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Alternatives to Replace the Use of Zinc Oxide in Nursery Pig Diets

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Summary

A total of 300 pigs (DNA; 241 × 600; initially 10.6 lb) were used to evaluate the effects of different nutritional strategies to replace zinc oxide (ZnO) in nursery diets. At weaning, 5 pigs were allotted to each pen and pens were assigned to 1 of 6 dietary treatments in a completely randomized design. There were 10 replicate pens per treatment. Treatments consisted of A) Positive control (ZnO providing 3,000 ppm Zn from d 0 to 7, and 2,000 ppm Zn from d 7 to 25); B) Negative control (NC; no ZnO); C) NC plus 1.2% Na diformate; D) NC with 4% coarse ground wheat bran; E) NC with low crude protein (18%) by adding high levels of feed grade amino acids; and F) the combination of NC with 18% crude protein (CP), 1.2% Na diformate, and 4% coarse ground wheat bran. Pigs were weighed on d 7, 14, 25, 37, and 46 to evaluate body weight (BW), average daily gain (ADG), average daily feed intake (ADFI), and feed-to-gain ratio (F/G). Fecal dry matter (DM) was obtained by collecting feces on days 7, 14, 25, and 37 from 3 pigs per pen. Fecal scores were assessed daily for the entire trial. From d 0 to 7, no differences ($P > 0.05$) in any response variables were detected between treatments. From d 7 to 25, pigs fed the diet containing ZnO had greater ($P < 0.05$) ADG and ADFI than those fed all other treatments with pigs fed the 18% CP diet having the lowest ($P < 0.05$) ADG. Pigs fed ZnO had improved ($P < 0.05$) F/G compared with the treatments containing 18% CP with other treatments intermediate. From d 25 to 46, when pigs were fed a common diet (no ZnO), pigs previously fed the diets containing ZnO or those that were fed the combination of NC with 18% CP, 1.2% Na diformate, and 4% coarse ground wheat bran had greater ($P < 0.05$) ADG than pigs previously fed the NC with 18% CP with the response driven by ADFI. Overall (d 0 to 46), pigs fed diets with ZnO from d 0 to 25 had greater ADG ($P < 0.01$), ADFI ($P < 0.02$), and final BW ($P < 0.04$) than those fed the NC with 18% CP which was the lowest ($P < 0.05$) with pigs fed the other treatment diets intermediate. Pigs fed the NC diet without ZnO had the lowest ($P < 0.05$) fecal DM and highest ($P < 0.05$) fecal scores. Pigs fed diets with ZnO had similar fecal DM and scores as pigs fed the diet containing Na diformate, wheat bran, and 18% CP, but greater ($P = 0.02$) fecal DM than pigs fed singular strategies of Na diformate, wheat bran, or 18% CP. This study suggests that diets without ZnO reduce nursery performance, and lowering dietary

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CP and amino acids exacerbate this response. Combining the three alternatives tested (wheat bran, Na diformate, and low CP) as a replacement to ZnO improved fecal DM content and fecal score but did not result in improved performance.

Introduction

The addition of 2,000–3,000 ppm dietary zinc (Zn) as zinc oxide (ZnO) to nursery diets immediately after weaning is a common practice in the swine industry. Feeding supplemental Zn to nursery pigs began when reports from Europe suggested high concentrations of dietary Zn decreased the incidence of nonspecific postweaning diarrhea.

There are many possible contributors to the mechanism of increased growth and reduced diarrhea due to high Zn supplementation. Zinc ions may prevent *Escherichia coli* adhesion in the gut. Zinc also influences metallothionein, a protein involved in maintaining Zn homeostasis and physiological changes in the gastrointestinal tract that may enhance nutrient absorption by altering intestinal morphology.

However, the use of ZnO has been questioned in some parts on the world because of potential environmental concerns due to high Zn excretion and concerns about *Staphylococcus* resistance potentially being connected to feeding high Zn concentrations. Currently, ZnO is used worldwide and permitted in the European Union, except for Germany, France, and the Netherlands. In 2018, the Committee for Veterinary Medicinal Products established that the European Union has 5 years to remove pharmacological concentrations of Zn from the market.

In response to bans on using pharmacological levels of Zn, some reports support that low crude protein diets or added wheat bran may help maintain enteric health by lowering protein fermentation and promoting the proliferation of commensal microbiota. Researchers have suggested the use of diet acidifiers may be an alternative for improving weanling pig health and growth performance. Acidifiers have the potential to reduce the pH of the gastrointestinal tract, which improves nutrient digestion in weanling pigs. This treatment protects the GIT from pathogenic invasion and proliferation, making it a possible alternative to replace ZnO and antibiotics in the postweaning period. Therefore, the objective of this study was to evaluate the effects of different ingredients and diets, as alternatives to replace ZnO, on growth performance and fecal dry matter during the nursery phase.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted at the K-State Swine Teaching and Research Center in Manhattan, KS. A total of 300 pigs (DNA 241 × 600; initially 10.6 lb) were used in a 47-d growth trial. At weaning, pigs were individually weighed and assigned to pens based on weight and gender. Pens of pigs were randomly allotted to 1 of 6 treatments in a completely randomized design. There were 5 pigs per pen and 10 replicate pens per treatment. Pens had tri-bar flooring and allowed approximately 2.7 ft^2 per pig. Each pen contained a 4-hole, dry self-feeder and a cup waterer to provide *ad libitum* access to feed and water.

Diets were based on corn and soybean meal and were fed in three dietary phases: phase 1, fed from d 0 to 7 in pellet form; phase 2, fed from d 7 to 25 in meal form; and phase 3, fed from d 25 to 46 in meal form (Tables 1 and 2). Phase 1 diets were pelleted under the following parameters: 123°F average conditioning temperature, 161°F average hot pellet temperature, 3/16 × 1 1/4 inch die size (L/D = 6.0), 1,560 lb/h production rate, and 73°F ambient temperature.

Treatments consisted of 6 different diets: A) Positive control diet with 3,000 ppm Zn from ZnO from d 0 to 7 and 2,000 ppm Zn from d 7 to 25; B) Negative control diet without ZnO (NC); C) NC with 1.2% Na diformate; D) NC containing 4% coarse ground wheat bran; E) NC formulated to low crude protein (18% CP) with high levels of feed grade amino acids; and F) NC with the combination of low CP (18%), Na diformate, and coarse ground wheat bran. The low CP diets were formulated to lower standardized ileal digestible (SID) lysine levels (1.20 vs. 1.40% SID Lys) than the other diets to achieve the 18% CP while maintaining proper amino acid ratios.

Experimental diets were fed for 25 d (phase 1 and 2). From d 25 to 46 (phase 3), all pigs were fed the same common diet without the previously used feed additives fed from day 0 to 25. Pigs were weighed, and feed disappearance was measured on d 7, 14, 25, 37, and 46 to determine BW, ADG, ADFI, and F/G. All experimental diets were manufactured at the Kansas State University O.H. Kruse Feed Technology Innovation Center in Manhattan, KS.

All pens were individually assessed and scored daily by the same individual to determine fecal consistency. Fecal score was visually evaluated and was based on a numerical scale from 1 to 5: 1) hard, dry pellet; 2) firmly formed feces; 3) soft, moist feces that retained shape; 4) soft, unformed feces; and 5) watery liquid that could be poured. In addition, fecal samples were collected on d 7, 14, 25, and 37. The samples were collected from 3 randomly selected pigs per pen for a total of 18 samples per treatment. The samples were analyzed for fecal dry matter (DM). To determine DM percentage, samples were completely dried in a 105°F oven for 16 h.

Statistical analysis was performed using the GLIMMIX procedure of SAS version 9.4 (SAS Institute Inc., Cary, NC). Nursery growth performance data were analyzed as a completely randomized design using pen as the experimental unit and barn as a random effect. For fecal score and fecal DM, repeated measures over time analysis were conducted using pen as the experimental unit. Results were considered significant at $P \leq 0.05$ and considered a trend at $P \leq 0.10$.

Results and Discussion

In phase 1 (d 0 to 7), no effect ($P > 0.05$) was found in any growth performance variables between treatments (Table 3).

In phase 2 (d 7 to 25), pigs fed the diet containing ZnO had greater ($P < 0.01$) ADG and ADFI than other treatments. Pigs fed the 18% CP diet had the lowest ($P < 0.01$) ADG compared with all other treatments. No differences for ADG, ADFI, or F/G were observed between pigs fed NC, NC plus 1.2% Na diformate, NC plus 4% coarse ground wheat bran, or the combination of NC with 18% CP, 1.2% Na diformate, and

4% coarse ground wheat bran. Pigs fed the ZnO diet had improved ($P < 0.01$) F/G compared with those fed the 18% CP diet or the combination of NC with 18% CP, 1.2% Na diformate, and 4% coarse ground wheat bran, demonstrating that the lower SID lysine in the 18% CP diets was well below the pigs' requirement.

At d 25, pigs fed the diets containing ZnO from d 0 to 25 were heavier than those fed other diets. Pigs fed the 18% CP diet were lighter than other treatments, with NC plus Na diformate, NC plus wheat bran, or the combination of those ingredients in an 18% CP diet intermediate.

For phase 3 (d 26 to 46), when all pigs were fed the same diet, pigs previously fed diets containing ZnO or those previously fed the combination of NC plus 18% CP, 1.2% Na diformate, and 4% coarse ground wheat bran had greater ($P < 0.01$) ADG than pigs fed the 18% CP diet. For ADFI, pigs previously fed diets with ZnO had greater ($P < 0.01$) ADFI than pigs fed the NC plus 1.2% Na diformate. Pigs that were previously fed the diet with 18% CP had the lowest ($P < 0.02$) ADFI of all treatments. For F/G, no evidence for differences was observed between treatments during phase 3.

Overall (d 0 to 46), pigs fed diets with ZnO during phase 1 and 2 had greater ADG ($P < 0.01$), ADFI ($P < 0.02$), and final body weight ($P < 0.04$) than those fed other treatments. Pigs previously fed the 18% CP diet had the lowest ($P < 0.05$) ADG and ADFI. Pigs fed NC, NC plus Na diformate, NC plus 4% coarse ground wheat bran and the combination of NC and 18% CP, 1.2% Na diformate, and 4% coarse ground wheat bran had intermediate ADG and ADFI. Pigs fed positive control diets in phase 1 and 2 were more efficient ($P < 0.05$) than pigs fed the diet with 18% CP. The other treatments were intermediate for F/G.

There was no evidence for difference ($P > 0.05$) between treatments in fecal DM content on d 7 after weaning (Table 4). On d 14, pigs fed NC diets had the lowest ($P < 0.01$) fecal DM content. No evidence for difference was observed between pigs fed ZnO diets and pigs fed diets with combination of NC and 18% CP, 1.2% Na diformate, and 4% coarse ground wheat bran ($P < 0.05$). Pigs fed the combination diet had similar DM content with pigs that were fed NC diets plus Na diformate, NC plus wheat bran and NC plus 18% CP ($P < 0.05$).

Similar to d 14, on d 25, pigs fed NC diet had the lowest ($P < 0.01$) fecal DM content. No difference ($P > 0.05$) between positive control, NC plus Na diformate, NC plus 18% CP and the combination of NC plus the 3 alternative ingredients together was observed. The NC plus 4% coarse ground wheat bran was intermediate.

On d 37, the pattern of response was similar to the response observed on d 25. However, pigs fed NC and NC plus 4% coarse ground wheat bran had similar fecal DM content ($P > 0.05$).

For the overall mean of the four collection periods, pigs fed NC diets had the lowest ($P < 0.01$) fecal DM content. No evidence for difference was detected between positive control and pigs fed the combination of NC plus 1.2% Na diformate, 18% CP,

and 4% coarse ground wheat bran ($P > 0.05$). Pigs fed NC diets with only one of those alternative ingredients were intermediate.

For fecal score, treatment and day effects were observed. Pigs fed the NC had softer feces ($P = 0.02$) than all other treatments (Figure 1). From d 7 to 25, pigs had higher frequency distribution ($P = 0.02$) of soft unformed and soft moist feces compared to d 37 and d 46 (Figure 2) mainly driven by the higher percentage of pigs fed NC diets with softer feces on the average of the whole trial period.

In conclusion, the present study suggests that diets without ZnO reduce nursery performance and lowering dietary CP exacerbates it, which may be explained by the reduction in dietary SID lysine content. The use of a combination of the 3 alternatives (1.2% Na diformate, 4% coarse ground wheat bran, and 18% CP), as a replacement to ZnO, improved the appearance of feces and resulted in similar fecal DM content and fecal score to pigs fed diets containing ZnO. However, no alternative ingredient in this study was able to achieve equivalent growth performance of pigs fed the ZnO diet.

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Table 1. Diet composition, d 0 to 7 after weaning

Item	Positive control	Negative control (NC)	NC + 1.2% Na diformate	NC + 4% coarse ground wheat bran	NC + 18% CP	NC + Na diformate + wheat bran + 18% CP
Ingredient, %						
Corn	44.40	44.80	43.70	41.20	52.25	47.55
Soybean meal (46.5% CP)	18.10	18.10	18.15	17.75	10.55	10.35
Fish meal	4.50	4.50	4.50	4.50	4.50	4.50
Dried whey powder	25.00	25.00	25.00	25.00	25.00	25.00
Enzymatically treated soybean meal[1]	3.75	3.75	3.75	3.75	3.75	3.75
Wheat bran (coarse)	---	---	---	4.00	---	4.00
Choice white grease	1.50	1.50	1.50	1.50	1.50	1.50
Calcium carbonate	0.25	0.25	0.25	0.30	0.25	0.30
Monocalcium phosphate	0.30	0.30	0.30	0.20	0.40	0.30
Sodium chloride	0.30	0.30	0.15	0.30	0.32	0.30
L-Lysine-HCl	0.42	0.42	0.42	0.42	0.41	0.41
DL-Methionine	0.22	0.22	0.22	0.21	0.17	0.16
L-Threonine	0.21	0.21	0.21	0.20	0.19	0.18
L-Tryptophan	0.06	0.06	0.06	0.05	0.07	0.07
L-Valine	0.11	0.11	0.11	0.10	0.12	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[2]	0.07	0.07	0.07	0.07	0.07	0.07
Zinc oxide	0.40	---	---	---	---	---
Na diformate	---	---	1.20	---	---	1.20
Total	100	100	100	100	100	100

continued

Table 1. Diet composition, d 0 to 7 after weaning

Item	Positive control	Negative control (NC)	NC + 1.2% Na diformate	NC + 4% coarse ground wheat bran	NC + 18% CP	NC + Na diformate + wheat bran + 18% CP
Standardized ileal digestible (SID) amino acids, %						
Lysine	1.40	1.40	1.40	1.40	1.20	1.20
Isoleucine:lysine	56	56	56	56	55	55
Leucine:lysine	109	110	109	108	113	111
Methionine:lysine	38	38	38	37	37	36
Methionine and cystine:lysine	58	58	58	58	58	58
Threonine:lysine	65	65	65	65	66	65
Tryptophan:lysine	20.3	20.3	20.3	20.1	21.0	21.3
Valine:lysine	68	68	68	68	70	70
Histidine:lysine	32	32	32	32	32	32
Total lysine, %	1.54	1.54	1.54	1.54	1.32	1.32
ME, kcal/lb	1,551	1,557	1,541	1,539	1,559	1,524
NE NRC, kcal/lb[3]	1,169	1,174	1,161	1,156	1,192	1,162
SID lysine:NE, g/Mcal	5.43	5.41	5.47	5.49	4.57	4.68
Crude protein, %	21.0	21.0	20.9	21.1	18.0	18.0
Ca, %	0.65	0.65	0.65	0.65	0.64	0.64
P, %	0.64	0.64	0.64	0.65	0.63	0.64
Available P, %	0.55	0.55	0.55	0.54	0.57	0.55
STTD P, %	0.56	0.56	0.56	0.56	0.56	0.56
Ca:P	1.00	1.00	1.01	1.00	1.01	1.01

[1]HP 300, Hamlet Protein, Findlay, OH.
[2]Rhonozyme, 2700 (DSM Nutritional Products, Inc., Parsippany, NJ) provided 918.5 phytase units (FYT) per lb of diet, with a release of 0.10% available P.
[3]National Research Council. 2012. Nutrient Requirements of Swine: Eleventh Revised Edition. Washington, DC: The National Academies Press. https://doi.org/10.17226/13298.
CP = crude protein.
ME = metabolizable energy.
NE = net energy.
STTD = standardized total tract digestible.

Table 2. Diet composition d 7 to 25 after weaning

Item, %	Positive control	Negative control (NC)	NC + Na diformate	NC + wheat bran	NC + 18% CP	NC + Na diformate + wheat bran + 18% CP
Ingredient, %						
Corn	56.75	57.00	55.95	53.45	64.10	59.45
Soybean meal, 46.5%	29.05	29.05	29.10	28.70	21.65	21.40
Milk, whey powder	10.00	10.00	10.00	10.00	10.00	10.00
Wheat bran (coarse)	---	---	---	4.00	---	4.00
Calcium carbonate	0.92	0.92	0.92	0.95	0.92	0.97
Monocalcium phosphate	0.90	0.90	0.90	0.80	1.02	0.90
Sodium chloride	0.55	0.55	0.35	0.55	0.57	0.35
L-Lysine-HCl	0.50	0.50	0.50	0.50	0.54	0.54
DL-Methionine	0.21	0.21	0.21	0.20	0.23	0.22
L-Threonine	0.24	0.24	0.24	0.23	0.24	0.24
L-Tryptophan	0.04	0.04	0.04	0.03	0.07	0.07
L-Valine	0.10	0.10	0.10	0.10	0.16	0.16
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[1]	0.07	0.07	0.07	0.07	0.07	0.07
Zinc oxide	0.26	---	---	---	---	---
Na diformate	---	---	1.20	---	---	0.06
Total	100	100	100	100	100	100

continued

Table 2. Diet composition d 7 to 25 after weaning

Item, %	Positive control	Negative control (NC)	NC + Na diformate	NC + wheat bran	NC + 18% CP	NC + Na diformate + wheat bran + 18% CP
Standardized ileal digestible (SID) amino acids, %						
Lysine	1.35	1.35	1.35	1.35	1.20	1.20
Isoleucine:lysine	55	55	55	55	52	52
Leucine:lysine	112	112	111	111	111	109
Methionine:lysine	36	36	36	35	39	38
Methionine and cystine:lysine	57	57	57	57	60	60
Threonine:lysine	65	65	65	65	65	65
Tryptophan:lysine	19.1	19.1	19.1	19.0	21.2	21.0
Valine:lysine	67	67	67	67	70	70
Histidine:lysine	35	35	35	35	33	33
Total lysine, %	1.48	1.48	1.48	1.49	1.31	1.32
ME, kcal/lb	1,486	1,490	1,474	1,471	1,492	1,459
NE NRC, kcal/lb[2]	1,103	1,106	1,094	1,089	1,125	1,096
SID lysine:NE, g/Mcal	5.55	5.54	5.60	5.62	4.84	4.97
CP, %	20.6	20.6	20.5	20.7	17.8	17.9
Ca, %	0.75	0.75	0.75	0.75	0.75	0.75
P, %	0.62	0.62	0.61	0.62	0.61	0.61
Available P, %	0.47	0.47	0.47	0.46	0.49	0.47
STTD P, %	0.51	0.51	0.51	0.51	0.51	0.51
Ca:P	1.22	1.22	1.22	1.20	1.23	1.23

[1]Rhonozyme, 2700 (DSM Nutritional Products, Inc., Parsippany, NJ) provided 918.5 phytase units (FYT) per lb of diet, with a release of 0.10% available P.
[2]National Research Council. 2012. Nutrient Requirements of Swine: Eleventh Revised Edition. Washington, DC: The National Academies Press. https://doi.org/10.17226/13298.
CP = crude protein.
ME = metabolizable energy.
NE = net energy.
STTD = standardized total tract digestible.

Table 3. Diet composition d 25 to 47 after weaning

Item, %	
Ingredient, %	
Corn	65.60
Soybean meal, 46.5%	30.20
Calcium carbonate	1.00
Monocalcium phosphate	0.95
Sodium chloride	0.57
L-Lysine-HCl	0.55
DL-Methionine	0.23
L-Threonine	0.25
L-Tryptophan	0.07
L-Valine	0.13
Trace mineral premix	0.15
Vitamin premix	0.25
Phytase[1]	0.07
Total	100
Standardized ileal digestible (SID) amino acids, %	
Lysine	1.35
Isoleucine:lysine	54
Leucine:lysine	112
Methionine:lysine	37
Methionine and cystine:lysine	58
Threonine:lysine	64
Tryptophan:lysine	20.9
Valine:lysine	68
Histidine:lysine	35
Total lysine, %	1.49
ME, kcal/lb	1,487
NE NRC, kcal/lb[2]	1,101
SID lysine:NE, g/Mcal	5.56
CP, %	20.8
Ca, %	0.73
P, %	0.59
Available P, %	0.42
STTD P, %	0.46
Ca:P	1.24

[1]Rhonozyme, 2700 (DSM Nutritional Products, Inc, Parsippany, NJ) provided 918.5 phytase units (FYT) per lb of diet, with a release of 0.10% available P.
[2]National Research Council. 2012. Nutrient Requirements of Swine: Eleventh Revised Edition. Washington, DC: The National Academies Press. https://doi.org/10.17226/13298.
ME = metabolizable energy.
NE = net energy.
CP = crude protein.
STTD = standardized total tract digestible.

Table 4. Growth performance of nursery pigs with different alternatives to replace zinc oxide in nursery diets[1]

	Positive control	Negative control (NC)	NC + Na diformate	NC + wheat bran	NC + 18% CP	NC + Na diformate + wheat bran + 18% CP	SEM	*P*-value
BW, lb								
Weaning	10.59	10.65	10.66	10.63	10.63	10.61	0.035	0.984
d 7	11.51	11.49	11.47	11.45	11.41	11.56	0.254	0.978
d 25	25.75[a]	21.98[b]	22.23[b]	21.97[b]	20.17[c]	22.16[b]	0.713	<0.001
d 46	54.86[a]	50.50[b]	49.66[b]	50.21[b]	45.98[c]	50.90[b]	1.378	<0.001
Phase 1 (d 0 to 7)								
ADG, lb	0.13	0.12	0.10	0.12	0.12	0.14	0.034	0.763
ADFI, lb	0.22	0.23	0.25	0.24	0.23	0.25	0.018	0.754
F/G	1.92	2.14	2.60	2.52	2.63	2.16	0.756	0.242
Phase 2 (d 8 to 25)								
ADG, lb	0.79[a]	0.58[b]	0.60[b]	0.59[b]	0.49[c]	0.59[b]	0.032	<.001
ADFI, lb	1.05[a]	0.85[bc]	0.83[bc]	0.82[bc]	0.78[c]	0.86[b]	0.046	<.001
F/G	1.33[a]	1.42[ab]	1.37[ab]	1.42[ab]	1.63[c]	1.47[b]	0.051	0.001
Phase 3 (d 26 to 46)[2]								
ADG, lb	1.39[ab]	1.34[bc]	1.31[bc]	1.33[bc]	1.24[c]	1.37[ab]	0.044	0.134
ADFI, lb	2.05[a]	1.95[ab]	1.90[b]	1.93[ab]	1.76[c]	1.97[ab]	0.052	0.006
F/G	1.47	1.46	1.45	1.44	1.46	1.44	0.035	0.981
Overall (d 0 to 46)								
ADG, lb	0.96[a]	0.86[b]	0.84[b]	0.85[b]	0.76[c]	0.88[b]	0.035	<0.001
ADFI, lb	1.38[a]	1.25[b]	1.22[b]	1.23[b]	1.13[c]	1.27[b]	0.039	<0.001
F/G	1.43[a]	1.46[ab]	1.44[ab]	1.45[ab]	1.50[b]	1.46[ab]	0.025	0.410

[a,b,c]Different superscripts within a row indicate evidence for difference ($P < 0.05$) in average daily gain (ADG), average daily feed intake (ADFI), feed-to-gain ratio (F/G), and body weight (BW).

[1]A total of 300 weaned pigs (241 × 600, DNA Genetics, Columbus, NE) with an initial BW of 10.6 lb and 18.5 d of age were used. Pigs were allotted to pens in a completely randomized design with 5 pigs per pen and 10 pens per treatment.

[2]Common period where all pigs were fed the same diet without feed additives used from weaning to d 26.

CP = crude protein.

Table 5. Effect of different diets as alternative to replace ZnO in nursery diets on fecal dry matter, % [1,2]

Day of collection	Positive control	Negative control (NC)	NC + Na diformate	NC + wheat bran	NC + 18% CP	NC + Na diformate + wheat bran + 18% CP	SEM	*P*-value
d 7	22.01	19.03	21.35	21.46	20.26	24.37	2.668	0.149
d 14	25.50[a]	19.11[c]	22.17[b]	22.80[b]	23.14[b]	24.12[ab]	0.791	0.001
d 25	24.73[a]	20.91[c]	23.11[ab]	21.87[b]	22.97[ab]	23.39[ab]	0.709	0.001
d 37	25.83[a]	21.91[c]	23.94[ab]	22.73[bc]	24.79[a]	24.97[a]	0.698	0.001
Mean	24.52[a]	20.24[c]	22.64[b]	22.22[b]	22.79[b]	24.21[ab]	0.771	0.001

[a,b,c]Different superscripts within a row indicate evidence for difference ($P < 0.05$).

[1]Values represent the mean of 3 pigs per pen and 10 pens per treatment.

[2]Three pigs per pen were randomly selected and sampled. The fecal samples from the same pigs were collected and dried using a one stage drying method.

CP = crude protein.

SEM = standard error of the mean.

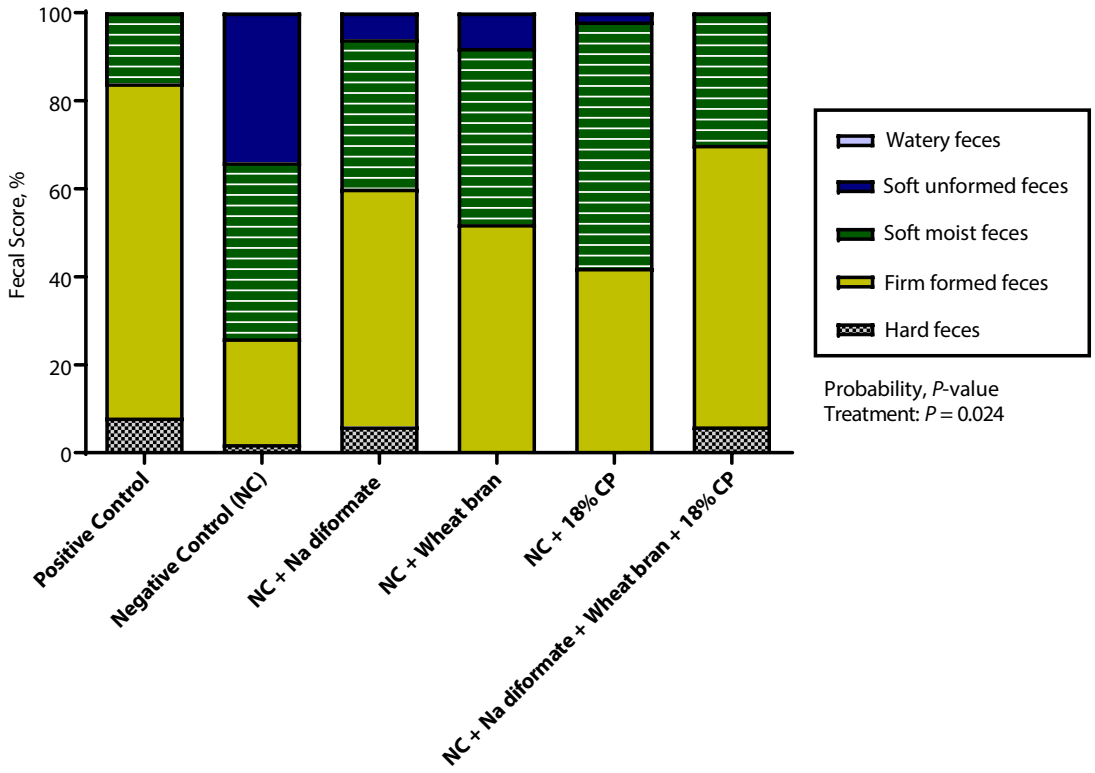

Figure 1. Frequency distribution of fecal score in nursery pigs by treatment (average of the 5 collection days). CP = crude protein.

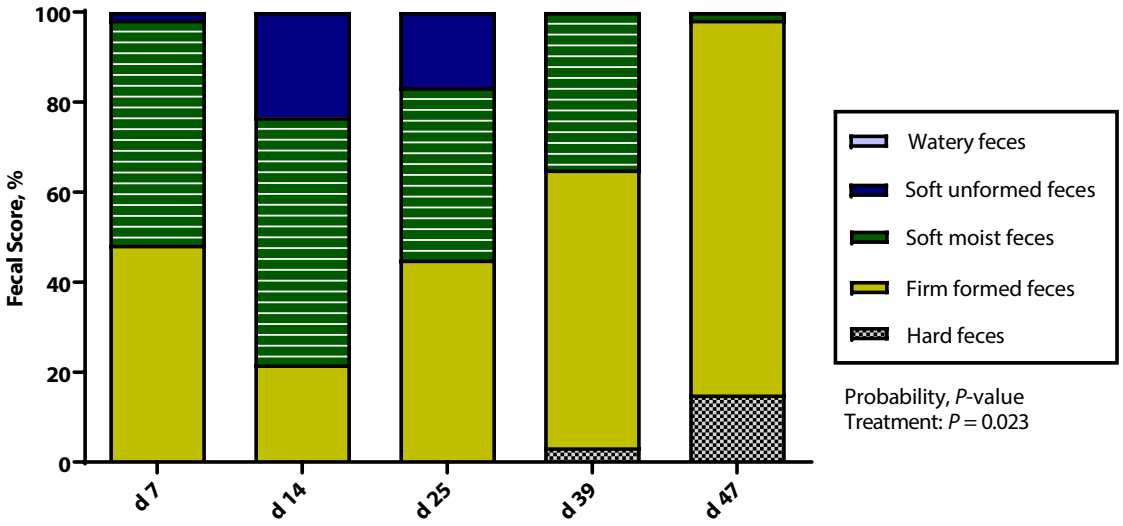

Figure 2. Frequency distribution of fecal score in nursery pigs by day (average of all treatments by day).