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Evaluating the Effects of Replacing Feed Grade Antibiotics with Yeast, Cinnamon, or Zinc Oxide and Copper Sulfate on Nursery Pig Performance

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Abstract

A total of 288 weaned pigs (Line 200 × 400; DNA, Columbus, NE; initially 11.8 lb) were used in a 42-d study to compare the effects of feeding antibiotic alternatives (pharmacological trace minerals, copper and zinc, yeast, or essential oils), alone or in combination, on nursery pig performance in replacement to a common antimicrobial agent (carbadox, Mecadox®, Phibro Animal Health, Teaneck, NJ). Pigs were allotted to 1 of 9 dietary treatments in pens of 4 at weaning in a randomized complete block design with 8 replications per treatment. Dietary treatments were arranged with a negative control diet with no medication or other feed additive, a positive control with added carbadox, or 7 treatments including added copper sulfate (CuSO₄; 0 vs. 125 ppm Cu) and added zinc oxide (ZnO; 0 vs. 3,000 ppm Zn from d 0 to 7 and 2,000 ppm Zn from d 7 to 28), essential oils from XTRACT 6930 (*Capsicum oleoresin* 2%, carvacrol 5%, cinnamaldehyde 3%, Pancosma North America, Drumondville, Quebec, Canada) at 2 lb/ton, Safmannan A (Yeast cell walls, Lesaffre Yeast Corporation, Milwaukee, WI) at 0.5 lb/ton, and Actisaf HR (yeast cells, Lesaffre Yeast Corporation, Milwaukee, WI) at 1.5 lb/ton. These supplements were fed alone or in combination. From d 0 to 7 experimental diets were a pelleted ration; and fed in a meal form from d 7 to 28, followed by a common corn-soybean meal-based diet without any antimicrobial, pharmacological trace minerals, essential oils, or yeast from d 28 to 42. Essential oils and yeast had no significant ($P > 0.05$) effect on ADG. Feeding carbadox or pharmacological trace minerals (Cu and Zn) improved ADG ($P < 0.05$) of nursery pigs compared to the non-medicated control diet. Carryover effects from any of these dietary treatments on subsequent growth performance were not significantly different ($P > 0.05$). The use of pharmacological trace minerals Cu and Zn alone or in conjunction with either yeast or essential oil allows for competitive ADG and F/G with an antimicrobial agent, like carbadox. In summary, under the conditions of this experiment, pigs fed the combination of zinc and copper had similar growth performance to those fed carbadox ($P > 0.05$).

Keywords

alternative, antibiotic, carbadox, copper, essential oil, nursery pig, pharmacological trace minerals, yeast, zinc

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Summary

A total of 288 weaned pigs (Line 200 × 400; DNA, Columbus, NE; initially 11.8 lb) were used in a 42-d study to compare the effects of feeding antibiotic alternatives (pharmacological trace minerals, copper and zinc, yeast, or essential oils), alone or in combination, on nursery pig performance in replacement to a common antimicrobial agent (carbadox, Mecadox[®], Phibro Animal Health, Teaneck, NJ). Pigs were allotted to 1 of 9 dietary treatments in pens of 4 at weaning in a randomized complete block design with 8 replications per treatment. Dietary treatments were arranged with a negative control diet with no medication or other feed additive, a positive control with added carbadox, or 7 treatments including added copper sulfate (CuSO_4 ; 0 vs. 125 ppm Cu) and added zinc oxide (ZnO ; 0 vs. 3,000 ppm Zn from d 0 to 7 and 2,000 ppm Zn from d 7 to 28), essential oils from XTRACT 6930 (*Capsicum oleoresin* 2%, carvacrol 5%, cinnamaldehyde 3%, Pancosma North America, Drummondville, Quebec, Canada) at 2 lb/ton, Safmannan A (Yeast cell walls, Lesaffre Yeast Corporation, Milwaukee, WI) at 0.5 lb/ton, and Actisaf HR (yeast cells, Lesaffre Yeast Corporation, Milwaukee, WI) at 1.5 lb/ton. These supplements were fed alone or in combination. From d 0 to 7 experimental diets were a pelleted ration; and fed in a meal form from d 7 to 28, followed by a common corn-soybean meal-based diet without any antimicrobial, pharmacological trace minerals, essential oils, or yeast from d 28 to 42. Essential oils and yeast had no significant ($P > 0.05$) effect on ADG. Feeding carbadox or pharmacological trace minerals (Cu and Zn) improved ADG ($P < 0.05$) of nursery pigs compared to the non-medicated control diet. Carryover effects from any of these dietary treatments on subsequent growth performance were not significantly different ($P > 0.05$). The use of pharmacological trace minerals Cu and Zn alone or in conjunction with either yeast or essential oil allows for competitive ADG and F/G with an antimicrobial agent, like carbadox. In summary, under the conditions of this experiment, pigs fed the combination of zinc and copper had similar growth performance to those fed carbadox ($P > 0.05$).

Key words: alternative, antibiotic, carbadox, copper, essential oil, nursery pig, pharmacological trace minerals, yeast, zinc

Introduction

Since feed-grade antibiotics became available to the swine industry in the mid-1950s, research has shown that dietary inclusions of these antimicrobial agents improve growth rate and feed efficiency of nursery pigs. Recently, considerable discussion has been focused on the potential of antimicrobial resistance and its potential ties to feeding antimicrobial agents to swine. The push to eliminate use of antimicrobial agents for growth promotion is a primary objective of the swine industry. Many swine producers have shared their concern with possible production losses caused by the elimination of antimicrobial agents' use in swine diets, particularly in the nursery phase. Thus, we conducted this experiment because of three critical points. First, as consumers rightfully become more concerned, major retailers and meat producing companies are taking a proactive stance on antibiotic-free pork. Secondly, several classes of feed additives have been postulated to be able to replace antimicrobial agents in nursery diets. These include, but are not exclusive to the following classes of compounds; phytochemicals (essential oils), yeast and yeast cell walls, pharmacological levels of trace minerals, and combinations of these additives. Lastly, because of initial research by Feldpausch we hypothesized that feeding a combination of these feed additives would provide a direct comparison to a popular feed antimicrobial, carbadox, on nursery pig performance. Therefore, the objective of this experiment was to compare the growth performance of nursery pigs fed diets containing carbadox and different dietary supplements that are commonly fed as antibiotic alternatives (pharmacological levels of Zn and Cu, essential oils, and yeast), alone or in combination with each other.

Procedures

This trial was conducted as a follow-up study to Feldpausch with the primary objective of evaluating the potential impact of different types of feed additives used as antibiotic alternatives in replacing antimicrobial agents. This report describes the growth performance of nursery pigs and the effects of antibiotic alternatives on growth performance.

The protocol for this experiment was approved by the Kansas State University Institutional Animal Care and Use Committee. The study was conducted at the K-State Swine Teaching and Research farm nursery in Manhattan, KS.

A total of 288 nursery pigs (Line 200 × 400; DNA, Columbus, NE; initially 11.8 lb BW) were used in a 42-d study with 4 pigs per pen and 8 replications per treatment. Each pen had one 4-hole self-feeder, metal tri-bar flooring, and a nipple waterer to provide ad libitum access to feed and water. Pigs were weaned at approximately 21 d of age. Allotment divided the pigs into heavy and light blocks based on initial BW. Pigs were grouped to achieve equal average pen weights. Based on d 0 weights, pigs were randomly allotted to 1 of 9 dietary treatments in blocks by barn location. The 9 dietary treatments consisted of a corn-soybean meal-based diet and were arranged with treatments of pharmacological trace minerals with added Cu from copper sulfate (CuSO_4 ; 0 vs. 125 ppm Cu) and added Zn from zinc oxide (ZnO ; 0 vs. 3,000 ppm Zn from d 0 to 7 and 2,000 ppm Zn from d 7 to 28), essential oil blend from XTRACT 6930 (*Capsicum oleoresin* 2%, carvacrol 5%, cinnamaldehyde 3%, Pancosma North America, Drummondville, Quebec, Canada) from d 0 to 28 at 2 lb/ton, Safmannan A (Yeast cell walls, Lesaffre Yeast Corporation, Milwaukee, WI) from d 0 to 28 at 0.5 lb/ton, Actisaf

HR (yeast cells, Lesaffre Yeast Corporation, Milwaukee, WI) from d 0 to 28 at 1.5 lb/ton, and carbadox (Mecadox®, Phibro Animal Health, Teaneck, NJ) from d 0 to 28 at 50 g/ton. Equivalent amounts of corn were replaced with treatment diet to form the experimental treatments.

The experimental diets were fed from d 0 to 28. Phase 1 experimental diets were a pelleted ration fed from d 0 to 7 (Table 1). All diets had an acidifier (Kem-Gest, Kemin, Des Moines, IA) at 0.4 lb/ton added to diets during the Phase 1 period. Phase 2 experimental diets were fed in meal form, from d 7 to 28 (Table 2). From d 28 to 42, pigs were fed a common Phase 3 meal feed diet, (Table 3) until the completion of the trial on d 42. No medication, yeast, essential oils, or pharmacological levels of Cu or Zn were fed to all pigs, during this period, to evaluate any carryover effects from the treatment diets.

All diets were prepared at the Kansas State University O.H. Kruse Feed Technology Innovation Center, Manhattan, KS. Diet samples were collected periodically throughout the study and pooled samples of each diet were analyzed. Average daily gain, ADFI, and F/G were determined by weighing pigs and measuring feed disappearance on d 7, 14, 21, 28, 35, and 42.

Growth data were analyzed as a randomized complete block design using PROC GLIMMIX in SAS with pen as the experimental unit. The model included the main effect of Cu from CuSO₄, Zn from ZnO, essential oils from XTRACT 6930, yeast from Safmannan A and Actisaf HR and carbadox, and weight block as a random effect. The Kenward-Roger adjustment was used for denominator degrees of freedom. Differences between treatments were determined by using the p-value difference option. Least squares means were considered significantly different at $P \leq 0.05$ and a trend at $P \leq 0.10$.

Results and Discussion

During Phases 1 and 2 of the experiment (d 0 to 7 and 7 to 28), pigs fed carbadox proved to have increased ADG ($P < 0.05$) compared to pigs fed a non-medicated control diet. This resulted in greater d-28 BW ($P < 0.05$). When carbadox was removed and pigs were fed a common diet from d 28 to 42 there was no significant difference in ADG ($P > 0.05$) compared to pigs fed a non-medicated control diet, ending in no effect overall from d 0 to 42 by carbadox. Carbadox did not improve feed efficiency during the entire experimental trial ($P=0.08$).

During the experimental treatment period, yeast alone or essential oils alone did not improve ($P > 0.05$) growth performance compared to those fed a non-medicated control diet. However, pigs fed pharmacological trace minerals (Cu and Zn) alone had similar growth performance to those fed carbadox during d 0 to 28 ($P > 0.05$). Additionally, pigs fed pharmacological levels of trace minerals in combination with yeast, essential oils or in combination with both yeast and essential oils also showed comparable ($P > 0.05$) growth performance to those pigs fed carbadox during Phases 1 and 2. Throughout the common diet phase from d 28 to 42, there were no differences in ADG, ADFI, and F/G for any dietary treatments. Overall, d 0 to 42, ADG, ADFI, and F/G of pigs fed pharmacological trace minerals alone had equal ($P > 0.05$) growth per-

formance with those fed carbadox. However, pigs fed pharmacological levels of Zn and Cu outperformed control pigs during this period. These trace minerals alone increased d-42 weights (49.4 lb.), compared to carbadox-fed pigs with d-42 weights (47.1 lb). The overall positive effects of combining Zn and Cu resulted in an average of a 5 lb per pig increase in weight at d-42 post-weaning compared to pigs fed control diets.

Typically, nursery pigs are fed a diet containing an antimicrobial agent. We fed carbadox to nursery pigs and found a consistent improvement in growth performance compared to pigs fed a non-medicated diet. However, feeding antibiotics to pigs is under increased scrutiny. Thus, our industry must research dietary ingredients that could be used as antibiotic alternatives.

Pharmacological levels of Cu and Zn are typically added during different dietary phases of the nursery period. Typically, Zn is added to diets fed to nursery pigs during early nursery period (d 0 to 14) and Cu during the later period (d to 14 to 42). Zinc oxide (ZnO) is the most common form of added dietary Zn, while Cu most commonly comes from copper sulfate. In our current experiment, we added zinc oxide and copper sulfate in combination to diets for nursery pigs. Pigs fed the Zn and Cu combination had equal to or even greater performance to pigs fed carbadox. In addition, pigs fed the zinc oxide and copper sulfate combination were over 5 pounds heavier ($P < 0.0081$) at the end of the nursery phase (d-42) compared to pigs fed a non-medicated control diet.

Finally, we investigated the effects of two popular ingredients that have been postulated to enhance nursery pig growth performance, as possible antibiotic replacements. When feeding yeast or essential oils alone or in combination, we found no consistent effects on nursery pig growth performance. Finally, we fed yeast or essential oils in combination with the mineral-supplemented treatment (CuSO_4 and ZnO). No further benefit in growth performance was seen, beyond the benefits of adding supplemental Cu and Zn, was found by adding yeast or essential oil. The benefits in growth performance was nearly entirely due to Zn and Cu supplementation during the feeding trial on nursery pigs.

In summary, we are optimistic that under the conditions of this experiment that a mineral combination of zinc oxide and copper sulfate could be an effective replacement for carbadox in diets fed to nursery pigs.

Table 1. Composition of Phase 1 diets¹

Ingredient, %	A ²	B ³	C ⁴	D ⁵	E ⁶	F ⁷	G ⁸	H ⁹	I ¹⁰
Corn	37.35	36.35	37.25	36.90	37.30	36.80	36.85	37.20	36.75
Soybean meal	19.85	19.85	19.85	19.85	19.85	19.85	19.85	19.85	19.85
Blood meal	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Blood plasma	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Corn DDGs, > 6 & < 9% Oil	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Fish meal	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Milk, whey powder	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
Choice white grease	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Monocalcium	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Limestone, ground	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Sodium chloride	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
L-Lys-HCL	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
DL-Met	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-Thr	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Choline chloride 60%	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Kemgest	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Mecadox	---	1.00	---	---	---	---	---	---	---
Biosaf-HR	---	---	0.08	---	---	0.08	---	0.08	0.08
Safman	---	---	0.03	---	---	0.03	---	0.03	0.03
Copper sulfate (125 ppm)	---	---	---	0.05	---	0.05	0.05	---	0.05
Zinc oxide	---	---	---	0.42	---	0.42	0.42	---	0.42
XTRACT 6930	---	---	---	---	0.05	---	0.05	0.05	0.05

¹All Phase I diets were pelleted.

²No antibiotic-negative control (with organic acid Phase 1 only, Phase 2, and Phase 3, no acid).

³Positive control-Mecadox 50 g/ton.

⁴N.C. + yeast (1.5 lb/ton Biosaf-HR; 0.5 lb/ton Safman).

⁵N.C. + Zinc oxide (Phase 1; 3,000 ppm d 0 to 7; Phase 2; 2,000 ppm d 7 to 28) and copper sulfate (125 ppm).

⁶N.C. + XTRACT 6930 (2.0 lb/ton).

⁷N.C. + ZnO and CuSO₄ + yeast.

⁸N.C. + ZnO and CuSO₄ + XTRACT 6930.

⁹N.C. + yeast + XTRACT 6930.

¹⁰N.C. + ZnO and CuSO₄ + yeast + XTRACT 6930.

Table 2. Composition of Phase 2 diets¹

Ingredient, %	A ²	B ³	C ⁴	D ⁵	E ⁶	F ⁷	G ⁸	H ⁹	I ¹⁰
Corn	54.71	53.71	54.61	54.38	54.66	54.28	54.33	54.56	54.23
Soybean meal	29.55	29.55	29.55	29.55	29.55	29.55	29.55	29.55	29.55
Blood meal	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Fish meal	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Milk, whey powder	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Monocalcium	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Limestone, ground	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Sodium chloride	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
L-Lys-HCL	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
DL-Met	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
L-Thr	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
HiPhos 2700	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Mecadox	---	1.00	---	---	---	---	---	---	---
Biosaf-HR	---	---	0.08	---	---	0.08	---	0.08	0.08
Safman	---	---	0.03	---	---	0.03	---	0.03	0.03
Copper sulfate (125 ppm)	---	---	---	0.05	---	0.05	0.05	---	0.05
Zinc oxide	---	---	---	0.28	---	0.28	0.28	---	0.28
XTRACT 6930	---	---	---	---	0.05	---	0.05	0.05	0.05

¹All Phase II rations were meal diets.

²No antibiotic-negative control (with organic acid Phase 1 only, Phase 2 and Phase 3, no acid).

³Positive control-Mecadox 50 g/ton.

⁴N.C. + yeast (1.5 lb/ton Biosaf-HR; 0.5 lb/ton Safman).

⁵N.C. + Zinc oxide (Phase 1; 3,000 ppm d 0 to 7; Phase 2; 2,000 ppm d 7 to 28) and copper sulfate (125 ppm).

⁶N.C. + XTRACT 6930 (2.0 lb/ton).

⁷N.C. + ZnO and CuSO₄ + yeast.

⁸N.C. + ZnO and CuSO₄ + XTRACT 6930.

⁹N.C. + Yeast + XTRACT 6930.

¹⁰N.C. + ZnO and CuSO₄ + yeast + XTRACT 6930.

Table 3. Composition of Phase 3 Diets

Ingredient, %	Phase 3 ¹
Corn	63.83
Soybean meal	32.85
Monocalcium	1.00
Limestone, ground	1.03
Sodium chloride	0.35
L-Lys-HCL	0.30
DL-Met	0.12
L-Thr	0.12
Trace mineral premix	0.15
Vitamin premix	0.25
HiPhos 2700	0.02

¹All treatments were fed a common corn-soybean meal, meal feed from d 28 to 42.

Table 4. Effects of pharmacological trace minerals, essential oils, yeast, and carbadox on nursery pig growth performance^{1,2}

Yeast/yeast cell walls ³ :	-	-	+	-	-	+	-	+	+	
Added Cu/Zn ⁴ :	-	-	-	+	-	+	+	-	+	
Essential oil blend ⁵ :	-	-	-	-	+	-	+	+	+	
Carbadox ⁶ :	-	+	-	-	-	-	-	-	-	SEM
BW, lb										
d 0	11.8	11.8	11.8	11.9	11.8	11.8	11.8	11.8	11.8	0.6006
d 7	12.8	13.6	12.9	13.8	13.0	14.0	13.7	13.2	13.5	0.6815
d 14	14.8	16.7	14.6	16.9	15.2	16.9	17.0	15.6	16.3	0.8406
d 28	27.6	30.5	27.6	32.5	28.1	30.8	31.0	28.8	30.3	1.3048
d 42	44.3	47.1	46.0	49.4	46.6	48.9	48.8	45.8	47.9	2.0132
d 0 to 7										
ADG, lb	0.15	0.26	0.15	0.27	0.16	0.33	0.27	0.21	0.25	0.0286
ADFI, lb	0.60	0.60	0.63	0.55	0.64	0.55	0.60	0.56	0.57	0.2384
F/G	3.99	2.30	4.23	2.03	3.98	1.67	2.24	2.69	2.28	0.3543
d 7 to 14										
ADG, lb	0.28	0.45	0.25	0.43	0.33	0.41	0.47	0.33	0.40	0.03672
ADFI, lb	0.60	0.64	0.52	0.66	0.53	0.67	0.58	0.57	0.62	0.03725
F/G	2.14	1.43	2.07	1.54	1.62	1.63	1.22	1.71	1.56	0.5007
d 0 to 14										
ADG, lb	0.22	0.35	0.20	0.35	0.24	0.37	0.37	0.27	0.32	0.02736
ADFI, lb	0.60	0.62	0.58	0.60	0.58	0.61	0.59	0.57	0.59	0.02154
F/G	2.73	1.76	2.89	1.73	2.42	1.64	1.60	2.10	1.86	0.2633
d 7 to 28										
ADG, lb	0.70	0.81	0.70	0.84	0.72	0.80	0.82	0.74	0.80	0.03606
ADFI, lb	1.26	1.40	1.19	1.43	1.19	1.41	1.34	1.26	1.38	0.05133
F/G	1.79	1.73	1.70	1.70	1.65	1.78	1.63	1.69	1.72	0.06045
d 28 to 42										
ADG, lb	1.19	1.18	1.32	1.28	1.32	1.29	1.27	1.21	1.26	0.07348
ADFI, lb	1.91	1.95	1.97	1.92	1.89	1.92	1.94	1.94	1.92	0.05828
F/G	1.61	1.65	1.50	1.49	1.43	1.49	1.53	1.60	1.53	0.09207
d 0 to 42										
ADG, lb	0.77	0.84	0.81	0.89	0.83	0.88	0.88	0.81	0.86	0.03884
ADFI, lb	1.37	1.45	1.36	1.45	1.33	1.44	1.42	1.37	1.42	0.03988
F/G	1.77	1.73	1.67	1.62	1.60	1.63	1.61	1.69	1.65	0.05839

¹A total of 288 nursery pigs (DNA Line 200 × 400, initially 11.8 lb BW) were used in a 42-day study with 4 pigs per pen and 8 replications per treatment.

²Experimental treatment diets were fed from d 0 to d 28. All treatments were fed a common diet from d 28 to d 42.

³Yeast and yeast cell walls were added as (1.5 lb/ton of Biosaf-HR; 0.5 lb/ton Safmannan).

⁴Pharmacological trace minerals; Cu from CuSO₄ was added to treatment diets at 0 vs. 125 ppm, and Zn from ZnO at 3,000 ppm from d 0 to 7 and 2,000 ppm from d 7 to 28.

⁵Essential oils were added as XTRACT 6930 at 2 lb/ton (*Capsicum oleoresin* 2%, carvacrol 5%, cinnamaldehyde 3%, hydrogenated rapeseed oil 90%) from d 0 to 28.

⁶Mecadox[®] was added at either 0 or 50 g/ton from d 0 to 28.

⁷Caloric efficiency is expressed as kcal per pound of live weight gain.

Table 5. Statistical analysis of dietary alternatives, pharmacological trace minerals Cu and Zn, essential oils, yeast, and carbadox on nursery pig growth performance¹

	Probability, P <												
	Control × Mecadox	Control × Cu/Zn	Mecadox × Yeast	Mecadox × Cu/Zn	Mecadox × Essential Oils (EO)	Mecadox × Cu/Zn + Yeast	Mecadox × Cu/Zn + EO	Mecadox × Yeast + EO	Mecadox × Yeast + EO	Mecadox × Cu/Zn + Yeast	Cu/Zn × Cu/Zn + Yeast	Cu/Zn × Cu/Zn + EO	Cu/Zn × Cu/Zn + Yeast + EO
BW, lb													
d 0	0.8468	0.0971	0.9230	0.2340	0.7280	0.8468	0.6993	0.9230	0.8468	0.1450	0.1572	0.1450	
d 7	0.0073	0.0004	0.0100	0.3145	0.0218	0.0821	0.6387	0.1916	0.8325	0.4532	0.5893	0.2248	
d 14	0.0002	< 0.0001	< 0.0001	0.7643	0.0030	0.6862	0.5151	0.0192	0.3838	0.9169	0.7249	0.2434	
d 28	0.0158	0.0001	0.0138	0.0947	0.0407	0.8279	0.6903	0.1524	0.8636	0.1440	0.1991	0.0663	
d 42	0.1345	0.0081	0.5569	0.2246	0.7986	0.3312	0.3490	0.5078	0.6501	0.8054	0.7780	0.4435	
d 0 to 7 ²													
ADG, lb	0.0083	0.0023	0.0098	0.6538	0.0206	0.0767	0.6771	0.1921	0.8980	0.1816	0.9744	0.5645	
ADFI, lb	0.5443	0.1602	0.0726	0.4195	0.2432	0.1488	0.7157	0.7461	0.7461	0.5179	0.2432	0.6274	
F/G	0.0018	0.0024	0.1524	0.9207	0.3497	0.8246	0.8246	0.4820	0.7219	0.7482	0.7482	0.7976	
d 7 to 14													
ADG, lb	0.0008	0.0028	< 0.0001	0.6874	0.0099	0.3918	0.5734	0.0161	0.2736	0.6484	0.3358	0.4861	
ADFI, lb	0.5710	0.9247	0.1399	0.6367	0.1887	0.7587	0.3343	0.0689	0.3962	0.8686	0.6200	0.7055	
F/G	0.0367	0.0117	0.0005	0.6437	0.1536	0.7791	0.3394	0.3907	0.9047	0.8552	0.6200	0.7315	

continued

Table 5. Statistical analysis of dietary alternatives, pharmacological trace minerals Cu and Zn, essential oils, yeast, and carbadox on nursery pig growth performance¹

	Probability, P <											
	Control × Mecadox	Control × Cu/Zn	Mecadox × Yeast	Mecadox × Cu/Zn	Mecadox × Essential Oils (EO)	Mecadox × Cu/Zn + Yeast	Mecadox × Cu/Zn + EO	Mecadox × Yeast + EO	Mecadox × Yeast + EO	Mecadox × Cu/Zn × Cu/Zn × Yeast	Mecadox × Cu/Zn × Cu/Zn × EO	Mecadox × Cu/Zn × Yeast + EO
d 0 to 14												
ADG, lb	0.0002	0.0003	< 0.0001	0.9711	0.0028	0.6905	0.6125	0.0164	0.3863	0.6641	0.5874	0.4062
ADFI, lb	0.3828	0.3828	0.0188	1.0000	0.0580	0.6304	0.3161	0.1190	0.5406	0.6304	0.3161	0.5406
F/G	< 0.0001	< 0.0001	0.0003	0.8556	0.0215	0.5830	0.3294	0.1838	0.7654	0.7132	0.4265	0.6311
d 7 to 28 ³												
ADG, lb	0.0266	0.0036	0.0189	0.4510	0.0574	0.8012	0.6954	0.1494	0.8667	0.3159	0.7161	0.3575
ADFI, lb	0.0299	0.0019	0.0036	0.3061	0.0034	0.8560	0.6006	0.0476	0.6870	0.3986	0.1245	0.1560
F/G	0.3802	0.4379	0.8258	0.9182	0.4913	0.7030	0.3647	0.8258	0.8258	0.7805	0.3135	0.7469
d 28 to 42												
ADG, lb	0.9303	0.2641	0.1192	0.2291	0.1034	0.1976	0.2960	0.7047	0.3753	0.9303	0.8726	0.7484
ADFI, lb	0.2860	0.7126	0.0304	0.4826	0.0054	0.6878	1.0000	0.4621	0.6393	0.2714	0.4826	0.2437
F/G	0.4137	0.1173	0.5156	0.4462	0.7111	0.0898	0.1998	0.8223	0.2785	0.3417	0.5980	0.7448
d 0 to 42												
ADG, lb	0.1629	0.0095	0.5932	0.2084	0.8000	0.3265	0.3404	0.5550	0.6127	0.7784	0.7569	0.4483
ADFI, lb	0.3007	0.0278	0.2756	0.2298	0.5188	0.9552	0.6133	0.3273	0.6331	0.2520	0.0905	0.0958
F/G	0.0813	0.0238	0.9105	0.5854	0.9360	0.3061	0.1858	0.9872	0.4609	0.6301	0.4324	0.8471

¹A total of 288 nursery pigs (DNA Line 200 × 400; initially 11.8 lb BW) were used in a 42-d study with 4 pigs per pen and 8 replications per treatment.

²Phase 1 Experimental treatment diets were fed from d 0 to 7. Supplements were added to diets as seen on Table 1.

³Phase 2 Experimental treatment diets were fed from d 7 to 28. Supplements were added to diets as seen on Table 2.