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Effect of Crude Protein Level and Coarse Wheat Bran on Nursery Pig Growth Performance

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Abstract

Two experiments were conducted to determine the effect of adding coarse wheat bran with reduced crude protein level in diets without pharmacological levels of zinc oxide on the growth performance and fecal dry matter of nursery pigs. Our objective was to determine if a low-crude protein diet with an added fiber source might provide similar growth performance and reduce the incidence of scours in weanling pigs compared to a typical, high-protein diet with added Zn. A total of 300 and 350 pigs (DNA 241 × 600), initially 15.4 and 13.7 lb body weight (BW), were used in Exp. 1 and 2, respectively. There were 5 pigs per pen and 12 and 14 replicates per treatment in Exp. 1 and 2, respectively. After weaning, pigs were fed a common pelleted diet with pharmacological levels (3,000 ppm Zn) of ZnO for 10 d in Exp. 1, and without pharmacological levels of ZnO for 14 d in Exp. 2. Then, pens were assigned to one of 5 dietary treatments in a randomized complete block design with BW as the blocking factor. In Exp. 1 and 2, treatment diets were offered in mash form and in one dietary phase. All dietary treatments contained 4% coarse wheat bran and consisted of: 1) positive control with ZnO (2,000 ppm Zn) and 21% crude protein (CP) formulated to 1.35% standardized ileal digestible (SID) lysine; 2) a diet with 110 ppm added Zn and 21% CP (1.35% SID lysine); 3) a diet with 110 ppm added Zn formulated to 18% CP (1.20% SID lysine); 4) an 18% CP diet with 110 ppm added Zn formulated to 1.35% SID lysine by the addition of feed grade amino acids; and 5) diet 4 with the addition of non-essential amino acids (glycine and glutamic acid). A common post-treatment pelleted diet was fed for 14 d in Exp. 2 but not in Exp. 1. Data were analyzed using the lmer function from the lme4 package in R. In Exp. 1, pigs fed diets with 21% CP had increased ($P < 0.05$) ADG and heavier ($P < 0.05$) final BW; however, treatment means did not separate when Tukey adjustment was applied during statistical analysis. Pigs fed diets with 21% CP had improved ($P < 0.05$) feed efficiency similarly to pigs fed 18% CP diets with the addition of non-essential amino acids. During the experimental period in Exp. 2, pigs fed high CP diets with ZnO had increased ($P < 0.05$) ADG compared to pigs fed the 18% CP diet with 1.2% SID lysine and the 18% CP diet with high levels of feed grade essential amino acids. Feed efficiency was improved ($P < 0.05$) for pigs fed the 18% CP diet with added non-essential amino acids and for pigs fed both 21% CP diets compared to the other 18% CP diets without ZnO. Compared to pigs fed 18% CP diets, pigs fed diets with 21% CP had increased ($P < 0.05$) d 13 BW. Visual fecal score was decreased ($P < 0.05$) for pigs fed the 18% CP diets compared to pigs fed 21% CP without added ZnO in Exp. 1. Pigs fed the 21% CP diet without ZnO experienced increased ($P < 0.05$) visual fecal score in Exp. 2. No evidence for differences in fecal dry matter were observed throughout either trial; however, when Exp. 1 and Exp. 2 were combined, increased ($P < 0.05$) fecal dry matter was observed for pigs fed the 1.2% SID lysine diet compared to pigs fed 21% CP diets on d 6. Fecal dry matter was increased ($P < 0.05$) on d 13 for pigs fed the reduced Lys (1.2% SID lysine) diet compared to pigs fed 21% CP without ZnO. In summary, results from these experiments suggest that reducing crude protein decreases growth performance compared to pigs fed high crude protein diets. Adding glycine and glutamine to the low CP diets improved feed efficiency, but not daily gain.

Keywords

crude protein, fecal dry matter, fiber, nursery pigs, zinc

Authors

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Effect of Crude Protein Level and Coarse Wheat Bran on Nursery Pig Growth Performance

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Summary

Two experiments were conducted to determine the effect of adding coarse wheat bran with reduced crude protein level in diets without pharmacological levels of zinc oxide on the growth performance and fecal dry matter of nursery pigs. Our objective was to determine if a low-crude protein diet with an added fiber source might provide similar growth performance and reduce the incidence of scours in weanling pigs compared to a typical, high-protein diet with added Zn. A total of 300 and 350 pigs (DNA 241 × 600), initially 15.4 and 13.7 lb body weight (BW), were used in Exp. 1 and 2, respectively. There were 5 pigs per pen and 12 and 14 replicates per treatment in Exp. 1 and 2, respectively. After weaning, pigs were fed a common pelleted diet with pharmacological levels (3,000 ppm Zn) of ZnO for 10 d in Exp. 1, and without pharmacological levels of ZnO for 14 d in Exp. 2. Then, pens were assigned to one of 5 dietary treatments in a randomized complete block design with BW as the blocking factor. In Exp. 1 and 2, treatment diets were offered in mash form and in one dietary phase. All dietary treatments contained 4% coarse wheat bran and consisted of: 1) positive control with ZnO (2,000 ppm Zn) and 21% crude protein (CP) formulated to 1.35% standardized ileal digestible (SID) lysine; 2) a diet with 110 ppm added Zn and 21% CP (1.35% SID lysine); 3) a diet with 110 ppm added Zn formulated to 18% CP (1.20% SID lysine); 4) an 18% CP diet with 110 ppm added Zn formulated to 1.35% SID lysine by the addition of feed grade amino acids; and 5) diet 4 with the addition of non-essential amino acids (glycine and glutamic acid). A common post-treatment pelleted diet was fed for 14 d in Exp. 2 but not in Exp. 1. Data were analyzed using the lmer function from the lme4 package in R. In Exp. 1, pigs fed diets with 21% CP had increased ($P < 0.05$) ADG and heavier ($P < 0.05$) final BW; however, treatment means did not separate when Tukey adjustment was applied during statistical analysis. Pigs fed diets with 21% CP had improved ($P < 0.05$) feed efficiency similarly to pigs fed 18% CP diets with the addition of non-essential amino acids. During the experimental period in Exp. 2, pigs fed high CP diets with ZnO had increased ($P < 0.05$) ADG compared to pigs fed the 18% CP diet with 1.2% SID lysine and the 18% CP diet with high levels of feed grade essential amino acids. Feed efficiency was improved ($P < 0.05$) for pigs fed

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the 18% CP diet with added non-essential amino acids and for pigs fed both 21% CP diets compared to the other 18% CP diets without ZnO. Compared to pigs fed 18% CP diets, pigs fed diets with 21% CP had increased ($P < 0.05$) d 13 BW. Visual fecal score was decreased ($P < 0.05$) for pigs fed the 18% CP diets compared to pigs fed 21% CP without added ZnO in Exp. 1. Pigs fed the 21% CP diet without ZnO experienced increased ($P < 0.05$) visual fecal score in Exp. 2. No evidence for differences in fecal dry matter were observed throughout either trial; however, when Exp. 1 and Exp. 2 were combined, increased ($P < 0.05$) fecal dry matter was observed for pigs fed the 1.2% SID lysine diet compared to pigs fed 21% CP diets on d 6. Fecal dry matter was increased ($P < 0.05$) on d 13 for pigs fed the reduced Lys (1.2% SID lysine) diet compared to pigs fed 21% CP without ZnO. In summary, results from these experiments suggest that reducing crude protein decreases growth performance compared to pigs fed high crude protein diets. Adding glycine and glutamine to the low CP diets improved feed efficiency, but not daily gain.

Introduction

Newly weaned piglets often experience a lag in growth post-weaning, which can be attributed to a change in diet, decreased feed intake, a reduction in intestinal absorptive capacity, and an immature immune and digestive system.[3] Post-weaning diarrhea (PWD) can be initiated by these factors in addition to the proliferation of *Escherichia coli*, exacerbating the reduced growth performance and economic loss. Pharmacological levels of zinc oxide (ZnO) are commonly used in the United States to mitigate PWD. However, stringent regulations on dietary use of ZnO in Europe may be adopted in the United States in the future. The lack of an alternative dietary strategy that offers similar growth and physiological benefits as ZnO in nursery pig diets indicates the need for further research.

Coarse wheat bran has been observed to decrease the ability of *Escherichia coli* to attach to the intestinal mucosal of nursery pigs, while regulating the microbiota and improving fermentation.[4] High levels of crude protein in post-weaning diets have been shown to increase the risk of PWD due to undigested protein and increased microbial fermentation.[5] Various studies have demonstrated that a low crude protein diet with crystalline essential amino acids decreases incidences of PWD and promotes intestinal health; however, decreased growth performance has been observed.[6] In low crude protein diets, it is hypothesized that deficiencies in lysine or other amino acids, either essential or non-essential, cause reductions in pig performance.[7] Therefore, the objective of these

[3] Pluske, J. R., D. J. Hampson, and I. H. Williams. Factors influencing the structure and function of the small intestine in the weaned pig: a review. 1997. Livest. Prod. Sci. 51(1-3):215-236. doi: 10.1016/S0301-6226(97)00057-2.

[4] Molist, F., R. G. Hermes, A. G. de Segura, S. M. Martín-Orúe, J. Gasa, E. G. Manzanilla, and J. F. Pérez. 2011. Effect and interaction between wheat bran and zinc oxide on productive performance and intestinal health in post-weaning piglets. Br. J. Nutr. 105(11):1592-1600. doi: 10.1017/S0007114510004575.

[5] Wellock, I. J., P. D. Fortomaris, J. G. M. Houdijk, and I. Kyriazakis. 2006. The effect of dietary protein supply on the performance and risk of post-weaning enteric disorders in newly weaned pigs. Anim. Sci. 82:327-335. doi: 10.1079/ASC200643.

[6] Nyachoti, C. M., F. O. Omogbenigun, M. Rademacher, and G. Blank. 2006. Performance responses and indicators of gastrointestinal health in early-weaned pigs fed low-protein amino acid-supplemented diets. J. Anim. Sci. 84:125-134. doi: 10.2527/2006.841125x.

[7] Wang, Y., J. Zhou, G. Wang, S. Cai, X. Zeng, and S. Qiao. Advances in low-protein diets for swine. 2018. J. Anim. Sci. Biotechnol. 9:60. doi: 10.1186/s40104-018-0276-7.

experiments was to determine the effect of dietary crude protein level and the supplementation of crystalline essential or non-essential amino acids in diets containing coarse wheat bran on the growth performance and fecal characteristics of nursery pigs fed diets without pharmacological levels of ZnO.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocols used in these experiments. Two experiments were conducted at the Kansas State University Swine Teaching and Research Center in Manhattan, KS. All experimental diets were manufactured at the Kansas State University O.H. Kruse Feed Technology Innovation Center in Manhattan, KS.

In Exp. 1, a total of 300 pigs (DNA 241 × 600; initial average BW of 15.4 lb) were used in a 13-d growth trial. In Exp. 2, 350 pigs (DNA 241 × 600; initial average BW of 13.7 lb) were used in a 27-d growth trial, where experimental diets were fed for 13 d and a common diet was fed for 14 d. Pigs were weaned at approximately 21 d of age and placed in pens of 5 pigs each based on initial BW and gender. A common phase 1 pelleted diet containing pharmacological levels of ZnO (3,000 ppm Zn) was fed for 10 d in Exp. 1, and a common phase 1 pelleted diet containing no pharmacological ZnO was fed for 14 d in Exp. 2 prior to initiating the dietary treatments. At d 10 or 14 after weaning, which was considered d 0 of the trial, pens of pigs were randomly allotted to 1 of 5 dietary treatments in a randomized complete block design with BW as the blocking factor. There were 12 replicates per treatment in Exp. 1 and 14 replicates per treatment in Exp. 2.

In Exp. 1 and 2, treatment diets were offered in mash form and in one dietary phase. All dietary treatments (Table 1) contained 4% coarse wheat bran and consisted of: 1) positive control with ZnO (2,000 ppm Zn) and 21% crude protein (CP) formulated to 1.35% standardized ileal digestible (SID) lysine; 2) a diet with 110 ppm added Zn and 21% CP (1.35% SID lysine); 3) a diet with 110 ppm added Zn formulated to 18% CP (1.20% SID lysine); 4) an 18% CP diet with 110 ppm added Zn formulated to 1.35% SID lysine by the addition of feed grade amino acids, and 5) diet 4 with the addition of non-essential amino acids (glycine and glutamic acid). Diet 3 was formulated to 18% CP while adding feed grade amino acids until the minimum Ile:Lys requirement of 52% was met. L-Ile and L-His were added along with other feed grade amino acids to formulate diet 4 to 1.35% SID lysine. The non-essential amino acids glycine and glutamic acid were added to diet 5. The combination of glycine and nitrogen from an additional amino acid has been determined to be required in low CP diets.[8] A common post-treatment diet was fed from d 13 to 27 in Exp. 2 (Table 2).

Each pen contained a 4-hole, dry self-feeder and a nipple waterer to provide *ad libitum* access to feed and water. Pigs were weighed and feed disappearance was measured on d 0, 7, and 13 in Exp. 1 and on d 0, 6, 13, 20, and 27 in Exp. 2.

[8] Powell, S., T. D. Bidner, R. L. Payne, and L. L. Southern. 2011. Growth performance of 20- to 50-kilogram pigs fed low-crude protein diets supplemented with histidine, cystine, glycine, glutamic acid, or arginine. J. Anim. Sci. 89(11):3643-3650. doi: 10.2527/jas.2010-3757.

Fecal samples were collected from the same three pigs per pen on d 0, 7, and 13 for Exp. 1, and on d 0, 6, 13, 20, and 27 for Exp. 2. Fecal samples were collected into clean, single use zipper storage bags and were then stored at -4°F until fecal dry matter analysis. Equal fecal samples from each pig were pooled by pen respective of day of collection and dried at 55°C in a forced air oven for 48 h. Fecal dry matter was determined as follows: (dried sample weight at 48 h – pan weight) / (initial wet sample weight – pan weight) × 100.

Chemical Analysis

Complete diet samples were taken during manufacturing of each diet and were stored at -4°F until they were homogenized, subsampled, and submitted for analysis. Duplicate composite samples per dietary treatment were analyzed (Ward Laboratories, Kearney, NE) for dry matter, CP, crude fiber, ADF, NDF, Ca, Zn, and P for each experiment.

Statistical Analysis

Statistical analysis was performed using the lmer function from the lme4 package in R (version 3.6.1 (2019-07-05), R Foundation for Statistical Computing, Vienna, Austria). Growth performance data were analyzed as a randomized complete block design with pen as the experimental unit, and the blocking factor of initial BW as a random effect. Pairwise comparisons were conducted on treatment means using a Tukey adjustment. A repeated measures statement, with random effect of block, was used for analyzing fecal dry matter and fecal consistency scores over time. No significant treatment × experiment interactions were observed, thus data from Exp. 1 and Exp. 2 were combined to evaluate growth performance during the experimental period (d 0 to 13) and fecal dry matter. 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 chemical analyses of the experimental diets were similar to formulated values with minor analytical variation for CP and Zn (Table 3).

Overall in Exp. 1, pigs fed diets with 21% CP had increased ($P < 0.05$) ADG and heavier ($P < 0.05$) final BW; however, treatment means did not separate when Tukey adjustment was applied during statistical analysis. Pigs fed 18% CP diets with the addition of non-essential amino acids had improved ($P < 0.05$) feed efficiency similarly to pigs fed diets with 21% CP (Table 4). No evidence for differences in fecal dry matter was observed in Exp. 1 (Table 7). In this experiment, reduced growth performance was expected and observed for the 18% CP diet formulated to 1.2% SID lysine with no ZnO. The 18% CP diet without ZnO formulated to 1.35% SID lysine by only increasing the essential amino acids was not expected to improve performance because of possible deficiencies in non-essential amino acids. Adding non-essential amino acids to this diet was hypothesized to improve growth performance; however, negligible improvements in growth were elicited, but an improvement in F/G was observed when non-essential amino acids were included.

Pigs fed the positive control diet that contained added ZnO in the 21% CP diet did not have improved growth performance compared with the 21% CP diet without ZnO, which was unexpected. Pigs were fed a common diet containing pharmacological levels of ZnO for 10 d from weaning until the beginning of the trial, which may have led to the lack of response to ZnO in Exp. 1.

In Exp. 2, during the experimental period (day 0 to 13), pigs fed 21% CP diets with ZnO had increased ($P < 0.05$) ADG compared to pigs fed the 18% CP diet with 1.2% SID lysine and the 18% CP diet with high levels of feed-grade essential amino acids (1.35% SID lysine; Table 5). Feed efficiency was improved ($P < 0.05$) for pigs fed the 18% CP diet with added non-essential amino acids and pigs fed 21% CP diets compared to the other 18% CP diets without ZnO. Compared to the means of pigs fed 18% CP diets, pigs fed diets with 21% CP and added ZnO had increased ($P < 0.05$) d 13 BW. No evidence for differences in fecal dry matter was observed during the experimental period when treatment diets were fed in Exp. 2 (Table 8).

During the common post-treatment phase (d 13 to 27), no evidence for differences was observed for ADG, ADFI, F/G, or fecal dry matter percentage for pigs previously fed any of the dietary treatments. Overall from d 0 to 27, pigs fed the 21% CP diet with ZnO had improved ($P < 0.05$) F/G compared to pigs fed 18% CP diet with 1.2% SID lysine, with all other treatments intermediate. Pigs fed a 21% CP diet without added ZnO had heavier ($P < 0.05$) final BW compared to pigs fed the 18% CP diet with the addition of essential amino acids.

When the results of Exp. 1 and 2 are combined (Table 6), pigs fed 21% CP with ZnO had increased ($P < 0.05$) ADG and heavier ($P < 0.05$) final BW compared to pigs fed 18% CP with 1.2% lysine and 18% CP with high levels of feed grade amino acids. Overall feed efficiency was improved ($P < 0.05$) for pigs fed 21% CP diets and for pigs fed the 18% CP diet with added non-essential amino acids compared to the other treatments. Fecal dry matter percentage (Table 9) on d 6 was increased ($P < 0.05$) for pigs fed the 1.2% SID lysine diet compared to pigs fed 21% CP diets, with the other dietary treatments intermediate. Marginal evidence for treatment differences was observed ($P = 0.084$); however, on d 13 increased ($P < 0.05$) fecal dry matter was observed for pigs fed the reduced lysine diet (1.2% SID lysine) compared to pigs fed 21% CP with no added ZnO.

In conclusion, results from these experiments suggest that decreasing CP along with SID lysine in an attempt to minimize post-weaning scours decreases growth performance compared to pigs fed high crude protein diets. No growth response to ZnO was observed in either experiment regardless if pharmacological levels of ZnO were fed or not fed prior to experimental diets. No improvements in growth were observed for pigs fed 18% CP diets balanced with high amounts of feed grade essential amino acids, while improvements in feed efficiency were observed with the addition of non-essential amino acids in diets containing coarse wheat bran and no pharmacological levels of ZnO.

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

	21% CP		18% CP, no ZnO		
Ingredient, %	ZnO	No ZnO	1.2% Lysine	1.35% Lysine	1.35% Lysine + NEAA
Corn	53.15	53.45	60.55	60.00	57.60
Soybean meal, 46.5% CP	28.75	28.70	21.35	21.25	21.40
Dried whey	10.00	10.00	10.00	10.00	10.00
Coarse wheat bran	4.00	4.00	4.00	4.00	4.00
Calcium carbonate	0.95	0.95	0.95	0.95	0.95
Monocalcium phosphate, 21% P	0.80	0.80	0.90	0.90	0.90
Salt	0.55	0.55	0.55	0.55	0.55
L-Lysine	0.50	0.50	0.54	0.74	0.74
DL-Methionine	0.20	0.20	0.23	0.31	0.31
L-Threonine	0.24	0.24	0.24	0.34	0.34
L-Tryptophan	0.03	0.03	0.07	0.11	0.11
L-Valine	0.10	0.10	0.17	0.27	0.27
L-Isoleucine	---	---	---	0.13	0.13
L-Histidine	---	---	---	0.04	0.04
Trace mineral premix	0.15	0.15	0.15	0.15	0.15
Vitamin premix	0.25	0.25	0.25	0.25	0.25
Phytase[2]	0.08	0.08	0.08	0.08	0.08
Zinc oxide	0.25	---	---	---	---
Glycine	---	---	---	---	1.10
Glutamic acid	---	---	---	---	1.10
Total	100	100	100	100	100

continued

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

	21% CP		18% CP, no ZnO		
Ingredient, %	ZnO	No ZnO	1.2% Lysine	1.35% Lysine	1.35% Lysine + NEAA
Calculated analysis					
Standardized ileal digestible (SID) amino acids, %					
Lysine	1.35	1.35	1.20	1.35	1.35
Isoleucine:lysine	55	55	52	55	55
Leucine:lysine	110	111	110	97	96
Methionine:lysine	35	35	39	40	40
Methionine and cysteine:lysine	57	57	61	60	59
Threonine:lysine	65	65	65	65	65
Tryptophan:lysine	18.9	18.9	21.0	21.1	21.1
Valine:lysine	67	67	70	70	69
Total lysine, %	1.49	1.49	1.32	1.47	1.47
Metabolizable energy, kcal/lb	1,467	1,471	1,475	1,479	1,476
Net energy, kcal/lb	1,086	1,089	1,109	1,112	1,109
SID lysine:NE, g/Mcal	5.64	5.62	4.91	5.51	5.52
Crude protein (CP), %	20.7	20.7	17.9	18.3	20.1
Calcium, %	0.75	0.75	0.75	0.75	0.75
Phosphorus, %	0.62	0.62	0.61	0.61	0.60
Available phosphorus, %	0.46	0.46	0.47	0.47	0.47
STTD[3] P, %	0.51	0.51	0.51	0.51	0.50

[1]Experimental diets were fed from approximately 15.4 to 25.9 lb in Exp. 1, and 13.7 to 26.1 lb in Exp. 2.
[2]HiPhos 2700 (DSM Nutritional Products, Parsippany, NJ) provided an estimated release of 0.10% STTD P.
[3]Standardized total tract digestible phosphorus.

Table 2. Phase 3 common diet composition, (Exp. 2, as-fed basis)[1]

Ingredient, %	Common diet
Corn	65.47
Soybean meal, 46.8% crude protein	28.30
Choice white grease	2.00
Calcium carbonate	0.75
Monocalcium phosphate, 21% P	1.10
Sodium chloride	0.60
L-Lysine-HCl	0.55
DL-Methionine	0.25
L-Threonine	0.23
L-Tryptophan	0.05
L-Valine	0.16
Trace mineral premix	0.15
Vitamin premix with phytase[2]	0.25
Pellet stabilizer[3]	0.15
Total	100.0
Standardized ileal digestible (SID) amino acids, %	
Lysine	1.30
Isoleucine:lysine	53
Leucine:lysine	111
Methionine:lysine	39
Methionine and cysteine:lysine	60
Threonine:lysine	63
Tryptophan:lysine	19.3
Valine:lysine	70
Histidine:lysine	35
Metabolizable energy, kcal/lb	1,509
Net energy, kcal/lb	1,092
Crude protein, %	19.9
Calcium, %	0.65
Available phosphorus, %	0.44
STTD P,[4] %	0.48

[1]Phase 3 common diets were fed only in Exp. 2 from d 13 to 27.
[2]Ronozyme HiPhos GT 2700 (DSM Nutritional Products, Parsippany, NJ) provided 306 FTU per lb of feed and an expected P release of 0.10%.
[3]Alltech All-Bind HD (Alltech, Nicholasville, KY).
[4]STTD P = standardized total tract digestible phosphorus.

Table 3. Analyzed diet composition (as-fed basis)[1,2]

	21% CP		18% CP, no ZnO		
Analyzed composition	ZnO	No ZnO	1.2% Lysine	1.35% Lysine	1.35% Lysine + NEAA
Exp. 1					
Dry matter, %	92.8	89.9	90.2	90.2	89.9
Crude fiber, %	1.8	2.1	1.5	1.8	1.9
Acid detergent fiber, %	4.1	4.0	3.2	3.4	3.6
Neutral detergent fiber, %	8.7	9.9	7.7	7.9	7.9
Crude protein, %	21.3	21.5	17.6	18.2	19.9[3]
Zn, ppm	1,377	130	168	121	100
Ca, %	0.82	0.62	0.76	0.69	0.58
P, %	0.58	0.57	0.53	0.52	0.50
Exp. 2					
Dry matter, %	90.1	89.6	89.6	89.5	90.0
Crude fiber, %	2.8	2.9	3.0	2.4	2.6
Acid detergent fiber, %	4.5	5.1	4.8	3.6	3.5
Neutral detergent fiber, %	11.4	10.4	12.1	8.9	8.6
Crude protein, %	20.9	21.0	18.2	18.0	20.2[3]
Zn, ppm	1,523	140	112	187	113
Ca, %	0.74	0.80	0.68	0.83	0.82
P, %	0.53	0.55	0.60	0.56	0.69

[1] In Exp. 1 diets were fed from d 0 to 13, and in Exp. 2, experimental diets were fed from d 0 to 13 and all pigs received the same common diet from d 13 to 27.
[2] Complete diet samples were taken at manufacture. Samples were stored at -20°C until they were homogenized and subsampled. Duplicate samples per treatment were submitted to Ward Laboratories, Inc., Kearney, NE for proximate analysis.
[3] Crude protein (CP) greater than 18% is observed due to higher nitrogen from the nonessential amino acids added to the diet.

Table 4. Effect of reducing dietary crude protein (CP) content with supplemented essential or non-essential amino acids in diets containing coarse wheat bran on nursery pig performance, Exp. 1[1]

	21% CP[2]		18% CP, no ZnO			
Item	ZnO	No ZnO	1.2% Lysine[3]	1.35% Lysine[4]	1.35% Lysine + NEAA[5]	SEM
BW						
d 0	15.5	15.5	15.4	15.4	15.5	0.23
d 13[6]	26.5	26.2	25.6	25.5	25.6	0.42
d 0 to 13						
ADG,[6] lb	0.85	0.83	0.76	0.76	0.78	0.029
ADFI, lb	1.24	1.22	1.22	1.24	1.18	0.045
F/G	1.46[c]	1.48[c]	1.63[ab]	1.64[a]	1.53[bc]	0.027

[ab]Means in the same row with different superscripts differ ($P < 0.05$).

[1]A total of 300 pigs (initial BW of 15.4 ± 0.1 lb) were used in a 13-d growth study with 5 pigs per pen and 12 pens per treatment. Pigs were fed a common diet containing pharmacological ZnO (3,000 ppm Zn) from weaning until the beginning of the trial for 10 d. All dietary treatments contained 4% coarse wheat bran.

[2]Diets were formulated to 21% CP (1.35% SID lysine) with or without pharmacological levels of ZnO (2,000 ppm Zn).

[3]Treatment diet was formulated to 18% CP and 1.2% SID lysine by adding feed grade amino acids until the minimum Ile:Lys requirement of 52% was met.

[4]Treatment diet was formulated to 18% CP and 1.35% SID lysine with high amounts of feed grade amino acids. L-Ile and L-His were added along with other feed grade amino acids.

[5]Treatment diet was formulated to 18% CP and 1.35% SID lysine with high amounts of feed grade amino acids and with the addition of non-essential amino acids (glycine and glutamic acid).

[6]Tukey adjustment was applied across all variables during statistical analysis. Treatment means did not separate out for d 13 BW and overall ADG.

BW = body weight. ADG = average daily gain. ADFI = average daily feed intake. F/G = feed efficiency.
SEM = standard error of mean.

Table 5. Effect of reducing dietary crude protein (CP) content with supplemented essential or non-essential amino acids in diets containing coarse wheat bran on nursery pig performance, Exp. 2[1]

	21% CP[2]		18% CP, no ZnO			
Item	ZnO	No ZnO	1.2% Lysine[3]	1.35% Lysine[4]	1.35% Lysine + NEAA[5]	SEM
BW						
d 0	13.7	13.7	13.8	13.7	13.7	0.21
d 13	27.2[a]	26.6[ab]	25.7[bc]	25.3[c]	25.8[bc]	0.44
d 27	45.6[ab]	46.2[a]	44.5[ab]	43.9[b]	44.1[ab]	0.76
Experimental period (d 0 to 13)						
ADG, lb	1.01[a]	0.99[ab]	0.92[bc]	0.89[c]	0.93[abc]	0.025
ADFI, lb	1.36	1.33	1.39	1.34	1.28	0.040
F/G	1.34[b]	1.35[b]	1.51[a]	1.52[a]	1.38[b]	0.026
Common diet (d 13 to 27)						
ADG, lb	1.32	1.36	1.32	1.33	1.31	0.032
ADFI, lb	1.96	2.04	2.00	1.98	1.99	0.044
F/G	1.50	1.50	1.52	1.49	1.52	0.021
d 0 to 27						
ADG, lb	1.17	1.18	1.12	1.12	1.13	0.025
ADFI, lb	1.67	1.69	1.70	1.67	1.65	0.038
F/G	1.43[c]	1.44[bc]	1.52[a]	1.50[ab]	1.46[abc]	0.016

[ab]Means in the same row with different superscripts differ ($P < 0.05$).
[1]A total of 350 pigs (initial BW of 13.7 ± 0.1 lb) were used in a 27-d growth study with 5 pigs per pen and 14 pens per treatment. Pigs were fed a common diet containing no pharmacological ZnO from weaning until the beginning of the trial for 14 d. All dietary treatments contained 4% coarse wheat bran.
[2]Diets were formulated to 21% CP (1.35% SID lysine) with or without pharmacological levels of ZnO (2,000 ppm Zn).
[3]Treatment diet was formulated to 18% CP and 1.2% SID lysine by adding feed grade amino acids until the minimum Ile:Lys requirement of 52% was met.
[4]Treatment diet was formulated to 18% CP and 1.35% SID lysine with high amounts of feed grade amino acids. L-Ile and L-His were added along with other feed grade amino acids.
[5]Treatment diet was formulated to 18% CP and 1.35% SID lysine with high amounts of feed grade amino acids and with the addition of non-essential amino acids (glycine and glutamic acid).
BW = body weight. ADG = average daily gain. ADFI = average daily feed intake. F/G = feed efficiency.
SEM = standard error of mean.

Table 6. Effect of reducing dietary CP content with supplemented essential or non-essential amino acids in diets containing coarse wheat bran on nursery pig performance, Exp. 1 and Exp. 2 combined[1]

	21% CP[2]		18% CP, no ZnO			
Item	ZnO	No ZnO	1.2% Lysine[3]	1.35% Lysine[4]	1.35% Lysine + NEAA[5]	SEM
BW						
d 0	14.5	14.5	14.5	14.5	14.5	0.24
d 13	27.0[a]	26.5[ab]	25.8[bc]	25.5[c]	25.8[bc]	0.39
d 0 to 13						
ADG, lb	0.95[a]	0.92[ab]	0.85[bc]	0.83[c]	0.87[abc]	0.027
ADFI, lb	1.32	1.29	1.33	1.31	1.25	0.038
F/G	1.40[b]	1.41[b]	1.57[a]	1.57[a]	1.45[b]	0.022

[ab]Means in the same row with different superscripts differ ($P < 0.05$).

[1]A total of 650 pigs (initial BW of 14.5 lb) were used in a 13-d growth study with 5 pigs per pen and 26 pens per treatment.

[2]Diets were formulated to 21% CP (1.35% SID lysine) with or without pharmacological levels of ZnO (2,000 ppm Zn).

[3]Treatment diet was formulated to 18% CP and 1.2% SID lysine by adding feed grade amino acids until the minimum Ile:Lys requirement of 52% was met.

[4]Treatment diet was formulated to 18% CP and 1.35% SID lysine with high amounts of feed grade amino acids. L-Ile and L-His were added along with other feed grade amino acids.

[5]Treatment diet was formulated to 18% CP and 1.35% SID lysine with high amounts of feed grade amino acids and with the addition of non-essential amino acids (glycine and glutamic acid).

BW = body weight. ADG = average daily gain. ADFI = average daily feed intake. F/G = feed efficiency. SEM = standard error of mean.

Table 7. Effect of reducing dietary crude protein (CP) content with supplemented essential or non-essential amino acids in nursery pig diets containing coarse wheat bran on fecal dry matter, Exp. 1, %[1]

	21% CP[2]		18% CP, no ZnO			
Item	ZnO	No ZnO	1.2% Lysine[3]	1.35% Lysine[4]	1.35% Lysine + NEAA[5]	SEM
Day of collection						
d 0	19.6	20.8	20.3	20.6	19.9	0.71
d 7	15.5	15.8	18.0	16.4	17.8	0.88
d 13	17.6	16.6	18.8	18.2	17.8	0.77

[1]Values represent the mean of 3 pigs per pen and 12 pens per treatment. Three pigs per pen were randomly selected and sampled. Fecal samples were then pooled by pen respective of day of collection and dried at 55°C for 48-h in a forced air oven.

[2]Diets were formulated to 21% CP (1.35% SID lysine) with or without pharmacological levels of ZnO (2,000 ppm Zn).

[3]Treatment diet was formulated to 18% CP and 1.2% SID lysine by adding feed grade amino acids until the minimum Ile:Lys requirement of 52% was met.

[4]Treatment diet was formulated to 18% CP and 1.35% SID lysine with high amounts of feed grade amino acids. L-Ile and L-His were added along with other feed grade amino acids.

[5]Treatment diet was formulated to 18% CP and 1.35% SID lysine with high amounts of feed grade amino acids and with the addition of non-essential amino acids (glycine and glutamic acid).

Table 8. Effect of reducing dietary crude protein (CP) content with supplemented essential or non-essential amino acids in nursery pig diets containing coarse wheat bran on fecal dry matter, Exp. 2, %[1]

	21% CP[2]		18% CP, no ZnO			
Item	ZnO	No ZnO	1.2% Lysine[3]	1.35% Lysine[4]	1.35% Lysine + NEAA[5]	SEM
Day of collection						
d 0	22.5	24.0	22.7	21.7	22.3	0.83
d 6	16.2	15.2	17.8	15.7	16.2	0.76
d 13	16.9	16.1	17.8	16.4	17.0	0.64
d 20[6]	20.7	22.2	20.4	20.4	20.9	0.78
d 27[6]	20.0	22.2	20.7	21.9	20.1	0.93

[1]Values represent the mean of 3 pigs per pen and 14 pens per treatment. Three pigs per pen were randomly selected and sampled. Fecal samples were then pooled by pen respective of day of collection and dried at 55°C for 48-h in a forced air oven.
[2]Diets were formulated to 21% CP (1.35% SID lysine) with or without pharmacological levels of ZnO (2,000 ppm Zn).
[3]Treatment diet was formulated to 18% CP and 1.2% SID lysine by adding feed grade amino acids until the minimum Ile:Lys requirement of 52% was met.
[4]Treatment diet was formulated to 18% CP and 1.35% SID lysine with high amounts of feed grade amino acids. L-Ile and L-His were added along with other feed grade amino acids.
[5]Treatment diet was formulated to 18% CP and 1.35% SID lysine with high amounts of feed grade amino acids and with the addition of non-essential amino acids (glycine and glutamic acid).
[6]A common diet was fed from d 13 to 27.

Table 9. Effect of reducing dietary crude protein (CP) content with supplemented essential or non-essential amino acids in nursery pig diets containing coarse wheat bran on fecal dry matter, Exp. 1 and Exp. 2 combined, %[1]

	21% CP[2]		18% CP, no ZnO			
Item	ZnO	No ZnO	1.2% Lysine[3]	1.35% Lysine[4]	1.35% Lysine + NEAA[5]	SEM
Day of collection						
d 0	23.1	24.4	23.5	23.2	23.2	0.67
d 6[6]	16.7[b]	16.4[b]	18.9[a]	17.0[ab]	18.0[ab]	0.58
d 13	18.0[ab]	17.2[b]	19.2[a]	18.1[ab]	18.2[ab]	0.51
d 20[7]	21.9	23.4	21.2	21.3	22.0	0.83
d 27[7]	20.9	23.0	21.5	22.8	20.8	0.94

[ab]Means in the same row with different superscripts differ ($P < 0.05$).
[1]Values represent the mean of 3 pigs per pen and 26 pens per treatment. Three pigs per pen were randomly selected and sampled. Fecal samples were then pooled by pen respective of day of collection and dried at 55°C in a forced air oven for 48 h.
[2]Diets were formulated to 21% CP with or without pharmacological levels of ZnO (2,000 ppm Zn).
[3]Treatment diet was formulated to 18% CP and 1.2% SID lysine by adding feed grade amino acids until the minimum Ile:Lys requirement of 52% was met.
[4]Treatment diet was formulated to 18% CP and 1.35% SID lysine with high amounts of feed grade amino acids. L-Ile and L-His were added along with other feed grade amino acids.
[5]Treatment diet was formulated to 18% CP and 1.35% SID lysine with high amounts of feed grade amino acids and with the addition of non-essential amino acids (glycine and glutamic acid).
[6]Group 1 samples were collected on d 7 and group 2 were collected on d 6 of each trial.
[7]Collection days consist of 3 pigs per pen and 14 pens per treatment. These collection days were only done for group 2 in the post-treatment period from d 13 to 27.