Kansas Agricultural Experiment Station Research Reports

Volume 1
Issue 7 *Swine Day*

Article 29

January 2015

Effects of Added Copper and Zinc on Growth Performance and Carcass Characteristics of Finishing Pigs Fed Diets with or without Ractopamine HCl

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Recommended Citation

Feldpausch, J. A.; Amachawadi, R. G.; Scott, H. M.; Tokach, M. D.; Dritz, S. S.; Woodworth, J. C.; Nagaraja, T. G.; Goodband, R. D.; and DeRouchey, J. M. (2015) "Effects of Added Copper and Zinc on Growth Performance and Carcass Characteristics of Finishing Pigs Fed Diets with or without Ractopamine HCl," *Kansas Agricultural Experiment Station Research Reports*: Vol. 1: Iss. 7. https://doi.org/10.4148/2378-5977.1134

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Abstract

A total of 480 pigs (PIC 327 × 1050; initially 107.4 lb) were used to determine the interactive effects of supplemental Cu, Zn, and Ractopamine HCl on finishing pig growth performance, carcass characteristics, and antimicrobial susceptibility of enteric bacteria. Dietary treatments were arranged in a 2 × 2 × 2 factorial with main effects of added copper sulfate ($CuSO_4$; 0 vs. 125 ppm Cu), added zinc oxide (ZnO; 0 vs. 150 ppm Zn), and Ractopamine HCl (0 vs. 10 ppm during the last 28 d prior to marketing; Paylean®; Elanco Animal Health, Greenfield, IN). All finishing diets were fed in four phases in meal form and contained 11 ppm Cu and 73 ppm Zn from the trace mineral premix. The study design was structured as a randomized complete block design and replicated with two finishing groups. Pigs were randomly allotted to pens upon entry into the finisher barn. Pens of seven (group 1) or eight (group 2) pigs were balanced on initial BW and randomly allotted to 1 of the 4 mineral treatment diets with two treatment replications per weight block and four weight blocks per finishing group. At 28 d prior to marketing, pens within each block and mineral treatment were randomly assigned to receive either 0 or 10 ppm Ractopamine HCl in addition to the mineral treatment. At the conclusion of the 90-d (group 1) or 83-d (group 2) finishing period, carcass characteristics were measured. Adding Cu or Zn alone resulted in numerical improvements in overall F/G and caloric efficiencies; however, the improvements were not additive (Cu × Zn, $P = 0.065$, 0.068, and 0.064 for F/G and caloric efficiency on a ME and NE basis, respectively). No significant improvements were observed in overall ADG or ADFI due to added Cu and/or Zn. In contrast, Ractopamine HCl improved ($P < 0.001$) overall ADG, F/G, and caloric efficiency, thereby increasing final BW by 3% with no change in ADFI.

Ractopamine HCl also increased ($P < 0.001$) HCW, percentage carcass yield, and HCW F/G. Adding Zn or Cu alone to diets containing Ractopamine HCl numerically improved percentage carcass yield and HCW F/G, but this effect was not present when the mineral was added to the control diet or when the minerals were fed in combination in the Ractopamine HCl diets (Cu × Zn × Ractopamine, $P = 0.011$ and 0.024 respectively). Regardless of HCW, pigs fed Ractopamine HCl had decreased ($P = 0.014$) backfat, increased ($P < 0.001$) loin depth, and percent fat-free lean. No effects of added minerals on these carcass traits were observed. In summary, the addition of 125 ppm Cu and/or 150 ppm Zn to diets containing Ractopamine HCl failed to improve finishing pig growth performance and carcass characteristics while 10 ppm Ractopamine HCl increased lean tissue deposition and improved feed and caloric efficiency.

Keywords

finishing pig, copper, zinc, Ractopamine

Cover Page Footnote

This project was funded through USDA-NIFA-AFRI Food Safety Challenge Program grant USDA NIFA 2013-68003-21257. Appreciation is also expressed to fellow graduate students for their assistance in conducting this study.

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Effects of Added Copper and Zinc on Growth Performance and Carcass Characteristics of Finishing Pigs Fed Diets with or without Ractopamine HCl[1]

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Summary

A total of 480 pigs (PIC 327 × 1050; initially 107.4 lb) were used to determine the interactive effects of supplemental Cu, Zn, and Ractopamine HCl on finishing pig growth performance, carcass characteristics, and antimicrobial susceptibility of enteric bacteria. Dietary treatments were arranged in a 2 × 2 × 2 factorial with main effects of added copper sulfate ($CuSO_4$; 0 vs. 125 ppm Cu), added zinc oxide (ZnO; 0 vs. 150 ppm Zn), and Ractopamine HCl (0 vs. 10 ppm during the last 28 d prior to marketing; Paylean®; Elanco Animal Health, Greenfield, IN). All finishing diets were fed in four phases in meal form and contained 11 ppm Cu and 73 ppm Zn from the trace mineral premix. The study design was structured as a randomized complete block design and replicated with two finishing groups. Pigs were randomly allotted to pens upon entry into the finisher barn. Pens of seven (group 1) or eight (group 2) pigs were balanced on initial BW and randomly allotted to 1 of the 4 mineral treatment diets with two treatment replications per weight block and four weight blocks per finishing group. At 28 d prior to marketing, pens within each block and mineral treatment were randomly assigned to receive either 0 or 10 ppm Ractopamine HCl in addition to the mineral treatment. At the conclusion of the 90-d (group 1) or 83-d (group 2) finishing period, carcass characteristics were measured. Adding Cu or Zn alone resulted in numerical improvements in overall F/G and caloric efficiencies; however, the improvements were not additive (Cu × Zn, P = 0.065, 0.068, and 0.064 for F/G and caloric efficiency on a ME and NE basis, respectively). No significant improvements were observed in overall ADG or ADFI due to added Cu and/or Zn. In contrast, Ractopamine HCl improved (P < 0.001) overall ADG, F/G, and caloric efficiency, thereby increasing final BW by 3% with no change in ADFI.

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Ractopamine HCl also increased ($P < 0.001$) HCW, percentage carcass yield, and HCW F/G. Adding Zn or Cu alone to diets containing Ractopamine HCl numerically improved percentage carcass yield and HCW F/G, but this effect was not present when the mineral was added to the control diet or when the minerals were fed in combination in the Ractopamine HCl diets (Cu × Zn × Ractopamine, $P = 0.011$ and 0.024 respectively). Regardless of HCW, pigs fed Ractopamine HCl had decreased ($P = 0.014$) backfat, increased ($P < 0.001$) loin depth, and percent fat-free lean. No effects of added minerals on these carcass traits were observed. In summary, the addition of 125 ppm Cu and/or 150 ppm Zn to diets containing Ractopamine HCl failed to improve finishing pig growth performance and carcass characteristics while 10 ppm Ractopamine HCl increased lean tissue deposition and improved feed and caloric efficiency.

Key words: finishing pig, copper, zinc, Ractopamine

Introduction

Ractopamine HCl (Paylean®; Elanco Animal Health, Greenfield, IN), a β-2-adrenergic agonist, is added to finishing pig diets to improve growth performance and carcass leanness. Current manufacturer feeding recommendations in conjunction with FDA regulations are to feed Paylean® to swine weighing more than 150 lb while providing a complete diet containing a minimum of 16% CP and inclusion of Ractopamine HCl at a level of 5 to 10 ppm for the last 45 to 90 lb of gain prior to slaughter. To maximize the gain, efficiency, and leanness responses in pigs consuming diets with Ractopamine HCl, considerable emphasis is placed on increasing the nutrient content of the diet. In particular, the concentration of protein and amino acids is typically increased via a 30% increase in lysine in a late finishing diet to support a greater rate of lean tissue deposition and maximize the potential response to Ractopamine HCl. In addition, limited research has been directed toward the effects of mineral supplementation on the response to Ractopamine HCl with some research proposing additional improvements in the response to Ractopamine HCl with supplemental Zn in the diet (Akey, 2011[4]; Patience et al., 2011[5]). However, the response has been mixed (Paulk et al., 2015[6]). Copper also has been shown to improve growth and feed intake of finishing pigs (Coble et al., 2014[7]).

Additionally, little research has been undertaken to determine the impact of these heavy metals and β-agonists on the ecology of antimicrobial-resistant bacteria in finishing pigs. Beta-agonists have a similar chemical structure to endogenous catecholamines. Catecholamines are known to be capable of affecting the growth, enteric colonization,

[4] Akey. 2011. Effects of Zinc Source and Level in Paylean Diets on Pig Performance and Carcass Characteristics. Akey Swine Newsletter.

[5] Patience, J. P. 2011. Impact of Zinc Source and Timing of Implementation on Grow-finish Performance, Carcass Composition, and Locomotion Score. IA St. Univ. Anim. Ind. Rep.

[6] Paulk, C. B., D. D. Burnett, M. D. Tokach, J. L. Nelssen, S. S. Dritz, R. D. Goodband, G. M. Hill, K. D. Haydon, and J. M. Gonzalez. 2015. Effect of added zinc in diets with Ractopamine hydrochloride on growth performance, carcass characteristics, and ileal mucosal inflammation mRNA expression of finishing pigs. J. Anim. Sci. 93:185-196.

[7] Coble K. F., J. M. DeRouchey, M. D. Tokach, S. S. Dritz, B. V. Lawrence, J. Escobar, J. C. Woodworth, R. D. Goodband, and N. Boettger. 2014. Effects of copper sources (copper sulfate and Mintrex Cu) on growthperformance, carcass characteristics, barn cleaning, and economics in finishing pigs. Swine Day 2014. Report of Progress 1110, pp. 155-163.

and possibly gene transfer of bacteria. Consequently, feeding Ractopamine HCl may possibly expedite the propagation of antibiotic-resistant bacteria.
This trial was conducted in collaboration with the Kansas State University College of Veterinary Medicine Department of Diagnostic Medicine/Pathology with the primary objective of determining the interactive effects of supplemental Cu, Zn, and Ractopamine HCl on finishing pig growth performance, carcass characteristics, antimicrobial susceptibility, and microbial ecology of enteric bacteria. The effects on growth performance and carcass characteristics only are discussed within this report.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol for this experiment. The study was conducted at the Kansas State University Swine Teaching and Research Center in Manhattan, KS. Pigs were housed in an environmentally controlled tunnel-ventilated barn and reared on completely slatted concrete flooring over deep pits for manure storage. Each pen was equipped with a 2-hole stainless steel dry self-feeder (Farmweld, Teutopolis, IL) and a cup waterer to provide pigs with ad libitum access to feed and water. Feed delivery to each individual pen was accomplished and recorded via a robotic feeding system (FeedPro; Feedlogic Corp., Wilmar, MN).

A total of 480 pigs (PIC 327 × 1050; initially 107.4 lb) from 2 finishing groups were used for this study. Prior to placement on experimental finisher diets, the pigs did not receive any chlortetracycline in their feed or water to avoid potential confounding study impacts due to disturbances to the intestinal microbiome. However, the pigs did receive dietary neomycin and oxytetracycline antibiotics immediately post-weaning. Individual pig treatments were recorded.

Dietary treatments were arranged in a 2 × 2 × 2 factorial with main effects of added copper sulfate ($CuSO_4$; 0 vs. 125 ppm Cu), added zinc oxide (ZnO; 0 vs. 150 ppm Zn) and Ractopamine HCl (0 vs. 10 ppm during the last 28 d prior to marketing; Paylean®; Elanco Animal Health, Greenfield, IN). The dietary treatments were as follows: (1) control, (2) control + 125 ppm Cu, (3) control + 150 ppm Zn, (4) control + 125 ppm Cu + 150 ppm Zn, (5) control + 10 ppm Ractopamine HCl during final 28 d only, (6) control + 125 ppm Cu + 10 ppm Ractopamine HCl during final 28 d only, (7) control + 150 ppm Zn + 10 ppm Ractopamine HCl during final 28 d only, and (8) control + 125 ppm Cu + 150 ppm Zn + 10 ppm Ractopamine HCl during final 28 d only.

All finishing diets were fed in meal form and contained a trace mineral premix that provided 73 ppm zinc and 11 ppm Cu to the diet (Table 1). The diets were formulated to be fed in 4 phases (80 to 125 lb, 125 to 175 lb, 175 to 220 lb, and 220 to 290 lb) during the finishing period and were prepared at the K-State O. H Kruse Feed Technology Innovation Center.

The finishing period of the first pig group spanned from January to April, and pigs in the second finishing group were housed in a different room from March to June. Upon entry into the finisher, pigs were randomly allotted to pens of either seven (group 1) or eight (group 2) pigs per pen. Pens contained 4 gilts and either 3 (group 1) or 4 (group

2) barrows each. Pen space was maintained at 10 ft^2/pig across both groups by adjusting pen size according to the number of animals per pen.

The study design was structured as a randomized complete block design with a split-plot and replicated over 2 finishing groups with 32 pens each. At the beginning of the study, 32 pens of pigs were arranged into four weight blocks per group based on similar pen initial average BW. Two pens per weight block were then randomly allotted to 1 of the 4 mineral treatment diets (negative control, +125 ppm Cu, +150 ppm Zn, or +125 ppm Cu with +150 ppm Zn) and balanced on initial pen average BW across blocks. At 28 d prior to marketing, pens within each block and mineral treatment diet were randomly assigned to receive either 0 or 10 ppm Ractopamine HCl in addition to their mineral treatment. Ractopamine HCl treatment assignments were balanced across blocks on current pen average BW at the time of allotment to Ractopamine HCl treatments. For the final 28 d of the finishing period, each weight block contained 1 pen for each of the eight diet treatments.

Feed samples from each batch were taken from feeders. Samples were pooled within each phase to form a composite diet sample that was subsequently analyzed for mineral levels (Table 2). Across both finishing groups, a composite sample of each of the 4 diets containing Paylean® was analyzed for Ractopamine HCl concentration (Table 2).

Pigs and feeders were weighed approximately every 3 wk to determine ADG, ADFI, F/G and both ME and NE caloric efficiency (kcal energy per lb diet × total diet intake per pen ÷ total pen weight gain) on a pen basis. Dietary ME and NE values were derived from feed ingredient energy values based on those in the NRC (2012[8]).

At the conclusion of the 90-d (group 1) or 83-d (group 2) experimental period, all pigs were individually weighed and tattooed with a unique identifier. Pigs were transported to a commercial harvesting facility (Triumph Foods LLC, St. Joseph, MO) and held in lairage overnight prior to processing and carcass data collection. Carcass characteristics measured at the plant included HCW immediately after evisceration, and backfat and loin depths via an optical probe.

Percent carcass yield was calculated by dividing individual HCW obtained at the packing plant by the corresponding individual final live weight obtained at the farm. An average percentage carcass yield for each pen was then calculated by averaging the observed yields of pigs for each pen. Pen average HCW was calculated by multiplying the pen average percent yield by the pen average final live weight. Percentage lean was calculated by dividing the standardized fat-free lean (SFFL; NPPC, 2000[9]) by individual HCW according to the following equation:

$$\text{SFFL, \%} = 100 \times [15.31 - (331.277 \times \text{backfat depth, in.}) + (3.813 \times \text{loin muscle depth, in.}) + (0.51 \times \text{HCW, lb})] \div \text{HCW, lb}$$

[8] NRC. 2012. Nutrient Requirements of Swine. 11th ed. Natl. Acad. Press, Washington, D.C.

[9] NPPC. 2000. Procedures for Estimating Pork Carcass Composition. Natl. Pork Prod. Council, Des Moines, IA.

Initial carcass weight on study d 0 was assumed to equal 75% of the initial pen average live BW, thus HCW gain on a pen basis was calculated using the formula: final pen average HCW, lb – (0.75 × initial pen average BW on d 0). Subsequently, HCW ADG was calculated by dividing the average individual HCW gain of each pen by the number of study days. Similarly, HCW F/G was calculated for each pen by dividing the average daily feed intake per pig (overall ADFI) by average daily HCW gain.

Growth and carcass data were analyzed as a randomized complete block design with a 2 × 2 × 2 treatment structure and replicated with two groups. Pen was the experimental unit. The MIXED procedure in SAS (v9.3, SAS Institute Inc., Cary, NC) was used to model diet treatment as a fixed effect with random effects of group and initial weight block nested within group. The main effects of Cu, Zn, and Ractopamine HCl, as well as their interactions, were tested using *a priori* orthogonal CONTRAST statements. The Kenward Roger method was used to compute denominator degrees of freedom for tests of fixed effects. Hot carcass weight was used as a covariate in the analyses of backfat, loin depth, and percentage lean. Results were considered statistically significant at $P \leq 0.05$; results with P-values > 0.05 and ≤ 0.10 were considered marginally significant.

Results and Discussion

No significant Cu × Zn × Ractopamine HCl (Rac) interactions were observed in the growth performance responses measured in this study. There was no difference among pig BW on d 0, except the pigs that would receive Ractopamine HCl later in the finishing period were initially slightly heavier ($P = 0.012$), (Table 3). Prior to the final 28 d of the finishing period, no effects of Cu or Zn on ADG or ADFI were observed. However, a significant interaction (Cu × Zn, $P < 0.05$) between Cu and Zn was observed for feed and caloric efficiency; pigs fed diets with either added Cu or Zn alone had numeric improvement in efficiency, but no improvement when both minerals were added together. On d 62 (d 55 for group 2), no difference was observed in the BW of pigs receiving 125 ppm added Cu and/or 150 ppm added Zn, nor was there a difference in the BW of pigs that would begin to receive 10 ppm Ractopamine HCl for the next 28 d compared to the BW of pigs that would not receive Ractopamine HCl.

On the final day of the study (d 90 and d 83 for groups 1 and 2, respectively), pigs receiving Ractopamine HCl for the previous 28 d showed heavier ($P < 0.001$) BW than pigs that had not received Ractopamine HCl (Table 3). The heavier final BW of pigs receiving Ractopamine HCl was the result of greater ($P < 0.001$) ADG in the final 28 d before harvest, which consequently improved ($P < 0.001$) their F/G and caloric efficiency on both a ME and NE basis compared to that of pigs not fed Ractopamine HCl. In contrast, no effect of added Cu and/or Zn was observed on the ADG or F/G of pigs during the final 28 d of the finishing period. No effects of the minerals or Ractopamine HCl on ADFI in the final 28 d of the finishing period were observed, aside from a tendency for pigs fed Zn and Ractopamine HCl in combination to have less (Zn × Rac, $P = 0.084$) ADFI than would have been expected considering added Zn numerically increased ADFI and Ractopamine HCl numerically decreased ADFI when each was fed not in combination with the other.

No effects of added Cu, Zn, and/or Ractopamine HCl were observed on overall ADFI (Table 3). Overall ADG, F/G, and caloric efficiency on both a ME and NE basis were improved ($P < 0.001$) due to feeding Ractopamine HCl in the last 28 d of the finishing period. Conversely, there were no main effects of added Cu or Zn on overall growth performance. Feeding Cu or Zn alone numerically improved F/G and overall caloric efficiency, but had no influence on efficiencies when both were added to the diet (Cu × Zn, $P = 0.065$, 0.068, and 0.064 for F/G, ME, and NE, respectively).

The added Cu and Zn had minimal effects on growth performance and congruently had minimal effects on carcass characteristics. No differences in pen average HCW or HCW ADG due to the added minerals were observed. However, the finishing growth performance improvements induced by feeding Ractopamine HCl during the last 28 d prior to marketing resulted in significantly increased ($P < 0.001$) HCW and HCW ADG (Table 5).

Feeding Ractopamine HCl also increased ($P < 0.001$) percentage carcass yield, and the magnitude of the increase was numerically greater when either Cu or Zn was added to the diet containing Ractopamine HCl; however, the minerals did not provide any carcass yield benefit when both were fed together with Ractopamine HCl (Cu × Zn × Rac, $P = 0.011$; Table 6). No main effects of Cu or Zn on percentage carcass yield were observed. Efficiency of carcass gain followed a similar pattern to yield, with no main effect due to added Cu or Zn and with a Cu × Zn × Rac interaction ($P = 0.024$). Again, Ractopamine HCl improved ($P < 0.001$) HCW F/G with further numeric improvement when either Cu or Zn was added with Ractopamine HCl, but no improvement due to the minerals was observed when both Cu and Zn were included in diets together with Ractopamine HCl.

When compared on a common HCW basis, pigs fed Ractopamine HCl had less ($P = 0.014$) backfat, greater ($P < 0.001$) loin depth, and percentage of fat-free lean compared to pigs not fed Ractopamine HCl. In contrast, no differences in backfat, loin depth, or fat-free lean were observed due to added Cu or Zn.

In summary, the addition of 125 ppm Cu and/or 150 ppm Zn failed to significantly improve late finishing or overall growth performance and efficiency, or carcass characteristics. Improved rate of gain in response to Cu and Zn supplementation is often observed due to increased feed intake. The pigs in this study entered the finisher phase at relatively heavy weights and had high levels of feed intake; moreover, this study was conducted in a research setting conducive to high growth performance. These factors possibly precluded any potential for mineral supplementation to improve the growth responses of these pigs.

Ractopamine HCl fed at 10 ppm during the final 28 d of the finishing period significantly improved late finishing growth rate, final BW, HCW, and percentage carcass yield without increasing feed intake. Consequently, Ractopamine HCl improved caloric and feed efficiencies on both a body weight and carcass gain basis. Furthermore, Ractopamine HCl increased lean tissue deposition as evidenced by increased loin depth and less backfat.

In closing, supplementation of 125 ppm Cu or 150 ppm Zn above basal premix TM levels in diets containing Ractopamine HCl did not improve finishing pig growth performance of pigs with high feed intake levels as observed in this study. Inclusion of 10 ppm Ractopamine HCl in the diet for 28 d prior to marketing dramatically improves carcass leanness as well as the feed and caloric efficiencies of pigs.

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

Item	Phase 1	Phase 2	Phase 3	Phase 4[2]
Ingredient, %				
Corn[3]	72.54	78.02	80.66	76.55
Soybean meal (47.7% CP)	25.00	19.70	17.20	21.20
Limestone	0.90	0.90	0.90	0.90
Monocalcium phosphate	0.60	0.50	0.40	0.40
Sodium chloride	0.35	0.35	0.35	0.35
L-lysine HCl	0.28	0.25	0.23	0.25
DL-methionine	0.05	0.02	0.00	0.04
L-threonine	0.08	0.05	0.05	0.10
Trace mineral premix	0.10	0.10	0.10	0.10
Vitamin premix	0.10	0.10	0.10	0.10
Phytase[4]	0.02	0.02	0.02	0.02
$CuSO_4$, ZnO, Ractopamine HCl additives[5]	0 – 0.07	0 – 0.07	0 – 0.07	0 – 0.27
Total	100.00	100.00	100.00	100.00
Calculated analysis				
Standardized ileal digestible (SID) amino acids, %				
Lys	1.01	0.86	0.78	0.90
Ile:lys	64	64	66	65
Leuc:lys	139	149	157	147
Met:lys	30	29	29	31
Met & cys:lys	56	57	57	58
Thr:lys	62	62	64	67
Trp:lys	18.3	18.1	18.2	18.3
Val:lys	70	73	75	72
Total Lys, %	1.14	0.97	0.89	1.02
CP, %	18.3	16.1	15.1	16.8
ME, kcal/lb	1,498	1,502	1,504	1,503
NE, kcal/lb[6]	1,122	1,137	1,145	1,134
SID Lys:ME, g/Mcal	3.06	2.60	2.35	2.71
SID Lys:NE, g/Mcal	4.08	3.43	3.09	3.59
Ca, %	0.55	0.51	0.49	0.50
P, %	0.50	0.45	0.42	0.44
Available P, %	0.30	0.27	0.24	0.25

[1] All diets were fed in meal form and formulated to be fed in 4 phases from 80 to 125, 125 to 175, 175 to 220, and 220 to 290 lb BW.
[2] Phase 4 diets were fed for the final 28 d prior to slaughter.
[3] Corn levels represent control level prior to addition of treatment diet ingredients, which replaced an equivalent amount of corn in respective experimental diets.
[4] HiPhos 2700 (DSM Nutritional Products, Inc., Parsippany, NJ) provided 184.3 phytase units (FTU)/lb and an estimated release of 0.10% available P.
[5] The 8 dietary treatments contained $CuSO_4$ at either 0 or 1.0 lb/ton, ZnO at either 0 or 0.42 lb/ton, and Paylean® (Elanco Animal Health, IN) in the final 28 d of the finishing period at either 0 or 4 lb/ton.

Table 2. Analyzed dietary concentrations (as-fed basis)[1]

	Analyzed Dietary Composition[2]						Analyzed Concentrations[3]		
Diets	DM, %	CP, %	Fat, %	Ash, %	Ca, %	P, %	Cu, ppm[4]	Zn, ppm[5]	Ractopamine HCl, g/ton[6]
Phase 1									
Control	87.70	20.6	2.85	5.26	0.74	0.58	25	117	---
Cu	87.70	20.4	2.97	5.20	0.74	0.57	196	116	---
Zn	87.65	20.3	2.77	5.15	0.76	0.60	26	298	---
Cu+Zn	87.70	20.2	3.00	5.44	0.77	0.57	187	299	---
Phase 2									
Control	87.75	18.0	3.22	5.10	0.80	0.53	24	140	---
Cu	87.65	18.3	3.26	5.43	0.85	0.55	179	126	---
Zn	87.45	18.2	3.28	5.38	0.71	0.52	44	279	---
Cu+Zn	87.70	17.7	3.63	5.07	0.71	0.52	182	307	---
Phase 3									
Control	87.40	16.9	3.23	4.36	0.67	0.48	25	138	---
Cu	87.55	17.0	3.37	4.88	0.72	0.50	181	133	---
Zn	86.35	17.1	3.28	4.75	0.75	0.52	49	276	---
Cu+Zn	81.85	16.8	3.26	5.13	0.77	0.50	175	309	---
Phase 4									
Control	75.30	19.1	3.71	5.14	0.71	0.52	39	129	---
Cu	88.15	18.8	3.45	4.95	0.74	0.51	182	106	---
Zn	87.75	18.8	3.57	5.19	0.78	0.52	31	320	---
Cu+Zn	87.65	18.7	3.97	4.86	0.74	0.53	191	297	---
Control+Rac	87.55	18.7	3.57	5.05	0.75	0.51	29	127	8.4
Cu+Rac	87.50	18.6	3.67	5.12	0.77	0.52	197	138	8.8
Zn+Rac	88.55	19.1	3.48	5.29	0.76	0.54	33	250	7.3
Cu+Zn+Rac	87.85	18.8	4.00	5.20	0.74	0.52	200	340	8.4

[1] Phase 1, 2, 3, and 4 diets fed in meal form from approximately 105 to 150, 150 to 200, 200 to 240, and 240 to 300 lb BW, respectively.
[2] Analysis performed by Cumberland Valley Analytical Services (Hagerstown, MD) on pooled diet samples within each dietary phase; results represent the average of both finishing groups.
[3] Mineral analysis was performed by Cumberland Valley Analytical Services (Hagerstown, MD) using ICP spectrometry; means represent the average of 2 to 4 duplicate feed samples within each dietary phase and each finishing group which were subsequently analyzed in duplicate.
[4] Cu from $CuSO_4$ was added at 125 ppm to diets containing 11 ppm Cu from the TM premix.
[5] Zn from ZnO was added at 150 ppm to diets containing 73 ppm Zn from the TM premix.
[6] Analysis was performed by Covance Laboratories (Greenfield, IN) on a composite sample of each of the 4 diets containing Ractopamine HCl across both finishing groups.

Table 3. Effects of added Cu, Zn, and Ractopamine HCl on carcass characteristics of finishing pigs[1]

[2]Added Cu, 125 ppm:	-	+	-	+	-	+	-	+	
[3]Added Zn, 150 ppm:	-	-	+	+	-	-	+	+	
[4]Ractopamine HCl, 9 g/ton:	-	-	-	-	+	+	+	+	SEM
BW, lb									
d 0	106.3	107.1	107.0	107.1	108.8	107.7	107.6	107.8	1.26
d 62[5]	239.3	239.8	240.6	240.0	239.6	239.6	240.2	240.2	5.72
d 90[6]	296.5	295.0	297.6	295.6	305.2	304.5	305.7	304.8	9.46
d 0 to 62[5]									
ADG, lb	2.27	2.27	2.28	2.28	2.24	2.26	2.27	2.27	0.054
ADFI, lb	5.78	5.76	5.75	5.79	5.80	5.76	5.74	5.85	0.084
F/G	2.55	2.54	2.53	2.55	2.59	2.55	2.53	2.58	0.082
d 62 to 90[5,6]									
ADG, lb	1.95	1.97	2.03	1.99	2.34	2.33	2.35	2.31	0.124
ADFI, lb	6.13	6.14	6.35	6.18	6.31	6.15	6.18	6.08	0.222
F/G	3.16	3.12	3.14	3.11	2.70	2.64	2.63	2.64	0.069
Overall (d 0 to 90)[6]									
ADG, lb	2.17	2.17	2.19	2.18	2.27	2.28	2.30	2.28	0.023
ADFI, lb	5.89	5.88	5.94	5.92	5.96	5.88	5.88	5.92	0.116
F/G	2.72	2.71	2.71	2.72	2.63	2.58	2.56	2.60	0.041
Caloric efficiency[7]									
d 0 to 62[5]									
ME	3,823	3,808	3,799	3,825	3,897	3,829	3,796	3,872	122.1
NE	2,892	2,879	2,873	2,892	2,947	2,894	2,871	2,928	91.1
d 62 to 90[5,6]									
ME	4,755	4,683	4,719	4,676	4,055	3,964	3,941	3,961	104.0
NE	3,588	3,536	3,560	3,527	3,060	2,991	2,974	2,989	78.5
d 0 to 90[6]									
ME	4,081	4,063	4,070	4,076	3,945	3,872	3,843	3,898	61.0
NE	3,084	3,070	3,075	3,080	2,982	2,925	2,904	2,946	45.4

[1] A total of 480 pigs (PIC 327 × 1050; initially 107.4 lb) were used in a 90-d (group 1) or 83-d (group 2) study with 7 (group 1) or 8 (group 2) pigs per pen and 8 replications per treatment.
[2] Cu from $CuSO_4$ was added to treatment diets at either 0 or 125 ppm. All diets contained 11 ppm Cu from the trace mineral premix.
[3] Zn from ZnO was added to treatment diets at either 0 or 150 ppm. All diets contained 73 ppm Zn from the trace mineral premix.
[4] Ractopamine HCl (Paylean®; Elanco Animal Health, Greenfield, IN) was added to treatment diets at either 0 or 10 ppm during the final 28 d prior to marketing.
[5] d 62 (group 1) corresponds to d 55 of group 2 and marks the beginning of the 28 d period of Ractopamine HCl treatments in addition to the mineral combination treatments.
[6] d 90 (group 1) corresponds to d 83 of group 2 and is the final day of the study.
[7] Caloric efficiency is expressed as kcal per lb of live weight gain.

Table 4. Statistical analysis of added Cu, Zn, and Ractopamine HCl on finishing pig growth performance[1]

	Probability, $P <$						
	Cu	Zn	Ractopamine HCl	Cu × Zn	Cu × Rac	Zn × Rac	Cu × Zn × Rac
BW, lb							
d 0	0.908	0.797	0.012	0.729	0.269	0.287	0.231
d 62[2]	0.982	0.516	0.994	0.801	0.963	0.917	0.781
d 90[3]	0.392	0.676	<0.001	0.920	0.737	0.883	0.959
d 0 to 62[2]							
ADG, lb	0.829	0.478	0.448	0.704	0.823	0.686	0.733
ADFI, lb	0.685	0.810	0.711	0.283	0.838	0.958	0.636
F/G	0.768	0.498	0.122	0.041	0.983	0.575	0.249
d 62 to 90[2,3]							
ADG, lb	0.565	0.540	<0.001	0.440	0.738	0.440	0.828
ADFI, lb	0.125	0.834	0.773	0.635	0.735	0.084	0.396
F/G	0.369	0.407	<0.001	0.466	0.824	0.704	0.669
Overall (d 0 to 90[3])							
ADG, lb	0.818	0.379	<0.001	0.456	0.993	0.872	0.833
ADFI, lb	0.694	0.778	0.920	0.595	0.966	0.435	0.480
F/G	0.801	0.390	<0.001	0.065	0.940	0.348	0.205
Caloric efficiency[4]							
d 0 to 62[2]							
ME	0.831	0.476	0.122	0.045	0.983	0.575	0.249
NE	0.874	0.483	0.124	0.039	0.984	0.576	0.250
d 62 to 90[2,3]							
ME	0.338	0.408	<0.001	0.467	0.819	0.705	0.670
NE	0.339	0.396	<0.001	0.480	0.835	0.721	0.654
d 0 to 90[3]							
ME	0.722	0.377	<0.001	0.068	0.942	0.349	0.205
NE	0.693	0.374	<0.001	0.064	0.933	0.359	0.201

[1] A total of 480 pigs (PIC 327 × 1050; initially 107.4 lb) were used in a 90-d (group 1) or 83-d (group 2) study with 7 (group 1) or 8 (group 2) pigs per pen and 8 replications per treatment.
[2] d 62 (group 1) corresponds to d 55 of group 2 and marks the beginning of the 28 d period of Ractopamine HCl treatments in addition to the mineral combination treatments.
[3] d 90 (group 1) corresponds to d 83 of group 2 and is the final day of the study.
[4] Caloric efficiency is expressed as kcal per lb of live weight gain.

Table 5. Effects of added Cu, Zn, and Ractopamine HCl on finishing pig growth performance[1]

[2]Added Cu, 125 ppm:	-	+	-	+	-	+	-	+	
[3]Added Zn, 150 ppm:	-	-	+	+	-	-	+	+	
[4]Ractopamine HCl, 9 g/ton:	-	-	-	-	+	+	+	+	SEM
Carcass characteristics									
HCW, lb	218.8	217.0	219.1	218.3	227.8	229.0	228.9	227.2	9.53
Carcass yield, %	73.8	73.5	73.6	73.8	74.6	75.2	74.9	74.5	0.86
Backfat, in[5]	0.76	0.76	0.74	0.76	0.72	0.71	0.71	0.70	0.035
Loin depth, in[5]	2.58	2.55	2.55	2.58	2.67	2.72	2.70	2.71	0.088
Fat-free lean, %[5,6]	51.5	51.7	51.6	51.5	52.6	52.8	52.6	53.1	0.30
Carcass performance									
HCW ADG, lb	1.61	1.58	1.60	1.59	1.69	1.71	1.71	1.69	0.043
HCW F/G	3.67	3.73	3.71	3.71	3.54	3.44	3.43	3.50	0.041

[1] A total of 480 pigs (PIC 327 × 1050; initially 107.4 lb) were used in a 90-d (group 1) or 83-d (group 2) study, with 7 (group 1) or 8 (group 2) pigs per pen, and 8 replications per treatment.
[2] Cu from $CuSO_4$ was added to treatment diets at either 0 or 125 ppm. All diets contained 11 ppm Cu from the trace mineral premix.
[3] Zn from ZnO was added to treatment diets at either 0 or 150 ppm. All diets contained 73 ppm Zn from the trace mineral premix.
[4] Ractopamine HCl (Paylean®; Elanco Animal Health, Greenfield, IN) was added to treatment diets at either 0 or 10 ppm during the final 28 d prior to marketing.
[5] Adjusted for individual HCW using HCW as a covariate.
[6] SFFL (NPPC. 2000. Procedures for Estimating Pork Carcass Composition. Natl. Pork Prod. Council, Des Moines, IA.) ÷ HCW.

Table 6. Statistical analysis of added Cu, Zn, and Ractopamine HCl on carcass characteristics of finishing pigs[1]

	Probability, P <						
	Cu	Zn	Ractopamine HCl	Cu × Zn	Cu × Rac	Zn × Rac	Cu × Zn × Rac
Carcass characteristics							
HCW, lb	0.494	0.829	<0.001	0.675	0.630	0.644	0.391
Carcass yield, %	0.710	0.638	<0.001	0.360	0.655	0.380	0.011
Backfat, in[2]	0.809	0.505	0.014	0.721	0.376	0.790	0.734
Loin depth, in[2]	0.465	0.826	<0.001	0.874	0.455	0.848	0.387
Fat-free lean, %[2,3]	0.334	0.829	<0.001	0.911	0.550	0.589	0.587
Carcass performance							
HCW ADG, lb	0.517	0.776	<0.001	0.582	0.419	0.855	0.197
HCW F/G	0.743	0.939	<0.001	0.230	0.322	0.501	0.024

[1] A total of 480 pigs (PIC 327 × 1050; initially 107.4 lb) were used in a 90-d (group 1) or 83-d (group 2) study, with 7 (group 1) or 8 (group 2) pigs per pen, and 8 replications per treatment.
[2] Adjusted for individual HCW using HCW as a covariate.
[3] SFFL (NPPC. 2000. Procedures for Estimating Pork Carcass Composition. Natl. Pork Prod. Council, Des Moines, IA.) ÷ HCW.