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Effects of Copper Sources (Copper Sulfate and Mintrex Cu) on Growth Performance, Carcass Characteristics, Barn Cleaning, and Economics in Finishing Pigs[1,2]

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Summary

A total of 1,196 mixed-sex pigs (PIC 337 × 1050, initially 56.7 lb) were used in a 111-d study. Pens of pigs were allotted to 1 of 6 dietary treatments in a randomized incomplete block design, with 26 pigs per pen (similar number of barrows and gilts) and 7 to 8 pens per treatment. All diets contained 17 ppm copper from copper sulfate ($CuSO_4$) in the premix and were formulated on a standardized ileal digestible (SID) lysine basis at 0.05% below the estimated requirement of the average pig weight during each feeding phase. Treatments included a control diet with no added Cu, diets with either 50 ppm of added Cu from $CuSO_4$ or Mintrex Cu (Novus International, Inc., St. Charles, MO), or 125 ppm of added Cu from $CuSO_4$. The diet containing 50 ppm of Cu from Mintrex Cu and the diet with 125 ppm of Cu from $CuSO_4$ were fed for either the first half of the finishing period (d 0 to 42), at which time they were switched to the control diet, or for the entire duration of the finishing period (d 0 to 111).

Overall (d 0 to 111), ADG did not differ among treatments; however, pigs fed either 50 or 125 ppm of Cu from $CuSO_4$ throughout the study had greater ADFI ($P < 0.05$) than pigs fed either the control or diet with 50 ppm of added Cu from Mintrex Cu fed only in early finishing. As a result, F/G was poorer ($P < 0.05$) for pigs fed either 50 or 125 ppm of added Cu from $CuSO_4$ fed continuously compared with those fed 50 ppm of Cu from Mintrex Cu only in early finishing. Manure texture, and more importantly, pen wash time, did not differ among treatments, but manure buildup was 1.44 times more likely ($P < 0.05$) to occur in pens where pigs were fed 125 ppm of added Cu from $CuSO_4$ for the first 42 d of the finishing period compared with those fed no added Cu.

For carcass characteristics, pigs fed 50 ppm of Cu from Mintrex Cu in early finishing had reduced backfat ($P < 0.05$) compared with pigs fed the control or 50 ppm of added Cu from $CuSO_4$ or Mintrex Cu throughout the study.

For economics, pigs fed 50 ppm of Cu from $CuSO_4$ throughout the study had a higher ($P < 0.05$) total feed cost than the control and diets with 125 ppm of added Cu from $CuSO_4$ fed in early finishing, and 50 ppm of added Cu from Mintrex Cu fed for the

[1] Appreciation is expressed to New Horizon Farms for use of pigs and facilities and to Richard Brobjorg and Marty Heintz for their technical assistance.

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[3] Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University.

[4] Novus International, Inc. (St. Charles, MO).

first 42 d. Cost per pound of gain was higher (*P* < 0.05) for pigs fed 50 or 125 ppm of Cu from $CuSO_4$ for the entire study than for pigs fed the control diet or the diet with 50 ppm of added Cu from Mintrex Cu fed for the first 42 d, with pigs fed the other diets having intermediate responses. No differences were detected in either carcass gain value or IOFC among treatments.

In summary, pigs fed 50 ppm of Cu from Mintrex Cu for the first 42 d of the finishing period had a better F/G compared with pigs fed 50 or 125 ppm of added Cu from $CuSO_4$ for the complete finishing period, but more research is needed to fully elucidate the appropriate source, level, and duration of feeding Cu to maximize growth performance and economic return.

Key words: finishing pig, copper, wash time

Introduction

Nutritionists and producers have traditionally included added copper in the form of copper sulfate ($CuSO_4$) at levels up to 250 ppm in nursery pig diets and early finishing because it improves growth performance during these stages of production. Most producers discontinue the use of $CuSO_4$ in the late finishing period, however, because growth benefits have not been found in this stage (Hastad et al., 2001[5]).

A number of new chelated sources of Cu, such as Mintrex Cu (Novus International, Inc., St. Charles, MO), have entered the market place in recent years. It is suggested that minerals chelated with amino acids may be more readily absorbed and therefore increase the beneficial response. Inorganic and chelated mineral sources have been studied extensively in nursery pigs, but their use in finishing pigs is less defined. In addition, reports from the field suggest that feeding diets higher in fiber and including high levels of supplemental Cu lead to increased manure buildup and pen wash time, but data confirming this are limited.

Therefore, the objectives of this study were to compare 2 sources of copper ($CuSO_4$ and Mintrex Cu) and the duration of feeding these Cu sources on growth performance, carcass characteristics, pen wash time, and economics of finishing pigs.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted at a commercial research-finishing site in southwest Minnesota. The barns were naturally ventilated and double-curtain-sided. Pens had completely slatted flooring and deep pits. Each pen was equipped with a 4-hole stainless steel feeder and cup waterer for ad libitum access to feed and water. Feed additions were made by a robotic feeding system (FeedPro; Feedlogic Corp., Willmar, MN) that measured feed amounts for each individual pen.

A total of 1,196 mixed-sex pigs (PIC 337 × 1050, initially 56.7 lb) were used in a 111-d study. Forty-six pens of pigs were allotted to 1 of 6 dietary treatments in a randomized incomplete block design, with 26 pigs per pen (similar number of barrows and gilts) and 7 to 8 pens per treatment. All diets contained 17 ppm Cu from $CuSO_4$ in the premix

[5] Hastad et al., Swine Day 2001. Report of Progress 880, pp. 111–117.

and were formulated on a standardized ileal digestible (SID) lysine basis at 0.05% below the estimated requirement of the average pig weight during each phase. Treatments included a control diet with no additional Cu or diets with either 50 ppm of added Cu from $CuSO_4$, 50 ppm of Cu from Mintrex Cu (Novus International, Inc., St. Charles, MO), or 125 ppm of Cu from $CuSO_4$. Both the diet containing the Mintrex Cu and the diet with 125 ppm of Cu from $CuSO_4$ were fed to pigs for either the first half of the finishing period (d 0 to 42) or for the entire duration of the finishing period (d 0 to 111). Treatment diets were fed in meal form in 5 dietary phases (Table 1). During the last phase, all diets contained 4.5 g/ton of ractopamine HCl (Paylean; Elanco Animal Health, Greenfield, IN). Each treatment diet was sampled at the start and before the last day of each phase, with samples mixed to form a composite sample. Diets were analyzed for Cu (Table 2).

Pens of pigs were weighed and feed disappearance was recorded at d 25, 42, 70, 90, and 111 to determine ADG, ADFI, and F/G. On day 90, the 3 heaviest pigs in each pen were weighed and sold according to standard farm procedures. Prior to marketing, the remaining pigs were individually tattooed with a pen ID number to allow for carcass measurements to be recorded on a pen basis. On day 111, final pen weights were taken and pigs were transported to a commercial packing plant (JBS Swift and Company, Worthington, MN) for processing and carcass data collection. Carcass measurements taken at the plant included HCW, loin depth, backfat, and percentage lean. Percentage carcass yield was calculated by dividing the average pen HCW by average final live weight at the farm and live weight at the plant. Hot carcass weight ADG was calculated by dividing HCW by the total number of days in the trial. From HCW ADG, HCW F/G was determined by dividing overall ADFI by HCW ADG.

At the conclusion of the trial, a digital photo of each pen was taken to allow 3 independent observers to score each pen for manure texture and buildup and to assess pen cleanliness prior to power-washing. Manure textures were categorized as firm, medium, and loose with scores of 1, 2, and 3, respectively, and the average of the 3 observers was used for statistical analysis. Manure buildup was categorized as 1 for visual manure buildup and -1 for no visual manure buildup. A binomial distribution was used to determine the likelihood of manure buildup for each treatment. Afterward, a professional power-washing crew recorded wash time for each pen with a stopwatch to determine the difference in wash time among treatments.

After the data collection process, an economic analysis was calculated to determine the value of feeding Cu by calculating the total feed cost per pig, cost per pound of gain, carcass gain value, and income over feed cost (IOFC). The total feed cost per pig was calculated by multiplying the ADFI by the feed cost per pound and the number of days in each respective period, then taking the sum of those values for each period. Cost per pound of gain was calculated by dividing the total feed cost per pig by the total pounds gained overall. Carcass gain value per pig was calculated by subtracting the product of the initial weight multiplied by an assumed initial carcass yield of 75% and $98.00/cwt carcass price from the product of final HCW multiplied by $98.00/cwt carcass price. To calculate IOFC, total feed cost was subtracted from the carcass gain value.

Experimental data were analyzed with PROC GLIMMIX in SAS (SAS Institute, Inc., Cary, NC) using pen as the experimental unit. Because only 4 treatments were fed from

d 0 to 42, the number of experimental units for pigs fed the control, 50 ppm of added Cu from $CuSO_4$, 50 ppm of added Cu from Mintrex Cu, and 125 ppm of added Cu from $CuSO_4$ were 7, 7, 16, and 16, respectively, during this period. For response criteria with a significant overall treatment *P*-value, individual pair-wise comparisons were used to determine individual treatment comparisons. Hot carcass weight served as a covariate for the analysis of backfat, loin depth, and lean percentage. To analyze manure texture data, the binomial distribution function of PROC GENMODE in SAS was used to determine the likelihood of manure buildup compared with the control diet without added Cu. Results from the experiment were considered significant at $P \leq 0.05$ and a tendency between $P > 0.05$ and $P \leq 0.10$.

Results and Discussion

Analyzed total Cu concentrations were similar to the formulated values for all diets (Table 2). The amount of variation from the true mean Cu concentrations was an allowable level based on past mineral analyses, lab assays, and sampling techniques. Phase 4 diets were not available for analysis.

During the early finishing phase (d 0 to 42), ADG did not differ among treatments (Table 3). Pigs fed 50 ppm of Cu from $CuSO_4$, however, tended ($P < 0.10$) to have greater ADFI than control pigs, which led to poorer ($P < 0.05$) F/G for pigs fed 50 ppm of added Cu from $CuSO_4$ compared with the control and 50 ppm of Cu from Mintrex Cu treatments.

During the late finishing period (d 42 to 111), there was no difference in ADG or F/G, but pigs fed 50 ppm of added Cu from $CuSO_4$ for the entire study had greater ($P < 0.05$) ADFI than pigs fed the control diet or the diet with 125 ppm of added Cu from $CuSO_4$ during only the early finishing period, with the other treatments intermediate.

Overall (d 0 to 111), ADG did not differ. Pigs fed either 50 or 125 ppm of added Cu from $CuSO_4$ throughout the study had a higher ($P < 0.05$) ADFI than pigs fed either the control or 125 ppm of added Cu from $CuSO_4$ fed only in early finishing. Because of the differences in feed intake combined with no differences in ADG, F/G was poorer ($P < 0.05$) in pigs fed either 50 or 125 ppm added $CuSO_4$ fed continuously compared with those fed 50 ppm of Cu from Mintrex Cu only in early finishing, whereas pigs fed the other treatments were intermediate. No differences were detected in final weight among treatments.

Manure texture, and more importantly, pen wash time did not differ among treatments, but manure buildup was 1.4 times more likely ($P < 0.05$) to occur in pens where pigs were fed 125 ppm of added Cu from $CuSO_4$ for the first 42 d of the finishing period compared with those fed no added Cu.

For carcass characteristics, limited differences existed among treatments, with the exception of backfat (Table 4). Backfat in pigs fed 50 ppm of Cu from Mintrex Cu in early finishing was reduced ($P < 0.05$) compared with pigs fed the control or 50 ppm of added Cu from $CuSO_4$ or Mintrex Cu fed throughout the study. Although no difference was found in HCW ADG, pigs fed 50 ppm of Cu from $CuSO_4$ throughout the

study had higher ($P < 0.05$) HCW F/G than those fed the control, or either 50 ppm of added Cu from Mintrex Cu or 125 ppm of added Cu from $CuSO_4$ in early finishing.

For economics, pigs fed 50 ppm added Cu from $CuSO_4$ throughout had higher ($P < 0.05$) total feed cost compared with pigs fed the control or 125 ppm of added Cu from $CuSO_4$ and 50 ppm of added Cu from Mintrex Cu fed in early finishing. Cost per pound of gain had a similar response to total feed cost, but both the 50 ppm and 125 ppm of added Cu from $CuSO_4$ fed for the duration of the study had higher ($P < 0.05$) feed costs than the control and 50 ppm of added Cu from Mintrex Cu fed in early finishing. No differences were detected, however, in either carcass gain value or IOFC among treatments.

In summary, pigs fed 50 ppm of Cu from Mintrex Cu in the first 42 d of the finishing period had better F/G than pigs fed 50 or 125 ppm of added Cu from $CuSO_4$ for the complete finishing period. All other treatments were intermediate. The responses observed suggest that supplementation level and duration do affect performance, but more research is needed to fully elucidate the appropriate source, level, and duration of feeding to maximize growth performance and economic return.

Table 1. Diet composition for Phases 1, 2, 3, 4, and 5 (as-fed basis)[1]

Ingredient, %	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Corn	35.96	40.93	44.61	47.21	39.56
Soybean meal, 46.5% CP	16.51	11.81	8.24	5.70	13.14
DDGS[2]	30.00	30.00	30.00	30.00	30.00
Bakery meal	15.00	15.00	15.00	15.00	15.00
Limestone	1.25	1.17	1.15	1.13	1.18
Monocalcium P, 21%	0.18	---	---	---	---
Salt	0.35	0.35	0.35	0.35	0.35
Biolys[3]	0.57	0.52	0.47	0.44	0.53
L-threonine	---	---	---	---	0.04
Trace mineral premix[4]	0.10	0.10	0.10	0.10	0.10
Vitamin premix	0.08	0.08	0.08	0.08	0.08
Phytase[5]	0.01	0.01	0.01	0.01	0.01
Ractopamine-HCl[6]	---	---	---	---	0.03
Copper source[7]	---	---	---	---	---
Total	100.00	100.00	100.00	100.00	100.00
Calculated Analysis					
Standardized ileal digestible (SID) amino acids, %					
Lysine	1.00	0.86	0.75	0.67	0.90
Methionine:lysine	31.9	34.7	37.7	40.5	33.8
Met & Cys: lysine	59.2	64.1	69.3	74.3	62.5
Threonine:lysine	59.5	61.8	64.4	66.9	64.9
Tryptophan:lysine	18.0	18.0	18.0	18.0	18.0
Valine:lysine	82.3	86.9	91.9	96.6	85.4
Total lysine	1.20	1.04	0.93	0.84	1.09
ME, kcal, lb	1,536	1,542	1,544	1,545	1,541
SID lysine:ME, g/Mcal	2.95	2.53	2.20	1.97	2.65
CP, %	21.3	19.5	18.0	17.0	20.0
Ca, %	0.58	0.51	0.49	0.48	0.52
P, %	0.47	0.41	0.39	0.38	0.41
Available P, %	0.35	0.31	0.30	0.29	0.31

[1] Phase 1 diets fed from d 0 to 25, Phase 2 from d 25 to 42, Phase 3 from d 42 to 70, Phase 4 from d 70 to 90, and Phase 5 from d 90 to 111.
[2] Dried distillers grains with solubles (Valero, Aurora, SD).
[3] Lysine source (Evonik, Inc., Kennesaw, GA).
[4] Trace mineral premix provided all diets with 17 ppm copper from copper sulfate.
[5] Optiphos 2000 (Enzyva LLC, Sheridan, IN) provided 1,816,000 phytase units (FTU)/lb, with a release of 0.10% available P.
[6] Ractopamine HCl (Elanco Animal Health, Inc., Greenfield, IN).
[7] Supplemental copper provided in the form of either $CuSO_4$ at 50 or 125 ppm or Mintrex Cu (Novus International, Inc., St. Charles, MO) at 50 ppm at the expense of corn to the control diet.

Table 2. Copper analysis of complete diets[1]

Cu source:	None	$CuSO_4$	Mintrex Cu[2]	$CuSO_4$
Added Cu, ppm:	None	50	50	125
Phase				
1	21	96	70	161
2	24	61	66	166
3	21	85	65	184
4[3]	---	---	---	---
5	28	70	59	164

[1] Values represent the mean analyzed total copper levels from one composite sample analyzed in duplicate. All diets contained 17 ppm Cu from copper sulfate ($CuSO_4$) in the trace mineral premix.
[2] Novus International, Inc., St. Charles, MO.
[3] Samples for Phase 4 diets were not available for Cu analysis.

Table 3. Effects of added copper from Mintrex Cu or $CuSO_4$ on growth performance and manure characteristics in finishing pigs[1,2]

Cu source:	---	$CuSO_4$	Mintrex Cu	$CuSO_4$	Mintrex Cu	$CuSO_4$		
Added Cu, ppm:	---	50	50	125	50	125		
Feeding length, d:	0 to 111	0 to 111	0 to 42	0 to 42	0 to 111	0 to 111	SE	Treatment, *P* <
Item								
BW, lb								
d 0	56.6	57.4	56.7	57.1	---	---	1.65	0.55
d 42	134.0	137.0	135.2	135.4	---	---	3.23	0.52
d 111	270.4	274.6	274.1	270.0	276.2	275.6	2.94	0.16
d 0 to 42								
ADG, lb	1.84	1.90	1.86	1.86	---	---	0.033	0.40
ADFI, lb	3.88[y]	4.08[x]	3.93[y]	3.98[xy]	---	---	0.071	0.07
F/G	2.11[b]	2.15[a]	2.11[b]	2.13[ab]	---	---	0.016	0.04
d 42 to 111								
ADG, lb	2.04	2.07	2.07	2.01	2.09	2.06	0.027	0.39
ADFI, lb	5.63[bc]	5.83[a]	5.66[ab]	5.60[c]	5.78[ab]	5.80[ab]	0.068	0.04
F/G	2.76	2.82	2.74	2.78	2.77	2.83	0.031	0.21
d 0 to 111								
ADG, lb	1.96	2.00	1.99	1.95	2.00	1.99	0.018	0.12
ADFI, lb	4.95[c]	5.14[a]	4.98[bc]	4.95[c]	5.08[abc]	5.10[ab]	0.060	0.02
F/G	2.52[bc]	2.57[a]	2.50[c]	2.54[abc]	2.53[abc]	2.57[ab]	0.019	0.04
Pen manure characteristics								
Texture[3]	2.17	1.67	1.92	2.21	2.33	1.90	0.219	0.28
Buildup[4]	0.00[a]	-0.03[a]	-0.51[a]	1.44[b]	0.00[a]	-0.61[a]	0.748	---
Wash time, s	345	332	323	365	324	352	15.2	0.26

[1] 1,196 pigs (PIC 337 × 1050; initial BW 56.7) were used in a 111-d finishing study with 6 treatments and 7 to 8 replications per treatment. Mintrex (Novus International, St. Charles, MO).

[2] Means within row with different superscripts differ: [abc] $P < 0.05$, [xyz] $P < 0.10$.

[3] Categorized as firm, medium, or loose with scores of 1, 2, and 3, respectively.

[4] Binomial distribution used to estimate odds for increased or decreased likelihood of manure buildup compared only to the control diet without added Cu.

[abc] Estimates with different superscripts from control differ ($P < 0.05$).

Table 4. Effects of added copper from Mintrex Cu or $CuSO_4$ on carcass characteristics and economics in finishing pigs[1,2]

Cu source:	---	$CuSO_4$	Mintrex Cu	$CuSO_4$	Mintrex Cu	$CuSO_4$		
Added Cu, ppm :	---	50	50	125	50	125		
Feeding length, d:	0 to 111	0 to 111	0 to 42	0 to 42	0 to 111	0 to 111	SE	Treatment, *P* <
Item								
Carcass characteristics								
Plant live wt., lb	258.9	262.5	260.3	258.4	262.4	262.8	2.53	0.15
HCW, lb	196.1	197.0	196.0	197.0	197.7	198.8	2.02	0.71
Yield,[3] %	75.76	75.14	75.33	76.26	75.34	75.72	0.417	0.40
Backfat,[4] in.	0.64[a]	0.66[a]	0.60[b]	0.63[ab]	0.66[a]	0.63[ab]	0.017	0.04
Loin depth,[4] in.	2.65	2.65	2.64	2.61	2.68	2.64	0.032	0.67
Lean,[4] %	57.01	56.76	57.62	57.06	56.79	57.04	0.234	0.11
Carcass performance								
HCW ADG,[5] lb	1.38	1.39	1.38	1.39	1.40	1.40	0.013	0.75
HCW F/G[6]	3.58[b]	3.70[a]	3.60[b]	3.56[b]	3.63[ab]	3.63[ab]	0.029	0.01
Economics, $/pig								
Feed cost	75.08[c]	78.05[a]	75.54[bc]	75.11[c]	77.47[ab]	77.50[ab]	0.918	0.01
Cost/lb gain	0.345[b]	0.352[a]	0.343[b]	0.347[ab]	0.348[ab]	0.352[a]	0.003	0.05
Carcass gain value[7]	162.26	163.38	163.01	162.29	164.45	164.02	1.950	0.93
IOFC[8]	87.18	85.42	87.47	87.18	86.97	86.61	1.365	0.93

[1] 1,196 pigs (PIC 337 × 1050; initial BW 56.7) were used in a 111-d finishing study with 6 treatments and 7 to 8 replications per treatment. Mintrex (Novus International, St. Charles, MO).

[2] Means within row with different superscripts differ, $P < 0.05$.

[3] Percentage yield calculated by dividing plant live weight by HCW.

[4] HCW used as covariate

[5] HCW ADG calculated using the following equation: (HCW - (initial wt. × 0.75))/111 d.

[6] HCW F/G calculated using the following equation: Overall ADFI/ HCW ADG.

[7] Carcass gain value calculated using a carcass value of $98.00/cwt and the following equation: ((ADG × 111 d + initial wt.) × yield × 0.98) - (initial wt. × 0.75 × 0.98).

[8] Income over feed cost = Carcass gain value – feed cost.