Effects of increasing dietary zinc on growth performance and carcass characteristics of pigs raised under commercial conditions[1,2]

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ABSTRACT: A total of 2,430 pigs (PIC 337 × 1050; Hendersonville, TN; initially 30.1 kg) were used in a 113-d growth trial to determine the effects of increasing dietary Zn on growth performance and carcass characteristics of finishing pigs raised under commercial conditions. Pens of pigs were assigned to be fed one of five dietary treatments in a randomized complete block design. Treatments consisted of 50, 87.5, 125, 162.5, or 200 mg/kg added Zn from Zn hydroxychloride (IntelliBond Z, Micronutrients, Indianapolis, IN). Two identical barns were used for a total of 18 pens per treatment with 27 pigs per pen. Experimental diets were fed in five phases and contained a vitamin-trace mineral premix without added Zn. Pens of pigs were weighed approximately every 2 wk to calculate average daily gain (ADG), average daily feed intake (ADFI), and gain-to-feed ratio (G:F). At the end of the experimental period, pigs were tattooed with a pen identification number and transported to a packing plant to measure hot carcass weight (HCW), backfat, loin depth, and calculated lean percentage. Data were analyzed block nested within barn as a random effect and pen as the experimental unit. From days 0 to 42, pigs fed diets with increasing added Zn had lower (linear, $P = 0.043$) ADFI and a tendency ($P = 0.092$) for lower ADG. From days 42 to 113, increasing added Zn resulted in a quadratic response ($P = 0.042$) for ADFI and a tendency (linear, $P = 0.056$) for improved G:F. Overall (days 0 to 113), there were tendencies for quadratic responses for ADFI ($P = 0.073$) and G:F ($P = 0.059$), with the greatest G:F observed when 125 mg/kg of Zn was fed. Increasing added Zn resulted in a linear increase ($P < 0.001$) in daily Zn intake. There were no differences ($P > 0.10$) in overall ADG, final body weight, HCW, backfat, loin depth, lean percentage, mortality, and removal rate. In conclusion, there were no improvements in ADG when feeding beyond 50 mg/kg added Zn; however, providing 125 mg/kg added Zn resulted in the greatest G:F.

Key words: finishing pig, growth performance, zinc hydroxychloride

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INTRODUCTION

Zinc (Zn) is an essential mineral for protein, carbohydrate, and lipid metabolism due to its essentiality as a component of metalloenzymes, such as DNA and RNA synthetases, digestive enzymes, and insulin (NRC, 2012). The dietary Zn requirement for 25 to 135 kg grow-finish pigs ranges from 50 to 60 mg/kg depending on body weight (BW) (NRC, 2012). This requirement is usually met through the trace mineral premix, which is commonly considered the sole source of added Zn (Miller, 1991). According to a U.S. swine industry survey, added Zn levels in grow-finish diets range from 72 to 86 mg/kg (Flohr et al., 2016), thus it is relatively common practice to supplement more Zn in growing pig diets than the requirement.

Traditionally, inorganic Zn sources such as Zn oxide and Zn sulfate are most commonly used in swine diets. Zinc hydroxychloride is a novel inorganic source of Zn manufactured through the reaction of high purity forms of the metal with water and hydrochloric acid (Leisure et al., 2014). This process forms hydroxychloride crystals that contain Zn covalently bonded to hydroxyl groups and chloride. The covalent bonds are expected to reduce reactiveness with other components of the diet and to improve bioavailability (Cao et al., 2000).

Currently, there are few studies with grow-finish pigs, especially conducted under large-scale commercial conditions, evaluating dietary Zn concentrations. Therefore, the objective of this study was to determine the effects of increasing dietary Zn from Zn hydroxychloride on growth performance and carcass characteristics of grow-finish pigs housed under commercial conditions.

MATERIAL AND METHODS

The Kansas State University Institutional Animal Care and Use Committee approved the protocols used in this experiment.

Animals and Diets

The study was conducted at a commercial research facility in southwestern Minnesota. Two identical barns, naturally ventilated and double-curtain sided, were used for a total of 90 pens with 27 pigs per pen. Pens (5.5 × 3.0 m) had completely slatted floors and were equipped with a four-hole stainless-steel dry self-feeder and a cup waterer. Feed additions were accomplished and recorded by a computerized feeding system (FeedPro; Feedlogic Corp., Wilmar, MN).

A total of 2,430 pigs (PIC 337 × 1050; Hendersonville, TN; initially 30.1 ± 0.70 kg BW) were used in a 113-d growth trial. Pens of pigs were blocked by BW within barn and were randomly assigned to one of five treatments in a randomized complete block design. Treatments consisted of 50, 87.5, 125, 162.5, or 200 mg/kg added Zn from Zn hydroxychloride (IntelliBond Z; Micronutrients, Indianapolis, IN). A vitamin-trace mineral premix was formulated without Zn to ensure Zn hydroxychloride was the only source of added Zn. There were 18 replicates per treatment. Diets were manufactured at the New Horizon Farms feed mill (Pipestone, MN) and offered in five phases in meal form (Table 1).

Pens of pigs were weighed and feed disappearance measured approximately every 2 wk to calculate average daily gain (ADG), average daily feed intake (ADFI), and gain-to-feed ratio (G:F). Daily Zn intake was calculated by multiplying overall ADFI by the inclusion of added Zn. Mortality and removals were recorded daily. On day 90, according to standard farm protocol, the three heaviest pigs in each pen were identified and transported to a packing plant (JBS Swift and Company, Worthington, MN) to be processed. At the end of the experimental period, final pen weights were recorded, and remaining pigs were tattooed with a pen identification number and were transported to a packing plant (JBS Swift and Company, Worthington, MN) for carcass data collection. Carcass measurements included hot carcass weight (HCW), loin depth, backfat, and percentage lean. Loin depth and backfat were measured using an optical probe (Fat-O-Meter; SFK, Herlev, Denmark). Percentage lean was calculated from a plant proprietary equation. Carcass yield was calculated by dividing the pen average HCW by the pen average final live weight.

Chemical Analysis

Representative samples were collected from 12 feeders per dietary treatment during each of the five phases. Samples were stored at −20 °C until analysis. Diet samples were analyzed for dry matter (method 935.29; Association of Official Analyst Chemists (AOAC) International, 1990), crude protein (990.03, AOAC International, 1990), calcium (Ca) and phosphorus (P; method 985.01; AOAC International, 1990), Zn, Fe, and

Table 1. Composition of the basal diets (as-fed basis)[1]

	Feeding phase				
	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Ingredients, %					
Corn	50.39	55.56	58.37	61.77	78.35
Soybean meal, 47% crude protein	17.08	11.95	9.34	5.92	9.64
DDGS	30.00	30.00	30.00	30.00	10.00
Calcium carbonate	1.35	1.35	1.25	1.25	1.10
Sodium chloride	0.35	0.35	0.35	0.35	0.35
L-Lysine HCl	0.50	0.50	0.45	0.45	0.30
DL-Methionine	0.05	0.02	—	—	0.01
L-Threonine	0.06	0.05	0.02	0.04	0.05
L-Tryptophan	0.04	0.04	0.03	0.03	0.02
Vitamin-trace mineral premix[2]	0.15	0.15	0.15	0.15	0.15
Zn hydroxychloride[3]	+/−	+/−	+/−	+/−	+/−
Total	100.0	100.0	100.0	100.0	100.0
SID amino acids, %					
Lysine	1.03	0.91	0.81	0.73	0.65
Isoleucine:lysine	63	62	64	63	64
Leucine:lysine	162	172	186	196	186
Methionine:lysine	30	29	29	31	30
Methionine and cystine:lysine	56	56	58	60	60
Threonine:lysine	61	61	61	63	66
Tryptophan:lysine	19	19	19	19	19
Valine:lysine	71	71	75	76	75
Net energy[4], kcal/kg	2,465	2,493	2,511	2,531	2,551
Crude protein, %	20.0	17.9	16.8	15.4	13.0
Calcium, %	0.59	0.56	0.52	0.50	0.46
STTD P, %	0.37	0.36	0.36	0.35	0.27

DDGS = distillers dried grains with soluble, SID = standardized ileal digestible, STTD P = standardized total tract digestible phosphorus.

[1] Phases 1, 2, 3, 4, and 5 were fed from approximately 30 to 45 kg, 45 to 64 kg, 64 to 82 kg, 82 to 104 kg, and 104 kg to marketing, respectively.

[2] The premix did not contain Zn and provided per kilogram of premix: 4,116,034 IU vitamin A; 661,387 IU vitamin D; 26,455 IU vitamin E; 1,764 mg vitamin K; 16.2 mg vitamin B12; 17,637 mg niacin; 11,759 mg pantothenic acid; 5,880 mg riboflavin; 50.7 g Fe from iron sulfate; 19 g Mn from manganese oxide; 10.8 g Cu from copper sulfate; 0.25 g I from calcium iodate; 0.2 g Se from sodium selenite; and 500,000 FTU phytase.

[3] IntelliBond Z (Micronutrients, Indianapolis, IN) was added at 0.009%, 0.016%, 0.022%, 0.029%, or 0.036% to achieve 50, 87.5, 125, 167.5, or 200 mg/kg of added Zn, respectively.

[4] Net energy values for ingredients used in diet formulation were derived from the NRC (2012).

Cu (985.01; AOAC International, 1990) in duplicate at both Midwest Laboratories Inc. (Omaha, NE) and Cumberland Valley Analytical Services (Hagerstown, MD).

Statistical Analysis

Data were analyzed as a randomized complete block design with block nested within barn as a random effect and pen as the experimental unit. Polynomial contrasts were constructed to evaluate the linear and quadratic effects of increasing Zn on ADG, ADFI, G:F, BW, daily Zn intake, and carcass characteristics. All data were modeled as normally distributed with the exception pig removals and mortality were modeled using a binomial distribution. Data were analyzed using the GLIMMIX procedure of SAS 9.4 (SAS Institute Inc., Cary, NC). Results were considered significant at $P \le 0.05$ and a tendency at $0.05 < P \le 0.10$.

RESULTS AND DISCUSSION

Chemical Analysis

Results of proximate analysis and total Zn analysis followed formulated values (Tables 2 and 3). Crude protein, total Ca, and total P levels were similar across treatments within dietary phase (Tables 2 and 3). The average analyzed total Zn across all phases was 110, 115, 142, 185, and 204 mg/kg for diets formulated to 50, 87.5, 125, 162.5, and 200 mg/kg added Zn, respectively. The analyzed total Fe and Cu were similar across treatments (Tables 2 and 3) and were, on average, 150 and 151 ppm, respectively.

Table 2. Chemical analysis of Phase 1, 2, and 3 diets (as-fed basis)[1]

	Phase 1 added Zn, mg/kg					Phase 2 added Zn, mg/kg					Phase 3 added Zn, mg/kg				
Item	50	87.5	125	162.5	200	50	87.5	125	162.5	200	50	87.5	125	162.5	200
Dry matter[2], %	87.1	87.2	87.2	87.4	87.2	86.9	86.8	86.4	86.6	86.3	86.8	86.7	86.8	86.5	86.7
Crude protein[2], %	21.5	21.2	21.3	21.5	22.3	19.6	18.9	19.3	19.7	18.9	19.4	18.6	18.2	18.5	18.7
Ca[2], %	0.62	0.69	0.64	0.66	0.65	0.56	0.46	0.61	0.59	0.57	0.47	0.56	0.54	0.48	0.59
P[2], %	0.51	0.50	0.51	0.53	0.52	0.47	0.47	0.47	0.47	0.46	0.49	0.47	0.49	0.48	0.48
Zn[3], mg/kg	99	108	146	172	198	93	114	138	177	183	173	117	134	184	198
Fe[4], mg/kg	138	145	147	184	170	133	133	185	217	160	132	120	172	135	162
Cu[4], mg/kg	146	167	163	137	139	149	166	157	155	160	143	136	143	137	135

[1] For each treatment, samples were collected from multiple feeders, blended, subsampled, ground, and analyzed.

[2] Values represent means of two samples from Cumberland Valley Analytical Services (Hagerstown, MD) and two samples from Midwest Laboratories Inc. (Omaha, NE).

[3] Values represent means of eight samples from Cumberland Valley Analytical Services (Hagerstown, MD) and six samples from Midwest Laboratories Inc. (Omaha, NE).

[4] Values represent means of two samples from Cumberland Valley Analytical Services (Hagerstown, MD).

Table 3. Chemical analysis of Phase 4 and 5 diets (as-fed basis)[1]

	Phase 4 added Zn, mg/kg					Phase 5 added Zn, mg/kg				
Item	50	87.5	125	162.5	200	50	87.5	125	162.5	200
Dry matter[2], %	86.3	86.4	86.6	86.4	86.6	85.5	86.4	85.3	85.7	85.8
Crude protein[2], %	16.9	17.1	16.8	16.0	17.2	12.9	13.4	13.3	12.9	13.0
Ca[2], %	0.33	0.46	0.43	0.57	0.48	0.53	0.65	0.50	0.62	0.61
P[2], %	0.45	0.45	0.45	0.44	0.45	0.32	0.35	0.33	0.34	0.32
Zn[3], mg/kg	89	116	147	201	208	94	121	147	190	231
Fe[4], mg/kg	132	184	169	177	136	123	127	123	130	128
Cu[4], mg/kg	125	146	150	154	145	159	170	154	178	172

[1] For each treatment, samples were collected from multiple feeders, blended, subsampled, ground, and analyzed.

[2] Values represent means of two samples from Cumberland Valley Analytical Services (Hagerstown, MD) and two samples from Midwest Laboratories Inc. (Omaha, NE).

[3] Values represent means of eight samples from Cumberland Valley Analytical Services (Hagerstown, MD) and six samples from Midwest Laboratories Inc. (Omaha, NE).

[4] Values represent means of two samples from Cumberland Valley Analytical Services (Hagerstown, MD).

Growth Performance and Carcass Characteristics

From days 0 to 42, pigs fed diets with increasing added Zn had decreased (linear, $P = 0.043$; Table 4) ADFI. There was a tendency for reduced ADG (linear, $P = 0.092$) and day-42 BW (linear, $P = 0.078$) as added dietary Zn increased. From days 42 to 113, increasing added Zn resulted in a quadratic response ($P = 0.042$) for ADFI, with ADFI decreasing for pigs fed 87.5 mg/kg of Zn and then returning to control intake values as Zn increased. As a result, there was a tendency (linear, $P = 0.056$) for improved G:F with increasing added Zn. For overall growth performance (days 0 to 113), there were tendencies for quadratic responses for ADFI ($P = 0.073$) and G:F ($P = 0.059$). The lowest ADFI was observed at 87.5 mg/kg added Zn and the greatest G:F was observed at 125 mg/kg added Zn. Pigs fed diets with increasing added Zn presented a linear increase in daily Zn intake ($P < 0.001$). There were no differences ($P > 0.10$) in overall ADG, final BW, HCW, backfat, loin depth, and lean percentage. Pig mortality and removal were low (0.8 and 2.5%, respectively) and were not influenced by dietary Zn inclusion.

On the basis of our results, there was no benefit to adding more than 50 mg/kg Zn for ADG and carcass characteristics, but 125 mg/kg of added Zn improved G:F. Cemin et al. (2019) evaluated 50, 100, and 150 mg/kg of added Zn from two sources (Zn sulfate and Zn hydroxychloride) for grow-finish pigs. In contrast to findings of the current study, it was observed that pigs fed diets with 100 mg/kg added Zn had a tendency for greater ADG and significantly greater HCW regardless of Zn source. Carcass yield increased linearly with increasing added Zn, and pigs fed Zn hydroxychloride had greater carcass yield and a tendency for heavier HCW than those fed Zn sulfate.

Although our experimental diets did not contain ractopamine hydrochloride, our results are in

Table 4. Effects of increasing added Zn on grow-finish pig performance and carcass characteristics[1]

	Added Zn, mg/kg						Probability, $P <$	
Item	50	87.5	125	162.5	200	SEM	Linear	Quadratic
BW, kg								
Day 0	30.1	30.1	30.1	30.1	30.1	0.70	0.947	0.895
Day 42	68.6	67.6	67.7	68.0	67.1	1.28	0.078	0.752
Day 113	132.2	129.7	130.7	131.7	130.9	2.50	0.830	0.314
Days 0 to 42								
ADG, kg	0.95	0.92	0.93	0.94	0.91	0.019	0.092	0.674
ADFI, kg	2.01	1.94	1.94	1.96	1.93	0.037	0.043	0.227
G:F	0.473	0.475	0.479	0.479	0.474	0.007	0.600	0.182
Days 42 to 113								
ADG, kg	0.93	0.91	0.94	0.93	0.94	0.023	0.208	0.407
ADFI, kg	2.93	2.85	2.88	2.89	2.91	0.038	0.868	0.042
G:F	0.318	0.320	0.325	0.323	0.323	0.004	0.056	0.155
Days 0 to 113								
ADG, kg	0.94	0.92	0.93	0.93	0.93	0.021	0.887	0.494
ADFI, kg	2.58	2.50	2.52	2.53	2.53	0.032	0.317	0.073
G:F	0.364	0.366	0.371	0.369	0.367	0.005	0.154	0.059
Zn intake, mg/d	129	215	310	412	507	4.58	0.001	0.142
Carcass characteristics								
HCW, kg	96.7	94.8	95.3	96.4	95.8	1.80	0.852	0.140
Yield, %	73.3	73.1	72.9	73.2	73.2	0.18	0.702	0.151
Backfat[2], mm	17.5	17.5	17.2	17.6	17.2	0.62	0.536	0.947
Loin depth[2], mm	68.6	69.0	68.0	69.1	68.7	1.18	0.817	0.767
Lean[2], %	56.4	56.5	56.5	56.4	56.6	0.51	0.470	0.851

[1] A total of 2,430 pigs were used in a 113-d study with 27 pigs per pen and 18 replicates per treatment.

[2] Adjusted using HCW as a covariate.

agreement with Paulk et al. (2015), who observed in one trial a tendency for a linear improvement in G:F of finishing pigs with increasing added Zn from Zn oxide from 50 to 150 mg/kg in diets with ractopamine. However, the results were inconsistent, and in a second trial Paulk et al. (2015) did not observe evidence for effects of increasing added Zn. A similar result was reported by Fry et al. (2013), where added Zn improved G:F for finishing pigs fed diets with ractopamine but results were not repeatable in subsequent trials. It is important to note that our diets did not contain ractopamine, thus these results may not be directly comparable

However, other research suggests there is little evidence for Zn effects on growth performance of grow-finish pigs. Feldpausch et al. (2016) observed no evidence for effects of 150 mg/kg added Zn from Zn oxide on growth performance and carcass characteristics of 48- to 136-kg pigs, as well as no additive effects of Zn and Cu. Holen et al. (2018) evaluated organic and inorganic Zn sources ranging from 60 to 140 mg/kg added Zn for grow-finish pigs raised under restricted floor space allowance and observed no effects on growth performance and carcass characteristics. Interestingly, Ma et al. (2012) observed no effects of removing supplemental trace minerals (Zn, Cu, Fe, and Mn) up to 6 wk preslaughter on growth performance, although some carcass characteristics were negatively affected. Moreover, Gowanlock et al. (2013) found no evidence for differences between pigs fed a basal corn–soybean meal diet without supplemental Zn, Cu, Fe, and Mn or the basal diet with 50% or 100% of the NRC (2012) mineral requirement estimates.

The NRC (2012) presents Zn requirement estimates as mg per kilogram of diet as well as mg per day. These values range from 50 to 60 mg/kg of diet and 90 to 139 mg per day for grow-finish pigs from 25 to 135 kg BW. In our study, pigs fed diets with 50 ppm added Zn had a daily Zn intake of 129 mg, which should meet the requirement estimated by the NRC (2012). Overall, available research suggests that there are no benefits of feeding higher levels of Zn to grow-finish pigs although in the current study G:F was improved with 125 mg/kg added Zn or 310 mg/d. It is important to note that most existing research evaluated other inorganic sources, such as Zn oxide and Zn sulfate, or organic Zn sources. It could be hypothesized that the contrasts observed between the available literature and our study were at least partially driven by differences in Zn availability in the Zn hydroxychloride used in our study. An important consideration is that excessive Zn excreted in the manure can pollute ground water by leaching or soil erosion (Hsu and Lo, 2001). As restrictions to nutrient excretion increase in the swine industry, the use of lower levels of added Zn close to the requirements may be beneficial.

In conclusion, our results suggest that supplementing grow-finish diets with greater than 50 mg/kg added Zn did not lead to improvements in ADG and carcass characteristics. However, there may be G:F benefits of supplementing up to 125 mg/kg added Zn. These results match some of the data found in the literature, but inconsistencies in response are apparent and differences in Zn source could at least partially explain the results observed in the current study. Further research is required to compare Zn hydroxychloride with other inorganic and organic Zn sources to determine if source of Zn has an impact on the response observed.

Conflict of interest statement. None declared.

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