Assessing current phytase release values for calcium, phosphorus, amino acids, and energy in diets for growing-finishing pigs[1,2]

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ABSTRACT: Two experiments were conducted to determine the effects of feeding 1,500 phytase units (FYT/kg; Ronozyme HiPhos 2,500; DSM Nutritional Products, Parsippany, NJ) when credited with its corresponding nutrient release values to growing-finishing pigs. The assumed phytase release values were 0.146% standardized total tract digestible (STTD) P, 0.102% STTD Ca, 8.6 kcal/kg of net energy (NE), and 0.0217%, 0.0003%, 0.0086%, 0.0224%, 0.0056%, 0.0122%, and 0.0163% standardized ileal digestible Lys, Met, Met+Cys, Thr, Trp, Ile, and Val, respectively. In Exp. 1, 1,215 pigs (PIC 359 × Camborough, initially 28.0 ± 0.46 kg) were used. Pens were assigned to one of three dietary treatments with 27 pigs per pen and 15 pens per treatment. Experimental diets consisted of a control with no added phytase or diets with 1,500 FYT fed either in the grower period (days 0–57) then switched to the control diet until market or fed throughout the entire study (day 0 to market). Diets containing added phytase were adjusted based on the supplier-provided expected nutrient release values. During the grower period, pigs fed the control diet with no added phytase had increased ($P < 0.05$) average daily gain (ADG) and gain-to-feed ratio (G:F) compared with pigs fed added phytase. Overall, pigs fed either the control or phytase only in the grower period had increased ($P < 0.05$) ADG and G:F compared with pigs fed phytase until market. In Exp. 2, 2,268 pigs (PIC 337 × 1050, initially 28.5 ± 1.96 kg) were used. There were six dietary treatments with 27 pigs per pen and 14 pens per treatment. Experimental diets consisted of a control with no added phytase or five diets with 1,500 FYT assuming nutrient release values for Ca and P; Ca, P, and Amino Acid (AA); Ca, P, AA, and half of the suggested NE; Ca, P, AA, and full NE; or no nutrient release. Overall, there was no evidence for difference in ADG or average daily feed intake among treatments; however, pigs fed the diet containing 1,500 FYT assuming that no nutrient release had improved ($P < 0.05$) G:F compared to pigs fed diets containing 1,500 FYT assuming either Ca and P or Ca, P, AA, and full NE release, with others intermediate. In summary, pigs fed phytase-added diets accounting for full nutrient release values in both experiments had the poorest performance. This suggests that using all of the nutrient release values attributed to this source of phytase was too aggressive and resulted in lower nutrient concentrations than needed to optimize performance.

Key words: growing-finishing pigs, phytase, super-dosing

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INTRODUCTION

Approximately 60% to 80% of phosphorus (P) in feedstuffs of plant origin is stored in phytic acid, typically in the form of phytate (Eeckhout et al., 1994). Pigs poorly utilize phytate-bound-phosphorus because they lack sufficient endogenous phytase. Therefore, phytate is commonly known as an antinutritional factor in swine diets as it reduces the digestibility of P (Swick et al., 1992). Adding exogenous phytase to swine diets has the ability to dephosphorylate phytate in a stepwise manner and liberate P. In response, P availability to the pig increases and the need for dietary inclusion of inorganic P decreases (Selle and Ravindran, 2008).

Previous data have demonstrated that phytase, when provided above conventional levels (500 to 1,000 FYT/kg) in the diet (Adeola et al., 2011), can also exert extra-phosphoric effects, improving the digestibility of nutrients other than P (Cowieson et al., 2011). When phytate reaches the digestive tract, it takes on an electro-negative charge, which allows phytate to bind and form stable insoluble complexes with minerals, Amino Acid (AA), and lipids, decreasing their absorption (Woyengo et al., 2013). High levels of added phytase have been observed to enhance the digestibility and absorption of these nutrients through a dissociation of such complexes (Selle and Ravindran, 2008; Adeola et al., 2011).

If added phytase indeed releases other nutrients in addition to P, crediting phytase with nutrient release values should allow nutritionists to decrease diet costs by reducing the amount of inorganic P and both feed-grade and intact AA used in formulation. However, there is limited data to confirm that the use of current nutrient release values, other than P, will maintain growth performance. Therefore, the objective of these experiments was to investigate the effects of feeding diets containing 1,500 FYT of phytase when credited with additional nutrient release values above Ca and P in diets for growing-finishing pigs.

MATERIALS AND METHODS

The Kansas State University Institutional Animal Care and Use Committee approved the protocols used in these experiments. Each trial was conducted at a commercial research wean-to-finish site in southwestern Minnesota. Barns were naturally ventilated and double-curtain sided. Pens had completely slatted flooring and deep pits. Each pen was equipped with a five-hole stainless steel feeder and cup waterer to allow ad libitum access to feed and water. Additionally, the facility was equipped with an automated feeding system (FeedPro; Feedlogic Corp., Willmar, MN) capable of measuring and recording daily feed additions to individual pens.

Experiment 1

A total of 1,215 barrows and gilts (PIC 359 × Camborough, initially 28 kg) were used in a 126-d growth trial. At placement (15.9 kg), pigs were fed a common diet containing 0.66% total Ca and 0.42% standardized total tract digestible (STTD) P until the initiation of the trial. On day 0 of the study, pens of pigs were blocked by body weight (BW) and randomly assigned to one of three dietary treatments in a randomized complete block design, with BW used as a blocking factor. There were 27 pigs per pen (either 14 barrows and 13 gilts or 14 gilts and 13 barrows per block) and 15 replicate pens per treatment. The three dietary treatments consisted of a control with no added phytase, or two treatments with 1,500 FYT of phytase fed either in the grower period (days 0–57) then switched to the control diet until market, or phytase fed throughout the entire grower and finisher period (day 0 to market).

The experimental diets were corn-soybean-meal–distiller's dried grains with solubles (DDGS) based and fed in four different phases (Tables 1 and 2). Phase 1 diets were fed from day 0 to 29 (28–51 kg); phase 2 diets were fed from day 29 to 57 (51–74 kg); phase 3 diets were fed from day 57 to 85 (74–99 kg); and phase 4 diets were fed from day 85 to 126 (99–135 kg). Ronozyme HiPhos 2,500 (DSM Nutritional Products, Parsippany, NJ) was included in the phytase-containing diets with assumed release values of 0.146% standardized total tract digestible (STTD) P, 0.102% STTD Ca, 10.9 kcal/kg of Metabolizable Energy (ME), 8.6 kcal/kg of NE, and 0.0217%, 0.0003%, 0.0086%, 0.0224%, 0.0056%, 0.0122%, and 0.0163% standardized ileal digestible Lys, Met, Met + Cys, Thr,

Table 1. Composition of Exp. 1 diets, phases 1 and 2 (as-fed basis)[a,b]

	Phase 1		Phase 2	
	Phytase, FYT/kg		Phytase, FYT/kg	
Item	0	1,500	0	1,500
Ingredient, %				
Corn	60.92	63.54	68.59	71.23
Soybean meal	24.57	24.16	17.13	16.72
Corn DDGS	10.00	10.00	10.00	10.00
Beef tallow	1.50	—	1.50	—
Monocalcium phosphate	0.90	0.15	0.75	—
Limestone	1.08	1.11	1.00	1.03
Sodium chloride	0.35	0.35	0.35	0.35
L-lysine HCl	0.37	0.35	0.39	0.37
DL-methionine	0.06	0.05	0.03	0.02
L-threonine	0.09	0.07	0.09	0.06
L-tryptophan	0.02	0.01	0.03	0.02
Phytase[c]	—	0.06	—	0.06
Vitamin and trace mineral premix[d]	0.15	0.15	0.15	0.15
Total	100.00	100.00	100.00	100.00
Calculated analysis				
SID[e] amino acids, %				
Lysine	1.10	1.10	0.93	0.93
Isoleucine:lysine	63	63	61	62
Leucine:lysine	142	143	149	150
Methionine:lysine	31	30	30	29
Methionine and cysteine:lysine	56	56	56	56
Threonine:lysine	62	62	62	62
Tryptophan:lysine	18.8	18.8	18.9	18.9
Valine:lysine	70	70	70	70
Total lysine, %	1.25	1.23	1.06	1.04
NE, kcal/kg	2,495	2,495	2,545	2,545
SID lysine:NE, g/Mcal	4.40	4.40	3.65	3.65
CP, %	20.0	20.0	17.1	17.1
Ca, %	0.72	0.60	0.62	0.51
STTD Ca, %	0.57	0.57	0.49	0.50
P, %	0.62	0.46	0.55	0.39
STTD P, %	0.37	0.37	0.32	0.32
Available P, %	0.32	0.34	0.28	0.30
STTD Ca:STTD P	1.55	1.55	1.55	1.55
Chemical analysis[g]				
DM	89.16	88.94	88.38	88.12
CP	20.08	19.85	19.78	18.00
Ca	0.73	0.42	0.63	0.63
P	0.55	0.43	0.53	0.42

[a]Phase 1 diets were fed from day 0 to 29 (28–51 kg) and phase 2 diets were fed from day 29 to 57 (51–74 kg).

[b]Dietary treatments consisted of a control with no added phytase, or two treatments with 1,500 FYT fed either in the grower period (days 0–57) then switched to control diet until market, or phytase fed throughout the entire grower and finisher period (day 0 to market).

[c]Ronozyme HiPhos 2,500 phytase (DSM Nutritional Products, Parsippany, NJ) was included at 1,500 FYT/kg with assumed release values of 0.146% STTD P, 0.166% available P, 0.102% STTD Ca, 10.9 kcal/kg of ME, 8.6 kcal/kg of NE, and 0.0217%, 0.0003%, 0.0086%, 0.0224%, 0.0056%, 0.0122%, and 0.0163% digestible Lys, Met, Met + Cys, Thr, Trp, Ile, and Val, respectively.

[d]Provided per kilogram of diet: 110 ppm Zn, 110 ppm Fe, 33 ppm Mn, 17 ppm Cu, 0.33 ppm I, 0.30 ppm Se, 5290 IU vitamin A, 1322 IU vitamin D, 26 IU vitamin E, 2.6 mg vitamin K, 49.6 mg niacin, 16.5 mg pantothenic acid, 5.0 mg riboflavin, and 0.02 mg vitamin B12.

[e]Standardized ileal digestibility.

[f]Representative samples of treatment diets were taken from six feeders per dietary treatment 3 d after the beginning and 3 d before the end of the phase and stored at −4 °F. After blending, subsamples were submitted to Ward Laboratories, Inc. (Kearney, NE) and were analyzed for DM, CP, Ca, and P.

Table 2. Composition of Exp. 1 diets, phases 3 and 4 (as-fed basis)[a,b]

	Phase 3		Phase 4	
	Phytase, FYT/kg		Phytase, FYT/kg	
Item	0	1,500	0	1,500
Ingredient, %				
Corn	73.86	76.43	83.23	85.65
Soybean meal	12.06	11.50	12.89	12.64
Corn DDGS	10.00	10.00	—	—
Beef tallow	1.45	—	1.45	—
Monocalcium phosphate	0.65	—	0.75	—
Limestone	0.95	1.04	0.73	0.77
Sodium chloride	0.35	0.35	0.35	0.35
L-lysine HCl	0.39	0.38	0.30	0.28
DL-methionine	0.01	—	0.02	0.01
L-threonine	0.10	0.08	0.10	0.08
L-tryptophan	0.03	0.03	0.03	0.02
Phytase[c]	—	0.06	—	0.06
Vitamin and trace mineral premix[d]	0.15	0.15	0.15	0.15
Total	100.00	100.00	100.00	100.00
Calculated analysis				
SID[e] amino acids, %				
Lysine	0.81	0.81	0.73	0.73
Isoleucine:lysine	59	60	60	62
Leucine:lysine	157	158	151	153
Methionine:lysine	29	28	30	29
Methionine and cysteine:lysine	57	57	58	58
Threonine:lysine	64	64	66	66
Tryptophan:lysine	18.9	18.7	19.5	19.5
Valine:lysine	70	70	70	70
Total lysine, %	0.93	0.91	0.83	0.81
NE, kcal/kg	2,576	2,576	2,603	2,603
SID lysine:NE, g/Mcal	3.14	3.14	2.80	2.80
CP, %	15.1	15.0	13.4	13.4
Ca, %	0.56	0.48	0.51	0.39
STTD Ca, %	0.44	0.48	0.40	0.41
P, %	0.50	0.37	0.47	0.31
STTD P, %	0.29	0.31	0.26	0.27
Available P, %	0.25	0.29	0.21	0.23
STTD Ca:STTD P	1.55	1.55	1.55	1.55
Chemical analysis[f]				
DM	88.36	88.30	88.14	88.26
CP	14.60	15.13	13.78	14.00
Ca	0.63	0.31	0.50	0.41
P	0.45	0.34	0.46	0.31

[a]Phase 3 diets were fed from day 57 to 85 (74–99 kg) and phase 4 diets were fed from day 85 to 126 (99–135 kg).

[b]Dietary treatments consisted of a control with no added phytase, or two treatments with 1,500 FYT fed either in the grower period (days 0–57) then switched to control diet until market, or phytase fed throughout the entire grower and finisher period (day 0 to market).

[c]Ronozyme HiPhos 2,500 phytase (DSM Nutritional Products, Parsippany, NJ) was included at 1,500 FYT/kg with assumed release values of 0.146% STTD P, 0.166% available P, 0.102% STTD Ca, 10.9 kcal/kg of ME, 8.6 kcal/kg of NE, and 0.0217%, 0.0003%, 0.0086%, 0.0224%, 0.0056%, 0.0122%, and 0.0163% digestible Lys, Met, Met + Cys, Thr, Trp, Ile, and Val, respectively.

[d]Provided per kilogram of diet: 110 ppm Zn, 110 ppm Fe, 33 ppm Mn, 17 ppm Cu, 0.33 ppm I, 0.30 ppm Se, 5290 IU vitamin A, 1322 IU vitamin D, 26 IU vitamin E, 2.6 mg vitamin K, 49.6 mg niacin, 16.5 mg pantothenic acid, 5.0 mg riboflavin, and 0.02 mg vitamin B12.

[e]Standardized ileal digestibility.

[f]Representative samples of treatment diets were taken from six feeders per dietary treatment 3 d after the beginning and 3 d before the end of the phase and stored at −4 °F. After blending, subsamples were submitted to Ward Laboratories, Inc. (Kearney, NE) and were analyzed for DM, CP, Ca, and P.

Trp, Ile, and Val, respectively. Phytase nutrient release values were provided by the manufacturer. Ingredient nutrient values were obtained from laboratory results of a previous trial in the same facility for corn, soybean meal, and vitamin trace mineral mix or from National Research Council (NRC 2012) for monocalcium P and calcium carbonate. Digestibility coefficients for P and AA were obtained from NRC (2012) and the digestibility coefficients for Ca were obtained from the literature (González-Vega et al., 2013, 2015; Stein, 2016). The diets were formulated to contain adequate STTD P across the dietary treatments in all phases based on the estimated requirement previously determined in the research facility (Vier et al., 2019). All diets were balanced for an STTD Ca:STTD P of 1.55:1.

Pens of pigs were weighed, and feed disappearance was recorded approximately every 14 d to determine average daily gain (ADG), average daily feed intake (ADFI), and gain-to-feed ratio (G:F). On day 99, the two heaviest pigs in each pen were selected, weighed, and marketed according to standard farm procedures. On day 126, final pen weights were taken, and pigs were individually tattooed with the specific pen identity on the shoulder to allow for carcass measurements to be recorded on a pen basis. These pigs were transported to a commercial packing plant in southwestern Minnesota (JBS Swift and Company, Worthington, MN) for processing and carcass data collection. Carcass measurements included hot carcass weight (HCW), loin depth, back fat depth, and percentage lean. Loin depth and back fat depth were measured with an optical probe inserted between the third- and fourth-last rib (counting from the ham end of the carcass) at a distance approximately 7 cm from the dorsal midline. Percentage lean was derived from a proprietary equation used by the packing plant based on carcass weight, back fat depth, and loin depth. Percentage carcass yield was calculated by dividing the average pen HCW by the average final live weight at the farm.

Experiment 2

A total of 2,268 barrows and gilts (PIC 337 × 1050, initially 28.5 kg) were used from two groups of pigs (1,134 in group 1 and 1,134 in group 2) in a 55-d growth trial. At placement (23.0 and 16.8 kg, respectively), pigs were fed a common diet containing 0.66% total Ca and 0.42% STTD P until the initiation of the trial. On day 0 of the study, pens of pigs were blocked by BW and randomly allotted to one of six dietary treatments with 27 pigs per pen (either 14 barrows and 13 gilts or 14 gilts and 13 barrows per block) and 14 replicate pens per treatment (7 pens per group). Diets were fed in two different phases. Phase 1 diets were fed from day 0 to 29 (28.5–51.2 kg) and phase 2 diets were fed from day 29 to 55 (51.2–72.4 kg). Treatments consisted of a control diet with inorganic P from monocalcium P and no added phytase or five diets with 1,500 FYT/kg assuming the same release values as those used in Exp. 1 but only accounting release values for Ca and P (CaP); Ca, P, and AA (CaPAA); Ca, P, AA, and half of the suggested net energy (CaPAA + half NE); Ca, P, AA, and full NE (CaPAA + full NE); or no nutrient release to form the five treatment diets (Tables 3 and 4).

The experimental diets were corn-soybean-meal–DDGS based with Ronozyme HiPhos 2,500 as the phytase source. The same ingredient loading values and digestibility coefficients for P and Ca in Exp. 1 were used. All diets were formulated to contain adequate STTD P across the dietary treatments in both phases based on the estimated requirement previously determined in the research facility (Vier et al., 2019). The STTD Ca:STTD P ratio for all diets was 1.60:1. Pens of pigs were weighed, and feed disappearance was recorded approximately every 14 d to determine ADG, ADFI, and G:F.

Feed Sampling

Experimental diets for both experiments were manufactured at the New Horizon Farms Feed Mill (Pipestone, MN) and fed in meal form. Representative samples of treatment diets were taken from six feeders per dietary treatment 3 d after the beginning and 3 d before the end of each phase and stored at −20 °C. After blending, subsamples were analyzed in duplicates for dry matter (DM; AOAC 934.01), crude protein (CP; AOAC 990.03; AOAC, 2006), Ca (AOAC 985.01; AOAC, 2006), and P (AOAC 985.01; AOAC, 2006), and average values were reported (Tables 1–4; Ward Laboratories, Inc., Kearney, NE).

Statistical Analysis

In Exp. 1, data were analyzed as a randomized complete block design, with pen considered the experimental unit and BW the blocking factor and evaluated as a random effect. Although fed the same diet in the grower phase, pigs were initially allotted to three individual treatments. The study was structured as a one-way treatment structure

Table 3. Composition of Exp. 2 diets, phase 1 (as-fed basis)[a,b]

	No Phytase	1500 FYT/kg Phytase				
Ingredient, %	Control	CaP	CaPAA	CaPAA + half NE	CaPAA + full NE	None
Corn	63.00	64.13	64.48	64.88	65.61	62.88
Soybean meal	22.15	22.07	21.82	21.79	21.74	22.16
Corn DDGS	10.00	10.00	10.00	10.00	10.00	10.00
Beef tallow	2.00	1.60	1.55	1.20	0.50	2.05
Monocalcium P	0.75	—	—	—	—	0.75
Limestone	1.08	1.13	1.13	1.10	1.13	1.08
Sodium chloride	0.35	0.35	0.35	0.35	0.35	0.35
L-Lysine-HCl	0.37	0.37	0.35	0.35	0.35	0.37
DL-Methionine	0.05	0.04	0.04	0.04	0.04	0.05
L-Threonine	0.09	0.09	0.07	0.07	0.07	0.09
L-Tryptophan	0.02	0.02	0.01	0.01	0.01	0.02
Vitamin mineral premix[c]	0.15	0.15	0.15	0.15	0.15	0.15
Phytase[d]	—	0.06	0.06	0.06	0.06	0.06
Total	100	100	100	100	100	100
Calculated analysis						
SID[e] amino acids						
Lysine, %	1.04	1.04	1.04	1.04	1.04	1.04
Isoleucine:lysine	62	62	63	63	63	62
Leucine:lysine	145	145	145	145	145	144
Methionine:lysine	31	30	30	30	30	31
Methionine and cysteine:lysine	56	56	56	56	57	56
Threonine:lysine	62	62	62	62	62	62
Tryptophan:lysine	18.6	18.6	18.5	18.5	18.5	18.6
Valine:lysine	70	70	70	70	70	70
Histidine:lysine	42	42	42	42	42	42
Total lysine, %	1.18	1.18	1.16	1.16	1.16	1.18
Metabolizable energy, kcal/kg	3,366	3,368	3,366	3,368	3,368	3,366
NE, kcal/kg	2,534	2,534	2,534	2,534	2,534	2,534
SID lysine:NE, g/Mcal	4.09	4.09	4.10	4.09	4.10	4.09
CP, %	19.0	19.1	19.0	19.0	19.0	19.0
Ca, %	0.68	0.57	0.57	0.56	0.57	0.68
STTD Ca, %	0.53	0.54	0.54	0.53	0.54	0.53
P, %	0.57	0.41	0.41	0.41	0.41	0.57
STTD P, %	0.33	0.34	0.33	0.33	0.34	0.33
Available P, %	0.29	0.29	0.29	0.29	0.29	0.29
STTD Ca:STTD P	1.60	1.60	1.60	1.60	1.60	1.60
Chemical analysis[f]						
DM	88.74	88.11	88.94	87.89	88.52	87.98
CP	18.80	17.20	17.50	18.95	18.45	18.50
Ca	0.61	0.62	0.62	0.60	0.61	0.66
P	0.41	0.34	0.38	0.31	0.36	0.51

[a]Diets were fed for 26 d from approximately 29 to 51 kg.

[b]Dietary treatments consisted of a control with no phytase, or five diets with 1,500 phytase units assuming supplier-provided nutrient release values for Ca and P (CaP), Ca, P, and AA (CaPAA), Ca, P, AA, and half of the suggested net energy (CaPAA + half NE), Ca, P, AA, and full NE (CaPAA + full NE) and no nutrient release (none).

[c]Provided per kilogram of diet: 110 ppm Zn, 110 ppm Fe, 33 ppm Mn, 17 ppm Cu, 0.33 ppm I, 0.30 ppm Se, 5290 IU vitamin A, 1322 IU vitamin D, 26 IU vitamin E, 2.6 mg vitamin K, 49.6 mg niacin, 16.5 mg pantothenic acid, 5.0 mg riboflavin, and 0.02 mg vitamin B12.

[d]Ronozyme HiPhos 2,500 phytase (DSM Nutritional Products, Parsippany, NJ) was included at 1,500 FYT/kg with assumed release values of 0.146% STTD P, 0.166% available P, 0.102% STTD Ca, 10.9 kcal/kg of ME, 8.6 kcal/kg of NE, and 0.0217%, 0.0003%, 0.0086%, 0.0224%, 0.0056%, 0.0122%, and 0.0163% digestible Lys, Met, Met + Cys, Thr, Trp, Ile, and Val, respectively.

[e]Standardized ileal digestibility.

[f]Representative samples of treatment diets were taken from six feeders per dietary treatment 3 d after the beginning and 3 d before the end of the phase and stored at −4 °F. After blending, subsamples were submitted to Ward Laboratories, Inc. (Kearney, NE) and were analyzed for DM, CP, Ca, and P.

Table 4. Composition of Exp. 2 diets, phase 2 (as-fed basis)[a,b]

	No Phytase	1500 FYT/kg Phytase				
Item	Control	CaP	CaPAA	CaPAA + half NE	CaPAA + full NE	None
Ingredient, %						
Corn	69.54	70.79	71.09	71.55	72.23	69.42
Soybean meal	15.55	15.46	15.21	15.18	15.13	15.55
Corn DDGS	10.00	10.00	10.00	10.00	10.00	10.00
Beef tallow	2.00	1.55	1.55	1.15	0.50	2.05
Monocalcium P	0.80	—	—	—	—	0.80
Limestone	1.10	1.13	1.13	1.11	1.13	1.10
Sodium chloride	0.35	0.35	0.35	0.35	0.35	0.35
L-Lysine-HCl	0.39	0.39	0.37	0.37	0.37	0.39
DL-Methionine	0.02	0.02	0.02	0.01	0.01	0.02
L-Threonine	0.09	0.09	0.07	0.06	0.06	0.09
L-Tryptophan	0.03	0.03	0.02	0.02	0.02	0.03
Vitamin mineral premix[c]	0.15	0.15	0.15	0.15	0.15	0.15
Phytase[d]	—	0.06	0.06	0.06	0.06	0.06
Total	100	100	100	100	100	100
Calculated analysis						
SID[e] amino acids						
Lysine, %	0.89	0.89	0.89	0.89	0.89	0.89
Isoleucine:lysine	60	60	61	61	61	60
Leucine:lysine	151	152	152	152	152	151
Methionine:lysine	29	30	29	29	29	29
Methionine and cysteine:lysine	56	56	56	56	56	56
Threonine:lysine	62	62	62	62	62	62
Tryptophan:lysine	18.7	18.8	18.7	18.7	18.7	18.7
Valine:lysine	70	70	70	70	70	70
Histidine:lysine	42	42	42	42	42	42
Total lysine, %	1.02	1.02	0.99	1.00	1.00	1.02
Metabolizable energy, kcal/kg	3,370	3,373	3,373	3,370	3,375	3,370
Net energy, kcal/kg	2,572	2,572	2,572	2,572	2,572	2,572
SID lysine:NE, g/Mcal	3.45	3.45	3.45	3.45	3.45	3.45
CP, %	16.4	16.5	16.3	16.4	16.4	16.4
Ca, %	0.66	053	0.53	0.53	0.53	0.66
STTD Ca, %	0.52	0.51	0.51	0.51	0.51	0.52
P, %	0.55	0.38	0.38	0.38	0.38	0.55
STTD P, %	0.32	0.32	0.32	0.32	0.32	0.32
Available P, %	0.29	0.28	0.28	0.28	0.28	0.29
Ca:P	1.20	1.40	1.40	1.38	1.39	1.20
STTD Ca:STTD P	1.60	1.60	1.60	1.60	1.60	1.60
Chemical analysis[f]						
DM	88.75	88.60	89.74	88.87	88.53	88.16
CP	16.25	16.35	15.55	15.50	16.20	17.70
Ca	0.74	0.62	0.53	0.62	0.57	0.75
P	0.46	0.31	0.36	0.32	0.34	0.43

[a]Diets were fed for 26 d from approximately 51 to 72 kg.

[b]Dietary treatments consisted of a control with no phytase, or five diets with 1,500 phytase units assuming supplier-provided nutrient release values for Ca and P (CaP), Ca, P, and AA (CaPAA), Ca, P, AA, and half of the suggested net energy (CaPAA + half NE), Ca, P, AA, and full NE (CaPAA + full NE), and no nutrient release (none).

[c]Provided per kilogram of diet: 110 ppm Zn, 110 ppm Fe, 33 ppm Mn, 17 ppm Cu, 0.33 ppm I, 0.30 ppm Se, 5290 IU vitamin A, 1322 IU vitamin D, 26 IU vitamin E, 2.6 mg vitamin K, 49.6 mg niacin, 16.5 mg pantothenic acid, 5.0 mg riboflavin, and 0.02 mg vitamin B12.

[d]Ronozyme HiPhos 2,500 phytase (DSM Nutritional Products, Parsippany, NJ) was included at 1,500 FYT/kg with assumed release values of 0.146% STTD P, 0.166% available P, 0.102% STTD Ca, 10.9 kcal/kg of ME, 8.6 kcal/kg of NE, and 0.0217%, 0.0003%, 0.0086%, 0.0224%, 0.0056%, 0.0122%, and 0.0163% digestible Lys, Met, Met + Cys, Thr, Trp, Ile, and Val, respectively

[e]Standardized ileal digestibility.

[f]Representative samples of treatment diets were taken from six feeders per dietary treatment 3 d after the beginning and 3 d before the end of the phase and stored at −4 °F. After blending, subsamples were submitted to Ward Laboratories, Inc. (Kearney, NE) and were analyzed for DM, CP, Ca, and P.

with dietary treatment as the factor level. Because carcass characteristics were recorded on an individual pig basis, a random effect of block by treatment was used to identify the pen as the experimental unit. Pairwise comparisons were conducted and means were reported as least-square means. Statistical models were fitted using GLIMMIX procedure of SAS (Version 9.3, SAS Institute Inc., Cary, NC). Results were considered significant at $P \leq 0.05$ and marginally significant at $0.05 \leq P \leq 0.10$.

In Exp. 2, similar to Exp. 1, pens were assigned to the six treatments based on average pig BW as a blocking factor. Therefore, data were analyzed as a randomized complete block design for one-way analysis of variance with pen as the experimental unit in a similar manner as Exp. 1 with treatment as fixed effect and weight block as random effect. Pairwise comparisons were conducted and means were reported as least-square means with a Tukey–Kamer adjustment. The pairwise comparisons were only evaluated if the overall treatment *F*-test was significant ($P \leq 0.05$). For the analysis, the lmer function from the lme4 package in R (version 3.5.1; July 2, 2018) was used, with pen considered the experimental unit. Results were considered significant at $P \leq 0.05$ and marginally significant at $0.05 \leq P \leq 0.10$.

RESULTS

Experiment 1

During the grower period, which corresponds to phases 1 and 2 (days 0–57), pigs fed the control diet with no added phytase had increased ($P < 0.05$) ADG compared to pigs fed phytase only in the grower period, with pigs fed phytase in grower and finisher intermediate (Table 5). There

Table 5. The effects of phytase feeding duration on growth performance and carcass characteristics of growing-finishing pigs, Exp. 1*a*

	Treatment[b,c]				
Item	Control	Phytase grower	Phytase grower and finisher	SEM	*P*[d]
Body weight, kg					
Day 0	27.9	27.9	27.9	0.463	0.780
Day 57	74.5[a]	73.2[b]	73.7[ab]	0.884	0.017
Day 126	136.5[a]	135.9[a]	133.2[b]	1.238	0.030
Grower period (days 0–57)					
ADG, kg	0.82[a]	0.80[b]	0.81[ab]	0.008	0.011
ADFI, kg	1.69	1.70	1.70	0.021	0.570
G:F	0.49[a]	0.47[b]	0.47[b]	0.003	<0.001
Finisher period (days 57–126)					
ADG, kg	0.92[a]	0.94[a]	0.89[b]	0.010	0.004
ADFI, kg	2.73	2.76	2.71	0.027	0.575
G:F	0.34[a]	0.34[a]	0.33[b]	0.003	<0.001
Overall period (days 0–126)					
ADG, kg	0.87[a]	0.87[a]	0.85[b]	0.006	0.017
ADFI, kg	2.24	2.25	2.23	0.021	0.651
G:F	0.39[a]	0.39[a]	0.38[b]	0.003	<0.001
Carcass characteristics					
HCW, kg	99.9	100.2	97.9	1.063	0.097
Yield, %	72.63	72.83	72.27	0.337	0.406
Back fat, mm	15.98	16.66	16.46	—[e]	0.509
Fat-free lean, mm	57.63	57.30	57.36	—[e]	0.717
Loin depth, mm	70.98	71.69	71.23	—[e]	0.797

[a]A total of 1,215 pigs (PIC 359 × Camborough, initial BW of 27.9 kg) were used in a 126-d growth trial with 27 pigs per pen and 15 pens per treatment.

[b]Dietary treatments consisted of a control with no added phytase, or two treatments with 1,500 FYT fed either in the grower period (days 0–57) then switched to control diet until market, or phytase fed throughout the entire grower and finisher period (day 0 to market).

[c]Ronozyme HiPhos 2,500 phytase (DSM Nutritional Products, Parsippany, NJ) was included at 1,500 FYT/kg with assumed release values of 0.146% STTD P, 0.166% available P, 0.102% STTD Ca, 10.9 kcal/kg of ME, 8.6 kcal/kg of NE, and 0.0217%, 0.0003%, 0.0086%, 0.0224%, 0.0056%, 0.0122%, and 0.0163% digestible Lys, Met, Met + Cys, Thr, Trp, Ile, and Val, respectively.

[d]Means with different superscripts within a row differ.

[e]SEM for back fat were 0.392, 0.479, and 0.385; SEM for fat-free lean were 0.287, 0.352, and 0.283; and SEM for loin depth were 0.668, 0.813, and 0.652 for the control, phytase fed only in the grower phase, and phytase fed throughout the grower and finisher, respectively.

was no evidence ($P > 0.10$) for difference in ADFI between treatments. Pigs fed the phytase-containing diets had decreased ($P < 0.01$) G:F compared to pigs fed the control.

During the finisher period, which corresponds to phases 3 and 4 (days 58–126), ADG was similar for pigs fed either the control or added phytase in the grower period. The ADG for these treatments was greater ($P < 0.05$) than that of pigs fed phytase in the grower and finisher. There was no evidence ($P > 0.10$) for difference in ADFI between treatments. As a result, pigs fed either the control or phytase in the grower period had increased G:F ($P < 0.05$) compared to pigs fed phytase in the grower and finisher. Overall (days 0–126), pigs fed either the control or phytase only in the grower period had increased ($P < 0.05$) ADG and G:F compared to pigs fed phytase in the grower and finisher, with no evidence ($P > 0.10$) for difference observed in ADFI between treatments.

A marginally significant ($P < 0.10$) treatment effect on HCW was observed with pigs fed either the control or phytase only in the grower period having heavier HCW compared to pigs fed phytase throughout grower and finisher. No evidence for differences ($P > 0.10$) was observed for carcass yield, back fat, fat-free lean, and loin depth characteristics.

Experiment 2

Overall (days 0–55), there was no evidence for difference observed in ADG or ADFI between treatments (Table 6). However, pigs fed the diet containing 1,500 FYT/kg assuming no nutrient release had increased ($P < 0.05$) G:F compared to pigs fed diets containing 1,500 FYT/kg assuming either CaP or CaPAA + full NE release, with others intermediate.

DISCUSSION

Phytate is a known antinutritional factor that decreases P availability. It has previously been demonstrated that the enzyme phytase, when supplemented in swine diets, can effectively dephosphorylate the phytic acid present in cereal grains and oilseeds, improving P digestibility (Selle et al., 2012). High levels of phytase have also been associated with the release of minerals, AA, and energy (Coweison et al., 2011). Phytate, while generally unreactive in feedstuffs, takes on an electro-negative charge once exposed to the acidic conditions of the stomach (Adeola et al., 2011). The reduced nutrient digestibility and subsequent efficiency of monogastric animals fed diets high in phytic acid is a result of insoluble binary and tertiary complexes that form with proteins, minerals, and their associated digestive enzymes (Selle et al., 2012). The chelation of these nutrients to phytate depends on the isoelectric point of the protein or mineral in relation to the electro-negative charge and concentration of phytate in the diet (Selle et al., 2012). The formation of insoluble phytate complexes leads to hypersecretion of pepsin, HCl, and mucin, increasing nutrient flow into the lumen, therefore, reducing the absorption of nutrients from the small intestine and increasing endogenous losses (Woyengo et al., 2013).

Table 6. Effects of different nutrient release values of Ronozyme HiPhos 2,500 phytase on pig growth performance, Exp. 2[a,b]

	No phytase[b]	1,500 FYT/kg Phytase[c]						
Item	Control	CaP	CaPAA	CaPAA + half NE	CaPAA + full NE	None	SEM	*P*
Body weight, kg								
Day 0	28.5	28.5	28.5	28.5	28.5	28.5	0.61	0.999
Day 55	72.4	72.9	72.5	71.9	72.2	72.6	0.95	0.786
Overall (days 0–55)								
ADG, kg	0.83	0.83	0.83	0.82	0.83	0.83	0.010	0.768
ADFI, kg	1.67	1.72	1.68	1.67	1.70	1.66	0.024	0.222
G:F	0.496[ab]	0.486[b]	0.495[ab]	0.491[ab]	0.484[b]	0.502[a]	0.0038	0.002

[a]A total of 2,268 mixed sex pigs (PIC 337 × 1050, initially 28.5 kg) were used in a 55-d growth study to determine the impact on performance when phytase is credited with additional nutrient release above P and Ca. There were 27 pigs per pen and 14 pens per treatment.

[b]Dietary treatments consisted of a control with no phytase, or five diets with 1,500 phytase units assuming supplier-provided nutrient release values for Ca and P (CaP), Ca, P, and AA (CaPAA), Ca, P, AA, and half of the suggested net energy (CaPAA + half NE), Ca, P, AA, and full NE (CaPAA + full NE), and no nutrient release (none).

[c]Ronozyme HiPhos 2,500 phytase (DSM Nutritional Products, Parsippany, NJ) was included at 1,500 FYT/kg with assumed release values of 0.146% STTD P, 0.166% available P, 0.102% STTD Ca, 10.9 kcal/kg of ME, 8.6 kcal/kg of NE, and 0.0217%, 0.0003%, 0.0086%, 0.0224%, 0.0056%, 0.0122%, and 0.0163% digestible Lys, Met, Met + Cys, Thr, Trp, Ile, and Val, respectively.

Several studies have investigated the extra-phosphoric potential of phytase; however, results have been inconsistent regarding its effects on the digestibility of AA. Improved apparent ileal digestibility (AID) of some AA in response to dietary phytase inclusion has been reported (Kemme et al., 1999; Adedokun et al., 2015). Zeng et al. (2016) observed that when supplementing diets with 20,000 FTU/kg, CP and AA utilization improved. Conversely, other studies that fed more conventional levels of phytase (1,000–4,000 FTU/kg) did not observe the same results (Traylor et al., 2001; She et al., 2018). A meta-analysis conducted by Cowieson et al. (2017) indicated that the effect of phytase on AID was more evident when diets were intrinsically low in digestible AA. Furthermore, the AID of AA tended to be similar from 250 to 2,000 FYT/kg, indicating that phytase dose may have less application in swine diets when it comes to AA digestibility (Coweison et al., 2017; Zouaoui et al., 2018). Nonetheless, there is evidence that nutrient release values credited to phytase are linked to the hydrolysis of phytate; therefore, phytases with similar P release values should have similar extra-phosphoric effects.

Limited research has been conducted regarding the effects of phytase on energy digestibility, but it appears that the implication may be similar to that of AA. She et al. (2018) evaluated increasing levels of phytase on the apparent total tract digestibility (ATTD) of nutrients in growing pigs. When super-dosing phytase up to 4,000 FTU/kg in P-deficient diets, no phytase effect on ATTD of AA or gross energy was observed. This observation confirms earlier reports that the energy effects of phytase are limited to improved protein digestibility (Selle and Ravindran, 2008). Conversely, Adedokum et al. (2015) demonstrated that ATTD of AA and energy improved as phytase in the diet increased up to the highest dose (2,000 FTU/kg). Similarly, when calculating performance on a carcass basis, Holloway et al. (2018) reported improved energy efficiency in pigs fed graded levels of phytase from 1,000 to 2,500 FTU/kg in diets with less than optimal lysine and energy. These studies indicate that when diets are nutrient deficient, there is the potential for phytase to improve energy digestibility and subsequent utilization.

The supplementation of high levels of phytase has resulted in inconsistent results in growing and finishing pig growth performance (Flohr et al., 2014; Holloway et at., 2018; Santos et al., 2014). Even fewer studies have investigated the effects on carcass characteristics (Flohr et al., 2014; Holloway et at., 2018). Results from Exp. 1 suggest that when full nutrient release values were utilized, growing-finishing pigs fed diets containing 1,500 FYT of phytase until market had poorer performance compared to pigs fed diets without added phytase. Moreover, pigs that were withdrawn from the phytase-containing diets after the grower period and switched to the control diets without phytase until market were able to recover the loss in performance. These findings suggest that the full nutrient release values attributed to the phytase were greater than what was actually released and, consequently, resulted in poorer performance.

In Exp. 1, nutrient release values were assigned not only to digestible P but also to digestible Ca, NE, and AA. Based on the results observed, we hypothesized that the detrimental effects in performance of pigs supplemented with phytase may be due to an overestimation of the release values for NE or AA. Therefore, Exp. 2 was conducted with growing pigs, approximately 27–75 kg, to confirm this response. Pigs fed either the control diet with inorganic P from monocalcium P or any of the phytase-containing diets should have had similar performance, perhaps with the exception of pigs fed the diet formulated to contain 1,500 FYT/kg assuming no release values. Pigs fed full nutrient release values had the lowest G:F, while pigs fed diets assuming Ca and P in addition to AA and half of the suggested NE release had G:F comparable to the control. Pigs fed diets assuming no release values were most efficient in converting feed into BW, indicating that high phytase levels added on top of nutritionally adequate diets provides additional nutrient release.

In summary, these studies provide valuable insight on the nutrient release values of phytase (Ronozyme HiPhos 2,500). These are the first studies, to our knowledge, that have been conducted to validate full nutrient release values associated with phytase in a commercial setting. In Exp. 1, growing-finishing pigs fed diets containing high levels of phytase with full nutrient release values until market had decreased ADG, G:F, and HCW compared with those not fed any phytase. Removing the phytase at the end of the grower period was sufficient for pigs to recover any loss in performance and to achieve similar overall growth rates and feed efficiency as the pigs fed diets without added phytase. A similar feed efficiency response was observed in Exp. 2 with growing pigs, confirming the hypothesis that full nutrient release values attributed to phytase, especially for NE, was too aggressive and resulted in diets contributing less nutrients than needed to optimize performance.

Conflict of interest statement. The authors declare no conflict of interest. However, J.R.B.

is an employee of DSM Nutritional Products, the company of the phytase source used for these studies.

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