Kansas Agricultural Experiment Station Research Reports

Volume 11
Issue 7 *Swine Day*

Article 20

2025

Effects of Increasing Lactose with or without Pharmacological Levels of Zinc on Performance, Fecal Dry Matter, and Plasma Zinc Concentration in Nursery Pigs

Joana Magoga
Kansas State University, joanam@k-state.edu

Julian Arroyave
Kansas State University, jarroyave@k-state.edu

Jordan T. Gebhardt
Kansas State University, jgebhardt@k-state.edu

See next page for additional authors

Effects of Increasing Lactose with or without Pharmacological Levels of Zinc on Performance, Fecal Dry Matter, and Plasma Zinc Concentration in Nursery Pigs

Authors

Joana Magoga, Julian Arroyave, Jordan T. Gebhardt, Robert D. Goodband, Jason C. Woodworth, Joel M. DeRouchey, Katelyn N. Gaffield, and Mike D. Tokach

Effects of Increasing Lactose with or without Pharmacological Levels of Zinc on Performance, Fecal Dry Matter, and Plasma Zinc Concentration in Nursery Pigs

Joana Magoga,[1] Julian Arroyave, Jordan T. Gebhardt,[1] Robert D. Goodband, Jason C. Woodworth, Joel M. DeRouchey, Katelyn Gaffield, and Mike D. Tokach

Summary

A study was conducted to evaluate the interactive effects of dietary lactose concentration and pharmacological levels of added Zn on growth performance, fecal DM, and plasma Zn concentrations in nursery pigs. At weaning, 360 pigs (initially 13.0 ± 0.24 lb) were randomly allotted within three body-weight blocks to one of six dietary treatments in a randomized complete block design. The study was arranged as a 2 × 3 factorial with main effects of added Zn (110 vs. 3,000 mg/kg Zn from ZnO) and three lactose concentrations: high (20% in phase 1 and 10% in phase 2), medium (10% in phase 1 and 5% in phase 2), and low (5% in phase 1 and none in phase 2). Experimental diets were fed for 21 d (phases 1 and 2), followed by a common diet fed for an additional 21 d (phase 3). There were five pigs per pen and 12 replicate pens per treatment. No lactose × Zn interactions were observed for growth performance ($P > 0.10$). From d 0 to 21, pigs fed pharmacological levels of Zn had improved ($P \leq 0.007$) ADG, ADFI, and F/G compared with pigs fed low Zn diets. Increasing lactose increased (linear, $P = 0.048$) BW on d 21. However, from d 0 to 42, ADG, ADFI, F/G, and d 42 BW were unaffected by increasing lactose or Zn. There were no lactose × Zn × day interactions for fecal DM, although pigs fed pharmacological Zn tended to have decreased fecal DM on both d 10 and 21 ($P \leq 0.078$). For plasma Zn, a linear lactose × Zn × day interaction (linear, $P = 0.004$) was observed. On d 10, but not d 0 or 21, plasma Zn concentration was greater in pigs fed 3,000 mg/kg of Zn when fed high lactose and declined as the lactose level decreased. In contrast, in pigs fed 110 mg/kg of Zn, the plasma Zn remained relatively low across lactose levels. For the main effect of Zn, on both d 10 and 21, pigs fed 3,000 mg/kg of Zn had greater ($P < 0.001$) plasma Zn concentrations compared to those fed 110 mg/kg of Zn. In conclusion, pharmacological levels of Zn improved early nursery growth performance and influenced plasma Zn concentrations; however, these benefits did not persist throughout the overall 42-d period. Increasing lactose improved the feed intake and early body-weight gains during phase 1 but had a limited impact on overall performance.

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

Introduction

Lactose is a key component in early nursery diets to help the pig transition from milk to solid feed. However, excessive lactose intake may lead to digestive disturbances, such as increased hindgut fermentation, osmotic imbalances, and abnormal gut motility, all of which can contribute to post-weaning diarrhea (PWD).[2] Although several studies have examined the effects of varying dietary lactose levels on nursery pig performance, there is no clear consensus on the optimal level. This variability suggests that additional factors, such as genetic background and environmental conditions, may influence the response to dietary lactose.[3]

Pharmacological levels of Zn, particularly from Zn oxide (ZnO), are commonly used in nursery diets to reduce the incidence of PWD and enhance growth performance. While the physiological Zn requirement for nursery pigs ranges from 26.6 to 72.4 mg/d,[4] pharmacological levels (e.g., 1,500 to 2,600 mg/d) are often fed during the early post-weaning period. In humans and in in vitro models, lactose has been shown to enhance zinc absorption; however, this interaction has not been fully explored in swine. It is hypothesized that ZnO may be more effective under conditions of increased nutrient fermentation in the hindgut, which might occur with high-lactose diets, whereas low lactose diets may reduce the need for pharmacological levels of Zn.

Understanding the interaction between dietary lactose and Zn is critical to developing more sustainable and effective feeding strategies that minimize PWD, optimize growth performance, and reduce environmental Zn excretion. Therefore, the objective of this study was to evaluate the effects of increasing dietary lactose with or without pharmacological Zn on growth performance, fecal, and plasma zinc concentration.

Materials and Methods

The Kansas State University Institutional Animal Care and Use Committee approved the protocol for this experiment. The experiment was conducted in two barns located at the Kansas State University Segregate Early Weaning Research Facility in Manhattan, KS. All diets were manufactured at the Kansas State University O.H. Kruse Feed Technology Innovation Center, Manhattan, KS.

Animals and diets

A total of 360 weanling pigs (Line 200 × 400; DNA Genetics, Columbus, NE), with an initial weight of 13.0 ± 0.24 lb, were used in a 42-d study. Pigs were weaned at approximately 21 d of age and divided into three body-weight (BW) categories: light, medium, or heavy. Within the BW categories, pigs were randomly assigned to pens, and pens were allotted to one of six dietary treatments. Each treatment consisted of 12 replicate pens, with five pigs per pen. Pens (4 × 5 ft) were equipped with a six-hole dry feeder and a cup waterer to provide *ad libitum* access to feed and water. The study was conducted in two identical barns, each housing an equal representation of dietary treatments and BW categories.

[2] Jang, K. B., and S. W. Kim. 2022. Role of milk carbohydrates in intestinal health of nursery pigs: a review. J. Anim. Sci. Biotechnol. 13(1):6. doi:10.1186/s40104-021-00650-7.
[3] Zhao, J., Z. Zhang, S. Zhang, G. Page, and N. W. Jaworski. 2021. The role of lactose in weanling pig nutrition: a literature and meta-analysis review. J. Anim. Sci. Biotechnol. 12(1):10. doi:10.1186/s40104-020-00522-6.
[4] NRC. 2012. Nutrient requirements of swine. 11th rev.ed. Natl. Acad. Press, Washington, DC.

Pigs were fed experimental diets during the first two dietary phases, with phase 1 lasting 10 d and phase 2 lasting 11 d (Tables 1 and 2). From d 21 to 42, all pigs were fed a common phase 3 diet. All diets across the three phases were fed in mash form.

The study was structured as a 2 × 3 factorial arrangement with the main effects of dietary Zn (110 or 3,000 mg/kg) and lactose (high, medium, and low). All diets contained 110 mg/kg of added Zn from zinc sulfate ($ZnSO_4$) via the trace mineral premix. In phases 1 and 2, pharmacological Zn levels were achieved by adding ZnO (72%) to provide 3,000 mg/kg. The lactose programs included 20% in phase 1 and 10% in phase 2 (high); 10% in phase 1 and 5% in phase 2 (medium); and 5% in phase 1 and none in phase 2 (low). The lactose source was a combination of whey powder and whey permeate, with a constant level of whey powder included across all diets, and lactose levels adjusted by varying the amount of whey permeate.

Pigs and feeders were weighed on d 0, 10, 21, 28, 35, and 42 to determine average daily gain (ADG), average daily feed intake (ADFI), and feed-to-gain ratio (F/G). To assess plasma Zn concentration, a blood sample was collected from one middle-weight pig per pen at placement (d 0) and on d 10 and 21. The plasma was obtained through centrifugation, and samples were stored at -80°C (-112°F).

Statistical analysis

The data were analyzed using a generalized randomized block design. All statistical analyses were performed in RStudio (Version 4.0.2; R Core Team, R Foundation for Statistical Computing, Vienna, Austria) using the lmer function from the lme4 package. The pen served as the experimental unit for all analyses.

For performance data, the model included lactose level, added Zn, their associated interactions, and body-weight block as fixed effects, with barn as a random effect. For fecal DM, the fixed effects were lactose level, added Zn, day of fecal collection, and their associated interactions as fixed effects, while pen, pig, and barn were included as random effects to account for subsampling of multiple pigs per pen. For plasma zinc concentration, the model used the same fixed and random effects as for fecal DM, except that pig was not included as a random effect.

Contrast coefficients were constructed based on the numeric lactose levels used in each dietary phase (phase 1 and phase 2) or based on a weighted average when analyzing the entire study period. The weighting accounted for the duration of each phase. Contrasts were performed to compare the effects of increasing lactose alone or with 110 or 3,000 mg/kg, added Zn to determine whether these effects varied across experimental phases. Treatment differences were considered statistically significant at $P \leq 0.05$, and marginally significant at $0.05 < P \leq 0.10$.

Results and Discussion

No interactions between lactose and Zn were observed for growth performance at any time during the study (Table 3). In phase 1 (d 0 to 10), pigs fed 3,000 mg/kg Zn had greater ($P < 0.004$) ADG and d 10 BW compared to those fed 110 mg/kg of Zn. Added Zn had no effect on ADFI but improved ($P = 0.002$) F/G. Increasing lactose tended (linear, $P \leq 0.083$) to increase ADG and BW on d 10. Average daily feed intake increased (linear, $P = 0.048$) as lactose content increased, and pigs fed medium lactose levels had improved (quadratic, $P = 0.007$) F/G.

In phase 2 (d 10 to 21), pigs fed 3,000 mg/kg of Zn had greater ($P < 0.001$) ADG, ADFI, and d 21 BW than pigs fed 110 mg/kg Zn. However, there was no effect of lactose level on ADG, ADFI, or F/G during this period.

Over the experimental period (d 0 to 21), pigs fed pharmacological levels of Zn had greater ($P \leq 0.007$) ADG, ADFI, and improved F/G than those fed 110 mg/kg added Zn. Although increasing lactose did not significantly increase ADG or ADFI, the numerical linear increase ($P = 0.102$) in ADG led to an increase ($P = 0.048$) in BW on d 21 with increasing lactose.

For the common period (d 21 to 42), pigs previously fed pharmacological levels of Zn had reduced ($P < 0.001$) ADG, poorer ($P = 0.005$) F/G, and a tendency for a higher ($P = 0.072$) ADFI in comparison to those pigs fed 110 mg/kg added Zn. No effect of prior lactose level was observed for ADG, ADFI, and F/G during this period.

For the entire 42-d period, no differences were observed among treatments for BW at day 42, ADG, ADFI, or F/G, indicating that the early growth advantages observed with pharmacological Zn or lactose did not persist through the end of the nursery phase.

For fecal DM, there was no evidence of a lactose × Zn × day interaction observed. On d 10 and 21, pigs fed 110 mg/kg of Zn tended to have increased ($P \leq 0.078$) fecal DM compared to those fed 3,000 mg/kg of Zn. Increasing lactose had no effect on fecal DM on d 10 or 21.

As expected, there were no differences in plasma Zn concentration on d 0 of the study. A lactose × Zn × day interaction (linear, $P = 0.004$) was observed for d 10, where pigs fed 3,000 mg/kg of added Zn had the greatest plasma Zn concentration when fed high lactose. In contrast, plasma Zn concentrations were relatively unchanged in pigs fed 110 mg/kg of Zn. However, no such interaction was evident on d 21. For the main effect of Zn, on both d 10 and 21, pigs fed 3,000 mg/kg of Zn had greater ($P < 0.001$) plasma Zn concentrations compared to those fed 110 mg/kg of Zn.

In conclusion, feeding pharmacological levels of Zn (3,000 mg/kg from ZnO) during the nursery period improved growth performance in weanling pigs, particularly during the first 21 d. While increasing lactose had limited effects on overall growth, it contributed to improved feed intake in phase 1 and was positively associated with increased body weight on d 21. Fecal DM was not significantly affected by dietary treatments. Plasma Zn concentrations increased with increased dietary Zn and were affected by increasing lactose. Despite early benefits, growth advantages from pharmacological levels of added Zn or added lactose did not persist beyond d 21. These results support the use of pharmacological levels of added Zn to enhance early nursery pig performance, while lactose effects appear more variable and phase dependent.

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

		Added Zn[2], mg/kg				
	110			3,000		
Item Lactose:	**High**	**Medium**	**Low**	**High**	**Medium**	**Low**
Ingredient, %						
Corn	42.67	54.47	60.36	42.24	54.04	59.93
Soybean meal (46.5% CP)	16.92	17.02	17.06	16.96	17.05	17.09
Spray-dried bovine plasma	3.00	3.00	3.00	3.00	3.00	3.00
Whey powder	5.00	5.00	5.00	5.00	5.00	5.00
Whey permeate	20.50	8.00	1.75	20.50	8.00	1.75
Soy protein concentrate[3]	7.50	7.50	7.50	7.50	7.50	7.50
Soybean oil	1.00	1.00	1.00	1.00	1.00	1.00
Calcium carbonate	0.52	0.58	0.61	0.52	0.58	0.61
Monocalcium phosphate, 21% P	0.90	1.05	1.13	0.90	1.05	1.13
Salt	0.08	0.53	0.76	0.08	0.53	0.76
L-Lys-HCl	0.36	0.36	0.36	0.36	0.36	0.36
DL-Met	0.23	0.20	0.19	0.23	0.20	0.19
L-Thr	0.20	0.18	0.18	0.20	0.18	0.18
L-Trp	0.02	0.03	0.04	0.02	0.03	0.04
L-Val	0.10	0.08	0.07	0.10	0.08	0.07
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
Choline chloride 60%	0.05	0.05	0.05	0.05	0.05	0.05
Phytase[4]	0.06	0.06	0.06	0.06	0.06	0.06
ZnO	---	---	---	0.40	0.40	0.40
TiO_2	0.50	0.50	0.50	0.50	0.50	0.50

continued

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

		Added Zn[2], mg/kg					
		110			3,000		
Item	**Lactose:**	**High**	**Medium**	**Low**	**High**	**Medium**	**Low**
Calculated analysis							
SID amino acids, %							
Lys		1.40	1.40	1.40	1.40	1.40	1.40
Ile:Lys		55	56	57	55	56	57
Leu:Lys		112	118	120	112	117	120
Met:Lys		36	35	34	36	35	34
Met and Cys:Lys		58	58	58	58	58	58
Thr:Lys		64	64	64	64	64	64
Trp:Lys		20.1	20.1	20.1	20.1	20.1	20.1
Val:Lys		70	70	70	70	70	70
His:Lys		35	36	37	35	36	37
NE, kcal/lb		1,172	1,149	1,138	1,167	1,144	1,133
SID Lys:NE, g/Mcal		5.42	5.53	5.58	5.44	5.55	5.61
CP, %		20.9	21.5	21.8	20.9	21.5	21.8
Lactose, %		20.0	10.0	5.0	20.0	10.0	5.0
Ca, %		0.63	0.65	0.67	0.63	0.65	0.67
P, %		0.63	0.65	0.66	0.63	0.65	0.66
STTD P, %		0.55	0.55	0.55	0.55	0.55	0.55

[1] Phase 1 diet was fed from day 0 to 10.
[2] All diets contained 110 mg/kg of supplemental Zn from $ZnSO_4$ via the trace mineral premix. The pharmacological levels of added Zn (3,000 mg/kg) were achieved with added ZnO (72% Zn).
[3] Bunge SPC Pure Pro (Bunge, Chesterfield, MO).
[4] HiPhorius 2400 (DSM, Parsippany, NJ), 1,500 FTU/kg, and assumed release of 0.12% STTD P.

Table 2. Phases 2 and 3 diet composition (as-fed basis)[1]

	Phase 2						
Zinc:[2]	110 mg/kg			3000 mg/kg			
Item Lactose:	High	Medium	Low	High	Medium	Low	Phase 3[3]
Ingredient, %							
Corn	53.27	59.17	65.06	52.84	58.74	64.63	64.44
Soybean meal, 46.5% CP	24.05	24.10	24.14	24.08	24.13	24.17	30.61
Whey permeate	12.50	6.25	---	12.50	6.25	---	---
Soy protein concentrate[4]	5.00	5.00	5.00	5.00	5.00	5.00	---
Soybean oil	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Calcium carbonate	0.68	0.71	0.75	0.68	0.71	0.75	0.73
Monocalcium phosphate, 21% P	1.07	1.14	1.22	1.07	1.14	1.22	1.05
Salt	0.35	0.58	0.79	0.35	0.58	0.79	0.60
L-Lys-HCl	0.48	0.48	0.48	0.48	0.48	0.48	0.48
DL-Met	0.24	0.23	0.22	0.24	0.23	0.22	0.20
L-Thr	0.24	0.23	0.23	0.24	0.23	0.23	0.22
L-Trp	0.04	0.05	0.05	0.04	0.05	0.05	0.04
L-Val	0.14	0.13	0.12	0.14	0.13	0.12	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[5]	0.06	0.06	0.06	0.06	0.06	0.06	0.06
ZnO	0.00	0.00	0.00	0.40	0.40	0.40	0.00
$CuSO_4$	---	---	---	---	---	---	0.07
TiO_2	0.50	0.50	0.50	0.50	0.50	0.50	---

continued

Table 2. Phases 2 and 3 diet composition (as-fed basis)[1]

		Phase 2						
	Zinc:[2]	**110 mg/kg**			**3000 mg/kg**			
Item	**Lactose:**	**High**	**Medium**	**Low**	**High**	**Medium**	**Low**	**Phase 3[3]**
Calculated analysis								
SID amino acids, %								
Lys		1.35	1.35	1.35	1.35	1.35	1.35	1.30
Ile:Lys		56	56	57	56	56	56	56
Leu:Lys		111	113	116	111	113	116	116
Met:Lys		38	38	37	38	38	37	37
Met and Cys:Lys		58	58	58	58	58	58	58
Thr:Lys		64	64	64	64	64	64	64
Trp:Lys		19.9	19.9	19.9	19.9	19.9	19.9	19.5
Val:Lys		70	70	70	70	70	70	69
His:Lys		35	36	37	35	36	36	37
NE, kcal/lb		1,144	1,133	1,121	1,139	1,128	1,116	1,122
SID Lys:NE, g/Mcal		5.35	5.41	5.46	5.38	5.43	5.49	5.26
CP, %		20.5	20.8	21.1	20.5	20.8	21.1	20.8
Lactose, %		10.0	5.0	---	10.0	5.0	---	---
Ca, %		0.68	0.70	0.71	0.68	0.70	0.71	0.67
P, %		0.62	0.63	0.64	0.62	0.63	0.64	0.61
STTD P, %		0.51	0.51	0.51	0.51	0.51	0.51	0.51

[1] Phases 2 and 3 diets were fed from day 10 to 21 and from day 21 to 42, respectively.
[2] All diets contained 110 mg/kg of supplemental Zn from $ZnSO_4$ via the trace mineral premix. The pharmacological levels of added Zn (3,000 mg/kg) were achieved with added ZnO (72% Zn).
[3] Phase 3 was a common diet fed to all pigs d 21 to 42.
[4] Bunge SPC Pure Pro (Bunge, Chesterfield, MO).
[5] HiPhorius 2400 (DSM, Parsippany, NJ), 1,500 FTU/kg, and assumed release of 0.12% STTD P.

Table 3. Effects of lactose and zinc levels on growth performance of nursery pigs[1]

	Added Zn,[2] mg/kg									
	110 mg/kg			3,000 mg/kg						
Lactose:	High	Medium	Low	High	Medium	Low		P^3 =		
Phase 1, %:	20	10	5	20	10	5				
Phase 2, %:	10	5	None	10	5	None	SEM	Linear lactose	Quadratic lactose	Zinc
BW, lb										
d 0	13.0	13.0	13.0	13.0	13.0	13.0	0.24	0.843	0.833	0.867
d 10	16.8	16.7	16.3	17.4	17.4	16.8	0.28	0.074	0.138	0.004
d 21	28.6	28.6	27.9	30.3	30.3	29.2	0.44	0.048	0.225	< 0.001
d 42	59.8	59.1	58.5	59.5	60.1	58.9	0.70	0.209	0.418	0.486
d 0 to 10 (Phase 1)										
ADG, lb	0.38	0.37	0.33	0.44	0.44	0.39	0.025	0.083	0.151	0.004
ADFI, lb	0.44	0.41	0.40	0.47	0.45	0.41	0.022	0.048	0.628	0.128
F/G	1.16	1.10	1.20	1.10	1.03	1.09	0.034	0.894	0.007	0.002
d 10 to 21 (Phase 2)										
ADG, lb	1.08	1.07	1.05	1.17	1.17	1.13	0.025	0.226	0.471	< 0.001
ADFI, lb	1.37	1.37	1.35	1.45	1.49	1.44	0.032	0.634	0.396	< 0.001
F/G	1.28	1.28	1.28	1.25	1.27	1.27	0.018	0.364	0.874	0.294
Experimental period (d 0 to 21)										
ADG, lb	0.74	0.73	0.71	0.82	0.83	0.77	0.022	0.102	0.232	< 0.001
ADFI, lb	0.92	0.91	0.90	0.98	0.99	0.95	0.025	0.301	0.491	0.002
F/G	1.25	1.23	1.26	1.20	1.21	1.23	0.015	0.220	0.191	0.007
d 21 to 42 (Phase 3)										
ADG, lb	1.48	1.45	1.46	1.39	1.42	1.40	0.033	0.830	0.817	< 0.001
ADFI, lb	2.18	2.16	2.14	2.11	2.13	2.10	0.031	0.429	0.536	0.072
F/G	1.48	1.49	1.46	1.52	1.51	1.50	0.023	0.387	0.488	0.005
d 0 to 42 (Overall)										
ADG, lb	1.11	1.09	1.08	1.10	1.12	1.09	0.024	0.318	0.341	0.634
ADFI, lb	1.55	1.53	1.52	1.53	1.56	1.53	0.026	0.431	0.421	0.656
F/G	1.40	1.40	1.40	1.40	1.40	1.40	0.016	0.771	0.869	0.997
Fecal DM, %[4]										
d 10	24.56	23.92	24.87	22.14	24.24	23.84	0.718	0.153	0.836	0.078
d 21	24.52	22.61	23.00	21.68	23.13	22.21	0.718	0.498	0.916	0.077
Plasma Zn concentration, mg/L[5]										
d 0	0.844	0.871	0.858	0.858	0.877	0.798	0.079	0.816	0.595	0.838
d 10	0.729	0.677	0.835	1.935	1.846	1.415	0.079	0.011	0.444	< 0.001
d 21	1.046	0.888	0.923	1.408	1.458	1.398	0.079	0.383	0.834	< 0.001

[1]A total of 360 weaned pigs (initially 13.0 ± 0.24 lb) were assigned in a 2 × 3 factorial design nursery trial to determine the effect of two zinc levels and three levels of lactose on growth performance. Treatments were assigned in a randomized block design with five pigs per pen and 12 replications per treatment. Experimental diets were fed from d 0 to 21 (phase 1: d 0 to 10, and phase 2: d 10 to 21), followed by a common diet from d 21 to 42 (phase 3).

[2]All diets contained 110 mg/kg of supplemental Zn from $ZnSO_4$ via the trace mineral premix. The pharmacological levels of added Zn (3,000 mg/kg) were achieved with added ZnO (72% Zn).

[3] There were no linear or quadratic lactose × Zn interactions for growth performance.

[4] Lactose × Zn × day interaction (linear, quadratic, $P \geq 0.737$).

[5] Lactose × Zn × day interaction (linear, $P = 0.004$). Linear and quadratic lactose × Zn ($P \leq 0.015$) for d 10. Lactose × Zn ($P > 0.10$) d 0 and d 21.