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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

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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 12.4 lb) were used to evaluate specialty soybean products and organic acids to alter the acid-binding capacity-4 (ABC-4) level of the diet on nursery pig performance and fecal dry matter (DM). At weaning, pigs were allotted to 1 of 6 dietary treatments. Diet 1 was formulated with 12.0% specialty soy protein concentrate (AX3 Digest; Protekta; Plainfield, IN), 1.06% citric acid, and 0.5% fumaric acid to achieve an ABC-4 of 223 meq/kg. Diets 2 and 3 were the same as diet 1 except citric and fumaric acid were reduced by 50 and 100% to achieve an ABC-4 of 280 or 338 meq/kg, respectively. Diets 4 and 5 were formulated with 50 and 100% replacement of specialty soy protein concentrate with enzymatically treated soybean meal (HP 300; Hamlet Protein; Findlay, OH) on a SID Lys basis with 1.06% citric acid and 0.5% fumaric acid to achieve 280 and 338 meq/kg, respectively. Diet 6 was a positive control with the same formulation as diet 5 except for the addition of 2,500 ppm of Zn from ZnO to achieve a diet ABC-4 of 410 meq/kg. The dietary treatment structure facilitated the comparison of an increase in the ABC-4 level (223 to 338 meq/kg), and the method achieve the change (decreasing acidifier vs. specialty soy protein concentrate replacement diets) as well as their interactions. Pigs were fed the experimental diet for 24 d postweaning (d 0 to 24) followed by a common diet for an additional 18 d. There were no significant ($P > 0.05$) ABC-4 method × level interactions through the duration of the study. From d 0 to 10, pigs fed increasing ABC-4 had poorer (linear, $P = 0.046$) F/G. Pigs fed the decreasing acidifier diets had increased ($P = 0.038$) fecal percentage DM on d 17 than pigs fed the soy source replacement diets. During the experimental period (d 0 to 24), pigs fed the diet with ZnO had improved ($P < 0.05$) BW, ADG, ADFI, and F/G compared to pigs fed diets without ZnO. In summary, ZnO was able to improve nursery pig performance when experimental diets were fed. Increasing the ABC-4 level and the method to do so had minimal effects on nursery pig performance. However, further investigation is warranted to determine if a lower ABC-4 level would provide more benefit.

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

Introduction

Pigs weaned between 17 and 21 days of age have an underdeveloped gastrointestinal tract with limited hydrochloric acid production until approximately 7 to 8 weeks of age at which point the gut is fully mature.[2] Switching pigs to a solid diet at weaning may lead to an increase in gastric pH of newly weaned pigs. Low stomach pH is important for protein digestion and when stomach pH increases above 3.5, pepsin activity rapidly declines which decreases nutrient utilization.[3] Increased gastric pH also creates an opportunity for pathogens to proliferate and compromise the gastrointestinal tract, leading to clinical infection, disease, and possible death.[4]

Poor acidification in the stomach can be attributed to the high acid-binding capacity of feed ingredients. The concept of acid-binding capacity-4 (ABC-4) involves manipulating the stomach's acidity by incorporating low acid-binding dietary ingredients to maintain an acidic stomach pH and improve nursery pig performance.[5] Acid-binding capacity-4 is measured as the amount of acid in milliequivalents (meq) required to lower 1 kg of an ingredient or diet to a pH of 4. A previous study by Stas et al.[6] reported a low ABC-4 diet can be utilized to improve nursery pig performance and reduce the instance of morbidity and mortality compared to a high ABC-4 diet. However, further research is warranted to understand if the method used to achieve a low ABC-4 affects the response to ABC-4 level in the diet. Therefore, the objective of this study was to evaluate the use of specialty soybean products and organic acids to alter the acid-binding capacity-4 (ABC-4) level of the diet on nursery pig performance and fecal dry matter.

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.

Animals and diets

A total of 300 pigs (241 × 600, DNA; initially 12.4 lb) were used in a 42-d nursery trial. Pigs were weaned at approximately 21 d of age and placed in pens of 5 pigs each based on initial weight and gender. At weaning, pigs were randomly allotted to 1 of 6 dietary treatments with 10 replications per treatment. Dietary treatments consisted of

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[2] Pluske, J. R. 2016. Invited review: Aspects of gastrointestinal tract growth and maturation in the pre- and postweaning period of pigs. J. Anim. Sci. 94:399-411. doi:10.2527/jas2015-9767.

[3] Yen, J. T. 2001. Anatomy of the digestive system and nutritional physiology, In: Lewis, A. J., Southern, L. L. (Eds.), Swine Nutrition, CRC Press, Boca Raton, FL, pp. 21-64.

[4] Bolduan, G., H. Jung, R. Schneider, J. Block, and B. Klenke. 1988. Influence of fumaric-acid and propandiol-formiat on piglets. J. Anim. Physiol. Anim. Nutr. 59, 72-78. doi:10.1111/j.1439-0396.1988.tb00057.x

[5] Lawlor, P. G., P. B. Lynch, P. J. Caffrey, J. J. O'Reilly, and M. K. O'Connell. 2005. Measurements of the acid-binding capacity of ingredients used in pig diets. Ir. Vet. J. 58, 447-452. doi:10.1186/2046-0481-58-8-447.

[6] Stas, E. B., A. J. Warner, C. W. Hastad, M. D. Tokach, J. C. Woodworth, J. M. DeRouchey, R. D. Goodband, and J. T. Gebhardt. 2022. Effects of varying the acid-binding capacity-4 in diets utilizing specialty soy products with or without pharmacological levels of zinc on nursery pig performance. Kansas Agri. Exp. Station Research Reports: Vol. 8: Iss. 10. https://doi.org/10.4148/2378-5977.8370.

increasing the levels of ABC-4 by either altering the acidifier level or feeding different specialty soybean products to change diet ABC-4 levels. Treatment 1 was formulated with 12.0% specialty soy protein concentrate (AX3 Digest; Protekta; Plainfield, IN), 1.06% citric acid, and 0.5% fumaric acid to achieve the low ABC-4 level of 223 meq/kg. Treatments 2 and 3 increased ABC-4 through a 50 and 100% reduction of acidifiers for the medium and high ABC-4 levels, respectively. Treatments 4 and 5 increased ABC-4 by a 50 and 100% replacement of specialty soy protein concentrate with enzymatically treated soybean meal (HP 300; Hamlet Protein; Findlay, OH) on a SID Lys basis for the medium and high ABC-4 levels, respectively. Treatment 6 was a positive control diet with the same formulation as treatment 5 except 2,500 ppm of Zn from ZnO and achieved a diet ABC-4 level of 410 meq/kg.

Specialty soy protein concentrate (ABC-4 of -13 meq/kg) and enzymatically treated soybean meal (ABC-4 of 753 meq/kg) were selected because of their low and high ABC-4 values, respectively. Treatments 2 and 4 had an ABC-4 level of 280 meq/kg while treatments 3 and 5 both had an ABC-4 level of 338 meq/kg. The addition of ZnO in treatment 6 increased the diet ABC-4 by an additional 72 meq/kg. Diets were formulated to contain 1.36% SID Lys and met or exceeded other nutrient requirement estimates established by the NRC.[7] Treatment diets were fed for 24 d (d 0 to 24) followed by a common diet for an additional 18 d. Individual pig weights and feed disappearance were measured on d 10 and weekly thereafter to determine ADG, ADFI, and F/G.

Fecal samples were collected on d 10, 17, and 24 to determine fecal dry matter 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 and the ratio of dried to wet fecal weight determined the fecal percentage dry matter.

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. The main effect of method was tested by comparing treatments 2 and 3 (decreasing acidifier) vs. treatments 4 and 5 (specialty soybean product replacement). Polynomial effects of linear and quadratic diet ABC-4 levels were tested with treatment 1 as the low level, treatments 2 and 4 (280 meq/kg) as the medium level, and treatments 3 and 5 (338 meq/kg) as the high level. Interactions of both effects previously described were tested using the lmer function. The effect of ZnO was tested by a pairwise comparison of treatment 5 vs. 6. 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 $0.05 < P \leq 0.10$.

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

Results and Discussion

No significant method × ABC-4 level interactions were observed ($P > 0.05$) throughout the duration of the study. There were no differences for any response criteria in the common period (d 24 to 42) or overall (d 0 to 42).

From d 0 to 10, pigs fed decreasing ABC-4 had improved (linear, $P = 0.046$) F/G. A quadratic tendency was also observed for ADFI (quadratic, $P = 0.055$) where pigs fed an ABC-4 level of 280 meq/kg had the lowest ADFI. There were no differences with decreasing ABC-4 of the diet for fecal DM on d 10. Increasing the ABC-4 level by replacing the specialty soy protein concentrate with enzymatically treated soybean meal resulted in decreased ($P = 0.038$) fecal DM percentage on d 17 compared with pigs fed diets with increasing ABC-4 by removing acidifiers from the diet containing the specialty soy protein concentrate. For the overall experimental period (d 0 to 24), pigs fed specialty soybean product replacement diets tended to have increased ($P \leq 0.075$) BW and ADG compared to pigs fed the decreasing acidifier diets.

For pigs fed a diet with pharmacological levels of Zn from ZnO, from d 0 to 10 pigs fed diets with ZnO had improved ($P \leq 0.001$) BW, ADG, and F/G compared to pigs fed diets without ZnO. From d 10 to 24, pigs fed diets with ZnO had increased ($P \leq 0.001$) ADG and ADFI compared to pigs fed diets without ZnO. In the experimental period (d 0 to 24), pigs fed diets with ZnO had improved ($P \leq 0.005$) BW, ADG, ADFI, and F/G compared to pigs fed diets without ZnO. For fecal DM, pigs fed diets with ZnO had increased ($P = 0.002$) fecal DM percentage on d 17 and tended to have increased ($P = 0.061$) fecal DM percentage on d 24.

In conclusion, pharmacological levels of Zn improved nursery pig performance as expected. Decreasing ABC-4 levels of the diet and the method to do so had minimal effects on nursery pig performance. However, the decrease in levels of ABC-4 in the diets led to linear improvements in feed efficiency for the first 10 d post-weaning. Possibly, an increase in ABC-4 level from 223 to 338 meq/kg may not have been a large enough difference to show a response to changing ABC-4 of the diet. Further research is warranted to determine if a lower ABC-4 level or other ingredient changes to achieve target ABC-4 would provide more benefit.

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

Method:		Decreasing acidifier		Replacing specialty soy protein concentrate		
ZnO:	-	-	-	-	-	+
ABC-4, meq/kg:	223	280	338	280	338	410[2]
Ingredients, %						
Corn	51.77	52.55	53.33	50.37	49.05	48.72
Soybean meal, 46.8% CP[3]	20.30	20.30	20.30	20.30	20.30	20.30
Whey permeate, 80% lactose,	9.50	9.50	9.50	9.50	9.50	9.50
Specialty soy protein concentrate[4]	12.00	12.00	12.00	6.00	---	---
Enzymatically treated soybean meal[5]	---	---	---	7.35	14.65	14.65
Fumaric acid	0.50	0.25	---	0.50	0.50	0.50
Citric acid	1.06	0.53	---	1.06	1.06	1.06
Corn oil	2.00	2.00	2.00	2.00	2.00	2.00
Limestone	0.45	0.45	0.45	0.46	0.48	0.48
Monocalcium phosphate, 21.5% P	0.85	0.85	0.85	0.80	0.70	0.70
Salt	0.43	0.43	0.43	0.50	0.58	0.58
L-Lys	0.35	0.35	0.35	0.35	0.35	0.35
DL-Met	0.16	0.16	0.16	0.16	0.17	0.17
L-Thr	0.18	0.18	0.18	0.18	0.19	0.19
L-Trp	0.05	0.05	0.05	0.05	0.05	0.05
L-Val	0.02	0.02	0.02	0.02	0.03	0.03
Zinc oxide	---	---	---	---	---	0.33
Vitamin premix with phytase[6]	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15
Total	100	100	100	100	100	100

continued

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

Method:		**Decreasing acidifier**		**Replacing specialty soy protein concentrate**		
ZnO:	-	-	-	-	-	+
ABC-4, meq/kg:	223	280	338	280	338	410[2]
Calculated analysis						
SID amino acids, %						
Lys	1.36	1.36	1.36	1.36	1.36	1.36
Ile:Lys	64	64	64	64	64	64
Leu:Lys	125	125	126	123	121	120
Met:Lys	34	34	34	34	34	34
Met and Cys:Lys	56	56	56	56	56	56
Thr:Lys	66	66	66	66	66	66
Trp:Lys	22.3	22.3	22.3	22.4	22.5	22.5
Val:Lys	70	70	70	70	70	70
His:Lys	38	38	38	38	38	38
Total Lys, %	1.52	1.52	1.52	1.52	1.52	1.52
NE, kcal/lb	1,152	1,161	1,171	1,148	1,145	1,141
SID Lys:NE, g/Mcal	5.36	5.32	5.28	5.38	5.39	5.41
CP, %	23.0	23.1	23.1	22.9	22.8	22.8
Ca, %	0.53	0.53	0.53	0.54	0.54	0.54
P, %	0.56	0.56	0.56	0.56	0.56	0.56
STTD P, %	0.46	0.46	0.46	0.46	0.46	0.46

[1] Experimental diets were fed from approximately 12.4 to 25.0 lb.
[2] Diet contained 2,500 ppm of Zn from ZnO.
[3]CP = crude protein.
[4] AX3 Digest; Protekta; Plainfield, IN.
[5] HP 300; Hamlet Protein; Findlay, OH.
[6] Ronozyme HiPhos 2700 (DSM, Parsippany, NJ) provided an estimated release of 0.13% STTD P with 567 FYT/lb.

Table 2. Effects of two methods to increase dietary acid-binding capacity-4 (ABC-4) on nursery pig performance and fecal dry matter (DM)[1]

Method:		Decreasing acidifier[2]		Replacing soy source[3]				*P*[5] =			
ZnO:	-	-	-	-	-	+			ABC-4[7]		
ABC-4, meq/kg:	223	280	338	280	338	410[4]	SEM	Method[6]	Linear	Quadradic	ZnO[8]
BW, lb											
d 0	12.4	12.4	12.4	12.4	12.4	12.4	0.05	0.937	0.847	0.833	0.891
d 10	15.1	14.5	14.7	15.0	14.8	15.6	0.19	0.159	0.122	0.292	0.001
d 24	24.3	23.8	24.4	24.8	24.8	27.8	0.39	0.075	0.559	0.608	< 0.001
d 42	48.7	48.2	48.6	49.0	48.9	49.9	1.01	0.583	0.965	0.893	0.597
Phase 1 (d 0 to 10)											
ADG, lb	0.27	0.21	0.23	0.25	0.24	0.33	0.018	0.134	0.105	0.231	0.001
ADFI, lb	0.33	0.30	0.32	0.31	0.34	0.35	0.014	0.483	0.999	0.055	0.510
F/G	1.30	1.48	1.50	1.24	1.48	1.09	0.078	0.113	0.046	0.632	< 0.001
Phase 2 (d 10 to 24)											
ADG, lb	0.66	0.65	0.70	0.71	0.71	0.86	0.026	0.188	0.157	0.880	< 0.001
ADFI, lb	0.87	0.85	0.93	0.93	0.92	1.08	0.030	0.296	0.116	0.781	0.001
F/G	1.32	1.34	1.34	1.32	1.30	1.25	0.037	0.389	0.913	0.809	0.198
Experimental period (d 0 to 24)											
ADG, lb	0.50	0.47	0.50	0.52	0.51	0.64	0.017	0.066	0.563	0.509	< 0.001
ADFI, lb	0.64	0.62	0.68	0.67	0.68	0.78	0.021	0.291	0.194	0.439	0.004
F/G	1.30	1.35	1.35	1.30	1.32	1.21	0.033	0.190	0.359	0.796	0.005
Common period (d 24 to 42)											
ADG, lb	1.35	1.36	1.34	1.34	1.34	1.23	0.045	0.847	0.819	0.936	0.210
ADFI, lb	2.00	1.94	1.99	1.99	1.97	1.90	0.054	0.793	0.765	0.695	0.504
F/G	1.48	1.43	1.48	1.49	1.49	1.55	0.024	0.264	0.900	0.296	0.217
Overall (d 0 to 42)											
ADG, lb	0.86	0.84	0.86	0.87	0.86	0.89	0.027	0.514	0.933	0.791	0.494
ADFI, lb	1.22	1.17	1.24	1.24	1.22	1.26	0.035	0.537	0.769	0.556	0.479
F/G	1.42	1.41	1.44	1.42	1.42	1.41	0.019	0.971	0.616	0.470	0.737
Fecal DM, %[9]											
d 10	17.9	19.1	18.8	18.1	19.2	19.7	1.52	0.851	0.541	0.905	0.827
d 17	17.3	18.5	19.4	17.9	15.3	20.8	1.41	0.038	0.947	0.379	0.002
d 24	18.7	19.6	19.6	18.9	17.5	19.6	0.95	0.149	0.916	0.473	0.061

[1] A total of 300 pigs (initial BW of 12.4 ± 0.05 lb) across two rooms were used in a 42-d nursery trial. A total of 6 dietary treatments were utilized to alter diets' acid-binding capacity-4 using two different methods.
[2] Decreasing the level of fumaric and citric acid of the diet.
[3] Replacement of novel soy protein concentrate (AX3 Digest; Protekta; Plainfield, IN) with enzymatically treated soybean meal (HP 300; Hamlet Protein; Findlay, OH).
[4] Formulated the same as replacement of soy source at 338 meq/kg treatment with added 2,500 ppm of Zn from ZnO.
[5] No significant interactions were observed ($P > 0.05$).
[6] Comparison of decreasing acidifier vs. replacement of soy source diets.
[7] Analysis of low ABC-4 levels (223 meq/kg) compared to the average of medium levels (280 meq/kg) and the average of the high levels (338 meq/kg).
[8] Compares replacement of specialty soybean products at the 338 meq/kg ABC-4 level with or without ZnO.
[9] Treatment × day, $P = 0.555$; Treatment, $P = 0.193$; Day, $P = 362$. The *P*-values represented in the data table show the effect of treatment within day.