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Effect of Phytases in Pig Diets on Production Performance: Meta-analysis

Efecto de fitasas en la dieta de porcinos sobre el rendimiento productivo: meta-análisis

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Abstract: Feeding is one of the most critical items in pig production. Phosphorus, protein, and energy sources represent the most expensive ingredients in the feed. Phytases are enzymes used for many years to take advantage of plant phosphorus and reduce costs. Despite many studies with various methodologies and results, they have not been thoroughly systematized. Therefore, this research aims to evaluate the effect of the inclusion of phytases on performance in pigs. Effect size, heterogeneity, meta-regressions, and publication bias were determined. Phytase-supplemented pigs gained 25.17 g ($p < 0.05$) more daily weight than controls. Piglets can gain up to 39.89 g ($p < 0.05$). The pigs ingested a greater amount of feed, 23.44 and 28.61 g ($p < 0.05$), per day than the control in the general analysis and piglets, respectively. Crude protein, metabolizable energy, total calcium and phosphorus, duration, and level of phytases in the diet affected performance ($p < 0.05$). No publication bias was found. Including phytases favors weight gain and feed intake in general pigs and piglets but not in growing-finishing pigs. The effect of other nutrients and the duration and level (dose) of phytases must be considered at the time of formulation.

Keywords: enzyme activity, nutrition, feeding, growth period, enzymes, phosphorus, piglets.

Resumen: La alimentación es uno de los rubros más importantes en la producción porcina. Las fuentes de fósforo, proteína y energía representan los ingredientes más costosos del alimento. Las fitasas son enzimas que se han usado desde hace muchos años para aprovechar mejor el fósforo vegetal y reducir costos. Si bien se han generado muchas investigaciones, con distintas metodologías y resultados, su sistematización ha sido limitada. Por consiguiente, el objetivo de este trabajo fue evaluar el efecto de la inclusión de fitasas sobre el rendimiento productivo en porcinos. Se determinó tamaño de efecto, heterogeneidad, metaregresiones y sesgo de publicación. Los cerdos tratados con fitasas ganaron 25,17 g ($p < 0.05$) más peso al día frente al control. Los lechones pueden ganar hasta 39,89 g ($p < 0.05$). Los cerdos tratados con fitasas consumieron mayor cantidad de alimento 23,44 g y 28,61 g ($p < 0.05$) más al día que el control en el análisis general y en lechones, respectivamente. La proteína cruda, la energía metabolizable, el calcio y fósforo total, la duración y el nivel de fitasas en la dieta afectan el rendimiento ($p < 0.05$). No se encontró sesgo de publicación. En conclusión, la inclusión de fitasas favorece la ganancia de peso y el consumo de alimento en cerdos en general y en lechones, no así en cerdos en crecimiento-finalización. Se debe tener en cuenta el efecto de otros nutrientes al momento de la formulación, así como la duración y el nivel (dosis) de fitasas.

Palabras clave: Actividad enzimática, nutrición, alimentación, enzimas, fósforo, período de crecimiento, lechones.



Introduction

The sustainability of animal production is based on the careful use of phosphorus (P). Phosphate, the extracted source of agricultural phosphorus, is a non-renewable resource. However, it is essential for animals' growth, health, and well-being (Misiura et al., 2020). P must be provided by efficient and sustainable means that minimize its waste. About 60 % of the phosphorus in an animal's body is found in the bones in a fixed ratio with calcium (Ca), and the rest is found in the muscles (Lautrou et al., 2021). P is essential for various biological processes in the pig, and nutritionists strive to meet the precise requirement for this mineral. The cell membrane is made of phospholipids; the phospholipid-based bilayer structure provides cell structural integrity and controls the flow of molecules in and out of the cell (Berndt & Kumar, 2009). Adenosine-5"-triphosphate is dubbed the molecular currency unit for intracellular energy transfer, which entails the enzyme-catalyzed transfer of the phosphoryl group (Knowles, 1980). The P demand for a growing pig comprises maintenance and tissue deposition requirements (Zhai et al., 2022a).

Phosphorus is stored mainly as phytate in plant seeds, making it poorly available to monogastric animals such as pigs and birds. Because phytate is a polyanionic molecule, it has the ability to chelate positively charged cations, especially calcium, iron, and zinc (Selle et al., 2009). In addition, it compromises the utilization of other dietary nutrients, such as protein, starch, and lipids. Reduced phosphorus utilization efficiency implies both higher levels of supplementation and a greater discharge of undigested nutrients to the environment (National Research Council, 2012).

The enzyme phytase catalyzes the gradual hydrolysis of phytate. Regarding animal nutrition, there are four possible sources of this enzyme available to animals: endogenous mucosal phytase, gut microbiota phytase, plant phytase, and exogenous microbial phytase. As endogenous mucosal phytase in monogastric organisms appears unable to hydrolyze sufficient amounts of phytate-bound P, supplementation with exogenous microbial phytase in diets is a standard method to increase the absorption of minerals and other nutrients (Cowieson et al., 2017; Humer et al., 2015). Several research papers have tested phytases in pig diets to improve nutrient use and lower costs (Dersjant-Li et al., 2019; Rosenfelder-Kuon et al., 2020). However, there is wide variability in the studies on genetics, duration and dose of supplementation, physiological stage, dietary levels of crude protein, metabolizable energy, calcium, and phosphorus, among others. This generates uncertainty in professionals dedicated to swine nutrition regarding phytases in diets.

Meta-analysis is a group of statistical tools that quantitatively synthesizes knowledge by analyzing the results of previously published scientific studies (Sauvant et al., 2008). It makes it possible to obtain a measure of the combined effect with more precision than that of the individual studies, and, therefore, they have greater statistical power (Catalá-López & Tobías, 2014). This research hypothesized that the dietary inclusion of phytases favors production performance in pigs despite the original studies' variability of factors (moderators). This research aimed to determine the effect of the dietary inclusion of phytases on the production performance in pigs and the impact of various moderators (crude protein level, metabolizable energy, total calcium, total

dietary phosphorus, days and level of phytase supplementation, and number of replicates per treatment) through a meta-analysis.

Materials and Methods

The meta-analysis consisted of searching for scientific articles in various electronic databases using keywords. Subsequently, those documents that met the inclusion criteria (mean, variability measure, number of repetitions, etc.) were selected. Finally, the effect size, heterogeneity, meta-regression, and publication bias tests were run. This study followed the methodology suggested by Palencia et al. (2016) and Rufino et al. (2019).

Source of information (data)

An electronic search of scientific articles was carried out in journals indexed to the following electronic databases: CAB Direct, Elsevier Biobase CABS, Google Scholar, Medline, PubMed, Science Direct (Journal), Scopus, Latindex, Scielo, Academic Search Complete, CAB Abstract, Directory of Open Access Journals, and Web of Science. For this purpose, a combination of keywords was used: phytases, diet, feed, nutrition, pigs, piglets, growth, finishing, production performance, and their equivalents in Spanish and Portuguese, without date restrictions, locating 157 articles.

Inclusion criteria

Experimental research articles in Spanish, English, and Portuguese were included, in which phytases were administered to healthy animals exclusively through the diet. The experiments had to have been conducted on piglets and pigs in the growing or finishing stage without considering race or country as exclusion factors. Also, they had to include at least two treatments (including the control group without phytase supplementation) containing the variables of interest (production performance) with their respective mean values, variability measures, and number of repetitions per treatment. Race was not considered an evaluation factor due to the high number of crossings (more than 35) reported in the included works. All the studies used were carried out under an intensive breeding system (information reported in the methodology of each research).

The data was obtained from 32 articles published between 1993 and 2019 (Adeola et al., 2006; Arredondo et al., 2019; Atakora et al., 2011; Bernal et al., 2006; Biehl & Baker, 1996; Blavi et al., 2019; Boling et al., 2000; Bournazel et al., 2018; Broomhead et al., 2019; Cromwell et al., 1993, 1995; Dersjant-Li et al., 2017; Duffy et al., 2018; Gentile et al., 2003; Hill et al., 2009; Holloway et al., 2019; James et al., 2008; Jang et al., 2017; Jendza et al., 2005; Jolliff & Mahan, 2012; Kies et al., 2006; Murry et al., 1997; Nortey et al., 2007; Olukosi et al., 2007; Omogbenigun et al., 2003; Peter et al., 2001; Sands & Kay, 2007; She et al., 2017, 2018; Varley et al., 2010, 2011; Woyengo et al., 2008), on which the respective analyses were performed, as shown in Figure 1.

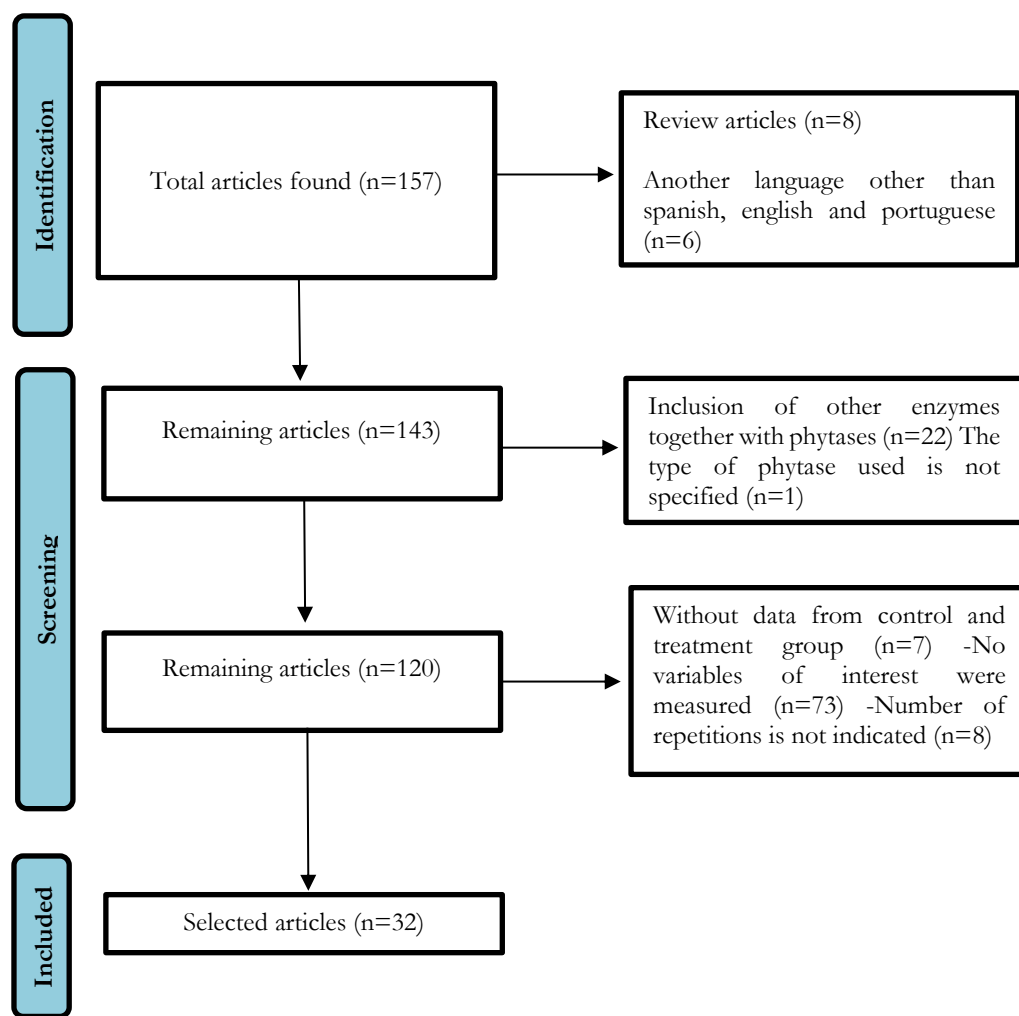


Figure 1. Flowchart for the selection of scientific articles based on PRISMA (2020) suggestions. Source: Prepared by the authors.

Statistical Analysis

The professional software MIX 2.0 Pro in Microsoft Excel (Bax, 2016) was used for the statistical analysis of the data. The effect size of phytase supplementation was determined by the mean difference (MD) between the treatment and control groups, with 95 % confidence intervals. Heterogeneity was assessed using the inconsistency index (I^2) (Cochran, 1954; Higgins & Thompson, 2002). In the cases where heterogeneity was found, meta-regressions were performed (Borenstein et al., 2011). A random effects model was used according to the recommendations of Sauvnt et al. (2008). The study effect should be considered random because when the database contains different individual studies, each study is a random outcome from a large population of studies, and the study effect represents the sum of the effects of many factors, all with minor effects on the dependent variable (Sauvant et al., 2008). Relationships between variable Y and the primary explanatory variable X were studied using the quadratic model in Equation 1:

$$Y_{ij} = \mu + \mu_i + \beta_1 X_{ij} + \beta_2 [X_{ij}]^2 + e_{ij} \quad (1)$$

Where Y_{ij} is the dependent variable Y in experiment i with level j of phytase; X_{ij} is the independent variable; μ is the overall intercept across all studies; μ_i is the effect of experiment i on the intercept μ with the condition that $\Sigma\mu_i = 0$; β_1 and β_2 are respectively the linear and quadratic coefficients of the relationship, and e_{ij} is the residual error.

Based on the available data, the production performance variables analyzed were average daily weight gain (ADG), average daily feed intake (ADFI), and feed efficiency (FE). For each variable, three meta-analyses (MAs) were carried out: a general MA (without considering the production stage) and another considering the production stage, divided into two categories: piglets and growing-finishing pigs, totaling 12 MAs.

Results and Discussion

Table 1 shows the mean value and standard deviation of the evaluated production variables: ADG, ADFI, and FE.

Table 1. Summary of production variables

Response variable	Meta-analysis	Summarized response variable			
		Treatment		Control	
		Mean	SD	Mean	SD
ADG (g/day)	General pigs	576.76	210.64	552.74	219.75
	Piglets	487.60	143.54	463.07	149.17
	Growing-finishing pigs	875.68	84.10	853.38	133.30
ADFI (g/day)	General pigs	1,143.69	770.31	1,111.95	772.13
	Piglets	771.69	276.88	735.93	261.96
	Growing-finishing pigs	2,303.47	649.78	2,284.24	647.71
FE (kg/kg)	General pigs	0.59	0.17	0.59	0.15
	Piglets	0.62	0.15	0.63	0.11
	Growing-finishing pigs	0.35	0.07	0.34	0.08

ADG: average daily gain; ADFI: average daily feed intake; FE: feed efficiency; SD: standard deviation

Source: Prepared by the authors.

For all the categories analyzed, the variables ADG and ADFI are higher in those animals that received phytases (Table 1). Regarding feed efficiency, it was found to be higher in the control group in the general analysis (0.59 vs. 0.59 kg/kg) and in piglets (0.63 vs. 0.62 kg/kg). Feed efficiency was higher in the growing-finishing stage in those pigs supplemented with phytases (0.35 vs. 0.34 kg/kg); no significant difference was found. Table 2 shows the size of the effect

of the dietary inclusion of phytases on ADG, ADFI, and FE in pigs. The general analysis reveals that the supplemented pigs gained 25.17 g ($p < 0.05$) more weight per day than those that did not receive phytases (Table 2). A similar trend occurs in the case of piglets, which gained between 13.22 and 39.89 g ($p < 0.05$) more per day versus those not supplemented. In the case of pigs in the growing-finishing stage, although no significant difference was found ($p = 0.16$), ADG is higher in pigs that ingest phytases 875.68 vs. 853.37 g/day than those unsupplemented. This shows that phytases increase the availability of phosphorus for the pig (Arredondo et al., 2019). With this, there is a greater amount of this mineral for the different metabolic processes (ATP generation) with which the animal can deposit more tissue (Rosenfelder-Kuon et al., 2020). By including fewer sources of phosphorus in the diet, production costs decrease (Dersjant-Li et al., 2019). Additionally, there is less phosphorus excretion into the environment (Hill et al., 2009). The pigs that received phytases ingested more feed, 23.44 and 28.61 g more per day, compared to the control group in the general analysis and in piglets, respectively (Table 2).

Table 2. Effect size of dietary inclusion of phytases on pigs' ADG, ADFI, and FE

Response variable	Meta-analysis	Effect size			
		<i>MD</i>	<i>CI</i>		<i>p</i>
ADG (g/day)	General pigs	25.17	12.01	38.33	0.00
	Piglets	26.56	13.23	39.89	0.00
	Growing-finishing pigs	22.47	-8.60	53.54	0.16
ADFI (g/day)	General pigs	23.45	11.02	35.87	0.00
	Piglets	28.61	14.06	43.17	0.00
	Growing-finishing pigs	-1.24	-18.90	16.43	0.89
FE (kg/kg)	General pigs	0.00	-0.01	0.01	0.99
	Piglets	-0.00	-0.02	0.02	0.77
	Growing-finishing pigs	0.01	-0.01	0.02	0.27

ADG: average daily gain; ADFI: average daily feed intake; FE: feed efficiency; *MD*: mean difference; *CI*: confidence interval; *p*: probability value

Source: Prepared by the authors.

Table 3 shows the results of the inconsistency index for each production variable. As mentioned by Higgins and Thompson (2002), this study found high heterogeneity (>75 %) in all ADG and

FE categories. However, the ADFI presented moderate heterogeneity (<50 %) for general pigs and piglets. There was a low heterogeneity of 24.96 % in the category of growing-finishing pigs.

Table 3. Index of inconsistency of the dietary inclusion of phytases on ADG, ADFI, and FE in pigs

Variable	Meta-analysis	I ² (%)
ADG	General pigs	87.33
	Piglets	81.34
	Growing-finishing pigs	93.05
ADFI	General pigs	65.25
	Piglets	68.42
	Growing-finishing pigs	24.96
FE	General pigs	93.64
	Piglets	93.45
	Growing-finishing pigs	89.81

ADG: average daily gain; ADFI: average daily feed intake; FE: feed efficiency

Source: Prepared by the authors.

Tables 4 to 10 present the results of the meta-regressions. Crude protein level, metabolizable energy, total calcium, total dietary phosphorus, days and level of phytase supplementation, and number of replicates per treatment were used as moderator variables in this study. For each percentage unit that crude protein in the diet increases, the ADG of all production categories decreases ($p < 0.01$) by 5.05 g/day (general pigs), 8.09 g/day (piglets), and 11.98 g/day (growing-finishing pigs) (Table 4). A similar trend occurs for the feed efficiency variable; in all stages, the increase in CP makes the pig less efficient ($p < 0.01$): general pigs (0.16), piglets (0.20), and growing-finishing pigs (0.12). The effect of CP on these production variables could be because the level of CP in the diet is higher than required, which generates a waste of energy in the pig to metabolize and eliminate excess nitrogen in the form of urea (Jha & Berrocoso, 2016). Part of this is because many published articles are not recent and did not formulate diets using the ideal protein and synthetic amino acids (van Milgen & Dourmad, 2015).

Table 4. Meta-regression for crude protein level in diets

Variable	Meta-analysis	Meta-regression: crude protein			
		Intercept (a)		CP (b)	
		Estimated	<i>p</i>	Estimated	<i>p</i>
ADG	General pigs	129.46	<0.01	-5.05	<0.01
	Piglets	210.89	<0.01	-8.10	<0.01
	Growing-finishing pigs	233.63	<0.01	-11.99	<0.01
ADFI	General pigs	-12.93	0.49	1.47	0.10
	Piglets	120.23	0.00	-4.32	0.02
	Growing-finishing pigs	-3.42	0.93	0.08	0.97
FE	General pigs	0.16	<0.01	-0.01	<0.01
	Piglets	0.20	<0.01	-0.01	<0.01
	Growing-finishing pigs	0.12	<0.01	-0.01	<0.01

CP: Crude Protein; ADG: average daily gain; ADFI: average daily feed intake; FE: feed efficiency; *p*: probability value

Source: Prepared by the authors.

Regarding the level of metabolizable energy (ME) of diets for each kilocalorie that increases in the diet, the evaluated variables decrease ADG (<0.01) and FE (<0.01; Table 5). The higher the energy density in the diet, the less the feed consumption by satiating the pig's appetite more quickly (Li & Patience, 2017), even more so when phytases are included in the diet since these increase the digestibility of nutrients and, therefore, satiety (Arredondo et al., 2019).

For each percentage unit (%) that increases in total Ca and P in diets (Tables 6 and 7), the production performance of the pig, average daily gain in piglets and growing-finishing pigs (<0.01), and FE (<0.01) in all the production categories analyzed decrease. This tendency was not found in ADFI (Ca) in the growing-finishing pigs ($p = 0.98$) nor in FE in piglets (P) ($p = 0.02$), where the values were positive. The tendency to reduce production performance is probably due to excess macrominerals in diets, which generate competition between them at the intestinal level, limiting the absorption of other minerals through the enterocyte (Gerlinger et al., 2021). Setting the same total Ca/total P ratio in diets supplemented with increasing doses of phytases creates an imbalance of digestible Ca and P, which could harm bone mineralization and, therefore, compromise the efficacy of phytases in relationship with P and the production performance of the animal (Zhai et al., 2022b). In addition, there is evidence that high levels of minerals in the diet reduce feed intake, and therefore, ADG and FE will be affected. An important factor to consider is that the phytase use arrays may not be correctly calculated, underestimating the release of Ca and P from dietary ingredients (Bedford & Cowieson, 2020; Dersjant-Li et al., 2019; Lautrou et al., 2020). Additionally, the significant variability in the level of nutrients between the different raw materials used in the formulation of swine diets must be considered (National Research Council, 2012; Rostagno et al., 2017).

Table 5. Meta-regression for metabolizable energy levels of diets

Variable	Meta-analysis	Meta-regression: metabolizable energy			
		Intercept (a)		ME (b)	
		Estimated	<i>p</i>	Estimated	<i>p</i>
ADG	General pigs	55.62	0.25	-0.01	0.52
	Piglets	233.84	<0.01	-0.06	<0.01
	Growing-finishing pigs	-1,113.21	<0.01	0.34	<0.01
ADFI	General pigs	239.54	0.00	-0.02	0.01
	Piglets	469.08	<0.01	-0.13	<0.01
	Growing-finishing pigs	481.41	0.02	-0.15	0.02
FE	General pigs	0.18	<0.01	-0.00	<0.01
	Piglets	0.32	<0.01	-0.00	<0.01
	Growing-finishing pigs	-2.04	<0.01	0.00	<0.01

ME: metabolizable energy; ADG: average daily gain; ADFI: average daily feed intake; FE: feed efficiency; *p*: probability value

Source: Prepared by the authors.

Table 6. Meta-regression for total Ca level of diets

Variable	Meta-analysis	Meta-regression: total calcium			
		Intercept (a)		Ca (b)	
		Estimated	<i>p</i>	Estimated	<i>p</i>
ADG	General pigs	113.25	<0.01	-13.35	<0.01
	Piglets	95.56	<0.01	-9.56	<0.01
	Growing-finishing pigs	161.48	<0.01	-21.69	<0.01
ADFI	General pigs	106.10	<0.01	-13.78	<0.01
	Piglets	123.87	<0.01	-15.48	<0.01
	Growing-finishing pigs	-3.28	0.94	1.81	0.98
FE	General pigs	0.05	<0.01	-0.07	<0.01
	Piglets	0.03	<0.01	-0.03	0.03
	Growing-finishing pigs	0.07	<0.01	-0.10	<0.01

Ca: total calcium; ADG: average daily gain; ADFI: average daily feed intake; FE: feed efficiency; *p*: probability value

Source: Prepared by the authors.

Table 7. Meta-regression for total P level of diets

Variable	Meta-analysis	Meta-regression: total phosphorus			
		Intercept (a)		P (b)	
		Estimated	<i>p</i>	Estimated	<i>p</i>
ADG	General pigs	85.48	<0.01	-11.03	<0.01
	Piglets	55.41	<0.01	-4.05	<0.01
	Growing-finishing pigs	187.91	<0.01	-28.61	<0.01
ADFI	General pigs	39.91	<0.01	-4.27	<0.01
	Piglets	49.47	<0.01	-4.79	<0.01
	Growing-finishing pigs	10.92	0.68	-2.61	0.61
FE	General pigs	0.04	<0.01	-0.06	<0.01
	Piglets	0.00	0.84	0.03	0.02
	Growing-finishing pigs	0.09	<0.01	-0.12	<0.01

P: total phosphorus; ADG: average daily gain; ADFI: average daily feed intake; FE: feed efficiency; *p*: probability value

Source: Prepared by the authors.

For each day that phytases are supplemented in diets, the ADG increases by 2.31 g/day ($p < 0.01$) in the general analysis and by 2.38 g/day ($p < 0.01$) in piglets and growing-finishing pigs (Table 8). ADFI also increases for each day of phytase supplementation by 1.93 g/day in general pigs ($p < 0.01$), 2.09 g/day in piglets ($p < 0.01$), and 0.93 g/day in the growing-finishing pigs ($p = 0.29$). In all production categories, feed efficiency is improved between 1.1 and 1.4 g ($p < 0.01$) for each day that phytase supplementation increases. This effect is related to the fact that phytases increase the digestibility of the ingredients in the diet, providing the animal with a greater amount of nutrients for the deposition of body tissue (Zouaoui et al., 2018).

Regarding the level of phytase supplementation (Table 9), for each unit of phytase increment ADG in general pigs (5 g/day, $p < 0.01$) and piglets (7 g/day, $p < 0.01$) but not in growing-finishing pigs. In growing-finishing pigs, the ADG decreased by 39 g/day ($p < 0.01$). ADFI increases as the level of phytases increases by 9 g/day ($p < 0.01$) in general pigs and 8 g/day ($p < 0.01$) in piglets. However, it is reduced by 7 g/day ($p = 0.57$) in growing-finishing pigs. The feed efficiency is less affected by the increase in the level of phytases in all the categories analyzed. The preceding would be contradictory since studies show that an increase in the level of phytases in the diet increases nitrogen retention and the concentration of metabolizable energy (Arredondo et al., 2019).

Table 8. Meta-regression for days of supplementation

Variable	Meta-analysis	Meta-regression: days of phytase supplementation			
		Intercept (a)		Days of supplementation (b)	
		Estimated	<i>p</i>	Estimated	<i>p</i>
ADG	General pigs	-37.83	<0.01	2.31	<0.01
	Piglets	-27.70	<0.01	2.38	<0.01
	Growing-finishing pigs	-63.25	<0.01	2.39	<0.01
ADFI	General pigs	-25.87	<0.01	1.93	<0.01
	Piglets	-22.80	0.00	2.10	<0.01
	Growing-finishing pigs	-23.58	0.27	0.93	0.29
FE	General pigs	-0.03	<0.01	0.00	<0.01
	Piglets	-0.03	<0.01	0.00	<0.01
	Growing-finishing pigs	-0.03	<0.01	0.00	<0.01

ADG: average daily gain; ADFI: average daily feed intake; FE: feed efficiency; *p*: probability value

Source: Prepared by the authors.

Table 9. Meta-regression for the level of phytase supplementation

Variable	Meta-analysis	Meta-regression: supplementation level (dose)			
		Intercept (a)		Supplementation level (b)	
		Estimated	<i>p</i>	Estimated	<i>p</i>
ADG	General pigs	16.41	<0.01	0.01	<0.01
	Piglets	24.73	<0.01	0.01	<0.01
	Growing-finishing pigs	45.96	<0.01	-0.04	<0.01
ADFI	General pigs	5.65	0.14	0.01	<0.01
	Piglets	11.07	0.01	0.01	<0.01
	Growing-finishing pigs	2.88	0.79	-0.01	0.57
FE	General pigs	-0.01	<0.01	0.00	<0.01
	Piglets	0.01	<0.01	0.00	<0.01
	Growing-finishing pigs	-0.00	0.89	-0.00	0.01

ADG: average daily gain; ADFI: average daily feed intake; FE: feed efficiency; *p*: probability value

Source: Prepared by the authors.

Table 10. Meta-regression for number of repetitions per treatment

Variable	Meta-analysis	Meta-regression: replicates per treatment			
		Intercept (a)		Replicates (b)	
		Estimated	<i>p</i>	Estimated	<i>p</i>
ADG	General pigs	61.72	<0.01	-4.51	<0.01
	Piglets	26.68	0.09	0.92	0.62
	Growing-finishing pigs	98.93	<0.01	-11.70	<0.01
ADFI	General pigs	2.08	0.90	1.92	0.35
	Piglets	58.40	0.02	-4.03	0.17
	Growing-finishing pigs	-6.85	0.81	0.71	0.86
FE	General pigs	0.10	<0.01	-0.01	<0.01
	Piglets	0.09	<0.01	-0.01	<0.01
	Growing-finishing pigs	0.06	<0.01	-0.01	<0.01

ADG: average daily gain; ADFI: average daily feed intake; FE: feed efficiency; *p*: probability value

Source: Prepared by the authors.

Regarding the number of repetitions per treatment (Table 10), it can be seen that for each repetition that increases, feed efficiency decreases by 11.18 g ($p < 0.01$) in general pigs, 9.12 ($p < 0.01$) in piglets, and 7.26 g ($p < 0.01$) in growing-finishing pigs. It is important to consider this when designing an experiment and determining the number of replicates per treatment. Few repetitions do not allow for the detection of significant effects in research (Aron & Hays, 2004). Table 11 shows the results of publication biases evaluated using Egger's test. We found no publication bias in any of the evaluated variables; that is, research papers are published showing an effect in favor of phytases on production performance or no effect.

Table 11. Publication biases of the dietary inclusion of phytases on ADG, ADFI, and FE in pigs

Variable	Meta-analysis	<i>p</i>
ADG	General pigs	0.33
ADFI	General pigs	0.49
FE	General pigs	0.43

ADG: average daily gain; ADFI: average daily feed intake;

FE: feed efficiency; *p*: probability value. Source: Prepared by the authors.

Conclusion

In this study, the various macro ingredients of the diet were not considered for the effect of phytases on the production performance of pigs. It is important to remember that phytic phosphorus is found in ingredients of plant origin, so phytases would affect other nutrients' digestibility.

It is necessary to develop more experiments in which the effect of phytases is considered in different breeds (crossings), particle sizes, and forms of food. We should seek to be more precise in estimating the enzyme's effect and generate benefits for the pork producer and the environment.

The dietary inclusion of phytases favors daily weight gain and average daily feed intake in general pigs and piglets but not in growing-finishing pigs. The effect of other nutrients in the diet, such as crude protein, metabolizable energy, Ca, and P, and the duration and level (dose) of phytases depending on the production variable you want to improve must be taken into account at the time of formulation.

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Authors' Contributions

Ronny Alexander Guachamín-Guachamín: registration of information, construction of databases and preparation of manuscript; Jimmy Rolando Quisirumbay-Gaibor: supervision of activities, analysis of information and preparation of manuscript.

Ethical Implications

This article has the endorsement presented on September 16, 2020, by the Titling Unit of the Faculty of Veterinary Medicine and Animal Science of the Central University of Ecuador.

Conflict of Interest

The authors declare no conflicts of interest in this study.

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