Effects of increasing copper from either copper sulfate or combinations of copper sulfate and a copper–amino acid complex on finishing pig growth performance and carcass characteristics[1,2]

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ABSTRACT: A total of 1,089 pigs (PIC 280 × 1050; initially 37.3 ± 2.8 kg) were used to determine the effects of increasing Cu provided from either $CuSO_4$ alone or a 50:50 blend of $CuSO_4$ and a Copper–amino acid complex (Cu-AA) on growth performance and carcass characteristics of finishing pigs. Pens of pigs were blocked by body weight; within blocks, pens were randomly allotted to one of six dietary treatments. The six dietary treatments consisted of a control diet which contained 17 mg/kg Cu from $CuSO_4$ from the trace mineral premix, or the control diet with either added $CuSO_4$ to provide 70 and 130 mg/kg total Cu or a 50:50 blend of Cu from $CuSO_4$ and Cu-AA ($CuSO_4$/Cu-AA blend) to provide 70, 100, and 130 mg/kg total Cu. Experimental diets were corn–soybean meal-dried distillers grains with solubles-based and fed in meal form in five phases (approximately 37 to 46, 46 to 63, 63 to 77, 77 to 103, and 103 to 129 kg body weight). From d 0 to 43, neither Cu source nor level influenced growth performance. From d 43 to 105, average daily feed intake (ADFI) decreased (P = 0.037) for pigs fed the $CuSO_4$/Cu-AA blend compared to those fed added Cu from $CuSO_4$ alone. Gain:feed ratio (G:F) tended to be improved (linear, P = 0.056) as Cu concentration increased. Overall, d 0 to 105, neither Cu level nor source influenced average daily gain (ADG). Pigs fed 70 or 130 mg/kg total added Cu from the $CuSO_4$/Cu-AA blend had lower (P = 0.045) ADFI but G:F tended to be improved (P = 0.051) compared with those fed the same amount of total Cu from only CuSO4. Owing to the decreased ADFI and improved G:F of pigs fed the $CuSO_4$/Cu-AA blend, carcass G:F also improved (P = 0.033) compared with those fed added Cu from CuSO4 alone. In conclusion, providing a 50:50 blend of $CuSO_4$ and Cu-AA improved G:F on both a live and carcass weight basis compared to CuSO4 alone with no differences in ADG or carcass ADG observed.

Key words: carcass characteristics, copper, growth performance, swine

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INTRODUCTION

Studies have shown that increasing Cu regardless of Cu source has the potential to increase rate of gain and feed intake during the nursery period (Cromwell et al., 1989; Dove, 1995). Additional data support a similar growth response to

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increasing Cu during the finishing phase of growth (Davis et al., 2002; Hastad, 2002; Coble et al., 2017).

Previous research suggests there may be a growth benefit for pigs fed added Cu from a Copper–amino acid complex (Cu-AA) compared with those fed added Cu from $CuSO_4$ (Coffey et al., 1994; Zhou et al., 1994; Ma et al., 2015). However, Apgar et al. (1995) observed no evidence of a growth benefit between pigs fed added Cu from a Cu-AA compared with those fed added Cu from $CuSO_4$. On the other hand, in a second study, Apgar and Kornegay (1996) observed that growing pigs fed added Cu from a Cu–lysine complex tended to have greater average daily gain (ADG) and had greater ending body weight (BW) than those fed added Cu from $CuSO_4$. Thus, from the literature there is inconsistency regarding if an organic Cu source will affect growth differently than an inorganic source.

Further investigation is warranted to better understand how increasing levels of Cu from either an inorganic or an inorganic–organic Cu blend will affect growing-finishing pig performance. Therefore, the objective of this experiment was to determine the effects of increasing Cu provided from either $CuSO_4$ alone or a 50:50 blend of $CuSO_4$ and Cu-AA on growth performance and carcass characteristics of finishing pigs housed in a commercial environment.

MATERIALS AND METHODS

General

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment (IACUC protocol number 3523). The experiment was conducted in a commercial research facility in southwestern Minnesota. The barn was double-curtain-sided with completely slatted concrete flooring and deep pits for manure storage. The barn contained 42 pens with 25 or 26 pigs in each. Each pen was equipped with a 4-hole conventional dry self-feeder (Thorp Equipment, Thorp, WI) and one cup waterer, providing ad libitum access to feed and water. Pigs were placed in mixed-sex pens with equal number of barrows and gilts and stocked to allow 0.63 to 0.66 m^2 per pig. Daily feed additions to each pen were accomplished through a robotic feeding system (FEEDPro; Feedlogic Corp., Willmar, MN). All diets were manufactured in a commercial feed mill located in Pipestone, MN.

Live Animal Management

A total of 1,089 pigs (280 × 1050; Genus PIC, Hendersonville, TN; initially 37.3 ± 2.8 kg) were used in a 105-d experiment. On d 0 of the experiment, pens of pigs were weighed, blocked by average pen weight, and randomly allotted to one of six dietary treatments with seven replicate pens per treatment. The six dietary treatments consisted of a control diet with 17 mg/kg Cu from $CuSO_4$ from the trace mineral premix or the control diet with either added $CuSO_4$ to provide 70 and 130 mg/kg total Cu or a 50:50 blend of Cu from $CuSO_4$ and Cu-AA ($CuSO_4$/Cu-AA blend) to provide 70, 100, and 130 mg/kg total Cu. The source of Cu-AA was Availa-Cu (Zinpro Corporation, Eden Prairie, MN). All dietary treatments used the same basal diet formulation within each phase and were manufactured separately, with no feed blending performed. All diets contained 17 mg/kg Cu from $CuSO_4$ provided from the trace mineral premix.

Experimental diets were corn–soybean meal-corn-dried distillers grains with solubles (DDGS)-based and were fed in meal form in five phases (approximately 37 to 46, 46 to 63, 63 to 77, 77 to 103, and 103 to 129 kg BW; Table 1). For diets that contained added Cu above that provided from the trace mineral premix, Cu was added at the expense of corn. Nutrient values for the ingredients were based on the NRC (2012). Pigs were weighed and feed disappearance was measured approximately every 2 wk to calculate ADG, average daily feed intake (ADFI), gain:feed ratio (G:F), carcass ADG and G:F.

Harvest and Sample Collection

On d 79 of the trial, pens were weighed and the three heaviest pigs from each pen were removed and transported 95 km to a commercial packing plant (JBS USA, Worthington, MN) for harvest. These pigs were used in calculation of growth performance, but not carcass characteristics. On d 105, final pen weights were recorded and feed disappearance was measured. The remaining pigs in the barn were individually tattooed with a pen identification number to allow individual carcass measurements to be recorded, and transported to the packing plant for harvest. Carcass yield was calculated using hot carcass weight (HCW) at the plant divided by average individual live weight at the farm. Backfat and loin depth were measured with an optical probe (Fat-O-Meter; SFK, Herlev, Denmark) inserted between the third and fourth last rib (counting from the ham end of the carcass) at a distance approximately 7 cm from the dorsal midline. Pen was the experimental unit with carcass as the observational unit. Percentage lean was calculated using equations from the National Pork Producers Council (2000).

Table 1. Diet composition (as-fed basis)

Item	Phase[1]				
	1	2	3	4	5
Ingredient, %					
Corn	56.03	61.32	65.85	69.32	79.47
Soybean meal (46 % crude protein)	21.61	16.52	11.97	8.52	8.39
Corn DDGS[2]	20.00	20.00	20.00	20.00	10.00
Calcium carbonate	1.25	1.20	1.18	1.15	1.13
Monocalcium P (21.5% P)	0.15	—	—	—	0.09
Salt	0.35	0.35	0.35	0.35	0.35
L-lysine HCL	0.36	0.37	0.39	0.39	0.32
DL-methionine	0.01	—	—	—	—
L-threonine	0.05	0.04	0.05	0.06	0.07
L-tryptophan	—	0.01	0.02	0.02	0.02
Phytase[3]	0.01	0.01	0.01	0.01	0.01
Trace mineral premix[4]	0.10	0.10	0.10	0.10	0.10
Vitamin premix[5]	0.08	0.08	0.08	0.08	0.05
Cu source[6,7,8]	—	—	—	—	—
Total	100.00	100.00	100.00	100.00	100.00
Calculated analysis					
Standardized ileal digestible (SID) AA, %					
Lys	1.02	0.91	0.82	0.74	0.65
Ile:Lys	63	62	60	59	59
Met:Lys	29	29	30	31	30
Met & Cys:Lys	55	56	57	59	59
Thr:Lys	61	61	61	63	65
Trp:Lys	18.4	18.5	18.5	18.5	18.5
Val:Lys	70	70	70	70	70
Total Lys, %	1.18	1.06	0.96	0.87	0.76
Net energy, kcal/kg	2,431	2,466	2,494	2,515	2,547
SID Lys:Net energy, g/Mcal	4.20	3.69	3.29	2.94	2.55
Available P, %	0.29	0.26	0.25	0.25	0.22
Chemical analysis[9]					
Dry matter, %	86.14	86.03	86.04	86.00	85.96
Crude protein, %	20.38	18.77	16.10	14.35	13.63
Ash, %	4.40	3.92	3.54	3.43	3.30
Ca, %	0.61	0.53	0.53	0.55	0.58
P, %	0.51	0.46	0.40	0.38	0.37

[1]Phases 1, 2, 3, 4, and 5 were fed from approximately 37 to 46, 46 to 63, 63 to 77, 77 to 103, and 103 to 129 kg body weight, respectively.

[2]Corn distillers dried grains with solubles (Valero Renewables, Aurora, MN).

[3]OptiPhos 2000 (Huvepharma, Peachtree City, GA) was added with an assumed available P release value of 0.10.

[4]Supplied: zinc 110 g, iron 110 g, manganese 33 g, copper 17 g, iodine 0.33 g, and selenium 0.30 g per kg of premix.

[5]Supplied: vitamin A 7,054,720 IU, vitamin D3 1,102,300 IU, vitamin E 35,274 IU, vitamin B12 26, riboflavin (B2) 6,173 mg, niacin 39,683 mg, D-pantothenic acid 22,046 mg, and menadione 3,527 mg per kg of premix.

[6]Dietary treatments which contained only $CuSO_4$ were formed by adding 0, 53, or 113 mg/kg of Cu from $CuSO_4$, at the expense of corn. Dietary treatments which contained a combination of $CuSO_4$ and Cu-AA were formed by adding 18, 33, or 48 mg/kg of additional Cu from $CuSO_4$ combined with 35, 50, or 65 mg/kg of Cu from Cu-AA, respectively, at the expense of corn. The trace mineral premix was formulated to contribute 17 mg/kg of Cu from $CuSO_4$.

[7]Copper sulfate (Prince Agri Products, Quincy, IL).

[8]Copper–amino acid complex, Availa-Cu (Zinpro Corporation, Eden Prairie, MN).

[9]Multiple samples of each diet were collected, blended, and subsampled before being analyzed at Minnesota Valley Testing Laboratory (New Ulm, MN). Values listed represent the mean for all dietary treatments within a phase for the respective component.

Chemical Analysis

Complete diet samples were collected from a minimum of six feeders in significant amounts and combined to make one composite sample per treatment within dietary phase. Each sample was then split, subsampled, ground, and sent to Minnesota Valley Testing Laboratories (New Ulm, MN) for analysis in duplicates of dry matter (method 930.15, AOAC, 2000), crude protein (method 990.03; AOAC, 2000), ash (method 942.05; AOAC, 2000), Ca, P, and Cu concentrations (method 985.01; AOAC, 2000).

Statistical Analysis

Data were analyzed as a randomized complete block design using PROC GLIMMIX (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Percentage lean, loin depth, and backfat were adjusted to a common HCW for evaluation. Contrasts were used to determine the effect of Cu source ($CuSO_4$ vs. $CuSO_4$/Cu-AA blend) based on diets containing 70 and 130 mg/kg Cu. Linear and quadratic effects of Cu level (17, 70, 100, and 130 mg/kg) were also analyzed. Coefficients for polynomial contrasts were determined using PROC IML (SAS Institute, Inc.). Significant results were defined as $P \leq 0.05$ and marginally significant as $P > 0.05$ and ≤ 0.10.

RESULTS

Chemical Analysis

The chemical analyses of dry matter, crude protein, ash, Ca, and P of complete diets supported the calculated values based on diet formulation (Table 1). For Cu analysis, the results presented in Table 2 represent a feed intake-based weighted average of chemical Cu analysis for each treatment within early finishing (d 0 to 43, diet phases 1, 2, and 3 fed from 37 to 77 kg BW), late finishing (d 43 to 105, diet phases 4 and 5 fed from 77 to 129 kg BW), and overall.

Growth Performance and Carcass Characteristics

Growth performance of finishing pigs from d 0 to 43 was consistent within the period, as well as growth performance evaluated within in the period from d 43 to 105. Therefore, growth performance data was combined into periods and presented as early finishing (d 0 to 43, from 37 to 77 kg BW) and late finishing (d 43 to 105, from 77 to 129 kg BW) periods.

From d 0 to 43 (37 to 77 kg BW), neither Cu source nor level influenced growth performance ($P > 0.14$; Table 3). From d 43 to 105 (77 to 129 kg BW), ADFI was decreased ($P = 0.037$) for pigs fed the $CuSO_4$/Cu-AA blend compared to those fed added Cu from $CuSO_4$ alone. Feed efficiency tended to be improved (linear, $P = 0.056$) as level of Cu increased.

Table 2. Copper analysis of diets (as-fed basis)[1,2]

	Added Cu[3], mg/kg					
	Control	$CuSO_4$[4]		$CuSO_4$/Cu-AA[5]		
Item	17	70	130	70	100	130
Early finishing (d 0 to 43)	43	73	95	97	87	112
Late finishing (d 43 to 105)	31	86	123	89	117	139
Overall (d 0 to 105)	36	82	114	93	107	130

[1]Multiple samples of each diet were collected, blended, and subsampled before being analyzed at Minnesota Valley Testing Laboratory (New Ulm, MN).

[2]Values represent a feed intake-based weighted average of chemical Cu analysis for each treatment within early finishing (diet phases 1, 2, and 3 fed from 37 to 77 kg body weight), late finishing (diet phases 4 and 5 fed from 77 to 129 kg body weight), and overall. Permitted analytical variation for Cu analysis is 25% (AAFCO, 2018).

[3]The trace mineral premix was formulated to contribute 17 mg/kg of Cu from $CuSO_4$ to the complete basal diet.

[4]$CuSO_4$ = copper sulfate (Prince Agri Products, Quincy, IL). Values represent the sum of added Cu from the premix and supplemental Cu from $CuSO_4$.

[5]$CuSO_4$/Cu-AA = 50:50 blend of Cu from copper sulfate and copper–amino acid complex (Availa-Cu, Zinpro Corporation, Eden Prairie, MN). Values represent the sum of added Cu from the premix and supplemental Cu from $CuSO_4$/Cu-AA blend.

Overall (d 0 to 105; 37 to 129 kg BW), neither Cu level nor source influenced ADG. Pigs fed 70 and 130 mg/kg total added Cu from the $CuSO_4$/Cu-AA blend had decreased ($P = 0.045$) ADFI, but G:F was marginally improved ($P = 0.051$) compared with those fed the same amount of added Cu from only CuSO4. Carcass G:F was also improved ($P = 0.033$; Table 4) in pigs fed the CuSO4/Cu-AA blend compared with those fed added Cu from CuSO4 alone; however, neither Cu source nor level influenced any other carcass criteria ($P > 0.17$).

DISCUSSION

The current NRC (2012) requirement estimate for finishing pigs from 50 to 135 kg BW is 3.0 to 3.5 mg/kg Cu. Corn, soybean meal, and corn DDGS can contain on average 15, 50, and 52 mg/kg Cu, respectively (NRC, 2012). On the basis of these Cu concentrations, corn, soybean meal, and corn DDGS may have contributed around 14 mg/kg Cu to the complete diet in our study, exceeding the nutrient requirement estimated for Cu for finishing pigs. Considering the estimated inert Cu content of major ingredients (NRC, 2012) and the permitted analytical variation for Cu analysis of 25% (AAFCO), the analyzed value of Cu within treatments was within reason to those expected from diet formulation. Flohr et al. (2016) reported that swine nutritionists typically formulate swine diets to contain levels of Cu above the requirement estimate of NRC (2012). This may be

Table 3. Effects of increasing Cu from either $CuSO_4$ or combinations of $CuSO_4$ and Cu-AA on finishing pig growth performance[1]

	Control[2]	$CuSO_4$[3], mg/kg		$CuSO_4$/Cu-AA[4], mg/kg				Probability, $P <$		
									Level	
Item	17	70	130	70	100	130	SEM	Cu source[5]	Linear	Quadratic
BW, kg										
d 0	37.2	37.2	37.3	37.2	37.4	37.2	1.12	0.848	0.748	0.867
d 43	76.9	77.2	77.9	77.5	78.1	77.3	1.70	0.880	0.292	0.559
d 105	127.7	129.4	129.7	129.0	130.5	128.3	1.82	0.467	0.247	0.235
d 0 to 43										
ADG, kg	0.92	0.93	0.94	0.94	0.95	0.93	0.016	0.936	0.264	0.408
ADFI, kg	2.14	2.16	2.19	2.17	2.21	2.13	0.039	0.321	0.186	0.142
G:F	0.432	0.429	0.429	0.433	0.428	0.437	0.0041	0.170	0.964	0.512
d 43 to 105										
ADG, kg	0.83	0.85	0.85	0.85	0.85	0.83	0.013	0.400	0.455	0.334
ADFI, kg	2.64	2.68	2.67	2.64	2.64	2.56	0.034	0.037	0.603	0.349
G:F	0.315	0.317	0.319	0.320	0.321	0.325	0.0031	0.110	0.056	0.811
d 0 to 105										
ADG, kg	0.87	0.88	0.89	0.89	0.89	0.87	0.010	0.573	0.249	0.264
ADFI, kg	2.43	2.46	2.47	2.44	2.46	2.38	0.029	0.045	0.916	0.208
G:F	0.358	0.359	0.360	0.363	0.362	0.368	0.0030	0.051	0.125	0.914

[1]A total of 1,089 pigs (PIC 280 × 1050; Genus PIC, Hendersonville, TN) were used with 25 or 26 pigs per pen and 7 pens per treatment in a 105-d growth study.

[2]The trace mineral premix was formulated to contribute 17 mg/kg of Cu from $CuSO_4$ to the complete basal diet.

[3]$CuSO_4$ = copper sulfate (Prince Agri. Products, Quincy, IL). Values represent the sum of added Cu from the premix and supplemental Cu from $CuSO_4$.

[4]$CuSO_4$/Cu-AA = 50:50 blend of Cu from copper sulfate and copper-amino acid complex (Availa-Cu, Zinpro Corporation, Eden Prairie, MN). Values represent the sum of added Cu from the premix and supplemental Cu from $CuSO_4$/Cu-AA blend.

[5]Based on diets containing 70 and 130 mg/kg Cu.

Table 4. Effects of increasing Cu from either $CuSO_4$ or combinations of $CuSO_4$ and Cu-AA on finishing pig carcass characteristics[1]

	Control[2]	$CuSO_4$[3], mg/kg		$CuSO_4$[3]/Cu-AA[4], mg/kg				Probability, $P <$		
									Cu level	
Item	17	70	130	70	100	130	SEM	Cu source[5]	Linear	Quadratic
Yield, %	72.36	72.57	71.91	72.66	72.61	72.44	0.333	0.329	0.796	0.179
HCW, kg	93.04	93.84	93.89	93.72	94.73	92.92	1.353	0.547	0.493	0.247
Backfat[6], mm.	17.3	17.4	17.4	17.5	17.2	17.1	0.36	0.836	0.687	0.770
Loin depth[6], mm.	63.6	63.5	63.1	63.9	63.3	65.2	1.06	0.201	0.790	0.617
Lean[6], %	55.91	55.84	55.82	55.81	55.98	56.22	0.264	0.363	0.605	0.581
HCW ADG[7], kg	0.620	0.628	0.628	0.627	0.635	0.619	0.0079	0.552	0.519	0.229
HCW G:F	0.259	0.260	0.259	0.264	0.263	0.266	0.0025	0.033	0.213	0.589

[1]A total of 1,089 pigs (PIC 280 × 1050; Genus PIC, Hendersonville, TN; initially 37.3 ± 2.8 kg) were used with 25 or 26 pigs per pen and 7 pens per treatment in a 105-d growth study.

[2]The trace mineral premix was formulated to contribute 17 mg/kg of Cu from $CuSO_4$ to the complete basal diet.

[3]$CuSO_4$ = copper sulfate (Prince Agri. Products, Quincy, IL). Values represent the sum of added Cu from the premix and supplemental Cu from $CuSO_4$.

[4]$CuSO_4$/Cu-AA = 50:50 blend of Cu from copper sulfate and copper-amino acid complex (Availa-Cu, Zinpro Corporation, Eden Prairie, MN). Values represent the sum of added Cu from the premix and supplemental Cu from $CuSO_4$/Cu-AA blend.

[5]Based on diets containing 70 and 130 mg/kg Cu.

[6]HCW was used as a covariate. Percentage lean was calculated using equations from the National Pork Producers Council (2000).

[7]An initial HCW was established using an assumed initial carcass yield of 75%.

because previous research has shown that feeding high concentrations of Cu has been associated with improved growth performance (Davis et al., 2002; Hastad, 2002; Coble et al., 2017).

Previous studies suggest that increasing Cu improves growth performance during the early finishing period, but not in the late finishing period. Coble et al. (2017) fed diets to pigs containing added Cu at 0, 75, or 150 mg/kg and reported that pigs provided increasing Cu had improved ADG and ADFI until an average BW of 89 kg. Similarly, Hastad (2002) fed diets to pigs containing added Cu at 50, 100, or 200 mg/kg and reported that pigs provided increasing Cu had improved growth performance until an average BW of 61 kg, with no benefit thereafter. A key contrast between our study and previous studies (Hastad, 2002; Coble et al., 2017) is the suggestion of growth benefit to increasing added Cu in early finishing by the latter. In our study, increasing Cu during the early finishing period (37 to 77 kg BW) did not affect growth performance regardless of Cu source. However, Zhao et al. (2014) observed that increasing added Cu from 6 to 170 mg/kg increased ADG of pigs from 90 to 101 kg and tended to increase ADG and G:F of pigs from 101 to 118 kg during late finishing. In addition, Davis et al. (2002) reported that pigs fed 125 mg/kg added Cu had improved growth performance in both the early (32 to 68 kg) and late (68 to 106 kg) finishing periods. Similar to our study, Davis et al. (2002) and Zhao et al. (2014) support that there may be a performance benefit to increasing added Cu in late finishing. In the overall finishing period, Zhao et al. (2014) reported that pigs (32 to 118 kg) fed increasing Cu had increased ADG and improved G:F, whereas Coble et al. (2017) observed that pigs (25 to 128 kg) had increased ADG and ADFI. In addition, HCW and loin depth also increased as added Cu increased in the study of Coble et al. (2017). In contrast, in the study herein we did not observe any differences in overall ADG, ADFI, G:F, or carcass characteristics with increasing added dietary Cu.

It has been reported in the literature that $CuSO_4$ has been the most commonly used Cu source in swine diets (Cromwell et al., 1998; Miles et al., 1998). The current body of literature lacks information regarding the comparison between feeding increasing Cu from a single source or a 50:50 blend of two different sources. Studies have compared the effects of dietary sources of Cu fed to growing-finishing pigs (Stansbury et al., 1990; Apgar and Kornegay, 1996; Hastad, 2002; Zhao et al., 2014; Coble et al., 2017). A series of experiments by Stansbury et al. (1990) showed that pigs provided Cu in the form of a chelate did not have greater performance compared with pigs fed Cu from $CuSO_4$. In contrast, recent study by Zhao et al. (2014) with diets containing added Cu from $CuSO_4$ or from a Cu-chelate [$Cu(HMTB_a)_2$] reported that pigs fed 80 mg/kg Cu from $Cu(HMTB_a)_2$ tended to have greater ADG and had greater HCW than pigs provided 160 mg/kg Cu from $CuSO_4$. Similarly, Apgar and Kornegay (1996) observed that pigs fed diets containing added Cu from Cu–lysine complex tended to have greater ADG than those fed added Cu from $CuSO_4$. Hastad (2002) observed that ADG tended to be greater and ADFI was greater for pigs fed added Cu from $CuSO_4$ compared with those fed added Cu from tribasic copper chloride. In contrast, Coble et al. (2017) observed similar growth performance and carcass characteristics for pigs fed added Cu from either $CuSO_4$ or tribasic copper chloride.

Our study agrees with the literature suggesting that growth performance may be dependent on Cu source. In our study, pigs fed added Cu from $CuSO_4$/Cu-AA blend during late finishing (77 to 129 kg) consumed less feed and had improved feed efficiency on a HCW basis compared to pigs fed added Cu from $CuSO_4$ alone. Similarly, in the overall finishing, pigs fed added Cu from $CuSO_4$/Cu-AA blend consumed less feed and tended to have improved feed efficiency compared to pigs fed added Cu from $CuSO_4$ alone. Although it appears that in the study of Zhao et al. (2014) growth rate was mostly responsible for the performance differences among Cu sources, in our study the performance differences for Cu source appear to be driven by feed efficiency. The differences in G:F between pigs fed added Cu from $CuSO_4$/Cu-AA blend compared to $CuSO_4$ appear to be primarily driven by the reduction in ADFI of pigs fed 130 mg/kg Cu added Cu from $CuSO_4$/Cu-AA blend. This response was unexpected because high levels of dietary Cu have been generally associated with a rather increased ADFI, a performance response that has been repeated and well demonstrated in the literature (Davis et al., 2002; Hastad, 2002; Coble et al., 2017).

In conclusion, feeding increasing levels of Cu from 17 to 130 mg/kg improved G:F of finishing pigs. Providing a 50:50 blend of $CuSO_4$ and Cu-AA improved G:F on both a live and HCW basis compared with feeding Cu from $CuSO_4$ alone. However, added Cu or Cu source did not affect ADG or carcass characteristics.

Conflict of interest statement. None declared.

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