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Evaluation of Crude Protein and Acid-Binding Capacity on Nursery Pig Growth Performance and Fecal Dry Matter

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Summary

A total of 360 weanling pigs (DNA 241 × 600; initially 11.5 ± 0.02 lb) were used in a 42-d study to evaluate the effects of crude protein (CP) and acid-binding capacity at a pH of 4 (ABC-4) on nursery pig growth performance and fecal dry matter (DM). Pens of pigs were randomly allotted to one of six dietary treatments in a generalized randomized block design with five pigs per pen and 12 pens per treatment. Pigs were blocked so there were four replications each of light-, medium-, and heavy-weight pens per treatment. Diets were corn-soybean meal-based and arranged in a 2 × 2 + 2 factorial. The first factor, ABC-4, was tested using a low ABC-4 diet formulation concept set at 200 meq/kg and 250 meq/kg in phases 1 and 2, respectively, compared to a traditional formulation concept where the ABC-4 level was not specifically considered. The second factor, CP, was tested at 21% (1.35% SID Lys) and 18% (1.15% SID Lys). Thus, the first four treatment diets consisted of: 1) low ABC-4 at 21% CP, 2) low ABC-4 at 18% CP, 3) traditional ABC-4 formulation strategy at 21% CP, and 4) traditional ABC-4 formulation strategy at 18% CP. Two diets served as controls: 5) treatment 3 with 3,000 ppm and 2,000 ppm of added Zn from zinc oxide (ZnO) in phases 1 and 2, respectively, and 6) treatment 4 with additional feed-grade amino acids (AA) at a SID Lys level of 1.35% while maintaining a CP of 18%. Treatment diets were fed in two phases from d 0 to 7 (phase 1) and d 7 to 21 (phase 2), followed by a common diet from d 21 to 42 (phase 3). On d 7 and 21, fecal samples were collected from the same three randomly selected pigs in each pen to determine fecal DM and fecal scoring. During the experimental period (d 0 to 21), an ABC-4 × CP interaction was observed ($P = 0.021$), where pigs fed diets formulated to 21% CP had improved feed efficiency ($P < 0.001$) compared to those fed the 18% CP diets, with the magnitude of improvement being greater when a low ABC-4 diet formulation was utilized. An improvement in ADG, ADFI, and feed efficiency was observed ($P \leq 0.035$) when ZnO was added to the traditionally formulated diet at 21% CP. Feed efficiency also improved ($P < 0.001$) when additional feed-grade AA were added to the traditional 18% CP diet. Overall (d 0 to 42), no ABC-4 × CP interactions were observed. However, pigs previously fed the low ABC-4 diets in phases 1 and 2 had improved ($P = 0.009$) feed efficiency compared to those fed the traditionally formulated diets. In addition, pigs previously fed 21% CP in

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phases 1 and 2 had improved ($P \leq 0.004$) ADG and feed efficiency compared to pigs fed 18% CP. Similar improvements ($P \leq 0.039$) in ADG and feed efficiency were observed when ZnO was added to the traditional 21% CP diet in phases 1 and 2 compared to the same diet without ZnO. Feed efficiency also improved ($P = 0.020$) in pigs fed the diet with additional feed-grade AA in phases 1 and 2 compared to those fed the traditional 18% CP diet without additional feed-grade AA. For fecal DM, there was an ABC-4 formulation strategy × CP × day interaction ($P = 0.043$); however, when evaluating ABC-4 × CP interactions on d 7 and d 21, there were no significant interactions within individual days ($P \geq 0.110$). Pigs fed low ABC-4 diets had higher fecal DM ($P \leq 0.005$) on d 7 and 21 compared to those on traditional diets. On d 7, the 21% CP + ZnO and 18% CP + AA treatments both had higher ($P \leq 0.027$) fecal DM compared to their respective treatments of comparison, but these differences were not seen on d 21. On d 21, diets formulated to 18% CP tended to increase ($P = 0.052$) fecal DM compared to pigs fed 21% CP. In summary, formulating diets using a low ABC-4 concept can improve both growth performance and fecal DM of nursery pigs, and reducing CP to 18% reduced the growth performance compared to 21% CP. Interestingly, formulating to 18% CP with additional AA maintained growth performance at a higher level than expected and warrants further investigation.

Introduction

Dietary protein serves as an important source of amino acids in swine diets, but excessive protein intake and an imbalance of amino acids in the diet can lead to a greater risk of diarrhea due to the proliferation of pathogenic bacteria and fermentation in the hindgut. Pharmacological levels of zinc are commonly used in nursery pig diets to promote gut health and improve growth performance. However, the uses of post-weaning diarrhea mitigants and growth promoters, such as pharmacological zinc and antibiotics, are increasingly regulated in some regions due to environmental concerns and the rise of antibiotic resistance. This has prompted the industry to seek alternative solutions. Various management and nutritional practices have been investigated to address the effects of post-weaning stress, including delayed weaning, modifications in crude protein, dietary acidifiers, fiber additions, and more. However, the effectiveness of these approaches remains inconsistent. The use of acidifiers has been an area of interest to overcome this post-weaning lag period by lowering stomach pH, thereby improving growth performance and fecal DM. A study conducted by Stas et al. (2025)[2] observed a benefit to low ABC-4 diets formulated to 200 and 250 meq/kg in phases 1 and 2, respectively, on nursery pig performance and fecal DM when compared to diets formulated to higher ABC-4 levels. Limbach et al. (2021)[3] observed an improvement in nursery pig growth performance as crude protein levels increased from 16 to 22%. However, fecal DM worsened as crude protein increased. There is limited research on the use of an ABC-4 formulation approach in conjunction with low crude protein levels and their interactive effects on growth performance and fecal DM. To address this gap, the present study was conducted alongside a related study utilizing the 2 × 2 dietary treatment structure in *Escherichia coli* F18-challenged pigs. Specifically, the objective of this study was to evaluate the effects of ABC-4 formulation strategy, CP

[2] Stas, E. B., M. D. Tokach, J. C. Woodworth, J. M. DeRouchey, R. D. Goodband, and J. T. Gebhardt. 2025. Evaluation of dietary acid-binding capacity level on nursery pig growth performance and fecal dry matter. J. Anim. Sci. 103. doi:10.1093/jas/skaf039.

[3] Limbach, J. R., C. D. Espinosa, E. Perez-Calvo, H. H. Stein. 2021. Effect of dietary crude protein level on growth performance, blood characteristics, and indicators of intestinal health in weanling pigs. J. Anim. Sci. 99(6). doi.org/10.1093/jas/skab166.

levels, and their interactive effects on non-challenged nursery pig performance and fecal DM.

Materials and Methods

Animals and diets

The protocol used in this experiment was approved by the Kansas State University Institutional Animal Care and Use Committee. This study was conducted at the Kansas State University Swine Research and Teaching nursery facility in Manhattan, KS. Each pen contained a 3-hole, dry self-feeder and a nipple waterer to provide *ad libitum* access to feed and water.

A total of 360 weanling pigs (DNA 241 × 600; initially 11.5 ± 0.02 lb) were used in a 42-d study to evaluate the effects of crude protein (CP) and acid-binding capacity at a pH of 4 (ABC-4) on nursery pig growth performance and fecal dry matter. Pens of pigs were randomly allotted to one of six dietary treatments in a generalized randomized block design with five pigs per pen and 12 pens per treatment. Pigs were blocked so there were four replications each of light (initially 9.0 ± 0.02 lb), medium (initially 11.4 ± 0.02 lb), and heavy (initially 13.9 ± 0.02 lb) weight pens per treatment. Diets were corn-soybean meal-based and arranged in a 2 × 2 + 2 factorial treatment design. The first factor, ABC-4, was tested using a low ABC-4 diet formulation concept set at 200 meq/kg and 250 meq/kg in phases 1 and 2, respectively, compared to a traditional formulation concept where the ABC-4 level was not specifically considered. The second factor, CP, was tested at 21% (1.35% SID Lys) and 18% (1.15% SID Lys). Thus, the first four treatment diets consisted of: 1) low ABC-4 with 21% CP, 2) low ABC-4 with 18% CP, 3) traditional ABC-4 formulation strategy with 21% CP, and 4) traditional ABC-4 formulation strategy with 18% CP. Two diets served as controls: 5) treatment 3 with 3,000 ppm and 2,000 ppm of added Zn from zinc oxide (ZnO) in phases 1 and 2, respectively, and 6) treatment 4 with additional feed-grade amino acids including Lys, Met, Thr, Trp, Val, and Ile at a SID Lys level of 1.35% while maintaining 18% CP. The common phase 3 diet was formulated to 1.30% SID Lys. All diets met or exceeded the nutrient requirement estimates of other amino acids as a ratio to Lys (NRC, 2012) for the specific weight ranges (Table 1). Treatment diets were fed in two phases from d 0 to 7 (phase 1) and d 7 to 21 (phase 2), followed by a common diet from d 21 to 42 (phase 3). Treatment diets were manufactured at the Kansas State University O.H. Kruse Feed Technology Innovation Center in Manhattan, KS, and fed in pellet form in phase 1 and meal form in phases 2 and 3. Pig weights and feed disappearance were measured on d 0, 7, 14, 21, 28, 35, and 42 to determine ADG, ADFI, and feed efficiency (G:F and F/G).

On d 7 and 21, fecal samples were collected from the same three randomly selected pigs in each pen to determine fecal dry matter (DM) and fecal score. Fecal scores were measured on a 0 to 4 scoring system: 0 = hard, pellet-like lumps; 1 = firm, formed feces; 2 = normal feces; 3 = mild looseness; and 4 = diarrhea. Fecal samples were dried at 131°F (55°C) in a forced air oven for 48 h, and the ratio of dried-to-wet fecal weight determined the percentage fecal dry matter. Fecal samples were analyzed separately for each pig and the average of the three samples from each pen was then used for statistical analysis.

Statistical analysis

Data were analyzed as a generalized randomized block design as a one-way ANOVA using the lmer function from the lme4 package in R Studio (Version 3.5.2, R Core

Team. Vienna, Austria) with pen serving as the experimental unit and dietary treatment and weight block as fixed effects. Fecal DM samples were analyzed using the fixed effects of day, treatment, and the associated interaction accounting for repeated measures over time. The effects of added zinc and additional feed-grade amino acids were tested by pairwise comparisons between the 21% and 18% CP traditional formulation diets, respectively. Fecal scores were summarized using the FREQ procedure of SAS OnDemand for Academics (SAS Institute, Inc., Cary, NC) and reported as a percentage of observations within each score category by treatment. When treatment was a significant source of variation, differences were determined by pairwise comparison using the Tukey-Kramer multiplicity adjustment to control for type 1 error. Results were considered significant with $P \leq 0.05$ and were considered marginally significant with $P \leq 0.10$.

Results and Discussion

Growth Performance

For phase 1 (d 0 to 7), no ABC-4 × CP interactions were observed (Table 2). A tendency for decreased ADFI and improvement in feed efficiency ($P \leq 0.057$) was observed for pigs fed the low ABC-4 diets compared to pigs fed diets using a traditional diet formulation strategy. An improvement in feed efficiency was observed ($P = 0.014$) in pigs fed diets with 21% CP compared to 18% CP. An increase in ADG and ADFI ($P \leq 0.011$) was observed, which resulted in a tendency for an improvement ($P = 0.051$) in feed efficiency when ZnO was added to the traditional 21% CP diet compared to the same diet without ZnO. Additionally, d 7 body weight (BW) increased ($P = 0.001$) when ZnO was added to the diet.

For phase 2 (d 7 to 21), no ABC-4 × CP interactions were observed. The low ABC-4 diets tended to decrease ($P = 0.067$) ADFI, which resulted in an improvement ($P = 0.017$) in feed efficiency compared to diets using a traditional formulation strategy. An improvement in ADG and feed efficiency ($P < 0.001$) was observed when pigs were fed diets with 21% CP compared to 18% CP. This led to a tendency for an increase in d 14 BW ($P = 0.088$) and an increase in d 21 BW ($P < 0.001$) for pigs fed diets formulated to 21% CP compared to those fed to 18% CP. Improvements in ADG and feed efficiency were observed ($P \leq 0.036$), as well as a tendency for increased ($P = 0.091$) ADFI when ZnO was added to the traditional 21% CP diet compared to the same diet without ZnO. Pigs fed the diet with ZnO also had greater d 14 and d 21 BW ($P < 0.001$) than pigs fed the 21% CP diet following a traditional formulation strategy without ZnO. Furthermore, an improvement in feed efficiency ($P = 0.002$) was observed when additional feed-grade AA was added to the traditional 18% CP diet compared to the same diet without additional feed-grade AA.

For the experimental period (d 0 to 21), an ABC-4 × CP interaction was observed ($P = 0.021$), where diets formulated to 21% CP improved feed efficiency ($P < 0.001$) compared to the 18% CP diets, with the extent being greater when a low ABC-4 diet formulation was used. An improvement in ADG, ADFI, and feed efficiency was observed ($P \leq 0.035$) when ZnO was added to the traditionally formulated diet at 21% CP. Feed efficiency also improved ($P < 0.001$) in pigs fed the traditional 18% CP diet with added feed-grade AA compared to those fed the same diet without the additional AA.

For phase 3 (d 21 to 42), no ABC-4 × CP interactions or treatment differences were observed. However, pigs previously fed either of the 21% CP diets had increased d 28, 35, and 42 BW ($P \leq 0.009$) compared to those previously fed either of the 18% CP diets. Additionally, an increase in d 35 and 42 BW was observed ($P \leq 0.05$) when ZnO was added to the traditional 21% CP diet from d 0 to 21 compared to when the same diet was fed without added ZnO.

Overall (d 0 to 42), no ABC-4 × CP interactions were observed. Pigs fed the diets formulated using a low ABC-4 diet formulation strategy had improved ($P = 0.009$) feed efficiency compared to those fed diets using a traditional formulation strategy. In addition, pigs fed diets formulated to 21% CP had improved ($P \leq 0.004$) ADG and feed efficiency compared to pigs fed 18% CP. Similarly, improvements ($P \leq 0.039$) in ADG and feed efficiency were observed when ZnO was added to the traditional 21% CP diet compared to the same diet without ZnO. An improvement in feed efficiency was also observed ($P = 0.020$) in pigs fed the diet with additional feed-grade AA compared to those fed the traditional 18% CP diet without additional feed-grade AA.

Fecal DM and scoring

For fecal DM, an ABC-4 × CP × day interaction was observed ($P = 0.043$), indicating the interactive response between ABC-4 and CP differed between days. However, there were no significant ABC-4 × CP interactions within individual days ($P \geq 0.110$). Thus, the ABC-4 × CP × day interaction is likely driven by differences in direction of response and magnitude between the two days. On both d 7 and 21, pigs fed the low ABC-4 diets had increased fecal DM ($P < 0.005$) compared to pigs fed diets following a traditional formulation strategy. On d 7, but not on d 21, pigs fed the diet with added ZnO had increased ($P = 0.027$) fecal DM compared to pigs fed the traditional 21% CP diet without ZnO. Adding feed-grade AA increased ($P = 0.012$) d 7 fecal DM compared to the traditional 18% CP diet. On d 21, a tendency for a CP effect was observed ($P = 0.052$) where feeding 18% CP diets resulted in an increase in fecal DM compared to pigs fed 21% CP.

For fecal scoring, an ABC-4 × CP × day interaction was not observed ($P > 0.05$). There was an ABC-4 × day interaction ($P = 0.007$) due to an effect of ABC-4 d 7 ($P < 0.001$), where a low ABC-4 formulation strategy lowered the frequency of diarrhea compared to the traditional ABC-4 formulation strategy. There was also a tendency for a CP effect ($P = 0.093$) where pigs fed 18% CP had lower frequency of diarrhea compared to pigs fed the diets formulated to 21% CP.

In summary, formulating diets using a low ABC-4 diet formulation concept can improve both growth performance and fecal dry matter, while reducing CP and SID Lys worsened the growth performance. Interestingly, formulating to 18% CP with additional AA maintained growth performance and fecal DM at a higher level than expected and warrants further investigation.

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

	Phase 1					
ABC-4 formulation approach:	**Low**		**Traditional**			
CP, %:	**21**	**18**	**21**	**18**	**21 + ZnO**	**18 + AA**
Ingredient, %						
Corn	49.84	58.03	45.60	53.36	45.17	54.22
Soybean meal (47% CP)	15.81	8.02	16.29	8.53	16.32	6.56
Enzymatically treated SBM[2]	---	---	12.50	12.50	12.50	12.50
Specialty soy protein concentrate[3]	12.50	12.50	---	---	---	---
Lactose	15.00	15.00	---	---	---	---
Whey powder	---	---	15.00	15.00	15.00	15.00
Whey permeate (80% lactose)	---	---	5.25	5.25	5.25	5.25
Soybean oil	2.00	2.00	2.00	2.00	2.00	2.00
Calcium carbonate	0.35	0.35	0.57	0.55	0.57	0.53
Monocalcium P (21% P)	1.51	1.62	0.85	0.95	0.85	0.98
Salt	0.79	0.80	0.47	0.48	0.47	0.47
L-Lys-HCl	0.49	0.48	0.42	0.40	0.42	0.72
DL-Met	0.26	0.21	0.25	0.20	0.25	0.34
L-Thr	0.23	0.21	0.20	0.18	0.20	0.33
L-Trp	0.06	0.06	0.03	0.04	0.03	0.09
L-Val	0.13	0.10	0.12	0.10	0.12	0.28
L-Ile	0.02	0.03	---	0.01	---	0.16
L-His HCl	---	---	---	---	---	0.12
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25
Phytase[4]	0.08	0.08	0.08	0.08	0.08	0.08
Zinc oxide	---	---	---	---	0.40	---
Fumaric acid	0.28	0.07	---	---	---	---
Formic acid	0.28	0.07	---	---	---	---
Total	100	100	100	100	100	100

continued

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

	Phase 1					
ABC-4 formulation approach:	**Low**		**Traditional**			
CP, %:	**21**	**18**	**21**	**18**	**21 + ZnO**	**18 + AA**
Calculated analysis						
SID AA, %						
Lys, %	1.35	1.15	1.35	1.15	1.35	1.35
Ile:Lys	60	60	60	60	60	60
Leu:Lys	114	119	115	119	114	97
Met:Lys	40	39	38	38	38	42
Met and Cys:Lys	60	60	60	60	60	60
Thr:Lys	65	65	65	65	65	65
Trp:Lys	20.2	20.2	20.2	20.2	20.2	20.2
Val:Lys	72	72	72	72	72	72
His:Lys	35	35	35	35	35	35
NE, kcal/lb	1,172	1,195	1,174	1,193	1,169	1,203
SID Lys:NE, g/Mcal	5.23	4.36	5.21	4.37	5.24	5.09
CP, %	21.1	18.0	21.1	18.0	21.1	18.0
Ca, %	0.61	0.60	0.70	0.68	0.70	0.67
STTD P, %	0.42	0.42	0.42	0.42	0.42	0.42
Ca:P	0.96	0.97	1.10	1.10	1.10	1.10
Calculated ABC-4, meq/kg	200	200	474	431	561	418

[1] Phase 1 diets were fed from d 0 to 7.
[2] HP 300; Hamlet Protein; Findlay, OH.
[3] AX3 Digest; Protekta; Newport Beach, CA.
[4] Ronozyme HiPhos 2700 (DSM-Firmenich; Parsippany, NJ) provided at an estimated release of 0.14% STTD P with 919 FTU/lb.

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

	Phase 2						
ABC-4 formulation approach:	Low		Traditional				Phase 3
CP, %:	21	18	21	18	21 + ZnO	18 + AA	Common
Ingredient, %							
Corn	58.84	67.08	56.33	64.11	56.04	64.79	66.30
Soybean meal (47% CP)	17.72	9.93	18.56	10.79	18.58	8.99	29.74
Enzymatically treated SBM[2]	---	---	10.00	10.00	10.00	10.00	---
Specialty soy protein concentrate[3]	10.00	10.00	---	---	---	---	---
Lactose	7.50	7.50	---	---	---	---	---
Whey powder	---	---	10.50	10.50	10.50	10.50	---
Soybean oil	1.00	1.00	1.00	1.00	1.00	1.00	---
Calcium carbonate	0.60	0.59	0.60	0.58	0.60	0.57	0.80
Monocalcium P (21% P)	1.30	1.40	0.86	0.96	0.86	0.99	0.91
Salt	0.69	0.70	0.56	0.58	0.56	0.58	0.61
L-Lys-HCl	0.52	0.51	0.47	0.46	0.47	0.77	0.50
DL-Met	0.25	0.20	0.24	0.19	0.24	0.33	0.23
L-Thr	0.24	0.22	0.22	0.19	0.22	0.35	0.23
L-Trp	0.06	0.06	0.05	0.05	0.05	0.10	0.05
L-Val	0.14	0.12	0.14	0.11	0.14	0.30	0.16
L-Ile	0.01	0.03	---	0.01	---	0.16	---
L-His HCl	---	---	---	---	---	0.11	---
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Phytase[4]	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Zinc oxide	---	---	---	---	0.27	---	---
Fumaric acid	0.33	0.11	---	---	---	---	---
Formic acid	0.33	0.11	---	---	---	---	---
Total	100	100	100	100	100	100	100

continued

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

	Phase 2						
ABC-4 formulation approach:	**Low**		**Traditional**				**Phase 3**
CP, %:	**21**	**18**	**21**	**18**	**21 + ZnO**	**18 + AA**	**Common**
Calculated analysis							
SID AA, %							
Lys, %	1.35	1.15	1.35	1.15	1.35	1.35	1.30
Ile:Lys	58	58	58	58	58	58	55
Leu:Lys	115	120	115	119	115	98	115
Met:Lys	40	39	38	38	38	42	39
Met and Cys:Lys	60	60	60	60	60	60	60
Thr:Lys	65	65	65	65	65	65	65
Trp:Lys	20.2	20.2	20.2	20.2	20.2	20.2	20.2
Val:Lys	72	72	72	72	72	72	72
His:Lys	35	35	36	35	36	35	37
NE, kcal/lb	1,139	1,164	1,143	1,162	1,140	1,171	1,104
SID Lys:NE, g/Mcal	5.37	4.48	5.36	4.49	5.37	5.23	5.34
CP, %	21.1	18.0	21.1	18.0	21.1	18.0	20.6
Ca, %	0.67	0.65	0.67	0.66	0.67	0.65	0.69
STTD P, %	0.39	0.39	0.39	0.39	0.39	0.39	0.46
Ca:P	1.10	1.10	1.10	1.10	1.10	1.10	1.20
Calculated ABC-4, meq/kg	250	250	436	392	495	382	423

[1] Phase 2 diets were fed from d 10 to 21. Phase 3 diets were fed from d 21 to 42.
[2] HP 300; Hamlet Protein; Findlay, OH.
[3] AX3 Digest; Protekta; Newport Beach, CA.
[4] Ronozyme HiPhos 2700 (DSM-Firmenich; Parsippany, NJ) provided at an estimated release of 0.14% STTD P with 919 FTU/lb.

Table 3. Effects of ABC-4 and CP on growth performance and fecal DM of nursery pigs[1]

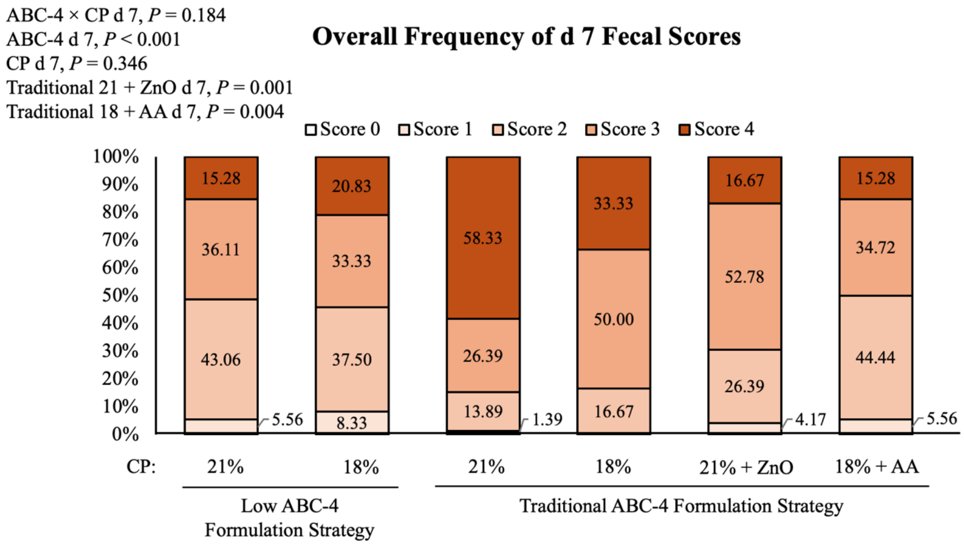
ABC-4 formulation approach:	Low		Traditional					*P* =				
CP, %:	21	18	21	18	21 + ZnO	18 + AA	SEM	ABC-4 × CP	ABC-4	CP	ZnO[2]	AA[3]
BW, lb												
d 0	11.5	11.4	11.4	11.5	11.5	11.5	0.02	0.626	0.920	0.840	0.830	0.962
d 7	13.3	13.1	13.3	13.2	14.1	13.5	0.15	0.940	0.870	0.396	0.001	0.190
d 14	15.4	14.9	15.6	15.1	17.2	15.4	0.28	0.947	0.551	0.088	< 0.001	0.514
d 21	21.7	19.7	21.6	20.0	24.0	20.9	0.37	0.588	0.805	< 0.001	< 0.001	0.113
d 28	28.7	27.3	29.4	26.9	30.1	27.9	0.46	0.281	0.788	< 0.001	0.255	0.129
d 35	39.0	37.4	39.3	37.0	40.8	37.9	0.56	0.524	0.862	0.001	0.050	0.239
d 42	48.9	47.2	48.8	47.0	51.0	48.4	0.65	0.901	0.859	0.009	0.023	0.136
Phase 1 (d 0 to 7)												
ADG, lb	0.26	0.24	0.26	0.25	0.37	0.29	0.021	0.996	0.880	0.374	0.001	0.182
ADFI, lb	0.25	0.27	0.30	0.30	0.37	0.31	0.019	0.700	0.057	0.590	0.011	0.813
G:F	1.07	0.85	0.88	0.83	1.02	0.93	0.053	0.110	0.052	0.014	0.051	0.176
F/G[4]	0.98	1.43	1.22	1.23	0.99	1.09	0.144	---	---	---	---	---
Phase 2 (d 7 to 21)												
ADG, lb	0.60	0.46	0.59	0.49	0.70	0.53	0.026	0.394	0.816	< 0.001	0.003	0.289
ADFI, lb	0.77	0.72	0.84	0.78	0.92	0.75	0.034	0.913	0.067	0.159	0.091	0.458
G:F	0.78	0.64	0.71	0.62	0.76	0.71	0.018	0.130	0.017	< 0.001	0.036	0.002
F/G[4]	1.30	1.58	1.43	1.62	1.32	1.43	0.038	---	---	---	---	---
Experimental period (d 0 to 21)												
ADG, lb	0.49	0.39	0.48	0.41	0.59	0.45	0.019	0.415	0.791	< 0.001	< 0.001	0.140
ADFI, lb	0.60	0.57	0.66	0.62	0.73	0.60	0.026	0.872	0.040	0.264	0.035	0.548
G:F	0.82	0.68	0.73	0.66	0.81	0.75	0.013	0.021	< 0.001	< 0.001	< 0.001	< 0.001
F/G[4]	1.23	1.48	1.38	1.54	1.24	1.35	0.025	---	---	---	---	---

continued

Table 3. Effects of ABC-4 and CP on growth performance and fecal DM of nursery pigs[1]

ABC-4 formulation approach:	Low		Traditional					*P* =				
CP, %:	21	18	21	18	21 + ZnO	18 + AA	SEM	ABC-4 × CP	ABC-4	CP	ZnO[2]	AA[3]
Phase 3 (d 21 to 42)												
ADG, lb	1.29	1.30	1.30	1.28	1.29	1.31	0.025	0.709	0.817	0.868	0.742	0.448
ADFI, lb	1.91	1.92	1.95	1.91	1.94	1.94	0.040	0.475	0.775	0.788	0.901	0.525
G:F	0.68	0.68	0.67	0.67	0.67	0.68	0.008	0.698	0.382	0.858	0.782	0.841
F/G[4]	1.47	1.48	1.50	1.49	1.50	1.48	0.018	---	---	---	---	---
Overall (d 0 to 42)												
ADG, lb	0.89	0.84	0.89	0.85	0.94	0.88	0.016	0.586	0.879	0.004	0.028	0.143
ADFI, lb	1.25	1.24	1.30	1.26	1.33	1.27	0.027	0.765	0.161	0.356	0.350	0.855
G:F	0.71	0.68	0.68	0.67	0.70	0.69	0.007	0.161	0.009	0.001	0.039	0.020
F/G[4]	1.41	1.48	1.46	1.50	1.42	1.45	0.015	---	---	---	---	---
Fecal DM, %[6]												
d 7	19.3	19.0	12.7	15.0	15.9	18.5	0.98	0.201	< 0.001	0.326	0.027	0.012
d 21	19.5	23.0	18.3	18.6	17.6	20.9	0.98	0.110	0.005	0.052	0.617	0.109

[1] A total of 360 pigs (initially 11.5 ± 0.02 lb) were used in a 42-d growth study with five pigs per pen and 12 replicates per treatment.
[2] Comparing 21% CP, traditional formulation strategy diet and 21% CP, traditional formulation strategy diet with zinc oxide.
[3] Comparing 18% CP, traditional formulation strategy diet and 18% CP, traditional formulation strategy diet with additional feed-grade animo acids.
[4] F/G was calculated taking the inverse of G:F. *P*-values are the same as reported for G:F.
[5] Simple effect of CP in low ABC-4 and traditional diets ($P < 0.001$). Simple effect of ABC-4 in high CP diets ($P < 0.001$).
[6] ABC-4 × CP × day interaction ($P = 0.043$).



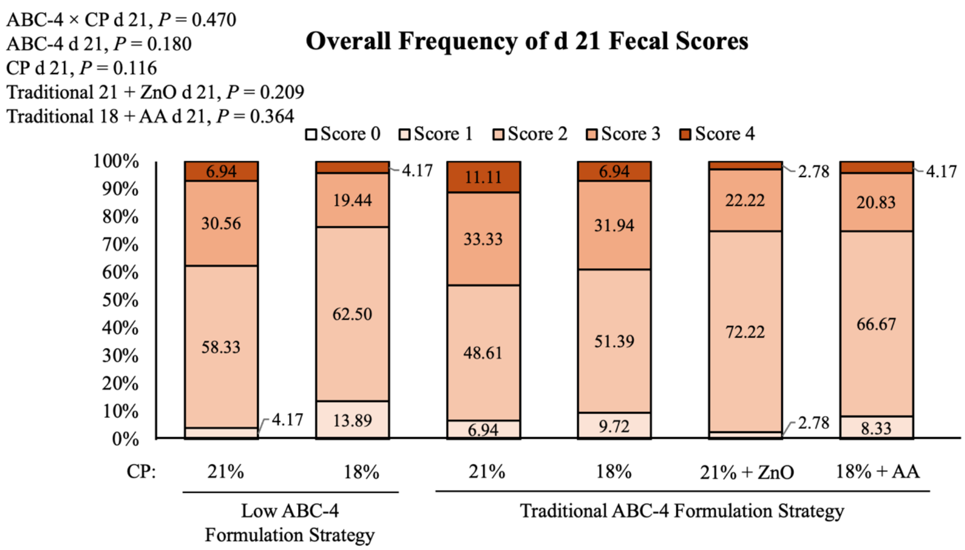


Figure 1. Overall frequency of diarrhea. Fecal scores are presented on a scale from 0 to 4 with 0 representing hard, pellet-like lumps and 4 indicating diarrhea. ABC-4 × CP × day (*P* = 0.122); ABC-4 × day (*P* = 0.007); CP × day (*P* = 0.627); ABC-4 × CP (*P* = 0.690); Traditional 21 + ZnO × day (*P* = 0.133); Traditional 18 + AA × day (*P* = 0.134); ABC-4 (*P* < 0.001); CP (*P* = 0.093).