Kansas Agricultural Experiment Station Research Reports

Volume 9
Issue 7 *Swine Day*

Article 6

2023

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Ethan B. Stas
Kansas State University, Manhattan, ebstas@ksu.edu

Mike D. Tokach
Kansas State University, Manhattan, mtokach@k-state.edu

Jason C. Woodworth
Kansas State University, Manhattan, jwoodworth@k-state.edu

See next page for additional authors

Recommended Citation

Stas, Ethan B.; Tokach, Mike D.; Woodworth, Jason C.; DeRouchey, Joel M.; Goodband, Robert D.; and Gebhardt, Jordan T. (2023) "Effects of Altering Dietary Acid-Binding Capacity-4 with Specialty Soy Protein Sources or Acidifiers on Nursery Pig Performance and Fecal Dry Matter," *Kansas Agricultural Experiment Station Research Reports*: Vol. 9: Iss. 7. https://doi.org/10.4148/2378-5977.8507

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Ethan B. Stas, Mike D. Tokach, Jason C. Woodworth, Joel M. DeRouchey, Robert D. Goodband, and Jordan T. Gebhardt[1]

Summary

A total of 300 pigs (241 × 600 DNA; initially 13.2 lb) were used to evaluate the effects of altering the dietary acid-binding capacity-4 (ABC-4) with specialty soy protein sources or acidifiers on nursery pig performance and fecal dry matter (DM). At weaning, pigs were allotted to 1 of 5 dietary treatments. There were 5 pigs per pen and 12 replications per treatment. Pigs were fed experimental diets in two phases with phase 1 fed from d 0 to 10 post-weaning followed by phase 2 from d 10 to 24. Diets were formulated with increasing ABC-4. A single low ABC-4 diet was formulated to 200 and 250 meq/kg in phase 1 and 2, respectively. The low ABC-4 diet utilized 0.38% fumaric acid, 0.36% formic acid, and specialty soy protein concentrate (AX3 Digest; Protekta; Newport Beach, CA) at 9.38 and 7.50% of the diet in phase 1 and 2, respectively. Two medium ABC-4 diets were formulated utilizing two different strategies. In the first medium ABC-4 diet, specialty soy protein concentrate was replaced with enzymatically treated soybean meal on an SID Lys-basis and resulted in an ABC-4 level of 290 and 322 meq/kg for phase 1 and 2, respectively. In the second medium ABC-4 diet, acidifiers were removed resulting in an ABC-4 level of 271 and 321 meq/kg for phase 1 and 2, respectively. In the high ABC-4 diet, specialty soy protein concentrate was replaced with enzymatically treated soybean meal and the acidifiers were removed, resulting in ABC-4 values of 362 and 394 meq/kg for phase 1 and 2, respectively. In addition, the high ABC-4 diet, but with added pharmacological levels of Zn from ZnO served as a control diet. Following phase 2, all pigs were fed a common diet until d 38 of the study. Increasing ABC-4 levels tended to decrease (linear, $P = 0.062$) the ADG during the experimental period. Pigs fed increasing ABC-4 diets had poorer (linear, $P \leq 0.043$) F/G during the experimental period (d 0 to 24) and overall (d 0 to 38). Increasing ABC-4 levels also decreased (linear, $P \leq 0.005$) fecal DM on d 10 and 24. Pigs fed diets containing pharmacological levels of Zn from ZnO had improved ($P \leq 0.047$) BW, ADG, ADFI, and F/G during the experimental period (d 0 to 24) but poorer ($P = 0.005$) ADG and F/G during the common period (d 24 to 38), compared to pigs fed diets not containing ZnO. Ultimately, this resulted in no benefit from ZnO for the overall study (d 0 to 38). There were no differences between the two medium

[1] Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University.

ABC-4 levels for the growth performance. However, pigs fed the medium ABC-4 diet based on specialty soy protein replacement had increased (*P* = 0.003) fecal DM on d 10 compared to the medium ABC-4 diet where acidifiers were removed. In conclusion, as dietary ABC-4 increased from 200 to 362 meq/kg in phase 1 and 250 to 294 meq/kg in phase 2, pigs had linearly decreased growth performance and fecal DM. The results of this study suggest a low ABC-4 diet can be utilized to improve growth performance and fecal consistency in diets without pharmacological Zn. Additionally, there were no differences between the medium ABC-4 diets for growth performance, suggesting the decreased performance was due to an increase in ABC-4 level and not a change in ingredients.

Introduction

Newly weaned pigs undergo a dramatic change when moving from a liquid diet in the form of sow's milk to a dry cereal-based diet. At this age, pigs have a limited capacity to produce enough hydrochloric acid in the stomach to maintain an acidic environment. Certain ingredients in the diet bind more acid than others, which can further increase gastric pH. High gastric pH is associated with decreased nutrient utilization and intestinal infection, leading to decreased performance and increased morbidity and mortality. Selection of ingredients with a low acid-binding capacity-4 (ABC-4) could assist newly weaned pigs in maintaining an acidic gastric environment.

Previous studies have shown a benefit to low ABC-4 diets on nursery pig performance compared to a high ABC-4 diet. A previous study by Stas et al. (2023)[2] showed a benefit to feeding a diet formulated to low ABC-4 levels of 200 and 250 meq/kg in phase 1 and 2, respectively compared to feeding a diet formulated to high ABC-4 levels of 300 and 350 meq/kg in phase 1 and 2, respectively. The results of this study also reported a linear reduction in fecal dry matter (DM) percentage as ABC-4 level of the diet increased. In this study, the low ABC-4 diet utilized a specialty soy protein concentrate (AX3 Digest; Protekta; Newport Beach, CA) and acidifiers. The high ABC-4 diets were formulated by using enzymatically treated soybean meal (HP 300; Hamlet Protein; Findlay, OH) as a replacement to specialty soy protein concentrate, and by decreasing the acidifiers. However, further validation is warranted to determine if the results from the previously mentioned trial were due to an ABC-4 level effect or an ingredient effect. Therefore, the objective of this experiment was to evaluate the effects on nursery pig performance and fecal DM after increasing the ABC-4 levels of the diet by replacing specialty soy protein sources and/or decreasing acidifiers.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The experiment was conducted at the Kansas State University Swine Teaching and Research Center in Manhattan, KS. Each pen was equipped with a 4-hole, dry self-feeder and nipple waterer to provide *ad libitum* access to feed and water.

A total of 300 pigs (241 × 600 DNA; initially 13.2 lb) were used in a 38-d nursery trial across two rooms. Pigs were weaned at approximately 21 d of age into pens of 5 pigs

[2] Stas, E. B., M. D. Tokach, J. C. Woodworth, J. M. DeRouchey, R. D. Goodband, and J. T. Gebhardt. 2023. Dietary acid-binding capacity influences nursery pig performance and fecal dry matter. In progress.

each based on initial weight and gender. Pens were randomly allotted to 1 of 5 dietary treatments with 12 replications per treatment. Pigs were fed experimental diets in two phases with phase 1 from d 0 to 10 postweaning, followed by phase 2 from d 10 to 24. Phase 1 and 2 diets were formulated to contain 1.36 and 1.35% SID Lys, respectively, and met or exceeded other nutrient requirement estimates established by the NRC.[3] Following phase 2, all pigs were fed a common corn-soybean meal-based diet until d 38 of the trial.

The five dietary treatments consisted of increasing ABC-4 levels (Table 1). Dietary treatments consisted of a low ABC-4 diet, two medium ABC-4 diets, and two high ABC-4 diets. The low ABC-4 diet was formulated to 200 and 250 meq/kg in phase 1 and 2, respectively. To achieve the low ABC-4 diet, specialty soy protein concentrate (AX3 Digest; Protekta; Newport Beach, CA) with an individual ingredient ABC-4 level of 13 meq/kg was included at 9.38 and 7.50% of the diet in phases 1 and 2, respectively. Fumaric acid and formic acid were also included at 0.38 and 0.36% of the diet, respectively for both phase 1 and phase 2 diets. Fumaric acid and formic acid had individual ABC-4 values of -10,873 and -8,287 meq/kg, respectively. The medium ABC-4 diets were achieved by utilizing two different strategies to determine if ingredient selection to increase ABC-4 levels would affect the response. The first medium ABC-4 diet was achieved by replacing specialty soy protein concentrate with enzymatically treated soybean meal (797 meq/kg; HP 300; Hamlet Protein; Findlay, OH) on an SID Lys basis and resulted in dietary ABC-4 values of 290 and 322 meq/kg for phase 1 and 2, respectively. The second medium ABC-4 diet was achieved by removing the organic acids and resulted in dietary ABC-4 values of 271 and 321 meq/kg for phase 1 and 2, respectively. The high ABC-4 diet was achieved by replacing specialty soy protein concentrate with enzymatically treated soybean meal on an SID Lys basis and removing organic acids resulting in dietary ABC-4 values of 362 and 294 meq/kg for phase 1 and 2, respectively. All four ABC-4 diets contained 110 ppm of Zn provided by the trace mineral premix and did not contain pharmacological levels of Zn. A positive control with the same formulation as the high ABC-4 diet was used but with the addition of 3,000 and 2,000 ppm of Zn from ZnO in phase 1 and 2, respectively. The addition of ZnO increased the dietary ABC-4 values by 87 and 54 meq/kg for phase 1 and 2, respectively. Individual pig weights and feed disappearance were measured on d 10, 17, 24, 31, and 38 to determine ADG, ADFI, and F/G.

Fecal samples were collected on d 10, 17, and 24 to determine fecal DM percentage from the same three medium weight pigs from each pen. After collection, fecal samples were dried at 131°F (55°C) in a forced air oven for 48 hours, and the ratio of dried to wet fecal weight determined the fecal percentage DM.

Statistical analysis

Data were analyzed as a completely randomized design using the RStudio environment (Version 1.3.1093, RStudio, Inc., Boston, MA) using R programming language [Version 4.0.2 (2020-06-22), R Core Team, R Foundation for Statistical Computing, Vienna, Austria] with pen as the experimental unit. Room was included in the model as a random effect. Linear and quadratic effects of dietary ABC-4 levels were tested. The contrast coefficients were developed using the assumption that the treatments were

[3] National Research Council. 2012. Nutrient Requirements of Swine: Eleventh Revised Edition. Washington, DC: The National Academies Press. https://doi.org/10.17226/13298.

evenly spaced based on dietary treatment formulation. The effect of the medium ABC-4 levels was tested by a pairwise comparison of both medium ABC-4 diets. The effect of ZnO was also tested by a pairwise comparison of the high ABC-4 diets with and without ZnO. Fecal DM were analyzed using the fixed effects of day, treatment, and the associated interaction accounting for repeated measures over time. Differences between treatments and day (where appropriate) as well as their interaction were considered significant at $P \leq 0.05$ and marginally significant at $0.05 < P \leq 0.10$.

Results and Discussion

Increasing dietary ABC-4 levels, during phase 1 (d 0 to 10) did not affect growth performance ($P > 0.10$; Table 3). In phase 2 (d 10 to 24), ADG decreased (linear, $P = 0.026$) as ABC-4 levels increased. Pigs fed increasing ABC-4 levels tended to have decreased (linear, $P = 0.098$) ADFI. In the experimental period (d 0 to 24), pigs fed increasing ABC-4 levels tended to have decreased (linear, $P \leq 0.064$) ADG and d 24 BW, and had poorer (linear, $P = 0.020$) F/G. In the common period (d 24 to 38), there was a quadratic response ($P \leq 0.025$) where pigs fed the medium ABC-4 diets had increased ADFI and poorer F/G compared to pigs fed the low and high ABC-4 diets. Overall (d 0 to 24), pigs fed increasing ABC-4 had poorer (linear, $P = 0.043$) F/G. Pigs fed increasing ABC-4 had decreased (linear, $P \leq 0.005$) fecal DM percentage on d 10 and 24. There were no differences in fecal DM on d 17 of the study ($P > 0.10$).

When comparing the two medium ABC-4 diets, there were no differences in growth performance for the duration of the study ($P > 0.10$). For fecal DM, pigs fed the medium ABC-4 diet based on specialty soy protein source replacement had increased ($P = 0.003$) fecal DM on d 10 compared to pigs fed the medium ABC-4 diet based on removing the acidifiers. There were no differences between the medium ABC-4 diets for d 10 or 24 fecal DM ($P > 0.10$).

Pigs fed diets containing ZnO tended to have improved ($P = 0.075$) F/G compared to pigs fed diets without ZnO during phase 1 (d 0 to 10). In phase 2 (d 10 to 24) and the experimental period (d 0 to 24), pigs fed diets containing ZnO had improved ($P \leq 0.047$) BW, ADG, ADFI, and F/G compared to pigs fed diets without ZnO. In the common period (d 24 to 38), pigs previously fed diets containing ZnO had poorer ($P = 0.005$) ADG and F/G compared to pigs previously fed diets without ZnO. Overall (d 0 to 38), there were no differences between pigs fed diets with or without ZnO ($P > 0.10$). For fecal DM, pigs fed diets containing ZnO had increased ($P < 0.001$) fecal DM on d 10 and tended to have increased ($P = 0.077$) fecal DM percentage on d 17. There were no differences in diets with or without ZnO for d 24 fecal DM ($P > 0.10$).

In conclusion, increasing dietary ABC-4 resulted in a linear decrease in pig growth performance and fecal consistency. Additionally, there were no significant differences between the medium ABC-4 diets for growth performance suggesting the decrease in performance as ABC-4 increased was not due to a specific dietary change but rather a change in the complete diet's ABC-4 value. However, removal of acidifiers negatively affected fecal DM compared to replacement of the specialty soy protein source on d 10 of the study. This study also suggests a low ABC-4 diet without ZnO can result in similar performance as diets containing ZnO.

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Table 1. Phase 1 diet composition (as-fed basis)[1]

	ABC-4				
ABC-4, meq/kg:	**Low**	**Medium 1**	**Medium 2**	**High**	**High[2]**
ZnO:	-	-	-	-	+
Ingredients, %					
Corn	50.56	48.52	51.37	49.27	48.87
Soybean meal	16.31	16.31	16.31	16.31	16.31
Crystalline lactose	15.00	15.00	15.00	15.00	15.00
Specialty soy protein concentrate[3]	9.38	---	9.38	---	---
Enzymatically treated soybean meal[4]	---	11.40	---	11.40	11.40
Spray-dried bovine plasma	2.50	2.50	2.50	2.50	2.50
Corn oil	2.00	2.00	2.00	2.00	2.00
Limestone	0.35	0.38	0.35	0.38	0.38
Monocalcium phosphate	0.93	0.85	0.93	0.83	0.83
Salt	0.70	0.83	0.70	0.83	0.83
L-Lys	0.44	0.44	0.44	0.44	0.44
DL-Met	0.19	0.19	0.19	0.20	0.20
L-Thr	0.22	0.24	0.23	0.24	0.24
L-Trp	0.08	0.08	0.08	0.08	0.08
L-Val	0.08	0.09	0.09	0.09	0.09
Fumaric acid	0.38	0.38	---	---	---
Formic acid	0.36	0.36	---	---	---
ZnO	---	---	---	---	0.40
Vitamin premix without phytase[5]	0.25	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15	0.15
Phytase	0.06	0.06	0.06	0.06	0.06
Total	100	100	100	100	100

continued

Table 1. Phase 1 diet composition (as-fed basis)[1]

	ABC-4				
ABC-4, meq/kg:	**Low**	**Medium 1**	**Medium 2**	**High**	**High[2]**
ZnO:	-	-	-	-	+
Calculated analysis					
SID amino acids, %					
Lys	1.36	1.36	1.36	1.36	1.36
Ile:Lys	56	56	56	56	56
Leu:Lys	116	112	116	112	112
Met:Lys	34	34	34	34	34
Met and Cys:Lys	56	56	56	56	56
Thr:Lys	66	66	66	66	66
Trp:Lys	22.2	22.4	22.2	22.4	22.4
Val:Lys	70	70	70	70	70
His:Lys	36	36	36	36	36
Total Lys, %	1.51	1.52	1.51	1.52	1.52
NE, kcal/lb	1,179	1,173	1,188	1,182	1,177
SID Lys:NE, g/Mcal	5.23	5.26	5.20	5.22	5.24
CP, %	21.1	20.9	21.2	21.0	21.0
Ca, %	0.50	0.52	0.50	0.51	0.51
P, %	0.53	0.54	0.53	0.54	0.54
STTD P, %	0.46	0.46	0.46	0.46	0.46
Calculated ABC-4, meq/kg	200	290	271	362	449

[1] Phase 1 diets were fed from d 0 to 10 post-weaning.
[2] Diet contained 3,000 ppm of Zn from ZnO.
[3] AX3 Digest; Protekta; Newport Beach, CA.
[4] HP 300; Hamlet Protein; Findlay, OH.
[5] Ronozyme HiPhos 2700 (DSM, Parsippany, NJ) provided an estimated release of 0.14% STTD P with 674 FYT/lb.

Table 2. Phase 2 diet composition (as-fed basis)[1]

	ABC-4				
ABC-4, meq/kg:	**Low**	**Medium 1**	**Medium 2**	**High**	**High[2]**
ZnO:	-	-	-	-	+
Ingredients, %					
Corn	57.11	55.33	57.85	56.07	55.82
Soybean meal	22.41	22.41	22.41	22.41	22.41
Crystalline lactose	7.50	7.50	7.50	7.50	7.50
Specialty soy protein concentrate[3]	7.50	---	7.50	---	---
Enzymatically treated soybean meal[4]	---	9.20	---	9.20	9.20
Corn oil	1.00	1.00	1.00	1.00	1.00
Limestone	0.51	0.53	0.51	0.53	0.53
Monocalcium phosphate	1.00	0.93	1.00	0.93	0.93
Salt	0.70	0.80	0.70	0.80	0.80
L-Lys	0.49	0.49	0.49	0.49	0.49
DL-Met	0.19	0.20	0.19	0.20	0.20
L-Thr	0.21	0.21	0.21	0.21	0.21
L-Trp	0.09	0.09	0.09	0.09	0.09
L-Val	0.12	0.13	0.12	0.13	0.13
Fumaric acid	0.38	0.38	---	---	---
Formic acid	0.36	0.36	---	---	---
ZnO	---	---	---	---	0.25
Vitamin premix without phytase[5]	0.25	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15	0.15
Phytase	0.06	0.06	0.06	0.06	0.06
Total	100	100	100	100	100

continued

Table 2. Phase 2 diet composition (as-fed basis)[1]

	ABC-4				
ABC-4, meq/kg:	**Low**	**Medium 1**	**Medium 2**	**High**	**High[2]**
ZnO:	-	-	-	-	+
Calculated analysis					
SID amino acids, %					
Lys	1.35	1.35	1.35	1.35	1.35
Ile:Lys	58	58	58	58	58
Leu:Lys	116	113	116	113	113
Met:Lys	35	35	35	35	35
Met and Cys:Lys	56	56	56	56	56
Thr:Lys	63	63	63	63	63
Trp:Lys	22.6	22.7	22.6	22.7	22.7
Val:Lys	71	71	71	71	71
His:Lys	36	36	36	36	36
Total Lys, %	1.50	1.50	1.50	1.50	1.50
NE, kcal/lb	1,134	1,130	1,143	1,139	1,136
SID Lys:NE, g/Mcal	5.40	5.43	5.36	5.39	5.40
CP, %	21.4	21.3	21.4	21.4	21.3
Ca, %	0.59	0.60	0.59	0.60	0.60
P, %	0.56	0.57	0.56	0.57	0.57
STTD P, %	0.46	0.46	0.46	0.46	0.46
Calculated ABC-4, meq/kg	250	322	321	394	448

[1] Phase 2 diets were fed from d 10 to 24 post-weaning.
[2] Diet contained 2,000 ppm of Zn from ZnO.
[3] AX3 Digest; Protekta; Newport Beach, CA.
[4] HP 300; Hamlet Protein; Findlay, OH.
[5] Ronozyme HiPhos 2700 (DSM, Parsippany, NJ) provided an estimated release of 0.14% STTD P with 674 FYT/lb.

Table 3. Evaluation of increasing the diet acid-binding capacity-4 (ABC-4) with specialty soy protein sources or acidifiers on nursery pig performance and fecal dry matter

	ABC-4						P[4] =		
ZnO:	-	-	-	-	+		ABC-4[5]		
ABC-4, meq/kg[2]:	Low	Medium 1	Medium 2	High	High[3]	SEM	Linear	Quadratic	ZnO[6]
BW, lb									
d 0	13.2	13.2	13.2	13.2	13.2	0.05	0.739	0.579	0.608
d 10	17.1	17.2	16.9	16.9	17.2	0.26	0.653	0.747	0.433
d 24	30.0	29.4	29.2	28.3	30.9	0.67	0.064	0.812	0.005
d 38	49.8	49.7	49.3	48.1	49.0	0.83	0.154	0.508	0.439
Phase 1 (d 0 to 10)									
ADG, lb	0.39	0.40	0.37	0.37	0.40	0.026	0.687	0.823	0.476
ADFI, lb	0.42	0.44	0.42	0.42	0.43	0.022	0.897	0.609	0.780
F/G	1.10	1.11	1.14	1.16	1.08	0.034	0.175	0.901	0.075
Phase 2 (d 10 to 24)									
ADG, lb	0.92	0.87	0.86	0.81	0.98	0.038	0.026	0.973	0.001
ADFI, lb	1.11	1.06	1.05	1.02	1.16	0.049	0.098	0.762	0.014
F/G	1.21	1.22	1.22	1.25	1.19	0.020	0.107	0.524	0.023
Experimental period (d 0 to 24)									
ADG, lb	0.70	0.67	0.66	0.63	0.74	0.030	0.062	0.978	0.005
ADFI, lb	0.82	0.80	0.78	0.77	0.85	0.035	0.187	0.862	0.047
F/G	1.18	1.19	1.20	1.22	1.16	0.012	0.020	0.625	0.001
Common period (d 24 to 38)									
ADG, lb	1.42	1.45	1.44	1.41	1.30	0.045	0.949	0.310	0.005
ADFI, lb	1.99	2.12	2.08	2.01	1.94	0.049	0.694	0.024	0.307
F/G	1.40	1.46	1.45	1.42	1.50	0.026	0.484	0.025	0.005
Overall (d 0 to 38)									
ADG, lb	0.96	0.96	0.94	0.92	0.94	0.022	0.159	0.695	0.454
ADFI, lb	1.25	1.29	1.26	1.23	1.25	0.031	0.564	0.291	0.516
F/G	1.30	1.34	1.34	1.33	1.33	0.013	0.043	0.059	0.897
Fecal DM, %[7]									
d 10[8]	23.3	22.1	18.4	19.5	25.0	1.25	0.002	0.181	<0.001
d 17	23.6	22.7	21.9	21.7	23.9		0.126	0.670	0.077
d 24	24.7	23.9	23.6	21.2	23.1		0.005	0.377	0.120

[1] A total of 300 pigs (initial BW of 13.2 ± 0.05 lb) were used in a 38-d nursery trial. A total of 5 dietary treatments with 12 replications per treatment were utilized with increasing acid-binding capacity-4 (ABC-4) levels plus a control diet.

[2] Increasing ABC-4 of the diet was done by replacing specialty soy protein concentrate (AX3 Digest; Protekta; Newport Beach, CA) with enzymatically treated soybean meal (HP 300; Hamlet Protein; Findlay, OH) and decreasing the levels of organic acids (fumaric acid and formic acid). The low ABC-4 diet was achieved by utilizing specialty soy protein concentrate and organic acids (fumaric acid and formic acid). The medium ABC-4 diet 1 was achieved by replacing specialty soy protein concentrate with enzymatically treated soybean meal on an SID Lys basis. The medium ABC-4 diet 2 was achieved by removing organic acids in the low ABC-4 diet. The high ABC-4 diet was achieved by replacing specialty soy protein concentrate with enzymatically treated soybean meal and removing organic acids. Phase 1 diets fed from d 0 to 10 were formulated with increasing ABC-4 levels from 200, 290, 271, and 362 meq/kg for the low, medium 1, medium 2, and high diets, respectively. Phase 2 diets fed from d 10 to 24 were formulated with increasing ABC-4 levels from 250, 322, 321, and 394 meq/kg for the low, medium 1, medium 2, and high diets, respectively.

[3] Formulated the same as the high ABC-4 diet with the addition of 3,000 and 2,000 ppm of Zn from ZnO in phase 1 and 2, respectively, which increased ABC-4 of the diet by 87 and 54 meq/kg, respectively.

[4] There were no significant differences when comparing pigs fed the two medium ABC-4 diets for growth performance or d 17 and 24 fecal DM ($P > 0.05$).

[5] For linear and quadratic analysis, the calculation takes the mean of medium ABC-4 diets 1 and 2 and excludes the diet containing ZnO.

[6] Compares pigs fed the high ABC-4 diets with and without Zn and excludes all other treatments.

[7] Treatment × day, $P = 0.022$; Treatment, $P < 0.001$; Day, $P < 0.012$. The P-values represented in the data table show the effect of treatment within day.

[8] Medium 1 vs. Medium 2, $P = 0.003$. All other comparisons of medium ABC-4 diets were not significant ($P > 0.10$).