	ADG	62	289.41	41.72	195.00	377.01	75	265.41	34.80	191.50	351.01
	ATTD Ca	25	63.20	8.33	42.69	77.58	23	58.11	9.17	33.10	77.30
	ATTD P	25	57.08	9.22	39.85	79.30	23	50.76	10.03	24.20	75.80
	CP	48	79.07	1.58	71.22	80.75	63	74.62	2.83	70.36	79.97
11–25	Ca/P ratio	118	1.29	0.27	0.73	1.90	150	1.25	0.25	0.64	1.90
	ADG	103	418.80	79.42	256.04	577.00	72	411.22	54.31	295.02	543.30
	ATTD Ca	114	72.10	9.94	43.00	90.00	76	56.05	9.32	35.00	72.50
	ATTD P	117	63.76	10.84	30.30	86.00	78	48.34	7.52	30.74	63.19
	CP	109	79.40	1.03	74.10	81.25	99	73.35	2.72	66.55	79.50
25–50	Ca/P ratio	54	1.35	0.19	1.00	1.79	105	1.29	0.20	0.83	1.68
	ADG	53	733.22	74.10	540.30	860.90	53	686.60	98.33	412.01	819.00
	ATTD Ca	49	67.79	11.44	45.60	85.60	56	53.56	9.50	35.40	73.80
	ATTD P	49	61.70	8.39	45.80	78.20	56	46.35	9.81	24.80	72.90
	CP	51	79.46	3.73	70.19	88.60	62	73.19	2.49	69.50	78.75
50–75	Ca/P ratio	52	1.21	0.15	0.92	1.61	63	1.29	0.21	0.94	1.83
	ADG	61	927.21	70.62	746.03	1,070.02	59	900.2	61.41	757.02	1,050.01
	ATTD Ca	52	69.96	6.88	58.52	82.36	42	62.87	7.08	49.00	79.80
	ATTD P	52	57.72	6.04	42.30	68.50	42	49.92	9.02	33.46	71.90
	CP	60	78.57	2.68	71.25	83.21	47	74.65	5.07	61.28	82.47
75–100	Ca/P ratio	68	1.34	0.12	1.14	1.70	67	1.29	0.25	1.00	2.19
	ADG	59	993.51	70.90	859.03	1,170.03	64	920.31	81.52	710.01	1,120.03
	ATTD Ca	56	70.58	3.53	61.28	78.69	60	61.42	3.95	52.96	69.68
	ATTD P	56	60.08	3.65	50.19	66.99	60	52.55	5.50	31.30	61.75
	CP	59	78.85	3.87	70.62	86.28	67	74.18	2.95	65.25	79.33
Overall	Ca/P ratio	372	1.28	0.20	0.73	1.90	520	1.28	0.22	0.64	2.19
	ADG	338	623.72	297.41	195.04	1,170.00	323	605.41	284.03	191.52	1,120.01
	ATTD Ca	296	69.14	9.01	42.69	90.00	257	58.34	8.64	33.10	79.80
	ATTD P	299	60.55	8.71	30.30	86.00	259	49.61	8.64	24.20	75.80
	CP	327	79.09	2.68	70.19	88.60	338	74.00	3.22	61.28	82.47

Ca/P, calcium to phosphorus ratio; ADG, average daily gain; ATTD, apparent total digestibility, Ca, calcium; P, phosphorus; CP, crude protein.

without dietary phytase), we performed a secondary regression analysis of dietary Ca/P to estimate the optimal ADG, ATTD-Ca, ATTD-P, and CP digestibility. The quadratic regression equation used was as follows:

$$Dietary\ Ca / P = aX^2 + bX + c,$$

where X includes ADG, ATTD-Ca, ATTD-P, and CP digestibility.

The regression models were estimated for the prediction of dietary Ca/P. The predictors of the secondary regression models were ADG (kg/d), ATTD-Ca (%), ATTD-P (%), and CP digestibility (%). The optimal value for Ca/P in diets was estimated as per the following formula:

$$Optimal\ dietary\ C / P = \frac{-a}{2b},$$

where *a* is the coefficient of the quadratic term in the regression equation and *b* is the coefficient of the first term in the regression equation.

Bootstrapping was used to estimate the mean and standard error of the optimal value for Ca/P in diets. The results of the estimated regression models for each of the five BW categories (with two phytase classifications) are presented in Table 1. The prediction model for each category included ADG (kg/d), ATTD-Ca (%), ATTD-P (%), and CP digestibility (%).

RESULT

The 6–11 kg bodyweight category

Linear and quadratic regression analysis was used to predict the effects of Ca/P with or without phytase supplementation on ADG, ATTD-Ca, ATTD-P, and CP digestibility. A summary of parameter estimates and accuracy indices (root mean square error [RMSE]) is provided in Table 2. As this table shows, the intercepts of ADG and CP in the phytase-supplemented (PS) group, and the intercept of CP in the without-phytase (WP) group were significant in the 6–11 kg category. Additionally, Ca/P had linear and quadratic effects on ADG in the PS group (Fig. 1). In contrast, no Ca/P effects were observed for ATTD-Ca, ATTD-P, and CP digestibility in both the PS and WP groups.

The 11–25 kg bodyweight category

For changing Ca/P in the 11–25 kg BW category (Table 2; Fig. 2), intercepts of ATTD-Ca, ATTD-P, and CP in the PS group, and digestibility of CP in the WP group were significant. A significant linear and quadratic response to Ca/P was observed for ADG in the PS group; however, no effects were detected for ATTD-Ca and ATTD-P in the PS or WP group. The CP digestibility increased linearly in response to increasing Ca/P in the WP group.

The 25–50 kg bodyweight category

For Ca/P in the 25–50 kg category (Table 2; Fig. 3), significant intercepts were observed for ATTD-Ca and CP digestibility in the WP group; however, no significant intercepts were observed for ADG, ATTD-Ca, ATTD-P, and CP digestibility in the PS group. There was a linear response of ADG and linear and quadratic responses of CP digestibility in the PS group. However, no regression response was observed for ATTD-P in the PS or WP group. A linear and quadratic increase in CP digestibility and a quadratic effect on ATTD-Ca were observed in the WP group.

The 50–75 kg bodyweight category

In the 50–75 kg BW category (Table 2; Fig. 4), there were significant intercepts for CP digestibility in the PS group, but no significant intercepts for ADG, ATTD-Ca, and ATTD-P in the PS or WP group. Using our equations, four different Ca/P effects were detected: 1) significant quadratic effects on ADG (PS and WP), 2) significant linear and quadratic effects on ATTD-Ca (PS and WP), 3) significant quadratic effects on ATTD-P (WP), and 4) a significant linear and quadratic increase in CP digestibility (WP).

The 75–100 kg bodyweight category

In the 75–100 kg category (Table 2, Fig. 5), there was a significant intercept for ADG in the PS group, and CP digestibility in the WP group. The linear and quadratic regression analysis showed a significant decrease in ATTD-Ca and ATTD-P in the PS and WP groups. No effects of Ca/P were observed for ADG in the PS or WP group, or for CP digestibility in the PS group; however,

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Table 2. Responses of pigs to calcium and phosphorus ratio to variations in ADG, ATTD of Ca, ATTD of P, and CP in different body weight categories

Weight (kg)	Independent variable	With phytase					Without phytase				
		Obs	Estimates	SE	*t*-value	*p*-value	Obs	Estimates	SE	*t*-value	*p*-value
6–11	Intercept	62	–1,034.10	281.20	–3.68	< 0.001	75	–2.19	197.40	–0.01	0.991
	ADG		1,964.20	443.60	4.43	< 0.001		382.40	303.40	1.26	0.216
	ADG^2		–717.50	172.50	–4.16	0.001		–135.40	115.10	–1.18	0.243
	Intercept	25	–13.06	122.80	–0.11	0.916	23	–76.59	104.60	–0.73	0.472
	ATTD Ca		124.01	197.60	0.63	0.536		208.81	162.40	1.29	0.213
	ATTD Ca^2		–50.30	78.50	–0.64	0.527		–79.53	61.87	–1.29	0.213
	Intercept	25	25.27	119.00	0.21	0.833	23	–46.58	100.60	–0.46	0.648
	ATTD P		43.45	191.4	0.23	0.822		151.84	156.10	0.97	0.342
	ATTD P^2		–15.14	76.03	–0.20	0.843		–57.73	59.49	–0.97	0.343
	Intercept	48	83.55	11.94	6.99	< 0.001	63	71.27	19.37	3.68	< 0.001
	CP		–4.13	19.05	–0.22	0.829		4.90	29.83	0.16	0.869
	CP^2		0.58	7.49	0.08	0.938		–1.72	11.30	–0.15	0.879
11–25	Intercept	103	–272.40	219.30	–1.24	0.217	72	19.90	445.50	0.04	0.964
	ADG		965.40	334.60	2.86	0.005		540.80	704.50	0.77	0.445
	ADG^2		–338.27	125.50	–2.69	0.008		–198.10	274.40	–0.72	0.472
	Intercept	114	58.70	22.60	2.60	0.010	76	22.14	31.14	0.71	0.479
	ATTD Ca		26.10	34.90	0.75	0.456		63.74	46.17	1.38	0.171
	ATTD Ca^2		–13.00	13.10	–0.99	0.323		–27.76	16.65	–1.67	0.099
	Intercept	117	66.28	26.98	2.46	0.015	78	35.27	31.43	1.12	0.265
	ATTD P		–2.22	41.45	–0.05	0.957		33.48	46.65	0.72	0.475
	ATTD P^2		–0.34	15.52	–0.02	0.982		–18.54	16.83	–1.1	0.274
	Intercept	109	80.05	3.04	26.28	< 0.001	99	55.98	8.22	6.81	< 0.001
	CP		–1.37	4.67	–0.29	0.769		25.77	12.40	2.06	0.042
	CP^2		0.52	1.75	0.30	0.767		–9.01	4.61	–1.95	0.053
25–50	Intercept	53	–288.20	460.10	–0.63	0.533	53	–443.20	590.40	–0.75	0.456
	ADG		1,413.20	685.70	2.06	0.044		1,721.30	903.80	1.9	0.063
	ADG^2		–482.10	252.90	–1.91	0.062		–642.00	340.90	–1.88	0.065
	Intercept	49	–41.50	95.10	–0.44	0.665	56	–117.40	59.10	–1.99	0.052
	ATTD Ca		161.00	147.50	1.09	0.28		262.80	91.50	2.87	0.066
	ATTD Ca^2		–58.80	56.50	–1.04	0.303		–99.10	34.90	–2.84	0.006
	Intercept	49	–8.29	67.82	–0.12	0.903	56	–52.66	64.31	–0.82	0.416
	ATTD P		102.74	105.10	0.98	0.333		154.10	99.40	1.55	0.127
	ATTD P^2		–37.30	40.28	–0.93	0.359		–58.84	37.95	–1.55	0.127
	Intercept	51	24.99	18.89	1.32	0.192	62	42.04	13.910	3.02	0.004
	CP		84.44	28.20	2.99	0.004		48.21	21.20	2.28	0.026
	CP^2		–32.06	10.44	–3.07	0.003		–18.25	7.92.00	–2.30	0.024
50–75	Intercept	61	–83.50	455.60	–0.18	0.855	59	–176.80	444.90	–0.40	0.692
	ADG		1,592.90	700.00	2.28	0.056		1,823.90	717.30	2.54	0.014
	ADG^2		–608.20	265.20	–2.29	0.025		–761.00	286.90	–2.65	0.011
	Intercept	52	–16.72	36.70	–0.46	0.65	42	2.33	24.00	0.10	0.923
	ATTD Ca		131.20	55.70	2.36	0.022		88.50	32.70	2.70	0.010
	ATTD Ca^2		–50.91	20.80	–2.45	0.047		–31.50	10.70	–2.93	0.006
	Intercept	52	6.75	39.86	0.17	0.866	42	–13.84	29.90	–0.46	0.646
	ATTD P		85.17	60.46	1.41	0.165		93.44	40.78	2.29	0.057
	ATTD P^2		–34.76	22.58	–1.54	0.13		–32.76	13.33	–2.46	0.018

Table 2. Continued

Weight (kg)	Independent variable	With phytase					Without phytase				
		Obs	Estimates	SE	*t*-value	*p*-value	Obs	Estimates	SE	*t*-value	*p*-value
50–75	Intercept	60	48.74	15.20	3.20	0.002	47	–3.51	19.95	–0.18	0.861
	CP		44.30	23.37	1.90	0.063		108.80	27.18	4.00	< 0.001
	CP^2		–16.11	8.85	–1.82	0.074		–34.65	8.88	–3.90	< 0.001
75–100	Intercept	59	1,460.80	1,371.00	1.07	0.291	64	83.80	426.10	0.20	0.844
	ADG		–680.20	2,046.00	–0.33	0.74		1,299.40	651.40	1.99	0.056
	ADG^2		244.80	760.10	0.32	0.748		–490.50	245.20	–2.00	0.050
	Intercept	56	–66.60	62.90	–1.06	0.294	60	6.52	21.70	0.30	0.765
	ATTD Ca		193.70	93.80	2.06	0.043		75.20	33.20	2.26	0.027
	ATTD Ca^2		–67.50	34.80	–1.94	0.048		–24.40	12.50	–1.95	0.036
	Intercept	56	–117.27	70.72	–1.66	0.103	60	–14.94	31.50	–0.47	0.637
	ATTD P		260.55	105.50	2.47	0.017		108.04	48.28	2.24	0.029
	ATTD P^2		–95.05	39.19	–2.43	0.019		–42.45	18.22	–2.33	0.023
	Intercept	59	–17.04	82.14	–0.21	0.836	67	57.08	8.40	6.79	< 0.001
	CP		143.14	122.50	1.17	0.247		24.49	11.59	2.11	0.038
	CP^2		–52.99	45.52	–1.16	0.249		–8.47	3.84	–2.20	0.031
Overall	Intercept	338	–2,141.40	581.60	–3.68	< 0.001	323	–76.60	765.50	–0.10	0.920
	ADG		41,110.10	887.70	4.63	< 0.001		1,188.80	1,187.00	1.00	0.317
	ADG^2		–1,493.70	335.00	–4.46	< 0.001		–503.60	454.80	–1.11	0.269
	Intercept	296	48.60	16.50	2.94	0.004	257	12.23	14.83	0.82	0.410
	ATTD Ca		33.40	25.29	1.32	0.187		71.70	21.58	3.32	0.001
	ATTD Ca^2		–13.65	9.57	–1.43	0.154		–27.20	7.69	–3.54	< 0.001
	Intercept	299	66.32	17.04	3.89	< 0.001	259	14.85	15.19	0.98	0.329
	ATTD P		–8.47	26.02	–0.33	0.745		58.12	22.12	2.63	0.009
	ATTD P^2		3.05	9.81	0.31	0.755		–23.90	7.88	–3.03	0.003
	Intercept	327	71.90	4.59	15.64	< 0.001	338	52.79	5.03	10.50	< 0.001
	CP		11.19	7.01	1.60	0.112		30.61	7.25	4.22	< 0.001
	CP^2		–4.26	2.64	–1.61	0.108		–10.45	2.56	–4.09	< 0.001

ADG, average daily gain; ATTD, apparent total digestibility, Ca, calcium; P, phosphorus; CP, crude protein; Obs, number of observations.

in the WP group, a linear and quadratic increase in ADG was detected as Ca/P increased.

All bodyweights

Overall, the analysis showed significant intercept differences for ADG, ATTD-Ca, ATTD-P, and CP digestibility in the PS and WP groups. The independent variables, Ca/P and phytase addition, led to a linear and quadratic increase in ADG in the PS group. In the WP group, ATTP-P and ATTD-Ca decreased linearly as Ca/P increased; however, CP digestibility had positive linear and quadratic responses to increased Ca/P.

DISCUSSION

Due to the importance of growth performance and environmental issues, various meta-analyses or reviews dealing with the influence of Ca/P or phytase supplementation on P or Ca utilization and growth performance in pigs have been reported previously [1,2,8,9]. However, genetic

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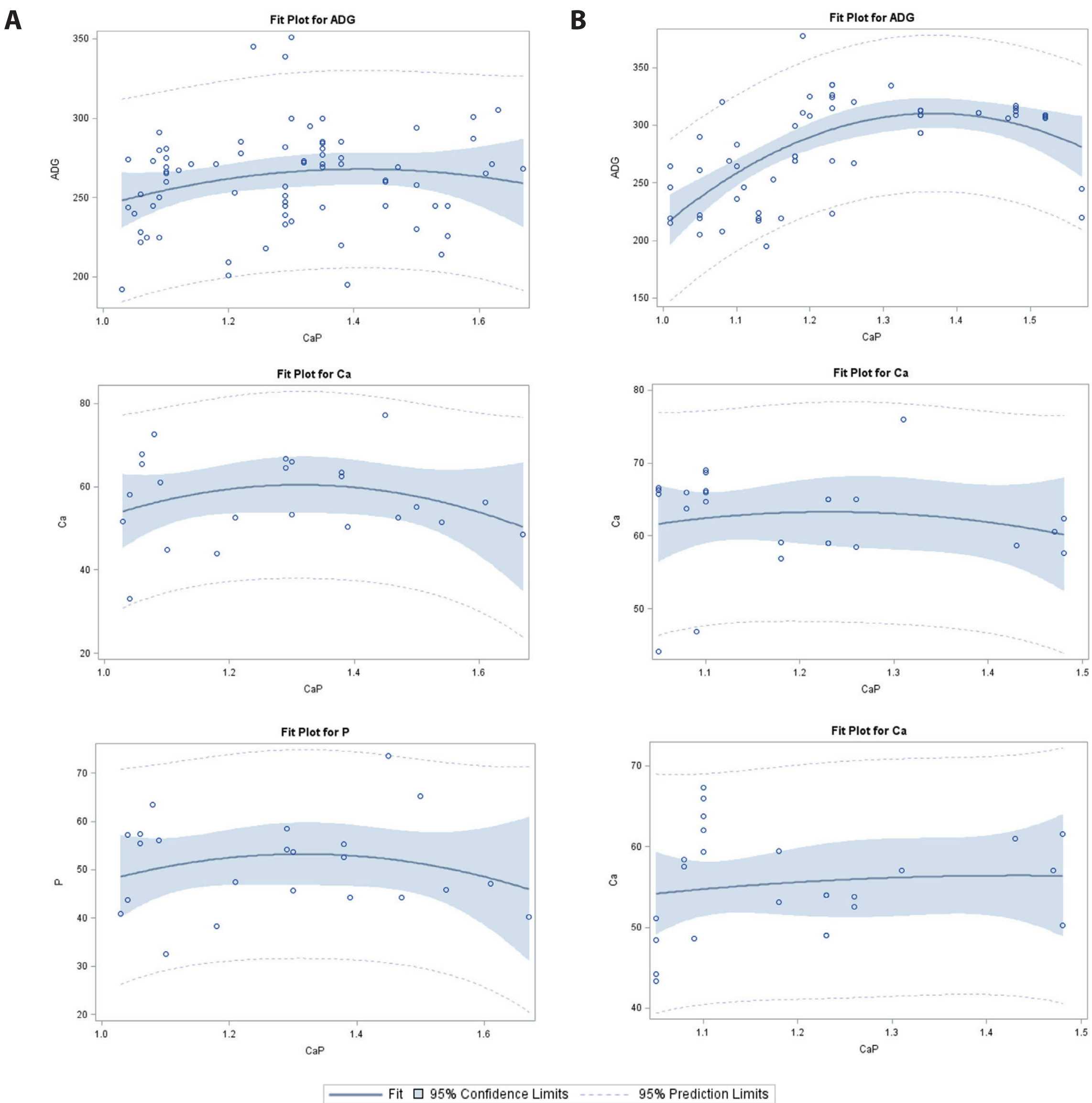

Fig. 1. Fit plot of 6–11 kg body weight category. (A) without phytase, (B) with phytase.

improvements have the potential to change the response of pigs to Ca and P supplementation; to the best of our knowledge, no meta-analysis has reviewed dietary Ca/P requirements in pigs. The current meta-analysis focuses on published data from 2010 onwards and offers a potential method for evaluating Ca and P requirements and their interactions with phytase supplementation. Pig Ca and P requirements were analyzed according to BW. A multi-criteria procedure, including available P, bone mineralization, and BW gain should be considered for balancing diets based on new recommendations regarding Ca and P levels, as should dietary phytase supplementation. We found that increasing Ca/P in the PS group increased the growth performance of pigs in the 6–11 and 11–25 kg BW categories. Despite the positive role of low dietary Ca in growth performance [2], there are some limitations associated with reduced Ca depending on growth stage. Low dietary Ca compromises bone mineralization when dietary P is high. Therefore, Ca supplementation is associated with phytase because of the significant increase in P availability that occurs when phytate

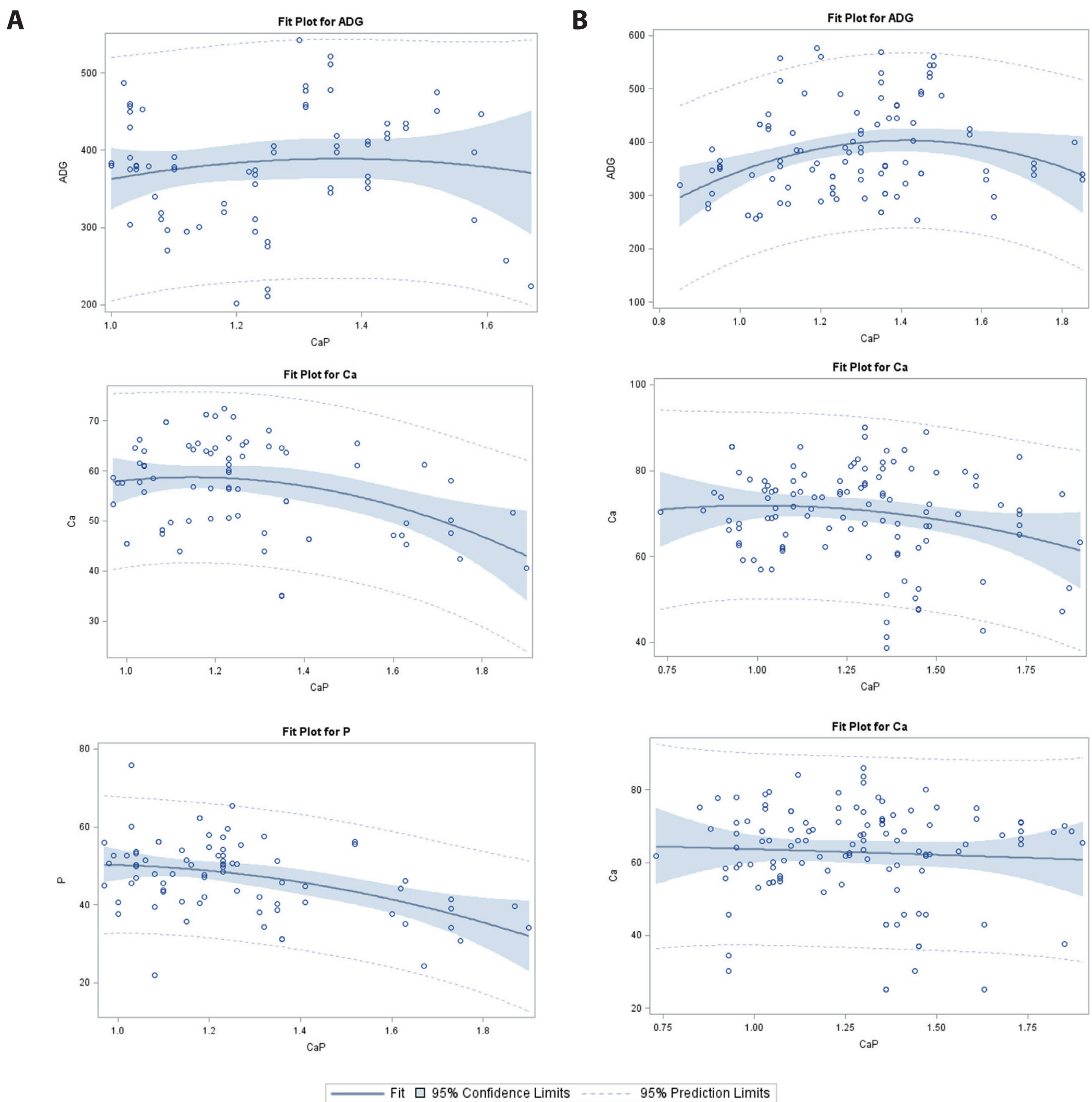

Fig. 2. Fit plot of 11–25 kg body weight category. (A) without phytase, (B) with phytase.

bonds are broken [1,2,15]. Low bioavailability of Ca compromises the deposition of P in bone, increasing loss of P through urine [9]. Low bone mass during skeletal development is known as osteoporosis, which is characterized by low Ca and P deposition [16,17]. Ca absence is considered an important factor in the development of skeletal disorders and decreased growth performance [5,6]. Importantly, Ca and P retention was not decreased by Ca/P in the 6–11, 11–25, and 25–50 kg BW categories; this explains the linear increase in ADG with increasing Ca/P.

Digestibility of Ca in pig production is not only affected by Ca level, but also by the exogenous phytase and Ca/P to which the pigs are subjected, as well as the growth stage [5,18]. For pigs, the aim is to optimize BW while decreasing Ca excretion. Optimum growth performance and bone formation with minimum P excretion is also a target. No differences in ATTD-P and ATTD-Ca were observed as a result of phytase supplementation in low-weight categories. This may be due to the diets provided after weaning, which are based primarily on highly digestible ingredients; in these

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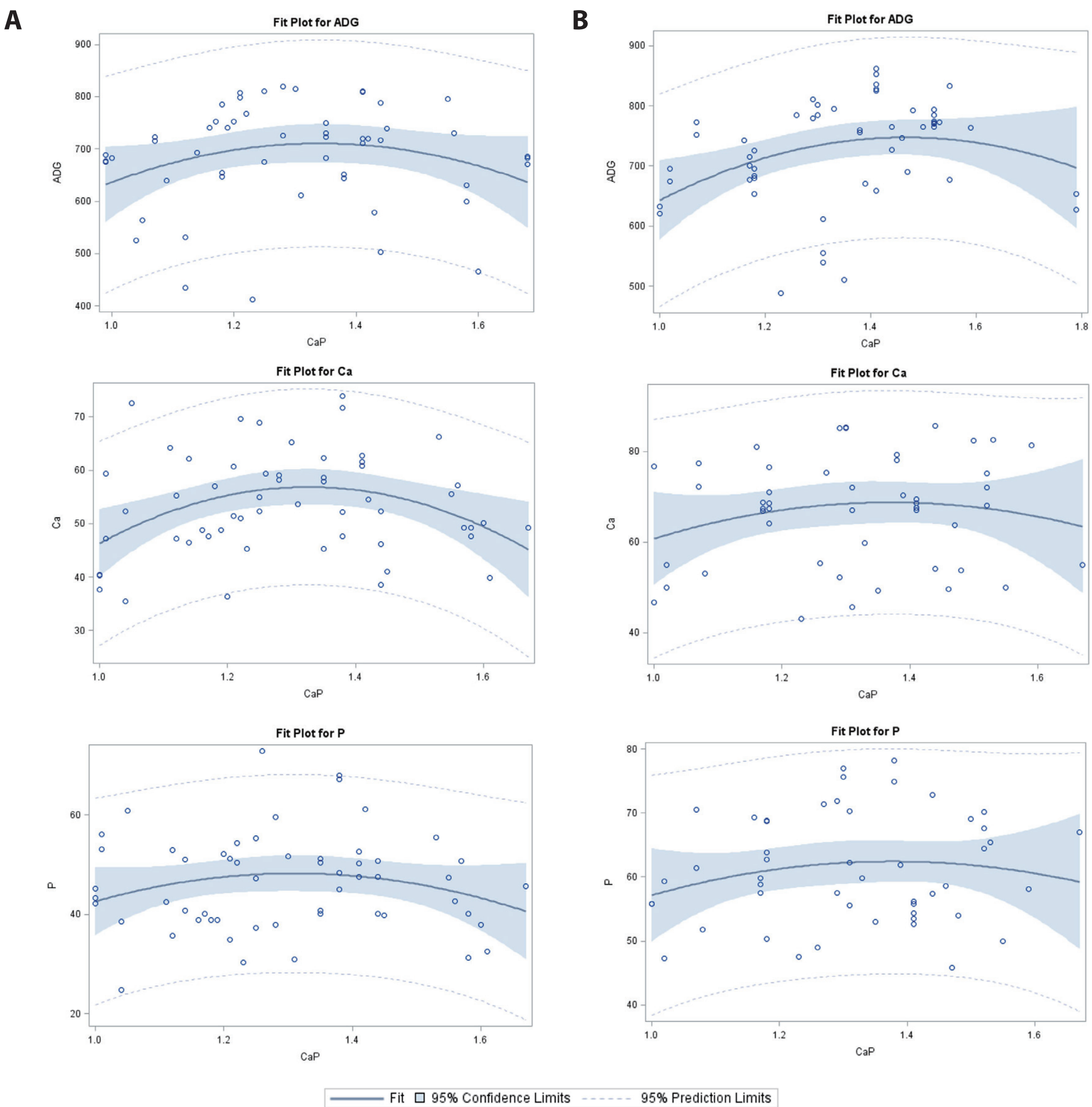

Fig. 3. Fit plot of 25–50 kg body weight category. (A) without phytase, (B) with phytase.

conditions, changes in the Ca level did not affect the efficiency of the phytase enzyme. In high-weight categories (50–75 and 75–100 kg) ATTD was decreased by increasing Ca/P. It is likely that the high Ca content in diets compromises the absorption of Ca. Importantly, the formation of Ca-phytate complexes varies based on pH; as the pH increases, the solubility of Ca-phytate decreases [2,3,8]. Limestone, as the main Ca source in diets, increases the buffering capacity of digestion [16], resulting in increased Ca-phytate formation. It has been reported that a 0.5% increase in dietary Ca decreases the digestibility of P by 56% [19]. Therefore, to improve phytase activity, the level of Ca should be reduced in PS diets when considering skeletal formation or growth performance to increase the bioavailability of Ca. Quadratic responses have been identified for ATTD-Ca: the digestibility of Ca increased with increasing Ca/P until reaching a plateau; then, it linearly decreased, reaching the minimum digestibility. This may explain the quadratic result obtained in the 50–75 and 75–100 kg BW categories in the present study.

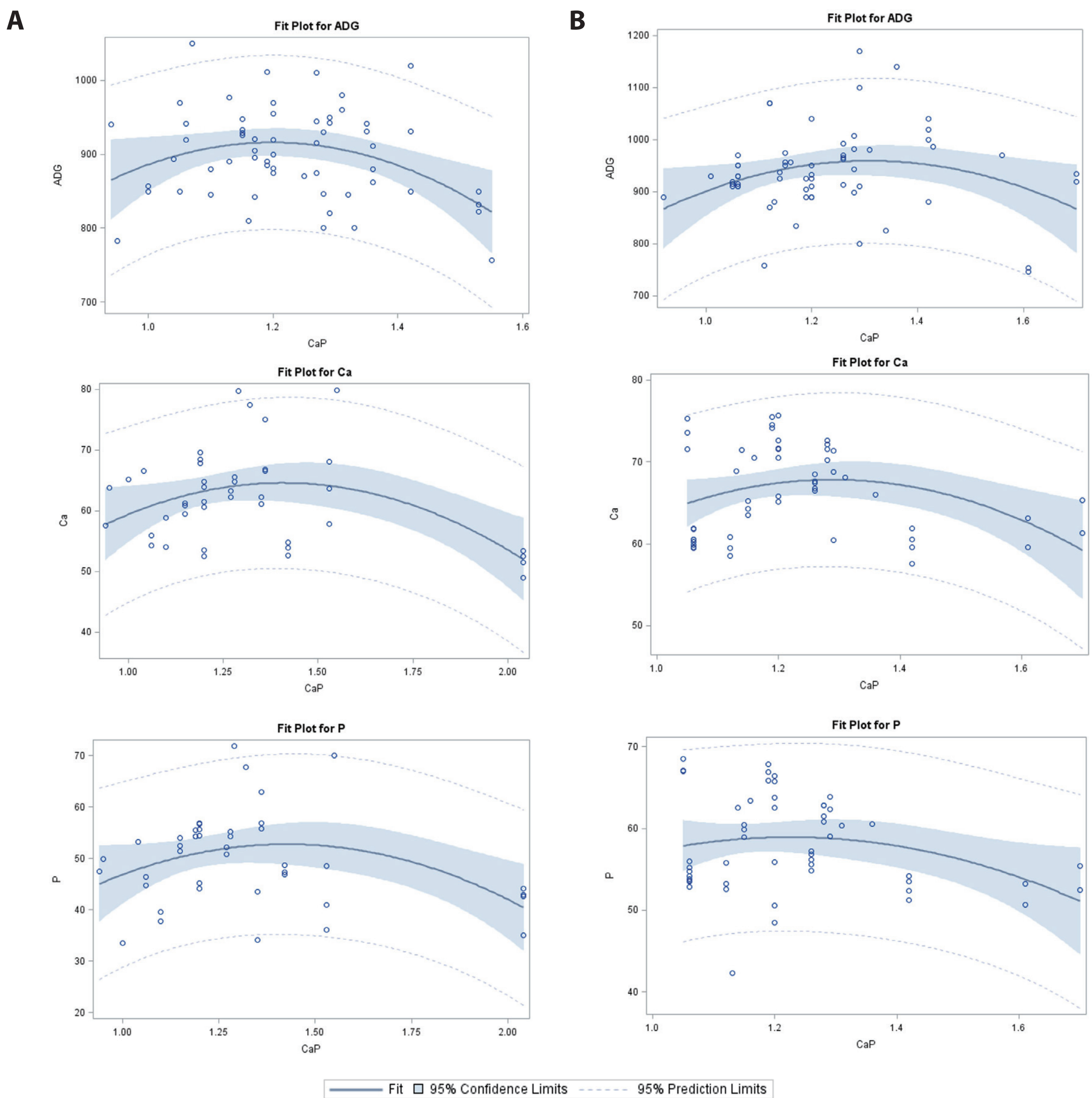

Fig. 4. Fit plot of 50–75 kg body weight category. (A) without phytase, (B) with phytase.

Digestibility represents the main factor in determining dietary P efficiency in farm animals. A considerable amount of P in grains is in the form of phytate; this is mostly unavailable or poorly absorbed by pigs, due to the lack of phytase in their intestine. Therefore, nutritional strategies for P addition in pig diets have been explored to reduce the excretion of P and improve growth performance, by fitting linear and quadratic regression models containing the explanatory variable of the P digestibility coefficient. Our results show that the effects of Ca/P on ATTD-P are significant in the 75–100 kg category, resulting in decreased digestibility of P through increased Ca/P. P bioavailability is regarded as one of the main factors adversely influencing bone mineralization and pig performance in the swine industry [3]. The results of the current study show the importance of Ca/P in the 75–100 kg BW category in phytase-supplemented diets. Supplementation with exogenous phytase enzyme to reduce P excretion has become a common practice in swine nutrition because excreted P has several adverse effects on the environment. This is especially the case

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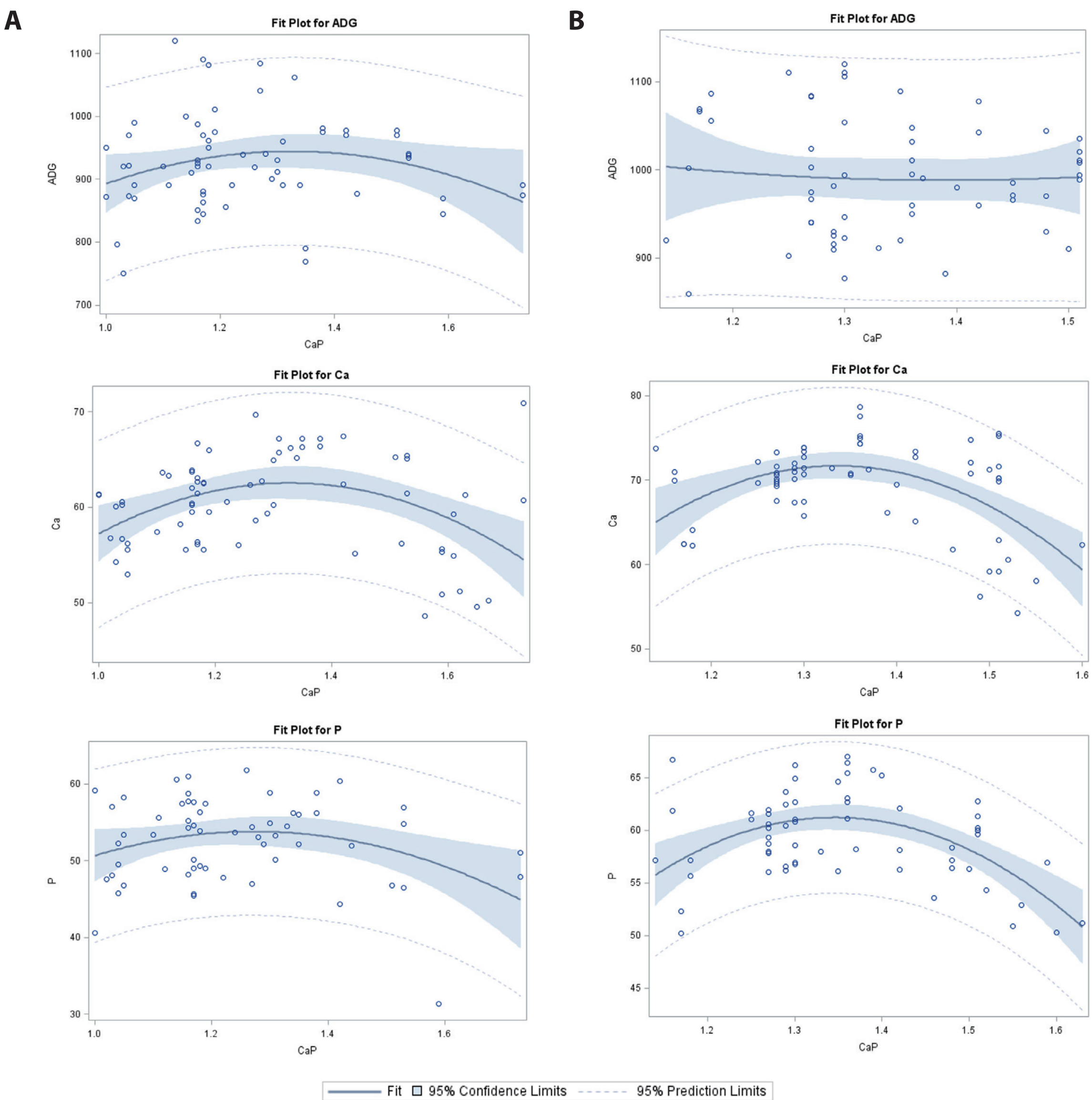

Fig. 5. Fit plot of 75–100 kg body weight category. (A) without phytase, (B) with phytase.

when pigs are supplemented in excessive doses, as when trying to maintain growth requirements [12,20]. In our database, the P that represented the principal supplementary P source was mainly mono-calcium phosphate and di-calcium phosphate, being present in 94% of experimental diets evaluated. However, our analysis showed no difference between P sources. It is reported that Ca/P range commonly falls between 1:1 to 1.7:1; thus, it was expected that the target P requirement values must be within this range. The results also show that Ca/P is not an effective parameter in P absorption in younger pigs; this was the case in both the PS and WP groups. It is accepted that higher Ca or Ca/P will result in a decrease in the efficiency of phytase enzyme by forming insoluble Ca-phytate complexes [1,8,21]. Therefore, it is likely that phytate may not be entirely hydrolyzed in the intestine due to solubility limitations and interactions with Ca.

This study aimed to better predict the effect of Ca/P and exogenous phytase enzyme on protein digestibility. The model generated herein indicated that Ca/P affects protein digestibility of pigs in PS and WP groups in higher BW categories (50–100 kg). With the increase in Ca/P from 1:1 to 1:1.7, the digestibility of CP was increased. Although several hypotheses are available to explain the adverse effect of phytate on nutrient digestibility, there is still uncertainty shrouding the mode of action involved. Interactions between phytates and proteins may be determining factors in evaluating the effect of phytate on protein digestibility [7,13]. The structure of proteins can be changed through these interactions, thereby reducing the solubility of proteins and decreasing the accessibility of protease to accomplish the hydrolysis process [2]. However, interestingly, there appears to be a greater effect of exogenous phytase on CP digestibility in heavier pigs than in weanling pigs. This may be due to the types of diets utilized in weaning or growing periods. Although many hypotheses have been stated to evaluate the role of phytic acid in decreasing protein digestibility (by forming phytate-protein complexes) [1], our results indicate that CP digestibility improves when Ca/P is increased, regardless of exogenous phytase supplementation. However, these results are still in agreement with Humer et al. [2], who reported that increasing Ca/P leads to a decrease in dietary phytate. Therefore, low dietary phytate content may decrease protein interactions and facilitate their absorption. It should be noted that there are strong kosmotropic influences of anionic phosphoryl groups in phytate, which stabilize protein structures by affecting the aqueous medium around the molecule [7,22]. The total secretion of mucin in the intestine increases by interacting with phytase [12,23,24], resulting in an increased loss of endogenous amino acids due to the low digestibility of mucin structural proteins. Another effect of phytate on protein digestibility in the intestinal lumen is associated with the phytase interaction that increases sodium ion (Na^+) influx into the intestine. The high buffering capacity of Na^+, triggers the secretion of hydrochloric acid (HCL), which reduces the digestibility of proteins [1,25]. Therefore, when considering CP digestibility, a lower P and higher Ca/P are recommended in growing and finishing pigs.

CONCLUSION

Overall, the present meta-analysis showed that phytase supplementation and to a lesser extent, Ca/P are key factors in affecting the growth performance of pigs. Results demonstrated that increased Ca/P decreases Ca and P retention in pigs in heavier categories (50–100 kg); however, it is not a determinant factor in Ca and P retention in lower weight pigs (6–25 kg). Increased Ca/P can increase CP digestibility in a wide BW range (11–100 kg). Based on our results, we suggest that the best practice would be to increase Ca levels in weanling pig diets and reduce Ca levels in diets for finishing pigs.

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