Kansas Agricultural Experiment Station Research Reports

Volume 11
Issue 7 *Swine Day*

Article 28

2025

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Recommended Citation

Corso, Maxwell L.; Woodworth, Jason C.; Tokach, Mike D.; Gebhardt, Jordan T.; Goodband, Robert D.; DeRouchey, Joel M.; Gaffield, Katelyn N.; Hastad, Chad W.; and Warner, Alan J. (2025) "Effect of Dietary Formulation Strategy, Water Source, and Water Acidification on Growth Performance and Fecal Dry Matter in Nursery Pigs," *Kansas Agricultural Experiment Station Research Reports*: Vol. 11: Iss. 7. https://doi.org/10.4148/2378-5977.8762

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Funding Source

The authors wish to thank New Fashion Pork, Jackson, MN for providing the animals and technical assistance with this study.

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Effect of Dietary Formulation Strategy, Water Source, and Water Acidification on Growth Performance and Fecal Dry Matter in Nursery Pigs

Maxwell L. Corso, Jason C. Woodworth, Mike D. Tokach, Jordan T. Gebhard,[1] Robert D. Goodband, Joel M. DeRouchey, Katelyn N. Gaffield, Chad W. Hastad,[2] and Alan J. Warner[2]

Summary

A total of 987 weanling pigs [PIC 800 × (Fast LW × PIC L02), initially 14.9 ± 0.8 lb] were used to determine the effect of dietary formulation strategy, water source, and water acidification on growth performance and fecal dry matter (DM). Treatments were arranged in a 2 × 2 × 2 factorial with main effects of dietary formulation strategy (low ABC-4 vs conventional with ZnO), water source (rural vs well), and water acidification (with or without). Experimental diets were fed in two phases followed by a common phase 3 diet. Diets were formulated to have a dietary ABC-4 value of either 199 or 427 meq/kg in phase 1, and 249 or 441 meq/kg in phase 2. The conventional formulation strategy contained pharmacological levels of Zn from ZnO (3,026 and 2,270 ppm Zn in phase 1 and 2, respectively), whereas the low ABC-4 diet had low levels of Zn (110 ppm) provided by the trace mineral premix. Water was supplied by either rural or well sources. For the water acidification treatment, PerpHect H2O (Acid Products Company Inc., Chicago, IL) was used to acidify both water sources to a targeted pH of 4.0. Numerous 2- and 3-way interactions were observed. Overall, (d 0 to 33), a tendency for a 3-way interaction was observed for ADG ($P = 0.081$) where pigs fed the conventional diet with ZnO had better performance than those fed the low ABC-4 formulation strategy when provided acidified or non-acidified well water or acidified rural water. However, formulation strategy did not result in a significant change in ADG when pigs were provided with non-acidified rural water. For overall ADFI, a three-way interaction was observed ($P = 0.034$) where pigs fed the conventional diets with ZnO had better ADFI than those fed the low ABC-4 formulation strategy, regardless of water source or water acidification, with the greatest magnitude of improvement in pigs provided the acidified rural water. Pigs provided with rural water tended ($P = 0.072$) to have increased fecal DM compared to pigs provided with well water. No differences were observed for removals and mortality. Conventional diets with added ZnO resulted in increased ($P < 0.05$) ADG and ADFI compared to low ABC-4 diets without ZnO, which was likely due to the ZnO in the conventional

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diets as opposed to the ABC-4 level itself. In conclusion, formulating diets with pharmacological levels of Zn improved performance compared to low ABC-4 diet formulation strategies without added Zn, with marginal effects on performance due to water source or its acidification.

Introduction

Weaning is stressful and can lead to sub-optimal growth performance and gastrointestinal tract disturbances leading to post-weaning diarrhea (PWD). To mitigate the reduction in growth rate and prevent PWD, pharmacological levels of Zn from ZnO are widely used. However, due to recent environmental concerns, alternative strategies to pharmacological levels of Zn are needed. One potential alternative is formulating diets to low-acid binding-capacity-4 (ABC-4) values. Stas et al. (2023) observed that formulating diets to low ABC-4 values improved pig growth performance and increased fecal dry matter (DM) compared to diets formulated to high ABC-4 values without added ZnO. However, to our knowledge, no research has evaluated the effects of dietary ABC-4 formulation strategy in conjunction with varying water sources, and water acidification. Therefore, the objective of this experiment was to determine the interactive effects of diet formulation strategy (low ABC-4 vs. conventional with added ZnO), water acidification, and water source on growth performance, and fecal DM in weanling pigs.

Materials and Methods

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted at a commercial research-nursery site in south-central Minnesota. At weaning, pigs were moved and housed in a temperature-controlled nursery facility. A total of 48 pens were used, with each pen (6.2 × 10 ft) having plastic grated flooring, one cup waterer, and one three-hole stainless steel self-feeder. Access to feed and water was provided *ad libitum*. Pigs were allowed approximately 2.8 ft^2 per pig. The barn was equipped to utilize either rural or well water, with four water lines available to use in each pen, with two water lines for each source. Daily feed additions to each pen were accomplished using a robotic feeding system (FeedPro; Feedlogic Corp., Wilmar, MN) able to record feed deliveries for individual pens.

Animals and diets

A total of 987 pigs (PIC 800 × (Fast LW × PIC L02, initially 14.9 ± 0.8 lb) were used in a 33- day trial and were housed in mixed-gender pens with six pens per treatment. There was a similar number of barrows and gilts in each pen. Pens were blocked by initial weight and randomly assigned to one of eight treatments in a randomized complete block design. Treatments were arranged as a 2 × 2 × 2 factorial with main effects of dietary formulation strategy (low ABC-4 or conventional with added ZnO), water source (rural or well), and water acidification (with or without). Experimental diets were fed in two phases, followed by a common phase 3 diet (Table 1). Diet formulation strategy was achieved by utilizing specialty ingredients and acidifiers to reduce the dietary ABC-4 value in the low diet and using traditional ingredients plus pharmacological levels of Zn from ZnO in the conventional formulation strategy. Experimental diets were formulated to have a dietary ABC-4 value of either 199 or 427 meq/kg in phase 1, and 249 or 441 meq/kg in phase 2. The conventional diets in phases 1 and 2 contained 3,026 and 2,270 ppm Zn, respectively, with low ABC-4 diets containing 110 ppm of added Zn from the trace mineral premix. Phase 3 was a common corn-soybean meal-based diet with an ABC-4 value of 426 meq/kg. Phase 1 and 2 diets were manufactured at New Vision feed mill in Worthington, MN, and the phase 3 diet was manufactured at the New Fashion Pork feed mill in Round Lake, MN. All diets were formulated to meet or exceed the NRC (2012) requirement estimates for respective weight ranges of nursery pigs.

PerpHect H2O (Acid Products Company Inc., Chicago, IL), an inorganic sulfuric acid product, was used as the water acidifier and applied via a stock solution utilizing a medicator and delivered at a rate of 1:128 into the water source to reduce water pH to 4.0 ± 0.40. Initially, 9 oz acid/gal of water was added to the stock solution for the well water treatment, while 6 oz acid/gal of water was added to the stock solution for the rural water treatment to reach the target pH. Four pens per treatment were randomly selected and water pH was monitored throughout the trial, and the amount of stock solution was adjusted to reach the targeted pH. Water samples from each water source were collected on d 0, 11 and 18 and sent to the Kansas State University Soils Laboratory, Manhattan, KS, to be analyzed for pH, Ca, and Mg concentrations utilizing the ICP-OES procedure (Table 2). To calculate total hardness, the equation from Boyd (2015) was used: Total Hardness, ppm $CaCO_3$/L = (Ca, ppm × 2.479) + (Mg, ppm × 4.118).

Pigs were weighed on d 0, 11, 18, 26, and 33 of the trial, and fecal samples were collected from five average-weight pigs per pen on d 11 and 18 to determine the percentage fecal DM. Fecal samples were individually placed in a sterile bag and stored at the Kansas State University Applied Swine Nutrition Laboratory in a -4°F (-20°C) freezer until the time of analysis. After collection, fecal samples were dried at 130°F (55°C) in a forced-air oven and the ratio of dried-to-wet fecal weight determined the fecal percentage of DM.

Statistical analysis

Experimental data were analyzed using R Studio (version 4.1.1 (2021-08-10), R Foundation for Statistical Computing, Vienna, Austria) with pen serving as the experimental unit, treatment considered a fixed effect, and weight block considered a random effect for all analysis. Main effects and all two- and three-way interactions of diet formulation strategy, water source, and water acidification were evaluated. Fecal dry matter was analyzed over time as repeated measures. Removals and mortality were analyzed using a binomial distribution, where the denominator was the initial pen inventory, and the numerator was total pigs removed or dead during trial. All results were considered significant at $P \leq 0.05$ and marginally significant at $0.05 \leq P \leq 0.10$.

Results and Discussion

Water analysis

The well water samples had greater concentrations of both Ca and Mg compared to the rural water source at each of the collection time points (Table 2). However, rural water samples had increased pH compared to that of the well water samples. As a result of the greater concentrations of both Ca and Mg in well water, it had greater hardness than the rural water. Water analysis results remained consistent across all three collection time points.

Growth performance

Two- and three-way interactions were observed throughout the study (Table 3). For the experimental period from d 0 to 26, a tendency for a 3-way interaction was observed for ADG ($P = 0.062$) where pigs fed the conventional diet with ZnO and provided acidified water had better performance than those fed all other treatments that were also provided rural water. However, for pigs offered well water, those fed the conventional diet with ZnO had greater performance than the low ABC-4 formulation strategy when water was acidified, but with no water acidification, diet formulation strategy did not influence ADG. Overall, (d 0 to 33), a tendency for a three-way interaction was observed for ADG ($P = 0.081$) where pigs fed the conventional diet with ZnO had better performance than those fed the low ABC-4 formulation strategy when using acidified or non-acidified well water or acidified rural water. However, the formulation strategy did not result in a significant change in ADG when pigs were provided with non-acidified rural water, although a similar pattern was observed compared to the combinations of water source and water acidification.

A three-way interaction was observed ($P = 0.004$) for d 26 BW where the lowest BW was observed for pigs fed diets formulated to the low ABC-4 strategy regardless of water source or acidification. However, for pigs fed conventional diets with added ZnO, the best performance was observed when pigs were offered acidified rural water, with the other pigs fed the conventional formulation strategy intermediate. A three-way interaction was observed ($P = 0.036$) for d 33 BW where the lowest BW was observed for pigs fed diets with the low ABC-4 formulation strategy and well water and the low ABC-4 formulation strategy with acidified rural water. The highest BW was observed for pigs fed the conventional diets with added ZnO with acidified rural water or non-acidified well water, with other treatments intermediate.

For overall ADFI, a three-way interaction was observed ($P = 0.034$) where pigs fed the conventional diets with ZnO had better ADFI than those fed the low ABC-4 formulation strategy regardless of water source or water acidification, with the greatest magnitude of improvement in pigs provided the acidified rural water.

Feed efficiency was poorer ($P < 0.05$) for pigs fed the low ABC-4 diets and no water acidification compared to the conventional diets with added ZnO without water acidification, with the other treatments intermediate.

Dietary ABC-4 formulation strategy, water source, or water acidification had no effect on removals and mortality during the entire trial. There were no two- or three-way interactions ($P > 0.10$) observed for fecal DM. However, pigs provided with rural water had marginally ($P = 0.074$) greater fecal DM compared to pigs that were provided with well water.

Despite observed interactions, for main effects, pigs fed conventional diets with added ZnO had better ($P < 0.05$) ADG and ADFI compared to low ABC-4 formulation strategy diets, with no differences observed based on water source or water acidification (Table 4).

Acknowledgments

The authors wish to thank New Fashion Pork, Jackson, MN for providing the animals and technical assistance with this study.

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

	Phase 1		Phase 2		Phase 3
Diet formulation strategy[2]:	**Low ABC-4**	**Conventional**	**Low ABC-4**	**Conventional**	**Common[3]**
Item ZnO:	-	+	-	+	-
Ingredients, %					
Corn	53.61	48.25	47.89	49.20	65.68
Soybean meal	12.82	12.77	22.75	22.75	30.26
Corn DDGS	---	5.00	10.00	10.00	---
Whey powder	---	16.60	---	11.10	---
Whey permeate	15.00	---	10.00	---	---
Specialty SPC[4]	10.25	---	4.05	---	---
Fermented soybean meal[5]	---	10.10	---	2.60	---
Spray-dried bovine plasma	2.50	2.50	---	---	---
Choice white grease	2.00	2.00	1.00	1.00	---
Limestone	0.28	0.28	0.43	0.46	0.68
Monocalcium phosphate	0.75	0.35	0.70	0.50	1.00
Salt	0.30	0.35	0.48	0.48	0.60
L-Lys-HCL	0.46	0.43	0.56	0.56	0.50
DL-Met	0.21	0.19	0.22	0.21	0.28
L-Thr	0.21	0.18	0.23	0.23	0.30
L-Trp	0.05	0.05	0.06	0.06	0.05
L-Val	0.10	0.08	0.11	0.13	0.20
Choline chloride	0.04	0.04	---	---	---
Phytase[6]	0.04	0.04	0.04	0.04	---
Fumaric acid	0.50	---	0.50	---	---
Formic acid	0.50	---	0.60	---	---
ZnO[7]	---	0.41	---	0.30	---
Vitamin premix	0.25	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15	0.15
Total	100	100	100	100	100

continued

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

	Phase 1		Phase 2		Phase 3
Diet formulation strategy[2]:	**Low ABC-4**	**Conventional**	**Low ABC-4**	**Conventional**	**Common[3]**
Item ZnO:	-	+	-	+	-
Calculated analysis					
SID amino acids, %					
Lys	1.35	1.35	1.35	1.35	1.25
Ile:Lys	55	57	56	56	55
Met:Lys	36	34	38	37	40
Met and Cys:Lys	58	58	58	58	58
Thr:Lys	64	64	64	64	66
Trp:Lys	21.1	21.5	20.2	20.2	20.0
Val:Lys	70	71	70	70	73
His:Lys	35	35	35	35	33
Total Lys, %	1.50	1.50	1.51	1.50	1.38
NE, kcal/lb	1,187	1,113	1,129	1,117	1,304
SID Lys:NE, g/Mcal	5.16	5.50	5.43	5.48	5.48
CP, %	20.7	20.7	21.5	21.1	19.7
Ca, %	0.47	0.48	0.53	0.55	0.63
STTD P, %	0.45	0.45	0.45	0.45	0.47
Calculated ABC-4, meq/kg	199	427	249	441	426

[1]Phase 1 diets were fed from approximately 14.9 to 17.2 lb, phase 2 from 17.2 to 32.4 lb, and phase 3 from 32.4 lb to 42.3 lb.
[2]Low ABC-4 and conventional diets formulated to 199 and 427 meq/kg respectively.
[3]Common phase 3 diet contained phytase in the vitamin mineral premix providing 1,250 FTU/kg. Tribasic copper chloride was also added at 0.03% of the diet.
[4]AX3 Digest; Proteka; Newport Beach, CA.
[5]Fermex 200; Purina Animal Nutrition; Shoreview, MN.
[6]Optiphos Plus 2500 G (Huevepharma; Sofia, Bulgaria); provided 876 FTU/kg in phases 1 and 2.
[7]ABC-4 diet contained 3,026 ppm of supplemental Zn from ZnO and the vitamin trace mineral premix, while the low ABC-4 diet contained Zn only from the vitamin trace mineral premix.

Table 2. Analyzed pH, Ca, and Mg concentrations of rural and well water sources[1]

	pH	Calcium, ppm	Magnesium, ppm	Total hardness, mg $CaCO_3$/L[2]
d 0				
Rural	8.01	116.7	36.0	437.4
Well	7.85	258.7	95.6	1034.8
d 11				
Rural	7.93	116.2	35.6	434.8
Well	7.75	262.2	95.9	1044.9
d 18				
Rural	7.88	115.0	35.2	430.0
Well	7.66	259.9	95.2	1036.3

[1]Total hardness, mg $CaCO_3$/L = (Ca, ppm × 2.479) + (Mg, ppm × 4.118).

Table 3. Interactive effects of diet formulation strategy, water source, and water acidification on growth performance of nursery pigs[1]

	Water source									
	Rural				Well					
	No acidifier		Added acidifier[2]		No acidifier		Added acidifier			*P* =
	Conv.[3]	Low ABC-4	Conv.	Low ABC-4	Conv.	Low ABC-4	Conv.	Low ABC-4	SEM	3-way interaction
Body weight, lb										
d 0	14.9	14.9	14.9	14.9	15.0	14.9	15.0	14.9	0.39	0.665
d 11[4]	17.4	16.8	18.4	6.4	17.3	16.6	17.7	16.3	0.85	0.200
d 26[4,5]	33.3[a]	31.1[c]	35.5[a]	30.3[c]	33.8[b]	31.4[c]	33.6[b]	31.1[c]	1.29	0.004
d 33[4]	43.4[ab]	41.2[bc]	45.1[a]	39.7[c]	43.8[a]	40.7[c]	43.6[ab]	40.6[c]	1.61	0.036
Period 1 (d 0 to 11)										
ADG, lb[4]	0.21	0.14	0.27	0.10	0.16	0.11	0.22	0.10	0.044	0.476
ADFI, lb[4]	0.29	0.24	0.34	0.21	0.26	0.23	0.29	0.22	0.036	0.285
F/G[4]	1.61	2.07	1.36	11.71	1.98	0.55	1.45	4.92	2.345	0.451
Period 2 (d 11 to 26)										
ADG, lb[4,5,6]	1.01[bcd]	0.93[de]	1.11[a]	0.91[e]	1.06[ab]	0.97[cde]	1.03[bc]	0.95[de]	0.033	0.014
ADFI, lb	1.40[b]	1.22[c]	1.51[a]	1.18[c]	1.45[ab]	1.24[c]	1.43[ab]	1.24[c]	0.049	0.006
F/G[5]	1.39	1.31	1.36	1.29	1.37	1.27	1.39	1.32	0.020	0.688
Experimental period (d 0 to 26)										
ADG, lb[4,5]	0.65[bc]	0.58[d]	0.73[a]	0.55[d]	0.65[bc]	0.58[cd]	0.66[b]	0.56[d]	0.030	0.062
ADFI, lb[4,5]	0.90[b]	0.78[c]	0.99[a]	0.74[c]	0.91[b]	0.78[c]	0.92[ab]	0.78[c]	0.034	0.015
F/G[4]	1.40	1.36	1.35	1.36	1.40	1.34	1.38	1.39	0.020	0.756
Period 3 (d 26 to 33)										
ADG, lb	1.45	1.44	1.37	1.35	1.42	1.33	1.43	1.36	0.065	0.854
ADFI, lb	2.09	2.00	2.10	1.99	2.11	1.97	2.10	1.98	0.060	0.639
F/G	1.46	1.40	1.53	1.48	1.49	1.50	1.47	1.47	0.049	0.927
d 0 to 33										
ADG, lb[4]	0.81[abc]	0.75[cd]	0.86[a]	0.71[d]	0.80[bc]	0.74[d]	0.82[ab]	0.72[d]	0.029	0.081
ADFI, lb[4]	1.14[b]	1.03[c]	1.21[a]	1.00[c]	1.15[ab]	1.02[c]	1.15[ab]	1.02[c]	0.034	0.034
F/G	1.41	1.37	1.41	1.41	1.43	1.39	1.41	1.42	0.021	0.911

continued

Table 3. Interactive effects of diet formulation strategy, water source, and water acidification on growth performance of nursery pigs[1]

	Water source									
	Rural				Well					
	No acidifier		Added acidifier[2]		No acidifier		Added acidifier			*P* =
	Conv.[3]	Low ABC-4	Conv.	Low ABC-4	Conv.	Low ABC-4	Conv.	Low ABC-4	SEM	3-way interaction
Removals, %	5.2	6.1	6.8	6.8	10.0	7.6	6.9	9.9	3.00	0.400
Mortality, %	0.7	0.0	0.7	0.7	0.7	0.7	0.7	0.7	0.80	1.000
Total removals %	6.1	6.3	7.7	7.8	11	8.6	7.8	10.9	3.00	0.500
Fecal DM, %[4]										
d 117	19.8	20.8	18.9	19.8	20.1	18.7	17.5	18.6	1.00	0.978
d 18	19.9	20.5	19.3	19.3	19.1	18.1	19.1	19.8	---	---

[a, b, c]Means on the same row with different superscripts differ, $P < 0.05$.

[1]A total of 987 pigs [PIC 800 × (Fast LW × PIC L02), initially 14.9 ± 0.8 lb] were used in a 33-day trial with six replicates per treatment.

[2]PerpHect H2O (Acid Products Company Inc., Chicago, IL) was added to the water source via a medicator at a rate of 1:128 to reach a target pH of 4.0 ± 0.40.

[3]Conventional diets were formulated to 427 and 441 meq/kg; low ABC-4 diets were formulated to 199 and 249 meq/kg for phases 1 and 2 respectively. Conventional diets included 3,026 and 2,270 ppm of Zn as ZnO in phases 1 and 2, while the low ABC-4 diet contained 110 ppm Zn provided from the trace mineral premix.

[4]Water acidification by formulation strategy interaction ($P < 0.05$).

[5]Water source by formulation strategy interaction ($P < 0.05$).

[6]Water source by acidification interaction ($P < 0.05$).

[a,b,c,d]The P-values presented in the data table show the effect of water source × diet formulation strategy × water acidification × day; source, $P = 0.075$; diet formulation strategy, $P = 0.616$; acidification, $P = 0.271$.

Table 4. Main effects of diet formulation strategy, water source, and water acidification on nursery pig performance and fecal dry matter (DM)[1]

	Diet formulation stratedgy[2]				Water source				Water acidification[3]			
	Conv.	Low ABC-4	SEM	*P* =	Rural	Well	SEM	*P* =	No	Yes	SEM	*P* =
Body weight, lb												
d 0	15.0	14.9	0.36	0.716	14.9	15.0	0.36	0.594	14.9	14.9	0.36	0.960
d 11	17.7	16.5	0.83	< 0.001	17.2	17.0	0.83	0.100	17.0	17.2	0.83	0.239
d 26	34.0	31.0	1.25	<0.001	32.5	32.5	1.25	0.834	32.4	32.6	1.25	0.420
d 33	44.0	40.6	1.6	<0.001	42.4	42.2	1.6	0.596	42.3	42.3	1.6	0.954
Period 1 (d 0 to 11)												
ADG, lb	0.21	0.11	0.041	<0.001	0.18	0.15	0.041	0.016	0.15	0.17	0.041	0.221
ADFI, lb	0.30	0.22	0.034	<0.001	0.27	0.25	0.034	0.049	0.26	0.27	0.034	0.313
F/G	1.60	4.80	1.227	0.057	4.19	2.23	1.227	0.237	1.55	4.86	1.227	0.050
Period 2 (d 11 to 26)												
ADG, lb	1.05	0.94	0.029	<0.001	0.99	1.00	0.029	0.423	0.99	1.00	0.029	0.609
ADFI, lb	1.45	1.22	0.045	<0.001	1.33	1.34	0.045	0.506	1.33	1.34	0.045	0.348
F/G	1.38	1.30	0.013	<0.001	1.34	1.34	0.013	0.834	1.33	1.34	0.013	0.642
Experimental period (d 0 to 26)												
ADG, lb	0.67	0.57	0.027	<0.001	0.63	0.61	0.027	0.264	0.61	0.62	0.027	0.277
ADFI, lb	0.93	0.77	0.031	<0.001	0.85	0.84	0.031	0.515	0.84	0.85	0.031	0.225
F/G	1.38	1.36	0.015	0.062	1.37	1.38	0.015	0.350	1.37	1.37	0.015	0.997
Period 3 (d 26 to 33)												
ADG, lb	1.42	1.37	0.051	0.156	1.41	1.38	0.051	0.539	1.41	1.38	0.051	0.340
ADFI, lb	2.10	1.99	0.050	< 0.001	2.05	2.04	0.050	0.854	2.05	2.04	0.050	0.939
F/G, lb	1.49	1.46	0.029	0.398	1.47	1.48	0.029	0.641	1.46	1.49	0.029	0.431
d 0 to 33												
ADG, lb	0.82	0.73	0.027	< 0.001	0.78	0.77	0.027	0.110	0.77	0.78	0.027	0.733
ADFI, lb	1.16	1.02	0.031	< 0.001	1.09	1.08	0.031	0.426	1.08	1.09	0.031	0.319
F/G	1.42	1.40	0.013	0.104	1.40	1.41	0.013	0.356	1.40	1.41	0.013	0.508
Removals, %	7.0	7.5	1.54	0.800	6.2	8.5	1.67	0.200	7.1	7.5	1.54	0.800
Mortality, %	0.7	0.0	1.92	1.000	0.0	0.7	1.91	1.000	0.0	0.7	1.92	1.000
Total removals, %	8.0	8.2	1.54	0.900	6.9	9.5	1.68	1.000	7.8	8.5	1.56	0.700
Fecal DM, %[4]												
d 11	19.1	19.5	0.50	0.754	19.8	18.7	0.50	0.712	19.9	18.7	0.50	0.255
d 18	19.3	19.4	0.50	---	19.8	19.0	0.50	---	19.4	19.4	0.50	---

[1]A total of 987 pigs (PIC 800 × (Fast LW × PIC L02), initially 14.9 ± 0.8 lb) were used in a 33-day trial with six replicates per treatment.
[2]Conventional diets were formulated to 427 and 441 meq/kg; low ABC-4 diets were formulated to 199 and 249 meq/kg for phases 1 and 2 respectively. Conventional diets included 3,026 and 2,270 ppm of Zn as ZnO in phases 1 and 2, while the low ABC-4 diet contained 110 ppm Zn provided from the trace mineral premix.
[3]Acidifier was added to the water source via a medicator at a rate of 1:128 to reach a target pH of 4.0 ± 0.40.
[4]The P-values represented in the data table show the effect of the main effect × day; source, *P* = 0.075; diet formulation strategy, *P* = 0.616; acidification, *P* = 0.271.