Effects of zinc source and level on growth performance and carcass characteristics of finishing pigs[1,2]

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ABSTRACT: An experiment was conducted to determine the effects of added Zn source and level on growth performance and carcass characteristics of finishing pigs. A total of 1,980 pigs divided into 2 groups [group 1: 1,008 pigs, TR4 × (Fast Large White × PIC L02) and group 2: 972 pigs, PIC 337 × 1,050], initially 33.3 kg, were used in a 103- or 114-d growth trial in groups 1 and 2, respectively. Treatments were arranged in a 2 × 3 factorial with 2 sources of added Zn, Zn hydroxychloride (ZnHyd; IntelliBond Z, Micronutrients, Indianapolis, IN) or Zn sulfate ($ZnSO_4$), and 3 levels of added Zn (50, 100, or 150 mg/kg). Diets contained a vitamin-trace mineral premix without added Zn and provided 76 and 162 mg/kg Fe and Cu, respectively. All diets contained 750 FTU/kg phytase. There was a total of 14 replicates per treatment. Pens of pigs were weighed approximately every 2 wk to determine average daily gain (ADG), average daily feed intake, and gain-to-feed ratio. At the end of the experiment, pigs were transported to a packing plant to determine hot carcass weight (HCW), backfat depth, loin depth, and lean percentage. Overall, there was no evidence ($P > 0.10$) for interactive effects of added Zn source and level for growth performance and carcass characteristics. Pigs fed diets with increasing added Zn had a tendency ($P = 0.093$) for a quadratic response in ADG, with the greatest ADG observed at 100 mg/kg added Zn. There was a linear improvement ($P = 0.010$) in carcass yield and a quadratic response ($P = 0.045$) in HCW, with pigs fed 100 mg/kg added Zn having the highest HCW. Pigs fed diets with ZnHyd had improved ($P = 0.017$) carcass yield and a tendency ($P = 0.058$) for greater HCW compared with pigs fed $ZnSO_4$. In summary, under the commercial conditions of the study and with diets containing 750 FTU/kg phytase, there were relatively small improvements in ADG of growing-finishing pigs fed added Zn beyond 50 mg/kg. Providing higher levels of added Zn improved carcass characteristics. Zinc source did not influence growth performance, but ZnHyd improved carcass characteristics compared with $ZnSO_4$.

Key words: grow-finish, mineral, performance, zinc

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INTRODUCTION

The swine industry traditionally supplements Zn in diets through inorganic sources, namely Zn oxide and Zn sulfate ($ZnSO_4$). The supplemental source is commonly considered the only source of added Zn due to the low availability of the mineral from feed ingredients (Miller, 1991). Recently, novel Zn sources have become available, such as Zn hydroxychloride (ZnHyd), an inorganic source produced through the reaction of high-purity forms of the metal with water and hydrochloric acid (Leisure et al., 2014). The process results in the formation of 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).

According to the NRC (2012), the dietary Zn requirement for grow-finish pigs is 50 to 60 mg/kg from 25 to 135 kg of body weight (BW). However, supplementing Zn above the NRC (2012) recommendations is a common practice in the United States (Flohr et al., 2016), and there may be benefits of feeding higher levels of added Zn for grow-finish pigs. In a large commercial study, Cemin et al. (2019) observed that average daily gain (ADG) was maximized at 50 mg/kg added Zn, but there was an improvement in gain-to-feed ratio (G:F) of pigs fed 125 mg/kg added Zn. Similarly, Fry et al. (2013) and Paulk et al. (2015) observed improvements in G:F of finishing pigs fed increasing added Zn. However, results are inconsistent, and there is a lack of grow-finish studies comparing $ZnSO_4$, a traditional Zn source, with ZnHyd. Therefore, the objective of this study was to determine the effects of Zn source and level on growth performance and carcass characteristics of grow-finish pigs housed in a commercial environment.

MATERIALS AND METHODS

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

Animals and Diets

An experiment was conducted at commercial research facilities in Minnesota. The research barns were double-curtain sided, naturally ventilated, had completely slatted floors, and each pen was equipped with a 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 1,980 pigs divided into 2 groups [group 1: 1,008 pigs, TR4 × (Fast Large White × PIC L02) and group 2: 972 pigs, PIC 337 × 1,050], with an average initial BW of 33.3 ± 0.55 kg, were used in a 103- or 114-d growth trial in groups 1 and 2, respectively. Pens of pigs were blocked by BW and randomly assigned to 1 of 6 treatments in a randomized complete block design. Treatments were arranged in a 2 × 3 factorial with 2 sources of added Zn, ZnHyd (IntelliBond Z, Micronutrients, Indianapolis, IN) or $ZnSO_4$ (Agrium Advance Technology, Loveland, CO for group 1 and Prince Agri Products Inc., Quincy, IL for group 2), and 3 levels of added Zn (50, 100, or 150 mg/kg). A vitamin-trace mineral premix was formulated without added Zn and utilized in all diets to provide other minerals and vitamins above the NRC (2012) requirement estimates. Diets (Table 1) were offered in 5 phases in meal form. A single source of corn and soybean meal was used in diets, but different between groups 1 and 2. The final phase contained ractopamine hydrochloride and was fed from approximately 104 kg BW to marketing. There were 14 replicates per treatment.

Pens of pigs were weighed and feed disappearance measured approximately every 2 wk to determine ADG, average daily feed intake (ADFI), and G:F. Data are presented as grower period (days 0 to 66 in group 1 and days 0 to 72 in group 2), finisher period (days 66 to 103 in group 1 and days 72 to 114 in group 2), and overall period (days 0 to 103 in group 1 and days 0 to 114 in group 2). At the end of the experimental period, final pen weights were recorded, and pigs were tattooed with a pen identification number and transported to a commercial packing plant for carcass data collection. Carcass measurements included hot carcass weight (HCW), loin depth, backfat, and percentage lean. 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 each of the 5 dietary phases. Samples were stored at −20 °C until analysis. Diet samples were analyzed for dry matter (method 935.29; AOAC International, 1990), crude protein (990.03, AOAC International, 1990), calcium and phosphorus (method 985.01; AOAC International, 1990), and

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

	Feeding phase[1]				
Ingredients, %	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Corn	48.07	52.12	55.69	58.30	68.99
Soybean meal, 47% crude protein	19.56	15.69	12.24	9.66	18.67
DDGS[2]	30.00	30.00	30.00	30.00	10.00
Calcium carbonate	1.35	1.35	1.25	1.25	0.95
Monocalcium phosphate, 21.5% P	0.15	—	—	—	0.30
Sodium chloride	0.35	0.35	0.35	0.35	0.35
L-Lysine HCl	0.35	0.33	0.30	0.28	0.35
Methionine hydroxy-analog	—	—	—	—	0.10
L-Threonine	—	—	—	—	0.09
L-Tryptophan	0.01	0.01	0.01	0.01	0.02
Vitamin-trace mineral premix[3]	0.15	0.15	0.15	0.15	0.15
Ractopamine HCl	—	—	—	—	0.03
Zn source[4]	+/−	+/−	+/−	+/−	+/−
Total	100.0	100.0	100.0	100.0	100.0
SID[5] amino acids, %					
Lysine	1.03	0.91	0.81	0.72	0.94
Isoleucine:lysine	70	72	74	77	63
Leucine:lysine	179	192	207	222	153
Methionine:lysine	32	34	37	39	37
Methionine and cystine:lysine	62	66	70	75	63
Threonine:lysine	61	63	66	68	64
Tryptophan:lysine	18.9	19.0	18.7	18.6	18.9
Valine:lysine	82	86	90	94	72
Net energy, kcal/kg	2,421	2,447	2,469	2,485	2,491
Crude protein, %	22.1	20.5	19.2	18.1	17.9
Calcium, %	0.66	0.62	0.57	0.56	0.52
STTD P[6], %	0.39	0.35	0.34	0.33	0.34

[1]Phases 1, 2, 3, 4, and 5 were fed from approximately 33 to 45, 45 to 64, 64 to 82, 82 to 104, and 104 kg to marketing, respectively.

[2]DDGS = distillers dried grains with solubles.

[3]The premix did not contain Zn and provided per kg 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; 500,000 FTU phytase.

[4]Zn hydroxychloride (IntelliBond Z, Micronutrients, Indianapolis, IN) or Zn sulfate (Agrium Advance Technology, Loveland, CO for group 1 and Prince Agri Products Inc., Quincy, IL for group 2) was included in the diets at 50, 100, or 150 mg/kg added Zn to form the dietary treatments.

[5]SID = standardized ileal digestible.

[6]STTD P = standardized total tract digestible phosphorus.

Zn (985.01; AOAC International, 1990) at Ward Laboratories Inc. (Kearney, NE) and Cumberland Valley Analytical Services (Hagerstown, MD).

Statistical Analysis

Data were analyzed as a randomized complete block design with block as a random effect and pen as the experimental unit. Polynomial contrasts were constructed to evaluate the interactive and main effects of added Zn source and level on ADG, ADFI, G:F, BW, and carcass characteristics. Data were analyzed using the GLIMMIX procedure of SAS 9.4 (SAS Institute Inc., Cary, NC). Results were considered significant at $P \leq 0.05$ and a tendency at $0.05 < P \leq 0.10$.

RESULTS AND DISCUSSION

Chemical Analysis

Results of proximate analysis and total Zn analysis generally matched formulated values (Tables 2 and 3). The average total analyzed Zn across phases for diets formulated with 50, 100, and 150 mg/kg added Zn from ZnHyd were 120, 174, and 218 mg/kg, respectively. For diets formulated with $ZnSO_4$, averages were 112, 149, and 198 mg/kg, respectively.

Growth Performance and Carcass Characteristics

In the grower period, there was an interaction (quadratic, $P < 0.05$) between added Zn source and

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

	Phase 1						Phase 2						Phase 3					
Zn source[2]	ZnHyd			$ZnSO_4$			ZnHyd			$ZnSO_4$			ZnHyd			$ZnSO_4$		
Zn level, mg/kg	50	100	150	50	100	150	50	100	150	50	100	150	50	100	150	50	100	150
Dry matter, %[3]	88.5	88.5	88.7	88.2	88.1	88.5	87.9	87.9	88.0	88.0	87.9	87.7	88.1	88.1	88.2	87.9	88.0	88.8
Crude protein, %[3]	22.2	21.8	20.7	20.5	20.7	22.0	20.0	20.9	21.0	20.7	21.7	21.8	19.3	19.6	19.7	19.6	19.3	20.5
Calcium, %[3]	0.80	0.92	0.95	0.84	0.89	0.97	0.84	0.89	0.83	0.87	0.83	0.86	0.87	0.67	0.76	0.92	0.73	0.89
Phosphorus, %[3]	0.59	0.63	0.62	0.61	0.58	0.62	0.56	0.57	0.60	0.57	0.60	0.58	0.55	0.57	0.54	0.54	0.53	0.55
Zinc, mg/kg[4]	113	176	196	132	137	197	115	157	193	111	171	229	169	165	266	107	156	193
Iron[4], mg/kg	225	139	158	139	150	148	153	146	154	147	148	154	155	120	148	140	118	151
Copper[4], mg/kg	306	187	209	176	202	234	232	229	190	238	219	222	213	187	207	201	138	194

[1]For each treatment, samples were collected from multiple feeders, blended, subsampled, ground, and analyzed (Ward Laboratories Inc., Kearny, NE and Cumberland Valley Analytical Services, Hagerstown, MD).

[2]Zinc sources were Zn hydroxychloride (ZnHyd; IntelliBond Z, Micronutrients, Indianapolis, IN) or Zn sulfate ($ZnSO_4$; Agrium Advance Technology, Loveland, CO for group 1 and Prince Agri Products Inc., Quincy, IL for group 2).

[3]Values represent means of 1 analysis from group 1 and 1 analysis from group 2.

[4]Values represent means from 3 analyses from group 1 and 5 analyses from group 2.

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

	Phase 4						Phase 5					
Zn source[2]	ZnHyd			$ZnSO_4$			ZnHyd			$ZnSO_4$		
Zn level, mg/kg	50	100	150	50	100	150	50	100	150	50	100	150
Dry matter, %[3]	88.1	87.6	88.2	87.9	88.4	88.3	87.4	87.3	87.0	87.0	87.2	87.4
Crude protein, %[3]	19.3	19.0	19.8	18.2	18.9	18.2	19.1	17.6	17.1	17.7	19.1	18.7
Calcium, %[3]	0.56	0.78	0.59	0.63	0.75	0.68	0.67	0.71	0.69	0.66	0.70	0.68
Phosphorus, %[3]	0.54	0.55	0.53	0.55	0.56	0.55	0.50	0.49	0.50	0.50	0.50	0.51
Zinc, mg/kg[4]	122	187	206	117	141	174	84	187	228	95	139	198
Iron[4], mg/kg	127	140	129	122	133	112	137	153	139	147	144	194
Copper[4], mg/kg	205	231	195	221	224	174	208	221	210	179	211	243

[1]For each treatment, samples were collected from multiple feeders, blended, subsampled, ground, and analyzed (Ward Laboratories Inc., Kearny, NE and Cumberland Valley Analytical Services, Hagerstown, MD).

[2]Zinc sources were Zn hydroxychloride (ZnHyd; IntelliBond Z, Micronutrients, Indianapolis, IN) or Zn sulfate ($ZnSO_4$; Agrium Advance Technology, Loveland, CO for group 1 and Prince Agri Products Inc., Quincy, IL for group 2).

[3]Values represent means of 1 analysis from group 1 and 1 analysis from group 2.

[4]Values represent means from 3 analyses from group 1 and 5 analyses from group 2.

level for ADFI and BW, and a tendency (quadratic, $P = 0.099$) for an interaction for ADG (Table 4). Pigs fed diets with ZnHyd had greater ADFI, BW, and ADG at 100 mg/kg added Zn, whereas pigs fed diets with $ZnSO_4$ presented greater ADFI, BW, and ADG at 150 mg/kg added Zn.

In the finisher period, there was an interaction (linear, $P = 0.020$) for G:F. Pigs fed diets with ZnHyd had improved G:F when fed increasing levels of added Zn, whereas pigs fed $ZnSO_4$ had similar G:F at all levels. In the finisher period and overall, there was a tendency ($P < 0.10$) for a quadratic response for ADG, with the greatest ADG observed at 100 mg/kg added Zn (Table 5).

Regarding carcass characteristics, pigs fed diets with ZnHyd had higher ($P = 0.017$) carcass yield and a tendency ($P = 0.058$) for heavier HCW than pigs fed $ZnSO_4$. Increasing added Zn resulted in a quadratic response ($P = 0.045$) in HCW, with the highest value observed at 100 mg/kg added Zn. Moreover, there was a linear response ($P = 0.010$) for carcass yield with increasing added Zn.

Our results suggest that there is no evidence for differences in growth performance between the tested Zn sources, although HCW and carcass yield improved when pigs were fed ZnHyd. Similarly, Fry et al. (2013) observed a tendency for improved carcass yield for pigs fed diets with an organic Zn source compared with $ZnSO_4$, although results were not consistent in subsequent trials. Ma et al. (2012) found no evidence for differences in growth performance or carcass traits of pigs fed organic or inorganic trace-mineral premixes. Holen et al. (2018) tested organic and inorganic Zn sources with Zn level ranging from 60 to 140 mg/kg for grow-finish pigs raised under restricted floor space

Table 4. Interactive effects of added Zn source and level on growth performance and carcass characteristics of grow-finish pigs[1,2]

	ZnHyd, mg/kg			$ZnSO_4$, mg/kg				Probability, *P*			
								Source × level			
Item[3]	50	100	150	50	100	150	SEM	Linear	Quadratic	Source	Level
BW, kg											
Day 0	33.3	33.3	33.3	33.3	33.3	33.3	0.55	<0.934	<0.931	<0.967	<0.998
Grower[4]	94.5	95.4	94.0	94.4	94.5	95.3	0.58	<0.106	<0.044	<0.748	<0.477
Finisher[5]	130.5	131.4	129.6	130.2	130.5	130.3	1.34	<0.559	<0.471	<0.788	<0.527
Grower											
ADG, kg	0.89	0.90	0.88	0.89	0.89	0.90	0.017	<0.130	<0.099	<0.677	<0.490
ADFI, kg	2.13	2.17	2.11	2.11	2.12	2.16	0.056	<0.079	<0.038	<0.688	<0.359
G:F, g/kg	418	415	420	421	421	418	3.979	<0.310	<0.246	<0.348	<0.852
Finisher											
ADG, kg	0.97	0.98	0.95	0.95	0.98	0.96	0.015	<0.422	<0.963	<0.505	<0.229
ADFI, kg	2.83	2.88	2.90	2.80	2.87	2.81	0.044	<0.385	<0.540	<0.181	<0.304
G:F, g/kg	344	341	330	340	340	341	4.477	<0.020	<0.408	<0.420	<0.115
Overall											
ADG, kg	0.92	0.93	0.91	0.91	0.92	0.92	0.012	<0.158	<0.351	<0.859	<0.241
ADFI, kg	2.36	2.41	2.38	2.35	2.37	2.38	0.047	<0.673	<0.425	<0.348	<0.254
G:F, g/kg	389	385	383	388	388	387	3.487	<0.362	<0.899	<0.245	<0.398
Carcass characteristics											
HCW, kg	95.5	97.3	95.7	94.0	95.6	95.6	0.759	<0.322	<0.486	<0.058	<0.061
Carcass yield, %	73.2	74.0	73.9	72.2	73.3	73.4	0.414	<0.487	<0.983	<0.017	<0.013
Backfat depth[6], mm	16.3	16.1	15.9	16.0	16.1	16.3	0.560	<0.253	<0.936	<0.904	<1.000
Loin depth[6], mm	55.8	55.9	56.0	55.5	55.9	55.9	0.678	<0.761	<0.591	<0.510	<0.389
Lean[6], %	66.1	66.1	66.4	64.8	66.5	66.4	0.986	<0.273	<0.296	<0.554	<0.222

[1]A total of 1,980 pigs (initial BW = 33.3 kg) were used in 2 groups with 21 to 27 pigs per pen and 14 replicates per treatment.

[2]Zn sources were Zn hydroxychloride (ZnHyd; IntelliBond Z, Micronutrients, Indianapolis, IN) or Zn sulfate ($ZnSO_4$; Agrium Advance Technology, Loveland, CO for group 1 and Prince Agri Products Inc., Quincy, IL for group 2).

[3]BW = body weight; ADG = average daily gain; ADFI = average daily feed intake; G:F = gain-to-feed ratio; HCW = hot carcass weight.

[4]Grower period was from days 0 to 66 in group 1 and from days 0 to 72 in group 2.

[5]Finisher period was from days 66 to 103 in group 1 and from days 72 to 114 in group 2.

[6]Adjusted using HCW as covariate.

allowance and observed no evidence for effects on growth performance and carcass characteristics. Feldpausch et al. (2018) evaluated inorganic and organic Zn sources at 50 and 130 mg/kg for grow-finish pigs under heat stress conditions and observed no evidence for source or level effect on growth performance and carcass characteristics. Similarly, Patience et al. (2013) found no evidence for differences in growth and carcass characteristics between organic and inorganic Zn added at 50 mg/kg for grow-finish pigs fed different lysine to calorie ratios. Overall, it seems there is little evidence in the literature to support differences in growth performance and carcass characteristics between Zn sources; however, the vast majority of available research compared with inorganic and organic Zn rather than ZnHyd, which could at least partially explain our findings.

Research results are inconsistent regarding Zn-level effects on growth performance of grow-finish pigs. We observed a marginal improvement in ADG when added Zn was increased from 50 to 100 mg/kg. Conversely, Cemin et al. (2019) observed no evidence for differences in ADG for grow-finish pigs fed 50 to 200 mg/kg added Zn from ZnHyd but an improvement in G:F as added Zn increased up to 125 mg/kg. Paulk et al. (2015) added 50 to 150 mg/kg Zn from Zn oxide to finishing diets that contained 83 mg/kg of Zn from the premix for a total of 133 to 233 mg/kg added Zn. The authors observed a tendency for a linear improvement in G:F in 1 trial, but the results were not reproduced in a second experiment. Interestingly, Paulk et al. (2015) also observed a tendency for quadratic improvement in loin weight, but, contrary to our findings, no evidence was observed for differences in HCW or carcass yield. Fry et al. (2013) had a similar observation regarding the lack of repeatability of Zn effects on G:F. Feldpausch et al. (2016) evaluated the addition of 0 or 150 mg/kg Zn to

Table 5. Main effects of added Zn source and level on growth performance and carcass characteristics of grow-finish pigs[1,2]

	Source				Level, mg/kg				Probability, *P*	
Item[3]	ZnHyd	$ZnSO_4$	SEM	Probability, *P*	50	100	150	SEM	Linear	Quadratic
BW, kg										
Day 0	33.3	33.3	0.55	<0.967	33.3	33.3	33.3	0.55	<0.987	<0.946
Grower[4]	94.6	94.7	0.58	<0.748	94.4	94.9	94.6	0.58	<0.655	<0.259
Finisher[5]	130.5	130.3	1.34	<0.788	130.4	130.9	129.9	1.34	<0.626	<0.309
Grower										
ADG, kg	0.89	0.89	0.016	<0.677	0.89	0.90	0.89	0.016	<0.516	<0.317
ADFI, kg	2.14	2.13	0.054	<0.688	2.12	2.15	2.14	0.054	<0.404	<0.246
G:F, g/kg	418	420	3.355	<0.348	420	418	419	3.521	<0.829	<0.602
Finisher										
ADG, kg	0.97	0.96	0.015	<0.505	0.96	0.98	0.96	0.015	<0.643	<0.099
ADFI, kg	2.87	2.82	0.044	<0.181	2.81	2.87	2.85	0.044	<0.342	<0.223
G:F, g/kg	338	341	4.477	<0.420	342	341	336	4.477	<0.050	<0.501
Overall										
ADG, kg	0.92	0.92	0.012	<0.859	0.91	0.92	0.91	0.012	<0.940	<0.093
ADFI, kg	2.38	2.37	0.047	<0.348	2.35	2.39	2.38	0.047	<0.321	<0.185
G:F, g/kg	386	388	3.487	<0.245	388	387	385	3.487	<0.178	<0.891
Carcass characteristics										
HCW, kg	96.2	95.1	0.759	<0.058	94.8	96.4	95.7	0.762	<0.198	<0.045
Carcass yield, %	73.7	73.0	0.414	<0.017	72.7	73.7	73.7	0.415	<0.010	<0.135
Backfat depth[6], mm	16.1	16.2	0.560	<0.904	16.1	16.1	16.1	0.560	<0.993	<0.998
Loin depth[6], mm	55.9	55.8	0.678	<0.510	55.6	55.9	56.0	0.678	<0.186	<0.682
Lean[6], %	66.2	65.9	0.986	<0.554	65.4	66.3	66.4	0.986	<0.109	<0.473

[1]A total of 1,980 pigs (initial BW = 33.3 kg) were used in 2 groups with 21 to 27 pigs per pen and 14 replicates per treatment.

[2]Zn sources were Zn hydroxychloride (ZnHyd; IntelliBond Z, Micronutrients, Indianapolis, IN) or Zn sulfate ($ZnSO_4$; Agrium Advance Technology, Loveland, CO for group 1 and Prince Agri Products Inc., Quincy, IL for group 2).

[3]BW = body weight; ADG = average daily gain; ADFI = average daily feed intake; G:F = gain-to-feed ratio; HCW = hot carcass weight.

[4]Grower period was from days 0 to 66 in group 1 and from days 0 to 72 in group 2.

[5]Finisher period was from days 66 to 103 in group 1 and from days 72 to 114 in group 2.

[6]Adjusted using HCW as covariate.

diets that contained 73 mg/kg Zn from the premix for a total of 73 to 223 mg/kg added Zn. Similar to others, the authors also found no evidence for differences on growth performance and carcass characteristics. In contrast to our findings, the majority of research available found no evidence for an improvement in ADG with increasing added Zn. In fact, some researchers showed that even completely removing (Ma et al., 2012) or decreasing (Gowanlock et al., 2013) the supplementation of the trace-mineral premix containing Zn, Cu, Fe, and Mn would not result in significant differences in growth performance of finishing pigs.

There are several factors that can influence the Zn requirements (NRC, 2012), such as added phytase and dietary Cu and Fe level. Adeola et al. (1995) evaluated the supplementation of 1,500 FTU/kg phytase in diets with 0 or 100 mg/kg added Zn and observed that Zn balance is increased when diets contain phytase. In a study with growing pigs, Bikker et al. (2012) observed that the use of 500 FTU/kg phytase increased Zn digestibility, serum Zn level, and liver Zn content. However, the improvement in Zn digestibility observed by Bikker et al. (2012) did not result in changes in growth performance. In the present study, all diets contained 750 FTU/kg phytase; thus, the potential impact of phytase on Zn digestibility needs to be considered. The complex interactions between Zn, Cu, and Fe and potential competitive inhibition of transport have also been recognized (Brewer et al., 1985). Arredondo et al. (2006) showed that Cu and Zn may inhibit Fe uptake, but Zn does not seem to inhibit Cu uptake in human cells. Abdel-Mageed and Oehme (1991) found that the dietary proportions of Zn, Cu, and Fe influence the intestinal and cellular transport levels of Zn, Cu, and Fe in rats. However, the ideal proportion of these minerals in swine diets is unclear.

In summary, our results suggest that supplementing grow-finish diets with greater than 50 mg/kg added Zn may result in a modest increase in ADG for mixed-gender pigs raised in commercial conditions and fed diets containing 750 FTU/kg phytase. However, HCW and carcass yield were improved by providing higher levels of added Zn. The use of ZnHyd did not affect growth performance, but improved HCW and carcass yield compared with $ZnSO_4$.

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