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Summary

A total of 360 pigs (Line 600 × 241, DNA; initially 12.6 ± 0.5 lb) were used to determine the effect of feeding different levels of dietary Na alone or in combination with pharmacological levels of Zn on growth performance and fecal dry matter of nursery pigs. At weaning, pigs were randomly allotted to pens (6 pigs per pen) and fed a common diet for 7 days. On d 7 after weaning (d 0 of the trial), pigs were assigned to 1 of 6 dietary treatments with 10 replications per treatment. Dietary treatments were arranged in a 2 × 3 factorial with main effects of added Zn (0 or 2,000 ppm Zn from ZnO) and Na (0.13, 0.24, or 0.35% from salt). All diets contained 110 ppm of Zn from ZnO from the trace mineral premix. Following a 14-d experimental period, pigs were fed a common phase 3 diet for 21 days. From d 0 to 14, increasing Na increased (linear, $P < 0.05$) ADG, ADFI, and BW. The addition of ZnO in the diet also increased ($P < 0.001$) ADG, ADFI, and BW. An interaction (linear, $P = 0.027$) was observed where increasing Na up to 0.35% improved F/G from d 0 to 14 only when pharmacological levels of Zn were fed. Within the interaction, pigs fed diets without ZnO showed a response (quadratic, $P = 0.027$) in F/G as Na increased. When Na was increased from 0.13 to 0.24% F/G improved, but when Na was further increased to 0.35% F/G worsened. When 2,000 ppm of Zn was added, F/G improved (linear, $P = 0.003$) as Na increased. From d 14 to 35 and overall, an interaction was observed (linear, $P < 0.05$) for F/G. Within the interaction, pigs fed diets without ZnO showed a linear increase in F/G as Na level increased (linear, $P \leq 0.011$). On d 7, fecal dry matter decreased and then subsequently increased (quadratic, $P = 0.026$) with increasing Na. Unexpectedly, pigs fed added Zn had decreased ($P = 0.008$) fecal dry matter on d 14. In summary, increasing dietary Na and the addition of pharmacological levels of Zn independently improved daily gain and feed intake in nursery pigs, but an improvement in F/G from increasing Na was only observed when pharmacological ZnO was also present.

Introduction

Post-weaning diarrhea often occurs in nursery pigs due to the stress associated with weaning, the change to dry feed, and social re-establishment leading to increased oppor-

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tunistic microorganisms. The inclusion of pharmacological levels of Zn has been shown to reduce diarrhea and improve performance of nursery pigs.[2] However, there are growing concerns with the use of high levels of Zn in nursery pig diets due to increased Zn accumulation in the environment. For this reason, EU countries have banned the use of pharmacological Zn in swine diets. Elevated levels of dietary salt have also been shown to increase growth performance in nursery pigs.[3] Salt is comprised of Na and Cl ions that are used for many physiological processes within the pig's body. Sodium is a cation that plays an important role in the sodium-potassium pump used for nerve impulses and muscle contraction. Chloride is an anion that is critical for digestion because it is a component of HCl within the stomach. For the purpose of this study, Na was the only component of salt that was evaluated. The NRC[4] requirement estimate for Na for 15 to 25 lb pigs is 0.35%, compared to the CVB[5] European estimate of 0.24% for a similar weight range. A European study by Millet et al. (2021) found no difference in growth performance with increasing Na in diets without ZnO.[6] However, a study by Shawk et al. (2018) observed a growth response to increasing Na with diets containing pharmacological levels of Zn.[7] Based on these observations, the objective of this experiment was to compare the NRC[4] and CVB[5] Na estimates, with or without the addition of pharmacological levels of ZnO on nursery pig growth performance and fecal dry matter, to determine if elevated levels of Zn influenced the response to Na in the diet.

Materials and Methods

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

Animals and diets

A total of 360 pigs (Line 241 × 600, DNA; initially 12.6 ± 0.5 lb) were used in a 35-d growth trial. Pigs were weaned at approximately 21 d of age and placed in pens of 6 pigs each based on initial weight and gender. A common phase 1 pelleted diet was fed for 7 d after weaning. The phase 1 diet had a Na level of 0.40% and a Zn level of 3,000 ppm. At d 7 after weaning, which was considered d 0 of the trial, pens of pigs were randomly allotted to 1 of 6 dietary treatments with 10 replications per treatment. Dietary treat-

[2] G. M. Hill, G. L. Cromwell, T. D. Crenshaw, C. R. Dove, R. C. Ewan, D. A. Knabe, A. J. Lewis, G. W. Libal, D. C. Mahan, G. C. Shurson, L. L. Southern, and T. L. Veum. 2000. Growth promotion effects and plasma changes from feeding high dietary concentrations of zinc and copper to weanling pigs (regional study), J. Anim. Sci., 78(4):1010-1016. https://doi.org/10.2527/2000.7841010x.

[3] D. J. Shawk, M. D. Tokach, J. C. Woodworth, R. D. Goodband, S. S. Dritz, and J. M. DeRouchey. 2018. Effects of Sodium and Chloride Source and Concentration on 15- to 25-lb Nursery Pig Growth Performance. Kansas Agricultural Experiment Station Research Reports*:* Vol. 4: Iss. 9. https://doi.org/10.4148/2378-5977.7671.

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

[5] CVB, 2020. Tabellenboek Voeding Varkens 2020. CVB-reeks nr. 63. http://www.cvbdiervoeding.nl/.

[6] S. Millet, B. Ampe, M. D. Tokach, 2021. The effects of salt and protein levels in the performance and fecal consistency of piglets between 4 and 9 weeks of age. *In progress.*

[7] D. J. Shawk, M. D. Tokach, J. C. Woodworth, R. D. Goodband, S. S. Dritz, and J. M. DeRouchey. 2018. Effects of Sodium and Chloride Source and Concentration on 15- to 25-lb Nursery Pig Growth Performance. Kansas Agricultural Experiment Station Research Reports*:* Vol. 4: Iss. 9. https://doi.org/10.4148/2378-5977.7671.

ments were arranged in a 2 × 3 factorial with main effects of added Zn (0 vs. 2,000 ppm) and Na (0.13, 0.24, or 0.35%). The Zn was increased by adding ZnO and the Na was increased by adding salt. All diets contained a trace mineral premix that contributed 110 ppm of Zn from ZnO. Treatment diets were fed from d 0 to 14. The basal diet without salt or added ZnO was manufactured in meal form at Hubbard Feeds in Beloit, KS. The basal diet was then divided into 6 batches and salt and/or ZnO were added and mixed at the Kansas State University O.H. Kruse Feed Technology Center in Manhattan, KS, to form the six experimental diets (Table 1). A common phase 3 diet was fed to all pigs from d 14 to 35. Individual pig weights were measured from d 0 to 14 followed by pen weights from d 14 to 35, and feed disappearance was also measured weekly to determine ADG, ADFI, and F/G.

Fecal samples were collected on d 7 and 14 to determine fecal dry matter percentage from the same three medium weight pigs from each pen. After collection, fecal samples were dried at 55°C (131°F) in a forced air oven for 48 h and the ratio of dried to wet fecal weight determined the fecal dry matter.

Representative diet samples were obtained from every fifth bag of manufactured feed. The diet samples were stored at -20°C (-4°F) until they were homogenized, subsampled, and submitted for analysis of Zn, Na, and Cl (K-State Research and Extension Soil Testing Laboratory, Manhattan, KS).

Representative water samples were obtained over a period of three days from a nipple waterer. Samples were collected to determine if a significant amount of Na was being supplied to the pigs through water intake. Water samples were submitted for analysis of Na to Ward Laboratories (Kearney, NE).

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 effects of Zn and Na, as well as their interactions, were tested. Differences between treatments were considered significant at $P \leq 0.05$ and marginally significant at $0.05 < P \leq 0.10$.

Results and Discussion

The Zn, Na, and Cl analysis matched the formulated values as expected (Table 1). From d 0 to 14, there was an Zn × Na interaction observed (linear, $P = 0.027$) for F/G (Table 2). A quadratic response with increasing Na level was observed for pigs fed without added ZnO ($P = 0.027$) where the lowest F/G was observed at 0.24% Na. When pigs were fed added ZnO, increasing Na level resulted in a linear improvement in F/G ($P = 0.003$).

From d 14 to 35 and overall, there was a Zn × Na interaction observed (linear, $P \leq 0.043$) for F/G. Within the interaction, increasing Na level without added ZnO resulted in linear worsening of F/G (linear, $P \leq 0.011$). However, pigs fed diets with ZnO showed no difference to increasing Na ($P \geq 0.174$). There were no Zn × Na interactions for ADG, ADFI, or BW ($P \geq 0.150$).

From d 0 to 14, pigs fed pharmacological levels of ZnO had increased ($P < 0.001$) ADG, ADFI, and BW. However, from d 14 to 35 when the pharmacological levels of Zn were removed from the diet, there were no differences among treatments for ADG, ADFI, or BW. Overall, there was no difference observed in growth performance from increasing ZnO from d 0 to 14.

From d 0 to 14, pigs fed diets containing increasing Na had increased (linear, $P \leq 0.008$) ADG, ADFI, and BW. From d 14 to 35 and d 0 to 35, there was no effect of increasing Na on ADG, ADFI, or BW.

On day 7, increasing dietary Na from 0.13 to 0.24% decreased (quadratic, $P = 0.026$) fecal dry matter content followed by an increase in fecal dry matter when Na was further increased to 0.35%. Interestingly, on d 14, pigs fed diets containing pharmacological levels of Zn had decreased ($P = 0.008$) fecal dry matter.

Representative water samples, on average, were determined to contain 37.3 ppm of Na. Therefore, very little Na was supplied to the pigs through water intake.

In summary, the addition of pharmacological levels of Zn and dietary Na up to 0.35% (NRC[4] estimates) improved growth performance in the experimental period similarly to the results of previous studies.[8,9] The results of this study indicate that the NRC4 estimate for Na optimizes ADG and ADFI in 15 to 25 lb pigs compared to the European CVB[5] estimate. In addition, the NRC[4] estimate of 0.35% Na in combination with pharmacological levels of Zn can improve F/G.

Brand names appearing in this publication are for product identification purposes only. No endorsement is intended, nor is criticism implied of similar products not mentioned. Persons using such products assume responsibility for their use in accordance with current label directions of the manufacturer.

[8] K. L. Batson, L. L. Thomas, J. C. Woodworth, M. D. Tokach, R. D. Goodband, S. S. Dritz, J. M. DeRouchey, and J. Bryte. 2019. Effect of Supplementation of Monomix and/or Pharmacological Levels of Zinc Oxide on Growth Performance of Nursery Pigs. Kansas Agricultural Experiment Station Research Reports: Vol. 5: Iss. 8. https://doi.org/10.4148/2378-5977.7837.

[9] D. J. Shawk, M. D. Tokach, J. C. Woodworth, R. D. Goodband, S. S. Dritz, and J. M. DeRouchey. 2018. Effects of Sodium and Chloride Source and Concentration on 15- to 25-lb Nursery Pig Growth Performance. Kansas Agricultural Experiment Station Research Reports: Vol. 4: Iss. 9. https://doi.org/10.4148/2378-5977.7671.

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

		No ZnO			Added ZnO	
Item **Na[2]:**	**0.13%**	**0.24%**	**0.35%**	**0.13%**	**0.24%**	**0.35%**
Ingredients, %						
Corn	56.25	55.94	55.68	55.97	55.71	55.40
Soybean meal	30.59	30.62	30.60	30.61	30.59	30.62
Whey powder	10.00	10.00	10.00	10.00	10.00	10.00
Calcium carbonate	0.85	0.85	0.85	0.85	0.85	0.85
Monocalcium phosphate	0.85	0.85	0.85	0.85	0.85	0.85
Salt	---	0.28	0.56	---	0.28	0.56
L-Lys HCl	0.45	0.45	0.45	0.45	0.45	0.45
DL-Met	0.21	0.21	0.21	0.21	0.21	0.21
L-Thr	0.20	0.20	0.20	0.20	0.20	0.20
L-Trp	0.06	0.06	0.06	0.06	0.06	0.06
L-Val	0.13	0.13	0.13	0.13	0.13	0.13
Vitamin premix	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
Zinc oxide[3]	---	---	---	0.26	0.26	0.26
Phytase[4]	0.02	0.02	0.02	0.02	0.02	0.02
Total	100	100	100	100	100	100

continued

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

		No ZnO			Added ZnO	
Item Na[2]:	**0.13%**	**0.24%**	**0.35%**	**0.13%**	**0.24%**	**0.35%**
Calculated analysis						
Standardized ileal digestible SID AA, %						
Lys	1.35	1.35	1.35	1.35	1.35	1.35
Ile:Lys	57	57	57	57	57	57
Leu:Lys	115	115	115	115	115	115
Met:Lys	36	36	36	36	36	36
Met and Cys:Lys	58	58	58	58	58	58
Thr:Lys	64	64	64	64	64	64
Trp:Lys	21.4	21.4	21.4	21.4	21.4	21.4
Val:Lys	70	70	70	70	70	70
His:Lys	36	36	36	36	36	36
Total Lys, %	1.49	1.49	1.49	1.49	1.49	1.49
NE NRC, kcal/lb	1,111	1,108	1,104	1,108	1,105	1,101
SID Lys:NE, g/Mcal	5.51	5.53	5.54	5.53	5.54	5.56
Crude protein, %	21.2	21.2	21.2	21.2	21.2	21.2
Ca, %	0.72	0.72	0.72	0.72	0.72	0.72
P, %	0.62	0.61	0.61	0.61	0.61	0.61
Available P, %	0.46	0.46	0.46	0.46	0.46	0.46
STTD P, %	0.50	0.50	0.50	0.50	0.50	0.50
Mineral analysis[5]						
Na, %	0.15	0.24	0.41	0.16	0.24	0.51
Cl, %	0.30	0.42	0.68	0.31	0.43	0.83
Zn, ppm	228	222	364	2,482	2,036	2,485

[1] Diets were fed to pigs from approximately 13 to 23 lb BW.
[2] Na was included in the diet at 0.13, 0.24, or 0.35% from d 0 to 14 using salt.
[3] Zinc oxide was included in the diet to provide 2,000 ppm of Zn.
[4] Quantum Blue 5G (ABVista, Marlborough, Wiltshire) provided an estimated release of 0.14% STTD P.
[5] A representative sample of each diet was collected from every fifth bag of feed manufactured for each treatment. Samples were stored at -20°C until they were homogenized, subsampled, and submitted to the K-State Research and Extension Soil Testing Laboratory (Manhattan, KS) for proximate analysis.

Table 2. Effects of increasing dietary salt and Zn on growth performance and fecal dry matter of nursery pigs[1,2]

	No zinc oxide			Added zinc oxide[3]				Probability, *P* =		
Na, %[4]	0.13	0.24	0.35	0.13	0.24	0.35	SEM	Zn	Na linear	Na quadratic
BW, lb										
d 0	12.6	12.5	12.6	12.6	12.8	12.5	0.31	0.792	0.796	0.719
d 14	22.0	22.6	23.2	23.5	24.3	24.9	0.75	<0.001	0.008	0.910
d 35	51.1	50.6	51.4	51.7	51.9	53.4	0.96	0.095	0.290	0.445
Experimental period (d 0 to 14)										
ADG, lb	0.67	0.72	0.76	0.77	0.82	0.88	0.035	<0.001	<0.001	0.855
ADFI, lb	0.90	0.93	1.02	1.05	1.09	1.12	0.037	<0.001	0.007	0.761
F/G[5]	1.34	1.29	1.35	1.36	1.33	1.28	0.025	0.816	0.042	0.148
Common period (d 14 to 35)										
ADG, lb	1.38	1.33	1.33	1.35	1.32	1.36	0.029	0.664	0.487	0.248
ADFI, lb	2.19	2.19	2.27	2.20	2.22	2.23	0.077	0.961	0.282	0.638
F/G[6]	1.59	1.64	1.71	1.64	1.69	1.64	0.046	0.697	0.018	0.385
Overall (d 0 to 35)										
ADG, lb	0.99	0.98	0.99	1.00	0.99	1.03	0.017	0.132	0.292	0.241
ADFI, lb	1.67	1.69	1.77	1.74	1.76	1.78	0.047	0.112	0.070	0.660
F/G[7]	1.69	1.73	1.79	1.74	1.78	1.73	0.042	0.527	0.103	0.451
DM, %										
d 7	19.5	18.6	20.0	20.2	17.1	18.4	1.11	0.251	0.486	0.026
d 14	20.8	19.8	20.3	17.7	19.0	18.4	0.87	0.008	0.911	0.942

[1] A total of 360 pigs were used in a 35-d nursery trial with 6 pigs per pen and 10 pens per treatment. Pigs were placed on experimental diets 7 days post-weaning (~19 d of age). All Zn × Na dose response interactions, $P \geq 0.150$, unless specified otherwise.
[2] BW = body weight; ADG = average daily gain; ADFI = average daily feed intake; F/G = feed efficiency; DM = dry matter.
[3] Zinc treatment consisted of diets without added Zn or with added 2,000 ppm of Zn from ZnO. All diets contained 110 ppm of Zn from ZnO from the trace mineral premix.
[4] Treatments consisted of increasing Na (0.13, 0.24, and 0.35%) provided by salt.
[5] Zn × Na interaction (linear, $P = 0.027$). Dose effect of Na when ZnO was not included at pharmacological levels, quadratic, $P = 0.027$. Dose effect of Na when ZnO was included at pharmacological levels, linear, $P = 0.003$.
[6] Zn × Na interaction (linear, $P = 0.032$). Dose effect of Na when ZnO was not included at pharmacological levels, linear, $P = 0.002$. Dose effect of Na when ZnO was included at pharmacological levels, $P \geq 0.174$.
[7] Zn × Na interaction (linear, $P = 0.043$). Dose effect of Na when ZnO was not included at pharmacological levels, linear, $P = 0.011$. Dose effect of Na when ZnO was included at pharmacological levels, $P \geq 0.182$.