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SWINE INDUSTRY DAY
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Swine Day 2014

Report of Progress 1110

K-STATE
Research and Extension

Kansas State University Agricultural Experiment Station and Cooperative Extension Service

SWINE DAY 2014

Contents

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Foreword

It is with great pleasure that we present the 2014 Swine Industry Day Report of Progress. This report contains updates and summaries of applied and basic research conducted at Kansas State University during the past year. We hope that the information will be of benefit as we attempt to meet the needs of the Kansas swine industry.

2014 Swine Day Report of Progress Editors
Bob Goodband, Mike Tokach, Steve Dritz, Joel DeRouchey, and Jason Woodworth

Standard Abbreviations

ADG	=	average daily gain
ADF	=	acid detergent fiber
ADFI	=	average daily feed intake
AI	=	artificial insemination
avg.	=	average
bu	=	bushel
BW	=	body weight
cm	=	centimeter(s)
CP	=	crude protein
CV	=	coefficient of variation
cwt	=	100 lb
d	=	day(s)
DE	=	digestible energy
DM	=	dry matter
DMI	=	dry matter intake
F/G	=	feed efficiency
ft	=	foot(feet)
ft^2	=	square foot(feet)
g	=	gram(s)
µg	=	microgram(s), .001 mg
gal	=	gallon(s)
GE	=	gross energy
h	=	hour(s)
HCW	=	hot carcass weight
in.	=	inch(es)
IU	=	international unit(s)
kg	=	kilogram(s)
kcal	=	kilocalorie(s)
kWh	=	kilowatt hour(s)
lb	=	pound(s)
Mcal	=	megacalorie(s)
ME	=	metabolizable energy
mEq	=	milliequivalent(s)
min	=	minute(s)
mg	=	milligram(s)
mL	=	cc (cubic centimeters)
mm	=	millimeter(s)
mo	=	month(s)
MUFA	=	monounsaturated fatty acid
N	=	nitrogen
NE	=	net energy
NDF	=	neutral detergent fiber
NFE	=	nitrogen-free extract
ng	=	nanogram(s), .001 Fg
no.	=	number
NRC	=	National Research Council
ppb	=	parts per billion
ppm	=	parts per million
psi	=	pounds per sq. in.
PUFA	=	polyunsaturated fatty acid
SD	=	standard deviation
sec	=	second(s)
SE	=	standard error
SEM	=	standard error of the mean
SEW	=	segregated early weaning
SFA	=	saturated fatty acid
UFA	=	unsaturated fatty acid
wk	=	week(s)
wt	=	weight(s)
yr	=	year(s)

K-State Vitamin and Trace Mineral Premixes

Diets listed in this report contain the following vitamin and trace mineral premixes unless otherwise specified.

- Trace mineral premix: Each pound of premix contains 12 g Mn, 50 g Fe, 50 g Zn, 5 g Cu, 90 mg I, and 90 mg Se.
- Vitamin premix: Each pound of premix contains 2,000,000 IU vitamin A, 300,000 IU vitamin D_3, 8,000 IU vitamin E, 800 mg menadione, 1,500 mg riboflavin, 5,000 mg pantothenic acid, 9,000 mg niacin, and 7 mg vitamin B_{12}.
- Sow add pack: Each pound of premix contains 100,000 mg choline, 40 mg biotin, 300 mg folic acid, and 900 mg pyridoxine.

Note

Some of the research reported here was carried out under special FDA clearances that apply only to investigational uses at approved research institutions. Materials that require FDA clearances may be used in the field only at the levels and for the use specified in that clearance.

Biological Variability and Chances of Error

Variability among individual animals in an experiment leads to problems in interpreting the results. Animals on treatment X may have higher average daily gains than those on treatment Y, but variability within treatments may indicate that the differences in production between X and Y were not the result of the treatment alone. Statistical analysis allows us to calculate the probability that such differences are from treatment rather than from chance.

In some of the articles herein, you will see the notation "$P < 0.05$." That means the probability of the differences resulting from chance is less than 5%. If two averages are said to be "significantly different," the probability is less than 5% that the difference is from chance, or the probability exceeds 95% that the difference resulted from the treatments applied.

Some papers report correlations or measures of the relationship between traits. The relationship may be positive (both traits tend to get larger or smaller together) or negative (as one trait gets larger, the other gets smaller). A perfect correlation is one (+1 or -1). If there is no relationship, the correlation is zero.

In other papers, you may see an average given as 2.5 ± 0.1. The 2.5 is the average; 0.1 is the "standard error." The standard error is calculated to be 68% certain that the real average (with unlimited number of animals) would fall within one standard error from the average, in this case between 2.4 and 2.6.

Many animals per treatment, replicating treatments several times, and using uniform animals increase the probability of finding real differences when they exist. Statistical analysis allows more valid interpretation of the results, regardless of the number of animals. In all the research reported herein, statistical analyses are included to increase the confidence you can place in the results.

Effects of Dietary Zinc Oxide and Chlortetracycline on Nursery Pig Growth Performance[1]

J.A. Feldpausch, J.A. DeJong, M.D. Tokach, S.S. Dritz[2], J.C. Woodworth, R.G. Amachawadi[2], H.M. Scott[2], J.L. Nelssen, and R.D. Goodband

Summary

A total of 240 weaned pigs (PIC 1050; initially 13.4 lb) were used in a 47-d study to compare the effects of added Zn from zinc oxide (ZnO), alone or in combination with a low or high dose of chlortetracycline (CTC), on nursery pig performance. Pigs were allotted to pens at weaning (d 0) and fed a common starter diet with no antimicrobial for 5 d before the start of the experiment. On d 5, pens of 5 pigs were allotted to 1 of 6 dietary treatments in a randomized complete block design with 8 replications per treatment. Dietary treatments were arranged in a 2 × 3 factorial with main effects of added ZnO (0 vs. 2,500 ppm of Zn) and CTC (0, 50, or 400 g/ton). Pigs were fed experimental diets from d 5 to 26 after weaning followed by a common corn-soybean meal–based diet without antimicrobial from d 26 to 47. Pigs on the 50 g/ton treatment received CTC continuously from d 5 to 26; however, to comply with FDA guidelines, CTC was removed on d 15 from the diets of pigs fed 400 g/ton CTC, then added again from d 16 to 26. All diets contained 110 ppm of Zn from ZnO in the trace mineral premix. No ZnO × CTC interactions were observed. Pigs fed added ZnO had increased ($P = 0.001$) ADG, ADFI, and ending BW during the treatment period but increased F/G ($P = 0.03$) from d 26 to 47 when a common diet was fed. Pigs fed CTC had increased (linear, $P < 0.05$) ADG, ADFI, and ending BW during the treatment period as well as a tendency (quadratic, $P = 0.08$) for improved F/G. Overall (d 5 to 47), pigs fed added ZnO had increased ($P < 0.05$) ADG and ADFI. Overall, pigs fed CTC tended to have increased (linear, $P = 0.06$) ADG and ADFI, but F/G tended (quadratic, $P = 0.07$) to decrease then increase as CTC increased. In summary, when ZnO or CTC were added to the diets, increased ADG and ADFI were observed, but additional carryover benefits were not evident after these feed additives were removed from the diets. The benefits of added Zn from ZnO and CTC are additive and could be included together in diets to get the maximum benefit in growth performance of weaned pigs.

Key words: growth, nursery pig, chlortetracycline, zinc

Introduction

It is well established that feeding pharmacological levels of Zn from zinc oxide (ZnO) consistently improves the growth rate of nursery pigs despite having mixed effects on feed intake and efficiency. Since feed-grade antibiotics became available in the 1950s,

[1] Appreciation is expressed to the National Pork Board for financial support as well as to fellow graduate students for their assistance in conducting this study.

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

research has also demonstrated that chlortetracycline (CTC) improves both the growth rate and the feed efficiency of nursery pigs. Although no study has directly examined the effects of concurrent inclusion of both pharmacological Zn and CTC concentrations in nursery pig diets, previous research suggests that the growth benefits are additive. Therefore, the objective of this experiment was to compare the performance of nursery pigs fed diets containing pharmacological levels of Zn, alone or in combination with high or low doses of chlortetracycline.

Procedures

This trial was conducted in collaboration with Kansas State University College of Veterinary Medicine Department of Diagnostic Medicine/Pathology with the primary objective of evaluating the potential association of high levels of dietary Zn supplementation and dietary sub-therapeutic or therapeutic CTC on the prevalence of methicillin resistant *Staphylococcus aureus* (MRSA) in pigs. This report describes the growth performance of these same pigs; the influence on MRSA will be reported elsewhere.

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 Segregated Early Weaning Facility in Manhattan, KS.

A total of 240 nursery pigs (PIC 1050; initially 13.4 lb BW) were used in a 47-d study with 5 pigs per pen and 8 replications per treatment. Each pen had metal tri-bar flooring, one 4-hole self-feeder, and a cup waterer to provide *ad libitum* access to feed and water. Pigs were weaned at approximately 21 d of age (study d 0) and allotted to pens based on initial BW to achieve equal average pen weights across all pens. For the first 5 d after weaning, pigs were fed a common pelleted starter diet that contained neither antimicrobial nor added Zn above that contained in the trace mineral premix (Table 1). On d 5, pens of pigs were weighed and allotted to 1 of 6 dietary treatments in a randomized complete block design with location within barn serving as a blocking factor as adjacent pens alternated among the treatment groups to facilitate equal bacteria exposure. The 6 dietary treatments consisted of a corn-soybean meal–based diet and were arranged in a 2 × 3 factorial with main effects of added Zn from ZnO (0 vs. 2,500 ppm of added Zn) and CTC (0, 50, or 400 g/ton). The ZnO and CTC were substituted for an equivalent amount of corn to form the experimental treatments.

The experimental diets were fed from d 5 to 26. Food and Drug Administration regulations prohibit the continuous feeding of therapeutic levels of CTC longer than 14 d.[3] Thus, on study d 15, the feeders from pens assigned to the 400 g/ton CTC diets were emptied and pigs were fed the control diet with or without the 2,500 ppm of added Zn. The normal treatment diet containing CTC at 400 g/ton was then re-added to the feeders on d 16 and fed for the remainder of the 21-d period. From d 26 to 47, a common corn-soybean meal–based diet with no added ZnO and no CTC was fed to all pigs to evaluate any carryover effects from the treatment diets.

All diets were prepared at the K-State O.H. Kruse Feed Technology Innovation Center and contained 110 ppm of Zn from the trace mineral premix. Diet samples

[3] Code of Federal Regulations. Title 21; Volume 6; Sec. 558.128. Accessed at: http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?fr=558.128 on August 14, 2014.

were collected periodically throughout the study, and pooled samples of each diet were submitted to Ward Laboratories, Inc. (Kearney, NE) for near-infrared reflectance (NIR) spectrometry analysis of Cu and Zn (Table 2). As determined by analysis, the Phase 1 common diet contained 166 ppm Zn and 29 ppm Cu, whereas the Phase 3 common diet contained 160 ppm Zn and 21 ppm Cu. Average daily gain, ADFI, and F/G were determined by weighing pigs and measuring feed disappearance on d 5, 26, and 47.

Growth data were analyzed as a randomized complete block design using the PROC MIXED procedure of SAS (v9.3, SAS Institute Inc., Cary, NC) with pen as the experimental unit and barn location as a blocking factor. The main effects of ZnO and CTC, as well as their interactions, were tested. Within the CTC treatments, linear and quadratic contrasts were determined. Differences between treatments were determined by using least squares means with results considered significant at $P \leq 0.05$ and considered a trend at $P \leq 0.10$.

Results and Discussion

No ZnO × CTC interactions were observed for any response criteria in any period (Table 3). Growth rates of pigs did not differ during the first 5 d when the common starter diet was fed. During the d 5 to 26 treatment period, pigs fed added Zn had increased ($P \leq 0.001$) ADG, ADFI, and BW on d 26. Similarly, increasing CTC increased ($P < 0.02$) ADG, ADFI, and BW on d 26. Although ZnO had no effect on F/G during the period when treatments were fed from d 5 to 26, increasing CTC level had a tendency to improve (quadratic, $P = 0.08$) F/G and caloric efficiency with pigs fed CTC at 50 g/ton having the lowest F/G.

From d 26 to 47 when the common diet was fed, there were no effects on growth rate or feed intake of pigs that had previously been fed ZnO or CTC in their diets; however, pigs previously fed pharmacological Zn had a significant ($P = 0.04$) but small increase in F/G. Overall, across both the 21-d treatment period and the subsequent 21-d common period (d 5 to 47), added Zn from ZnO increased ($P < 0.05$) ADG and ADFI but had no effect on feed efficiency. Added CTC tended to increase (linear, $P = 0.06$) ADG and ADFI from d 5 to 47. Feed efficiency and caloric efficiency of pigs fed CTC tended to improve (quadratic, $P = 0.08$) as 50 g of CTC was added to the diet, with no further improvement at the 400 g/ton level.

In summary, added Zn from ZnO and CTC increased ADG and ADFI but had a minimal effect on feed efficiency. This study illustrates the value of feeding pharmacological concentrations of Zn and other antimicrobials to newly weaned pigs to promote growth. However, neither ZnO nor CTC had a beneficial effect on subsequent nursery pig performance after ZnO and CTC were removed from the diets. Furthermore, our results agree with previous research findings with the data collectively suggesting that the benefits of feeding CTC and heavy metal micronutrients such as added Zn are additive for nursery pigs.

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

	Phase 1	Phase 2	Phase 3
Ingredient, %			
Corn	37.54	54.65	63.71
Soybean meal (47.7% CP)	19.86	29.50	32.86
Spray-dried blood cells	1.25	1.25	---
Spray-dried animal plasma	4.00	---	---
Corn DDGS[2], 6–9% oil	5.00	---	---
Select menhaden fish meal	1.25	1.25	---
Spray-dried whey	25.00	10.00	---
Choice white grease	3.00	---	---
Monocalcium phosphate	0.90	0.80	1.00
Limestone	1.00	1.10	1.03
Salt	0.30	0.30	0.35
L-lysine HCL	0.225	0.300	0.300
DL-methionine	0.150	0.175	0.115
L-threonine	0.085	0.150	0.115
Trace mineral premix	0.150	0.150	0.150
Vitamin premix	0.250	0.250	0.250
Choline chloride, 60%	0.035	---	---
Phytase[3]	---	0.125	0.125
Zinc oxide and CTC-50 additives[4]	---	0 to 0.747	---
Total	100.00	100.00	100.00

continued

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

	Phase 1	Phase 2	Phase 3
Calculated analysis			
Standardized ileal digestible (SID) amino acids, %			
Lysine	1.40	1.35	1.22
Isoleucine:lysine	56	58	63
Leucine:lysine	128	125	129
Methionine:lysine	32	35	33
Met & Cys:lysine	57	58	57
Threonine:lysine	63	64	63
Tryptophan:lysine	19	18	19
Valine:lysine	71	69	69
Total lysine, %	1.57	1.50	1.37
CP, %	22.2	22.1	21.4
ME, kcal/lb	1,574	1,491	1,483
NE, kcal/lb[5]	1,179	1,100	1,092
SID lysine:ME, g/Mcal	4.0	4.1	3.7
Ca, %	0.85	0.80	0.70
P, %	0.73	0.63	0.61
Available P, %	0.51	0.47	0.41

[1] Common Phase 1 diet was fed from d 0 to 5 after weaning, experimental Phase 2 diets were fed from d 5 to 26, and the common Phase 3 diet was fed from d 26 to 47. All diets contained 110 ppm of Zn from the trace mineral premix.
[2] Dried distillers grains with solubles.
[3] Phytase 600 (Phyzyme; Danisco Animal Nutrition, St Louis, MO), providing 340.5 phytase units (FTU)/lb and an estimated release of 0.12% available P.
[4] Experimental diets contained added ZnO at 0 or 0.347% to provide 0 or 2,500 ppm added Zn, respectively, and CTC-50 at 0, 0.050, or 0.400% to provide 0, 50, or 400 g/ton CTC, respectively. Addition of ZnO and CTC-50 ingredients replaced equivalent amounts of corn in the Phase 2 experimental diets.
[5] NE values for ingredients were derived from NRC (2012).

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

	Phase 2 treatment diets					
Zinc oxide, ppm:	0	0	0	2,500	2,500	2,500
Chlortetracycline, g/ton:	0	50	400	0	50	400
Analyzed composition						
Zinc, ppm	148	317	186	2,918	2,946	2,823
Copper, ppm	53	24	22	23	20	27

[1] Analysis was performed by Ward Laboratories, Inc. (Kearney, NE) on pooled diet samples.
[2] Experimental Phase 2 diets were fed from d 5 to 26, whereas a Phase 1 common diet (166 ppm Zn and 29 ppm Cu as per analysis) was fed to all pigs from d 0 to 5 and a Phase 3 common diet (160 ppm Zn and 21 ppm Cu as per analysis) was fed to all pigs from d 26 to 47.

Table 3. Effects of zinc oxide and chlortetracycline on nursery pig growth performance[1,2]

								Probability, *P* <				
ZnO, ppm:	0			2500				ZnO x CTC			CTC	
CTC, g/ton:	0	50	400	0	50	400	SEM	Linear	Quadratic	ZnO	Linear	Quadratic
BW, lb												
d 5	14.2	14.2	14.2	14.2	14.2	14.2	0.17	0.923	0.974	0.981	0.751	0.912
d 15	19.9	20.5	20.3	21.0	21.2	21.0	0.26	0.652	0.303	0.0001	0.857	0.119
d 26	30.7	31.9	32.1	32.6	32.6	33.6	0.45	0.986	0.175	0.0002	0.011	0.251
d 47	63.7	65.7	65.3	65.4	65.8	66.2	0.94	0.952	0.409	0.240	0.387	0.239
d 5 to 26												
ADG, lb	0.78	0.83	0.85	0.88	0.88	0.92	0.018	0.894	0.121	<.0001	0.002	0.208
ADFI, lb	1.11	1.13	1.16	1.21	1.20	1.26	0.026	0.826	0.399	<.0001	0.017	0.914
F/G	1.43	1.36	1.37	1.38	1.37	1.37	0.024	0.612	0.317	0.515	0.321	0.084
d 26 to 47												
ADG, lb	1.57	1.61	1.58	1.56	1.58	1.62	0.033	0.262	0.648	0.978	0.449	0.405
ADFI, lb	2.53	2.56	2.58	2.57	2.59	2.67	0.054	0.500	0.845	0.273	0.155	0.757
F/G	1.61	1.59	1.64	1.65	1.64	1.65	0.020	0.404	0.682	0.039	0.154	0.322
d 5 to 47												
ADG, lb	1.18	1.22	1.22	1.22	1.23	1.27	0.020	0.416	0.322	0.045	0.062	0.244
ADFI, lb	1.82	1.85	1.87	1.89	1.89	1.96	0.035	0.555	0.665	0.022	0.058	0.830
F/G	1.55	1.51	1.54	1.55	1.54	1.55	0.015	0.736	0.360	0.29	0.639	0.083
Caloric efficiency[3]												
d 5 to 26												
ME	2,125	2,026	2,033	2,057	2,028	2,023	35.5	0.611	0.315	0.359	0.207	0.083
NE	1,568	1,495	1,500	1,517	1,496	1,492	26.2	0.613	0.315	0.350	0.200	0.083
d 5 to 47												
ME	2,298	2,244	2,288	2,300	2,283	2,293	22.9	0.732	0.360	0.364	0.754	0.083
NE	1,693	1,653	1,685	1,695	1,682	1,689	16.9	0.730	0.361	0.368	0.762	0.083

[1] A total of 240 nursery pigs (PIC 1050, initially 21 d of age and 13.4 lb BW) were used in a 47-d study with 5 pigs per pen and 8 pens per treatment.
[2] Experimental treatment diets were fed from d 5 to d 26, and a common diet was fed to all pigs from d 26 to 47.
[3] Caloric efficiency is expressed as kcal per pound of live weight gain.

Comparative Effects of Dietary Copper, Zinc, Essential Oils, and Chlortetracycline on Nursery Pig Growth Performance[1]

J.A. Feldpausch, J.A. DeJong, M.D. Tokach, S.S. Dritz[2], J.C. Woodworth, R.G. Amachawadi[2], H. M. Scott[2], J.L. Nelssen, and R.D. Goodband

Summary

A total of 350 weaned pigs (PIC 1050; initially 13.3 lb) were used in a 47-d study to compare the effects of feeding antibiotic alternatives (copper, zinc, and essential oils), alone or in combination, on nursery pig performance. Pigs were allotted to pens at weaning (d 0) and fed a common starter diet with no antimicrobial for 5 d before the start of the experiment. On d 5, pens of 5 pigs were allotted to 1 of 10 dietary treatments in a randomized complete block design with 7 replications per treatment. Dietary treatments were arranged in a 2 × 2 × 2 + 2 factorial with main effects of added copper sulfate ($CuSO_4$; 0 vs. 125 ppm Cu), added zinc oxide (ZnO; none vs. 3,000 ppm Zn from d 5 to 12 and 2,000 ppm Zn from d 12 to 33), and Regano EX (0 vs. 45 g/ton essential oils blend; Ralco Animal Nutrition, Marshall, MN). The 2 additional treatments were growth-promoting and therapeutic levels of chlortetracycline (CTC at 50 or 400 g/ton). Pigs were fed experimental diets from d 5 to 33 followed by a common corn-soybean meal–based diet without any antimicrobial, essential oils, or pharmacological levels of Cu or Zn from d 33 to 47. To comply with FDA guidelines, CTC was removed on d 19 from the diet of pigs fed 400 g/ton CTC, then added again from d 20 to 33. All diets contained 16.5 ppm Cu and 165 ppm of Zn from the trace mineral premix. Essential oils had no effect on daily gain, but feeding CTC or pharmacological levels of Cu or Zn improved the growth rate of nursery pigs. Carryover effects from any of these dietary treatments on subsequent nursery growth performance were minimal. Although there were no improvements in feed efficiency due to Cu or Zn, the inclusion of an essential oils blend worsened feed and caloric efficiencies.

Key words: chlortetracycline, nursery pig, antibiotic, essential oil, copper, zinc

Introduction

As alternatives to dietary antibiotics are increasingly sought, essential oils are one type of feed additive being explored. Essential oils were once thought to improve feed palatability and intake due to their taste and strong aroma; however, the potential for essential oils to improve nursery pig growth performance may lie in enhancing immune function, exercising their antimicrobial properties in the gastrointestinal tract of the pig, or improving protein digestibility, thereby improving F/G. The nursery growth benefits obtained by feeding pharmacological levels of copper (Cu) and zinc (Zn) are

[1] 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.

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

well established, but a direct comparison of feed antimicrobials, pharmacologic levels of Cu and Zn, and essential oils is lacking. Therefore, the objective of this experiment was to compare the performance of nursery pigs fed diets containing chlortetracycline (CTC) and different dietary supplements that are commonly fed as antibiotic alternatives (Cu, Zn, and oregano essential oils), alone or in combination with each other.

Procedures

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 evaluating the potential impact of different types of feed additives used as antibiotic alternatives on antimicrobial resistance of enteric bacteria in pigs. This report describes the growth performance of these same pigs, whereas the impact on antimicrobial resistance will be reported elsewhere.

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 Segregated Early Weaning Facility in Manhattan, KS.

A total of 350 nursery pigs (PIC 1050; initially 13.3 lb BW) were used in a 47-d study with 5 pigs per pen and 7 replications per treatment. Each pen had metal tri-bar flooring, one 4-hole self-feeder, and a cup waterer to provide ad libitum access to feed and water. Pigs were weaned at approximately 21 d of age and allotted to pens based on initial BW to achieve equal average pen weights across all pens (d 0). During the time period in which the pigs were obtained, the sow farm of origin was experiencing active swine influenza circulation. Weaned pigs also exhibited clinical signs of influenza infection upon entry into the barn, and we believe this contributed to the elevated 4% removal rate during the study. To remove the confounding effect of concurrent diet treatment with injectable antimicrobial, pigs with clinical signs for which injectable treatment was deemed necessary were removed from the test, which contributed to the elevated removal rate. Removal rate was not influenced by dietary treatment.

Pigs were fed a common pelleted starter diet for the first 5 d after weaning. This diet contained no antimicrobial, no essential oils, nor any added Zn or Cu above that contained in the trace mineral premix. On d 5, pens of pigs were weighed and randomly allotted to 1 of 10 dietary treatments in blocks by barn location. The 10 dietary treatments consisted of a corn-soybean meal–based diet and were arranged as a 2 × 2 × 2 + 2 factorial with main effects of added Cu from copper sulfate ($CuSO_4$; 0 vs. 125 ppm Cu), added Zn from zinc oxide (ZnO; 0 vs. 3,000 ppm Zn from d 5 to 12 and 2,000 ppm Zn from d 12 to 33), or Regano EX (0 vs. 45 g/ton essential oils blend; Ralco Animal Nutrition, Marshall, MN). The 2 additional treatments were CTC at growth-promoting (50 g/ton) or therapeutic (400 g/ton) levels. The treatment ingredients were substituted for an equivalent amount of corn in the respective diets to form the experimental treatments (Table 1).

The experimental diets were fed from d 5 to 33. Food and Drug Administration regulations prohibit the continuous feeding of therapeutic levels of CTC longer than 14 d.[3]

[3] Code of Federal Regulations. Title 21; Volume 6; Sec. 558.128. Accessed at: http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?fr=558.128 on August 14, 2014.

Thus, on d 19 of the study, the feeders from pens assigned to the 400 g/ton CTC diet were emptied, and pigs were fed the control diet for 1 d. The normal treatment diet containing CTC at 400 g/ton was then re-added on d 20 and fed for the remainder of the 28-d period. From d 33 to 47, a common corn-soybean meal–based diet without any antimicrobial, essential oils, or pharmacological levels of Cu or Zn was fed to all pigs to evaluate any carryover effects from the treatment diets.

All diets were prepared at the K-State O.H. Kruse Feed Technology Innovation Center and contained 16.5 ppm Cu and 165 ppm of Zn from the trace mineral premix. Diet samples were collected periodically throughout the study, and pooled samples of each diet were submitted to Ward Laboratories, Inc. (Kearney, NE) for near-infrared reflectance (NIR) spectrometry analysis of Cu and Zn (Table 2). As determined by analysis, the Phase 1 common diet contained 114 ppm Zn and 24 ppm Cu, whereas the Phase 3 common diet contained 144 ppm Zn and 24 ppm Cu. Average daily gain, ADFI, and F/G were determined by weighing pigs and measuring feed disappearance on d 5, 12, 19, 33, and 47.

Growth data were analyzed as a randomized complete block design using PROC MIXED in SAS (v9.3, SAS Institute Inc., Cary, NC) with pen as the experimental unit and barn location as a blocking factor. The main effects of Cu from $CuSO_4$, Zn from ZnO, essential oils from Regano EX essential oils blend, and CTC from CTC-50, as well as any interactions, were tested using preplanned CONTRAST statements. Linear and quadratic contrasts were used for the CTC treatments. Differences between treatments were determined by using least squares means, with results considered significant at $P \leq 0.05$ and a trend at $P \leq 0.10$. Analysis of studentized residual values revealed a geographic cluster of four pens, each on a different treatment (essential oils, Cu+Zn, Cu+essential oils, Cu+Zn+essential oils), which had ADG or feed efficiency observations greater than three standard deviations from the mean. Taking this as evidence for data outliers, these pens were removed from the dataset used for analysis.

Results and Discussion

During the d 5 to 33 treatment period, increasing CTC increased (linear, $P = 0.03$) ADG, resulting in a tendency for pigs fed increasing CTC to have greater d-33 BW (linear, $P = 0.07$; see Tables 3 and 4). During this period, there was also a tendency for a linear increase in ADFI ($P = 0.08$) with increasing CTC. When the pigs ceased consuming CTC and were on the common diet from d 33 to 47, there was a tendency for a linear reduction in ADG for pigs previously fed CTC ($P = 0.10$). Consequently, CTC had no effect on overall ADG or ADFI from d 5 to 47. Although CTC failed to affect F/G during either the treatment period or the succeeding common period, increasing CTC level had a tendency to improve (quadratic, $P = 0.08$) overall F/G and caloric efficiency from d 5 to 47, with pigs fed CTC at 50 g/ton having the best feed efficiency.

During the treatment period from d 5 to 33, there was a tendency for a 3-way interaction between essential oils, Cu, and Zn (Cu × EO × Zn, $P = 0.10$), by which feeding all three in combination resulted in a lower ADG than would have been expected if improvements were additive. Both Cu and Zn increased ($P < 0.01$) ADG, resulting in greater ($P < 0.05$) BW on d 33 at the end of the treatment period. Furthermore, feeding

Zn increased ADFI, while Cu tended to do the same ($P < 0.01$ and $P = 0.06$, respectively). Although essential oils had no effect on feed intake during the treatment period, a Cu (regardless of Zn inclusion) × essential oils interaction ($P = 0.03$) was observed due to poorer than expected F/G of pigs when Cu was fed in combination with essential oils. The interaction thus facilitated the main effect of essential oils worsening F/G ($P = 0.01$) during the treatment period. This interaction and main effect of essential oils were also observed when considering efficiency on a caloric basis for both ME and NE (Cu × EO, $P = 0.03$; main effect of EO, $P = 0.02$) during the treatment period. A tendency for Zn to improve caloric efficiency ($P = 0.09$ for ME and 0.08 for NE) also was observed from d 5 to 33.

Despite a tendency for greater ADG (Cu × Zn, $P = 0.10$) of pigs previously fed diets with both Cu and Zn relative to growth of pigs previously fed diets with either Cu or Zn alone, during the 14-d common period from d 33 to 47, there was no effect of previous Zn, Cu, or essential oils dietary treatment on subsequent nursery pig growth performance. Overall from d 5 to 47, Zn increased ($P < 0.05$) ADG and ADFI, while Cu improved ($P = 0.02$) ADG, resulting in greater ending d-47 BW ($P = 0.03$ for Zn, 0.10 tendency for Cu). Although essential oils had no observed effect on overall ADG or ADFI, essential oils tended to have an adverse effect on overall F/G ($P = 0.10$).

In summary, feeding CTC or pharmacological levels of Cu or Zn improved the growth rate of nursery pigs with coinciding increases in feed intake. Feeding essential oils had no effect on daily gain but resulted in poorer feed and caloric efficiencies during the treatment period. In addition, carryover effects from any of the dietary treatments on subsequent nursery growth performance were minimal. Previous research at K-State found no effects of feeding essential oils, whereas other research has reported improved feed efficiency from feeding essential oils. This inconsistency in feed efficiency responses warrants further research to better characterize the effects of essential oils on feed efficiency amongst pigs with differing health statuses. In closing, this study further demonstrates the positive effects of added Zn, Cu, or CTC on the growth performance of weaned pigs.

Table 1. Diet composition (as-fed basis)

	Phase 1 common diet (d 0 to 5)	Phase 2 experimental diets (d 5 to 26)	Phase 3 common diet (d 26 to 47)
Ingredient, %			
Corn	37.54	54.73	63.83
Soybean meal (47.7% CP)	19.86	29.53	32.86
Spray-dried blood cells	1.25	1.25	---
Spray-dried animal plasma	4.00	---	---
Corn DDGS[1], 6 - 9% oil	5.00	---	---
Select menhaden fish meal	1.25	1.25	---
Spray-dried whey	25.00	10.00	---
Choice white grease	3.00	---	---
Monocalcium phosphate	0.90	0.80	1.00
Limestone	1.00	1.10	1.03
Salt	0.30	0.30	0.35
L-lysine HCL	0.225	0.300	0.300
DL-methionine	0.150	0.175	0.115
L-threonine	0.085	0.150	0.115
Trace mineral premix	0.150	0.150	0.150
Vitamin premix	0.250	0.250	0.250
Choline chloride, 60%	0.035	---	---
Phytase[2]	---	0.015	0.015
$CuSO_4$, ZnO, Regano EX, CTC-50 additives[3]	---	0 to 0.965	---
Total	100.00	100.00	100.000

continued

Table 1. Diet composition (as-fed basis)

	Phase 1 common diet (d 0 to 5)	Phase 2 experimental diets (d 5 to 26)	Phase 3 common diet (d 26 to 47)
Calculated analysis			
Standardized ileal digestible (SID) amino acids, %			
Lysine	1.40	1.35	1.22
Isoleucine:lysine	56	58	63
Leucine:lysine	128	125	129
Methionine:lysine	32	35	33
Met & Cys:lysine	57	58	57
Threonine:lysine	63	64	63
Tryptophan:lysine	19	18	19
Valine:lysine	71	69	69
Total lysine, %	1.57	1.50	1.37
CP, %	22.2	22.2	21.4
ME, kcal/lb	1,574	1,493	1,484
NE, kcal/lb[4]	1,179	1,102	1,093
SID lysine:ME, g/Mcal	4.0	4.1	3.7
Ca, %	0.85	0.80	0.70
P, %	0.73	0.63	0.61
Available P, %	0.51	0.44	0.39

[1] Dried distillers grains with solubles.
[2] HiPhos 2700 (DSM Nutritional Products, Inc., Parsippany, NJ), providing 184.3 phytase units (FTU)/lb and an estimated release of 0.10% available P.
[3] Treatment diets contained zinc oxide added at 0 or 0.415% from d 5 to 12 and at 0 or 0.28% from d 12 to 33, copper sulfate added at either 0 or 0.05%, Regano EX (Ralco Animal Nutrition, Marshall, MN) containing approximately 5% essential oils blend added at either 0 or 0.1%, and CTC-50 added at 0, 0.05, or 0.4%. Additions of treatment ingredients were made in place of an equivalent amount of corn in respective experimental diets.
[4] NE values for ingredients were derived from NRC (2012).

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

	Phase 2 treatment diets[2]				Analyzed composition	
Diets	Added Copper, ppm	Added Zinc, ppm	Essential oils blend, g/ton[3]	Chlortet-racycline (CTC), g/ton	Zn, ppm	Cu, ppm
Control	-	-	-	-	140	16
Cu	125	-	-	-	115	109
Zn[4]						
d 5 to 12	-	3,000	-	-	2,110	20
d 12 to 33	-	2,000	-	-	1,632	25
Essential oils (EO)	-	-	45	-	177	25
Cu + Zn[4]						
d 5 to 12	125	3,000	-	-	2,254	166
d 12 to 33	125	2,000	-	-	1,778	135
Cu + EO	125	-	45	-	385	161
Zn + EO[4]						
d 5 to 12	-	3,000	45	-	2,166	19
d 12 to 33	-	2,000	45	-	1,780	21
Cu + Zn + EO[4]						
d 5 to 12	125	3,000	45	-	2,181	120
d 12 to 33	125	2,000	45	-	1,701	137
CTC 50	-	-	-	50	219	22
CTC 400	-	-	-	400	205	22

[1] Analysis was performed by Ward Laboratories, Inc. (Kearney, NE) on pooled diet samples.
[2] Experimental Phase 2 treatment diets were fed from d 5 to 33, whereas a Phase 1 common diet (114 ppm Zn and 24 ppm Cu as per analysis) was fed to all pigs from d 0 to 5 and a Phase 3 common diet (144 ppm Zn and 24 ppm Cu as per analysis) was fed to all pigs from d 33 to 47.
[3] From Regano EX (Ralco Animal Nutrition, Marshall, MN).
[4] Pharmacological Zn diet treatments had an addition of 3,000 ppm Zn from added ZnO from d 5 to 12 and an addition of 2,000 ppm Zn from added ZnO from d 12 to 33.

Table 3. Effects of dietary copper, zinc, essential oils, and chlortetracycline (CTC) on nursery pig growth performance[1,2]

Added Cu[3]:	-	+	-	-	+	+	-	+	-	-	
Added Zn[4]:	-	-	+	-	+	-	+	+	-	-	
Essential oil blend[5]:	-	-	-	+	-	+	+	+	-	-	
CTC, g/ton:	-	-	-	-	-	-	-	-	50	400	SEM
BW, lb											
d 5	14.5	14.5	14.5	14.4	14.6	14.8	14.5	14.6	14.4	14.4	0.19
d 33	41.8	43.2	43.7	42.1	45.1	43.9	43.8	44.0	41.6	43.3	0.76
d 47	64.0	64.6	65.4	63.6	67.4	65.0	65.0	65.9	63.7	64.5	1.11
d 5 to 33											
ADG, lb	0.96	1.01	1.04	0.92	1.09	1.04	1.05	1.05	0.96	1.02	0.026
ADFI, lb	1.24	1.28	1.34	1.21	1.34	1.36	1.34	1.37	1.21	1.31	0.040
F/G	1.29	1.27	1.30	1.32	1.23	1.31	1.28	1.31	1.27	1.28	0.020
d 33 to 47											
ADG, lb	1.59	1.53	1.55	1.53	1.59	1.51	1.51	1.56	1.58	1.52	0.035
ADFI, lb	2.57	2.48	2.53	2.50	2.55	2.48	2.50	2.52	2.47	2.47	0.062
F/G	1.62	1.62	1.63	1.63	1.61	1.64	1.65	1.62	1.57	1.63	0.030
d 5 to 47											
ADG, lb	1.17	1.18	1.21	1.11	1.26	1.20	1.20	1.21	1.16	1.18	0.024
ADFI, lb	1.68	1.67	1.74	1.61	1.75	1.73	1.73	1.74	1.62	1.69	0.042
F/G	1.44	1.42	1.44	1.45	1.39	1.45	1.44	1.44	1.40	1.42	0.019
Caloric efficiency[6]											
d 5 to 33											
ME	1,933	1,888	1,929	1,968	1,836	1,952	1,903	1,947	1,889	1,902	27.6
NE	1,427	1,393	1,423	1,452	1,355	1,440	1,404	1,436	1,394	1,403	21.8
d 5 to 47											
ME	2,144	2,110	2,141	2,157	2,065	2,155	2,134	2,133	2,082	2,117	27.9
NE	1,580	1,555	1,578	1,589	1,522	1,589	1,573	1,572	1,535	1,560	20.6

[1] A total of 350 nursery pigs (PIC 1050, initially 13.3 lb BW) were used in a 47-d study with 5 pigs per pen and 7 replications per treatment except for 4 treatments (essential oils, Cu+Zn, Cu+essential oils, Cu+Zn+essential oils), which had 6 replications each.

[2] Experimental treatment diets were fed from d 5 to d 33. All diets contained 16.5 ppm Cu and 165 ppm of Zn from the trace mineral premix.

[3] Cu from $CuSO_4$ was added to treatment diets at either 0 or 125 ppm.

[4] Pharmacological Zn diet treatments had an addition of 3,000 ppm Zn from added ZnO from d 5 to 12 and an addition of 2,000 ppm Zn from added ZnO from d 12 to 33.

[5] Regano EX (Ralco Animal Nutrition, Marshall, MN) was added to treatment diets at either 0 or 45 g/ton.

[6] Caloric efficiency is expressed as kcal per pound of live weight gain.

Table 4. Statistical analysis of dietary copper, zinc, essential oils, and chlortetracycline (CTC) on nursery pig growth performance[1]

	Probability, $P <$								
								CTC	
	Cu	Zn	Essential oils (EO)	Cu × Zn	Cu × EO	Zn × EO	Cu × Zn × EO	Linear	Quadratic
BW, lb									
d 0	0.461	0.804	0.704	0.207	0.362	0.849	0.106	0.100	0.036
d 5	0.250	0.976	0.685	0.830	0.442	0.710	0.519	1.000	0.723
d 33	0.022	0.009	0.965	0.437	0.689	0.331	0.463	0.074	0.739
d 47	0.099	0.034	0.514	0.796	0.945	0.516	0.544	0.590	0.808
d 0 to 5									
ADG, lb	0.170	0.985	0.695	0.675	0.547	0.692	0.741	0.737	0.944
d 5 to 33[2]									
ADG, lb	0.003	<0.001	0.605	0.120	0.822	0.707	0.098	0.028	0.755
ADFI, lb	0.055	0.006	0.444	0.173	0.182	0.798	0.444	0.079	0.392
F/G	0.153	0.165	0.011	0.871	0.025	0.860	0.143	0.831	0.227
d 33 to 47									
ADG, lb	0.928	0.608	0.136	0.095	0.692	0.965	0.782	0.101	0.987
ADFI, lb	0.675	0.696	0.355	0.347	0.668	0.978	0.675	0.377	0.222
F/G	0.613	0.966	0.493	0.296	0.961	0.993	0.797	0.320	0.144
d 5 to 47									
ADG, lb	0.018	0.001	0.207	0.573	0.621	0.825	0.111	0.422	0.771
ADFI, lb	0.225	0.025	0.818	0.425	0.225	0.942	0.304	0.499	0.240
F/G	0.138	0.278	0.099	0.561	0.146	0.972	0.562	0.957	0.084
Caloric efficiency[3]									
d 5 to 33									
ME	0.138	0.089	0.015	0.870	0.025	0.858	0.144	0.645	0.226
NE	0.137	0.084	0.015	0.870	0.025	0.858	0.144	0.631	0.226
d 5 to 47									
ME	0.131	0.207	0.111	0.560	0.147	0.976	0.561	0.937	0.084
NE	0.131	0.202	0.111	0.560	0.147	0.977	0.560	0.930	0.084

[1]A total of 350 nursery pigs (PIC 1050; initially 13.3 lb BW) were used in a 47-d study with 5 pigs per pen and 7 replications per treatment except for 4 treatments (essential oils, Cu+Zn, Cu+essential oils, Cu+Zn+essential oils), which had 6 replications each.

[2] Experimental treatment diets were fed from d 5 to d 33. All diets contained 16.5 ppm Cu and 165 ppm of Zn from the trace mineral premix.

[3] Caloric efficiency is expressed as kcal per pound of live weight gain.

Evaluation of Different Zinc Sources and Levels on Nursery Pig Performance[1]

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Summary

A total of 294 pigs (PIC 327 × 1050, initially 14.1 lb BW) were used in a 31-d trial to evaluate the effects of increasing levels of two different zinc sources on nursery pig growth performance. Pigs were weaned at 21 d of age and were fed pelleted diets for the first 7 d and a mash diet for 24 d of the 31-d trial. Each treatment had 7 replicate pens with 7 pigs per pen. The 6 experimental diets were: (1) a control diet; (2) a diet with 500 ppm of Zn from Zinco+; (3) a diet with 1,500 ppm of added Zn from Zinco+; (4) a diet with 500 ppm of Zn from zinc oxide (ZnO); (5) a diet with 1,500 ppm of Zn from ZnO; and (6) a diet with 3,000 ppm of Zn from ZnO. All diets contained 110 ppm of Zn from the $ZnSO_4$ provided by the trace mineral premix. Zinco+ (Jefo, Quebec, Canada) is a fat-encapsulated form of ZnO that is suggested to be more bioavailable than ZnO.

From d 0 to 7, neither Zn source nor level influenced pig performance. From d 7 to 21, pigs fed increasing Zn from Zinco+ tended to have increased (linear, $P = 0.06$) ADG and had improved F/G (linear, $P < 0.01$). Pigs fed increasing levels of Zn from ZnO had greater ADG and ADFI (linear, $P < 0.01$) and improved F/G (quadratic, $P = 0.02$). Pigs had greater ($P < 0.01$) ADG and ADFI when fed diets containing 3,000 ppm of Zn from ZnO compared with pigs fed diets with 500 ppm of Zn from Zinco+. Day 21 BW increased with increasing Zn from Zinco+ (linear, $P < 0.03$) and Zn from ZnO ($P < 0.001$), with pigs fed 3,000 ppm of Zn from ZnO having heavier ($P < 0.01$) d-21 BW compared with those fed 500 ppm of Zn from Zinco+.

Overall, from d 0 to 31, increasing Zn from Zinco+ did not affect growth performance, but increasing Zn from ZnO increased ($P < 0.01$) ADG and ADFI. Pigs fed 500 ppm of Zn from Zinco+ had poorer ADG ($P < 0.02$) and ADFI ($P < 0.01$) than pigs fed 3,000 ppm of Zn from ZnO. This study shows the growth benefits of adding 3,000 ppm of Zn from ZnO in diets fed to newly weaned pigs. Lower levels of Zn from Zinco+ did not provide the same growth-promoting potential as the diet with 3,000 ppm of Zn from ZnO.

Key words: growth performance, nursery pig, zinc

Introduction

Zinc is a trace mineral that is essential for optimal protein and energy metabolism. In addition to meeting the basal requirement, research has shown that pharmacological levels (3,000 ppm) of dietary Zn from ZnO fed for the first 2 to 4 wk after weaning

[1] Appreciation is expressed to Jefo Nutrition Inc., Saint-Hyacinthe, Quebec, Canada, for partial financial support and for donating the specialty zinc source.

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

can increase growth rates and decrease the incidence of diarrhea. However, these high levels of dietary Zn are also associated with increased Zn concentrations in swine waste, which could lead to excess soil Zn concentrations. A recently introduced fat-encapsulated form of ZnO (Zinco+; Jefo, Quebec, Canada) has been suggested to be more bioavailable than the ZnO normally included in pig diets. If proven efficacious, this Zn source would allow for low levels to be fed and achieve the growth benefits while eliminating high concentrations of Zn in swine waste. Little research has been conducted to confirm this response, however, so the objective of this study was to compare the effects of different levels of Zn from Zinco+ and ZnO on the growth performance of nursery pigs.

Procedures

The protocol for this experiment was approved by the Kansas State University Institutional Animal Care and Use Committee. This experiment was conducted in the nursery facility at the Kansas State University Swine Teaching and Research Center in Manhattan, KS. The facility is a totally enclosed, environmentally controlled, mechanically ventilated barn. Each pen contains a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water. Pens had wire-mesh floors and allowed approximately 3 ft^2/pig.

A total of 294 pigs (PIC 327 × 1050, initially 14.1 lb BW) were used in a 31-d trial to evaluate the effects of increasing Zn from 2 different sources on nursery pig growth performance. Pigs were weaned at 21 d of age and were randomly allotted to 1 of 6 dietary treatments. Each treatment had 7 replicate pens with 7 pigs per pen and with gender balanced across the treatments. Pig weight and feed disappearance were measured on d 7, 14, 21, and 31 of the trial to determine ADG, ADFI, and F/G.

All dietary treatments were corn-soybean meal–based and fed in three phases, with pellet diets fed from d 0 to 7, then meal diets fed for the rest of the study (Table 1). All diets contained a trace mineral premix that provided 110 ppm of Zn from $ZnSO_4$. The 6 experimental treatments were a control diet, the control diet with 500 or 1,500 ppm of added Zn from Zinco+; or the control diet with 500, 1,500, or 3,000 ppm of added Zn from ZnO. Zinco+ is ZnO coated with a hydrogenated vegetable oil and was provided by the manufacturer. Diet samples were collected from each phase and analyzed for DM, CP, Ca, P, and Zn at Ward Laboratories, Inc. (Kearney, NE).

Data were analyzed as a randomized complete block design using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Weight block and room were included in the model as random effects. The effects of increasing Zn dose within source were determined by linear and quadratic polynomial contrasts. Contrast coefficients were determined for unequally spaced treatments using the IML procedure of SAS, and the treatment without supplemental Zn was used as the first dose for each of the treatments. In addition, a pairwise comparison was made between the diet containing 500 ppm of Zn from Zinco+ and the diet with 3,000 ppm of Zn from ZnO. Treatment differences were considered significant at $P \leq 0.05$ and a tendency from $P > 0.05$ to $P \leq 0.10$.

Results and Discussion

The chemical analyses of the experimental diets were similar to those calculated from diet formulation (Table 2).

From d 0 to 7, no differences were observed among pigs fed either Zn from Zinco+ or ZnO ($P > 0.10$) on growth performance (Table 3). From d 7 to 21, pigs fed increasing Zn from Zinco+ tended to have increased (linear, $P = 0.07$) ADG and had improved F/G (linear, $P < 0.01$). Pigs fed increasing Zn from ZnO had greater ADG and ADFI (linear, $P < 0.01$) and improved F/G (quadratic, $P = 0.03$). Pigs had greater ($P < 0.01$) ADG and ADFI when fed diets containing 3,000 ppm of Zn from ZnO compared with pigs fed diets with 500 ppm of Zn from Zinco+. Day-21 BW increased with increasing Zn from Zinco+ (linear, $P < 0.04$) and Zn from ZnO (linear; $P < 0.01$), with pigs fed 3,000 ppm of Zn from ZnO having heavier ($P < 0.01$) d-21 BW compared with those fed 500 ppm of Zn from Zinco+.

From d 21 to 31, ADG and ADFI were not influenced by treatment; however, F/G tended to worsen (linear, $P = 0.08$) when pigs were fed increasing Zn from Zinco+ and worsened (linear, $P = 0.02$) when pigs were fed increasing Zn from ZnO. Pigs fed 3,000 ppm of Zn from ZnO tended to have poorer ($P = 0.10$) F/G than pigs fed 500 ppm of Zn from Zinco+. These data agree with previous research indicating that growth-promoting levels of Zn should be fed only for the first 21 d after weaning.

Overall, from d 0 to 31, increasing Zn from Zinco+ did not affect growth performance, but increasing Zn from ZnO increased (linear; $P < 0.01$) ADG and ADFI. Pigs fed 500 ppm of Zn from Zinco+ had poorer ADG ($P < 0.02$) and ADFI ($P < 0.01$) than pigs fed 3,000 ppm of Zn from ZnO.

In conclusion, this study demonstrates the growth-promoting benefits of adding 3,000 ppm of Zn from ZnO in diets fed to newly weaned pigs. Pigs fed lower levels of added Zn from Zinco+ had poorer performance than those fed the diet containing 3,000 ppm of Zn from ZnO but similar performance to those fed diets containing the same levels of Zn from ZnO. This result suggests that the fat encapsulation around the ZnO of the Zinco+ product resulted in no growth benefits. Additional research could be conducted to determine if Zinco+ reduces the excretion of Zn compared with uncoated ZnO.

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

Item	Phase 1	Phase 2	Phase 3
Ingredient, %			
Corn	37.53	54.60	63.69
Soybean meal (47.5% CP)	19.86	29.54	32.86
Blood meal	1.25	1.25	--
Blood plasma	4.00	--	--
Dried distillers grains with solubles, >6 and <9% oil	5.00	--	--
Fish meal	1.25	1.25	--
Spray-dried whey	25.00	10.00	--
Choice white grease	3.00	--	--
Monocalcium phosphate	0.90	0.80	1.00
Limestone	1.00	1.10	1.03
Salt	0.30	0.30	0.35
L-lysine-HCl	0.23	0.30	0.30
DL-methionine	0.15	0.18	0.12
L-threonine	0.09	0.15	0.12
Trace mineral premix	0.15	0.15	0.15
Vitamin premix	0.25	0.25	0.25
Choline chloride 60%	0.04	--	--
Phytase	--	0.13	0.13
Total	100.00	100.00	100.00
Calculated analysis			
Standardized ileal digestible (SID) amino acids, %			
Lysine	1.40	1.35	1.22
Isoleucine:lysine	56	58	63
Leucine:lysine	128	125	129
Methionine:lysine	32	35	33
Met & Cys:lysine	57	58	57
Threonine:lysine	63	64	63
Tryptophan:lysine	19.0	18.1	18.7
Valine:lysine	71	69	69
Total lysine, %	1.56	1.50	1.37
ME, kcal/lb	1,574	1,491	1,483
NE, kcal/lb	1,179	1,100	1,092
SID lysine:ME, g/Mcal	4.04	4.11	3.73
CP, %	22.2	22.1	21.4
Ca, %	0.85	0.80	0.70
P, %	0.73	0.63	0.61
Available P, %	0.51	0.47	0.41

[1] Experimental diets were fed in 3 phases, with phases 1, 2, and 3 fed from d 0 to 7, 7 to 21, and 21 to 31, respectively. All diets contained 110 ppm of Zn from $ZnSO_4$ from the trace mineral premix.

Table 2. Chemical analysis of experimental diets[1]

Item	Control	Zinco+ 500	Zinco+ 1500	ZnO 500	ZnO 1500	ZnO 3000
Zn ppm	169	458	1,575	605	1,263	2,890

[1] Chemical analyses reported are averages from composite samples collected from d 0 to 31.

Table 3. Evaluation of Zn sources on nursery pig performance[1]

		Added Zn[2], ppm						Probability, *P* <				
	Control[2]	Zinco+		ZnO				Zinco+		ZnO		
Item	0	500	1,500	500	1,500	3,000	SEM	Lin	Quad	Lin	Quad	500 Zinco+ vs. 3000 ZnO
d 0 to 7												
ADG, lb	0.18	0.20	0.20	0.24	0.20	0.24	0.02	0.41	0.66	0.11	0.81	0.11
ADFI, lb	0.40	0.39	0.38	0.42	0.42	0.43	0.02	0.69	0.96	0.40	0.87	0.24
F/G	2.48	2.14	2.09	1.79	2.27	1.80	0.28	0.34	0.53	0.22	0.99	0.35
d 7 to 21												
ADG, lb	0.58	0.60	0.67	0.60	0.70	0.76	0.05	0.07	0.98	0.01	0.60	0.01
ADFI, lb	0.94	0.92	0.98	0.91	1.00	1.10	0.06	0.43	0.54	0.01	0.52	0.01
F/G	1.63	1.52	1.48	1.53	1.43	1.44	0.04	0.01	0.27	0.01	0.03	0.13
d 21 to 31												
ADG, lb	1.14	1.14	1.11	1.19	1.15	1.14	0.05	0.58	0.77	0.66	0.60	0.96
ADFI, lb	1.76	1.78	1.80	1.83	1.83	1.86	0.06	0.44	0.91	0.12	0.49	0.16
F/G	1.55	1.57	1.63	1.55	1.60	1.64	0.03	0.08	0.80	0.02	0.96	0.10
d 0 to 31												
ADG, lb	0.67	0.69	0.70	0.70	0.73	0.77	0.02	0.29	0.82	0.01	0.54	0.02
ADFI, lb	1.08	1.08	1.11	1.09	1.14	1.19	0.03	0.50	0.72	0.01	0.91	0.01
F/G	1.62	1.58	1.58	1.56	1.56	1.56	0.03	0.35	0.38	0.21	0.20	0.62
BW, lb												
d 0	14.3	14.3	14.3	14.3	14.3	14.3	0.05	0.20	0.27	0.48	0.34	0.14
d 7	15.5	15.7	15.8	16.0	15.7	16.0	0.15	0.30	0.83	0.09	0.96	0.07
d 21	23.6	24.1	25.2	24.7	25.5	26.9	0.67	0.04	0.97	0.01	0.66	0.01
d 31	35.0	35.5	36.4	36.5	37.0	38.3	0.69	0.16	0.92	0.01	0.56	0.01

[1] A total of 294 pigs (PIC 327 × 1050) were used in a 31-d study with 7 pigs per pen and 7 pens per treatment.
[2] All diets contained 110 ppm Zn from $ZnSO_4$ provided by the trace mineral premix.

Evaluation of Specialty Soy Protein Sources on Nursery Pig Performance[1]

K.E. Jordan, M.A.D. Goncalves[2], M.D. Tokach, S.S. Dritz[2], R.D. Goodband, J.M. DeRouchey, and J.C. Woodworth

Summary

A 35-d growth trial was conducted to evaluate the effects of a new soy protein source, Nutrivance (TechMix, Stewart, MN), on nursery pig growth performance. Nutrivance is a modified soy protein produced via a proprietary process combining extraction and enzymatic treatment of soybeans. Pigs (n = 1,188, PIC 337 × 1050; initially 9.8 lb BW) were weaned at 21 d of age and allotted by weight to pens with 27 pigs per pen. Pigs were fed a common diet for 15 d before the start of the study. Pens of pigs (13.5 lb BW) were then allotted to 1 of 4 dietary treatments fed for 14 d followed by a common diet fed for 21 d. The 4 experimental treatments were a corn-soybean meal–based control diet, or a corn-soybean meal–based diet with either 8% Nutrivance, 8.65% HP-300 (Hamlet Protein, Findlay, OH), or 6.85% Soycomil P (SPC; Archer Daniels Midland Co., Decatur, IL). The diets were formulated to the same standardized ileal digestible lysine level with specialty soy protein products replacing a portion of soybean meal in the control diet to form the experimental treatments.

From d 0 to 14, there were no differences in ADG or F/G; however, pigs fed the diets containing Nutrivance or HP-300 had decreased ADFI ($P < 0.02$) compared with those fed the control diet, with pigs fed diets containing SPC intermediate. From d 14 to 35 when a common diet was fed, pigs previously fed the diet with the HP-300 had lower ADFI ($P < 0.03$) compared with pigs fed the control diet, with pigs previously fed diets containing Nutrivance or SPC intermediate. From d 0 to 35, pigs fed diets containing Nutrivance or HP-300 had decreased ADG and ADFI ($P < 0.02$) compared with pigs fed the control diet, with pigs fed diets containing SPC intermediate. Final weight (d 35) was greatest ($P < 0.04$) for pigs fed the control diet and lowest for pigs fed the diet with Nutrivance, and pigs fed the diets with HP-300 or SPC were intermediate. In conclusion, differences exist between alternative specialty soy protein sources, but, the corn-soybean meal control diet elicited the greatest growth performance in this study.

Key words: growth performance, nursery pig, soy protein sources

Introduction

Providing high-quality sources of amino acids to weanling pigs is known to improve performance and aid in transitioning pigs to dry feed. However, increasing prices of some of the most common protein sources has encouraged the industry to search for alternative ingredients capable of replacing these expensive ingredients without negatively affecting performance.

[1] Appreciation is expressed to TechMix, LLC (Stewart, MN) for partial financial support and providing the specialty soy protein sources and to New Horizon Farms for use of pigs and facilities.
[2] Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University.

Nutrivance (TechMix, Stewart, MN) is a new specialty soybean protein ingredient that was developed from a proprietary process that combines extraction and enzymatic treatment of soybeans to create a modified soy protein for animal feeds. The enzymatic treatment reduces anti-nutritional factors found in soybean meal that are known to negatively affect pig performance. Little research has been conducted to determine how this new soy protein replacement product will affect nursery pig performance. Thus, the objective of this study was to evaluate the effects of different soy protein sources on growth performance of nursery pigs.

Procedures

The protocol for this experiment was approved by the Kansas State University Institutional Animal Care and Use Committee. This experiment was conducted at a commercial research-nursery site in southwest Minnesota. One room with 44 pens was used, with each pen (12 × 7.5 ft) equipped with a 6-hole stainless steel dry self-feeder (SDI Industries, Alexandria, SD) and a pan waterer for ad libitum access to feed and water. The nursery is equipped with a robotic feeding system that is capable of feeding each individual pen any of the individual diets as well as a pen scale to obtain pig weight on a pen basis.

At weaning, 1,188 pigs (PIC 337 × 1050; 9.8 lb BW) were used in a 5-d study. Pigs were allotted to 1 of 44 pens, with 27 pigs per pen and all pigs fed the same common diets for 15 d after weaning. At that point, pens of pigs (13.5 lb BW) were weighed and randomly allotted within weight blocks to 1 of the 4 dietary treatments with 11 pens per treatment. Experimental diets were fed for 14 d and consisted of: (1) a corn-soybean meal–based control diet, or a corn-soybean meal–based diet with either (2) 8% Nutrivance, (3.47% standardized ileal digestible lysine [SID Lys] as-fed), (3) 8.65% HP-300 (Hamlet Protein, Findlay, OH; 3.25% SID Lys as-fed), or (4) 6.85% Soycomil P (Archer Daniels Midland Co., Decatur, IL; 3.85% SID Lys as-fed) (Table 1). The diets were formulated to the same SID Lys concentration, with specialty soy protein product replacing 10.85% of the soybean meal in the control diet to form the experimental treatments. After the 14-d experimental treatment phase, a common diet was fed for 21 d. Pig weight and feed disappearance were measured on d 0, 7, 14, 28, and 35 of the trial to determine ADG, ADFI, and F/G.

Samples of each diet were collected during feed manufacturing and from a minimum of 6 feeders on each weigh day, combined, and subsampled to form a composite sample for each weigh day. These samples were submitted to Ward Laboratories, Inc. (Kearney, NE) for analysis of DM, CP, Ca, and P.

Data were analyzed as a randomized complete block design using PROC MIXED in SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Weight block was included in the model as a random effect. The effects of soy protein sources on performance criteria were determined by a pairwise comparison. Results were considered significant at $P \leq 0.05$ and tendencies from $P > 0.05$ to $P \leq 0.10$.

Results and Discussion

The chemical analyses of the dietary treatments were similar to expectations from diet formulation (Table 2).

Growth performance of pigs prior to the initiation of study was similar to expectations (Table 3). From d 0 to 14, there were no differences in ADG or F/G; however, pigs fed the diets containing Nutrivance or HP-300 had decreased ADFI ($P < 0.02$) compared with those fed the control diet, with pigs fed diets containing SPC intermediate. From d 14 to 35 when a common diet was fed, pigs previously fed the diet with the HP-300 had decreased ADFI ($P < 0.03$) compared with pigs fed the control diet, with pigs previously fed diets containing Nutrivance or Soycomil intermediate. From d 0 to 35, pigs fed diets containing Nutrivance or HP-300 had decreased ADG and ADFI ($P < 0.02$) compared with pigs fed the control diet; pigs fed diets containing SPC were intermediate. Final weight (d 35) was greatest ($P < 0.04$) for pigs fed the control diet and lowest for pigs fed the diet with Nutrivance, whereas pigs fed the diets with HP-300 or SPC were intermediate.

These data suggest that the specialty soybean protein sources tested in this study were not able to elicit the same growth performance as pigs fed the corn-soybean meal control diet. This was evident because pigs fed the control diet had the greatest numerical ADG and ADFI throughout the study. Because ADFI was the primary growth criteria negatively influenced by the specialty soybean source treatments HP 300 and Nutrivance, we speculate that diet palatability might have been adversely affected by the products. Furthermore, our data suggest that the other specialty soy protein sources tested in this study did not have the same impact on feed intake. Additional research should be conducted to further compare how different specialty soy protein products influence nursery pig growth performance.

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

Item	Control	Nutrivance[2]	HP 300[3]	Soycomil P[4]
Ingredient, %				
Corn	41.73	44.54	43.90	45.69
Soybean meal (47.5% CP)	33.60	22.75	22.75	22.75
Dried distillers grains with solubles	10.00	10.00	10.00	10.00
Dried whey	10.00	10.00	10.00	10.00
Corn oil	1.00	1.00	1.00	1.00
Dicalcium P (18.5% P)	1.00	1.05	1.00	1.03
Limestone	1.10	1.08	1.13	1.10
Salt	0.30	0.30	0.30	0.30
DL-methionine	0.14	0.15	0.14	0.15
L-threonine	0.12	0.12	0.12	0.12
Biolys	0.50	0.50	0.50	0.50
Optiphos 2000	0.03	0.03	0.03	0.03
Zinc oxide	0.25	0.25	0.25	0.25
Trace mineral premix	0.10	0.10	0.10	0.10
Vitamin premix	0.13	0.13	0.13	0.13
Nutrivance	--	8.00	--	--
HP-300	--	--	8.65	---
Soycomil P	--	--	----	6.85
Total	100.00	100.00	100.00	100.00
Calculated analysis				
Standardized ileal digestible (SID) amino acids, %				
Lysine	1.30	1.30	1.30	1.30
Isoleucine:lysine	63	63	63	64
Methionine:lysine	34	35	34	35
Met & Cys:lysine	58	58	58	58
Threonine:lysine	65	65	65	65
Tryptophan:lysine	19.6	19.2	19.5	18.3
Valine:lysine	66	67	68	68
Total lysine, %	1.46	1.46	1.45	1.46
ME, kcal/lb	1,508	1,517	1,525	1,525
NE, kcal/lb[5]	1,099	1,108	1,115	1,118
SID lysine:ME, g/Mcal	3.91	3.89	3.87	3.87
CP, %	23.0	22.9	23.1	22.8
Ca, %	0.80	0.80	0.80	0.80
P, %	0.66	0.66	0.66	0.65
Available P, %	0.50	0.51	0.50	0.50

[1] Experimental diets were fed from d 15 to 29 after weaning.
[2] Nutrivance, TechMix, LLC, Stewart, MN, formulated with 3.47% SID lysine.
[3] HP-300, Hamlet Protein, Findlay, OH, formulated with 3.25% SID lysine.
[4] Soycomil P, Archer Daniels Midland Co., Decatur, IL, formulated with 3.85% SID lysine.
[5] NRC, 2012.

Table 2. Chemical analysis of experimental diets[1]

Item	Control	Nutrivance[2]	HP-300[3]	Soycomil P[4]
DM, %	90.63	90.89	90.89	90.92
CP, %	25.3	24.8	25.0	24.2
Ca, %	1.00	1.07	0.96	1.06
P, %	0.59	0.64	0.62	0.63

[1] Values represent a single subsample of a homogenized group of a minimum of 12 samples per treatment analyzed at Ward Laboratories, Inc. (Kearney, NE).
[2] Nutrivance, TechMix, LLC, Stewart, MN.
[3] HP-300, Hamlet Protein, Findlay, OH.
[4] Soycomil P, Archer Daniels Midland Co., Decatur, IL.

Table 3. Effects of specialty soy protein sources on nursery pig performance[1]

Item	Control	Nutrivance[2]	HP-300[3]	Soycomil[4]	SEM	*P* <
d 0 to 14						
ADG, lb	0.71	0.65	0.65	0.70	0.03	0.14
ADFI, lb	0.98^{b}	0.89^{a}	0.89^{a}	0.95^{ab}	0.03	0.02
F/G	1.40	1.40	1.37	1.35	0.03	0.78
d 14 to 35						
ADG, lb	1.25	1.21	1.21	1.23	0.02	0.13
ADFI, lb	1.82^{b}	1.77^{ab}	1.73^{a}	1.77^{ab}	0.03	0.03
F/G	1.46	1.46	1.42	1.44	0.02	0.27
d 0 to 35						
ADG, lb	1.03^{b}	0.98^{a}	0.99^{a}	1.02^{ab}	0.02	0.02
ADFI, lb	1.49^{b}	1.41^{a}	1.39^{a}	1.44^{ab}	0.03	0.02
F/G	1.44	1.44	1.41	1.41	0.01	0.16
BW, lb						
d 0	13.5	13.5	13.6	13.6	0.44	0.97
d 14	23.4	22.5	22.6	23.2	0.66	0.23
d 35	49.9^{c}	48.2^{a}	48.3^{ab}	49.6^{bc}	0.93	0.04

[a,b,c] Means within the same row with different superscripts differ ($P \leq 0.05$).
[1] A total of 1,188 nursery pigs (PIC 337 × 1050, initially 13.5 lb BW) were used in a 35-d growth trial with 27 pigs per pen and 11 pens per treatment. Treatment diets were fed from d 15 after weaning, then a common diet was fed from d 21 to 35.
[2] Nutrivance, TechMix, LLC, Stewart, MN.
[3] HP-300, Hamlet Protein, Findlay, OH.
[4] Soycomil P, Archer Daniels Midland Co., Decatur, IL.

Effects of PepSoyGen Processing Method on Nursery Pig Growth Performance[1]

A.B. Clark , H.L. Frobose, J.M. DeRouchey, M.D. Tokach, S.S. Dritz[2], R.D. Goodband, and J.C. Woodworth

Summary

A total of 292 weanling pigs (PIC 327 × 1050; 13.3 ± 2.4 lb BW and 21 d of age) were used in a 31-d experiment evaluating the effects of alternative PepSoyGen processing methods for nursery pig diets. There were 11 replicate pens per treatment and 6 or 7 pigs per pen. At weaning, pigs were allotted to pens by initial weight to 1 of 4 treatments in a completely randomized design. A 3-phase diet series was used with treatment diets fed during Phase 1 (d 0 to 7) and Phase 2 (d 7 to 21), with a common diet fed from d 21 to 31. Diets were: (1) negative control (corn, soybean meal, and dried whey), (2) positive control (4% DPS 50 + 1% PepSoyGen), (3) PepSoyGen processing method 1 (PSG1; 5%), and (4) PepSoyGen processing method 2 (PSG2; 5%). The alternative PepSoyGen processing methods incorporated increasing levels of a proprietary additive post-fermentation (PSG2 > PSG1) aimed at further breakdown of anti-nutritional factors associated with soybean meal. Nutrient analyses generally matched formulated levels for negative and positive control diets, but for both PSG1 and PSG2, CP and amino acid concentrations were lower than formulated, with PSG1 generally 10% lower than PSG2.

In Phase 1, pigs fed the positive control diet had improved ($P < 0.01$) ADG and feed efficiency compared with pigs fed the negative control, whereas pigs fed PSG1 and PSG2 diets were intermediate for feed efficiency but tended ($P < 0.07$) to have increased ADG compared with those fed the negative control. For Phase 2, there were no significant differences in growth performance between treatment diets. For the overall experimental period (d 0 to 21), pigs fed the positive control diet and PSG2 diet had improved ADG ($P < 0.05$), whereas pigs fed the positive control, PSG1, and PSG2 diets had improved feed efficiency ($P < 0.05$) compared with pigs fed the negative control diet. Also, pigs fed PSG1 tended ($P < 0.06$) to have lower ADG compared with pigs fed the positive control diet. During the Phase 3 common period, no difference in growth performance was observed. Overall (d 0 to 31), ADG was greater ($P < 0.01$) for pigs fed the positive control diet and tended to be greater ($P < 0.07$) for pigs fed diets containing PSG2 than the negative control diet, with pigs fed PSG1 intermediate.

In conclusion, pigs fed the PSG1 or PSG2 diets had similar performance to pigs fed the positive control diet. Numerically, the PSG2 diet elicited greater performance than the PSG1 diet, but it is unclear whether this response is reflective of the reduced CP and amino acid content in the PSG1 diet or if the differences in processing method affected growth response.

Keywords: dried porcine solubles, fermented soybean meal, growth, nursery pig, protein sources

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[1] Appreciation is expressed to Nutra-Flo (Sioux City, IA) for partial financial support.

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

Introduction

Short amino acid chains, also known as peptides, comprise two-thirds of dietary amino acids digested by the newly weaned pig. These peptides are more easily absorbed than intact proteins. Consequently, highly digestible soy protein products containing high levels of peptides continue to receive more attention as an ingredient in postweaning nursery pig diets. Research has indicated that pigs fed fermented rather than solvent-extracted soybean meal have improved nutrient digestibility. The fermentation process is thought to reduce trypsin inhibitors and some oligosaccharides that may decrease pig performance; however, most research has indicated that soy proteins cannot fully replace animal protein sources postweaning and maintain equal pig growth performance.

PepSoyGen (Nutraferma Company, North Sioux City, SD) is a commercially available fermented soybean meal product that is intended for use in weanling pig diets. Initial research showed that PepSoyGen could elicit performance similar to that observed from pigs when menhaden fish meal was included in the diets, and performance could be improved further when dried porcine solubles (DPS 50; Nutra-Flo, Sioux City, IA) were added with the PepSoyGen. Optimization of the PepSoyGen manufacturing process has yielded two next-generation products that are designed to further improve the performance of pigs fed diets containing PepSoyGen, but they have not yet been tested in weanling pig diets. Therefore, the objective of this experiment was to compare the effects of two alternative PepSoyGen processing methods on nursery pig growth performance.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The trial was conducted at the K-State Swine Teaching and Research Center in Manhattan, KS.

A total of 292 mixed-sex weanling pigs (PIC 327 × 1050; 13.3 ± 2.4 lb BW and 21 d of age) were used in a 31-d experiment. There were 11 replicate pens per treatment and 6 or 7 pigs in each pen. At weaning, pigs were allotted to pens by initial weight to 1 of 4 treatments in a completely randomized design. Each pen contained a 4-hole, dry self-feeder (4 ft × 5 ft) and a nipple waterer to provide ad libitum access to feed and water.

A 3-phase diet series was used with treatment diets fed during Phase 1 (d 0 to 7) and Phase 2 (d 7 to 21), with a common diet fed from d 21 to 31 (Table 1). All diets were manufactured at the O. H. Kruse Feed Mill in Manhattan, KS. Phase 1 was fed in pelleted form, whereas Phase 2 and the common diet were provided in meal form. Experimental protein sources were provided by Nutraferma (North Sioux City, SD) and shipped to Kansas State University prior to diet manufacturing. The nutrient values used for diet formulation for PSG1 and PSG2 were assumed to be similar to the regular PepSoyGen that was provided by Nutraferma. After diet manufacturing, the products were analyzed for amino acid profile (Table 2) and proximate analysis at the University of Missouri Agricultural Experiment Station Chemical Laboratories (Columbia, MO). The 4 dietary treatments were: (1) negative control (no specialty protein source); (2) positive control (4% DPS 50 + 1% PepSoyGen), with PepSoyGen manufactured according to the standard process; (3) PepSoyGen processing method 1 (PSG1; 5%);

and (4) PepSoyGen processing method 2 (PSG2; 5%). Spray-dried whey was added to all diets at 25 and 10% for Phases 1 and 2, respectively. The soybean meal level for the negative control diet was 38.5 and 40.9%, whereas diets 2 to 4 contained 28.5 and 30.9% for Phases 1 and 2, respectively. The alternative PepSoyGen processing methods incorporated a proprietary additive included post-fermentation at increasing levels (PSG2 > PSG1) aimed at further breakdown of anti-nutritional factors associated with soybean meal. Average daily gain, ADFI, and F/G were calculated by weighing pigs and determining feed disappearance on d 0, 7, 14, 21, and 31 (Table 3).

Results were analyzed as a completely randomized design. Treatment means were analyzed using the LSMEANS statement of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Least squares means were calculated for each independent variable, and means were considered significant at $P < 0.05$ and tendencies at $0.05 < P < 0.10$.

Results and Discussion

For nutrient analyses, the positive control diet with DPS 50/PepSoyGen combined in a 4:1 ratio generally matched formulated concentrations; however, crude protein and crude fat levels in PSG1 and PSG2 were lower and Ca was higher than formulated levels. Matching the lower analyzed CP content, lysine, methionine, and threonine levels in PSG1 and PSG2 were lower than formulated, but other amino acids generally matched formulated concentrations. Between the two processing methods, amino acid levels were generally 10% lower in PSG1 than in PSG 2.

During Phase 1 (d 0 to 7), pigs fed positive control diets had improved ($P < 0.01$) ADG and feed efficiency compared with pigs fed the negative control. Pigs fed PSG1 and PSG2 were intermediate for feed efficiency but tended ($P < 0.07$) to have increased ADG compared with pigs fed the negative control diet. There were no differences in ADFI. For Phase 2 (d 7 to 21), there were no significant differences for ADG, ADFI, or feed efficiency among treatment diets. For the period when experimental diets were fed (d 0 to 21), pigs fed the positive control diet and PSG2 diets had improved ADG ($P < 0.05$), whereas pigs fed the positive control, PSG1, and PSG2 had improved feed efficiency ($P < 0.05$) compared with pigs fed the negative control diet. Also, pigs fed PSG1 tended ($P < 0.06$) to have lower ADG compared with pigs fed the positive control diet. Feed intake was not affected by dietary treatment during the experimental diet period. During the Phase 3 common period (d 21 to 31), no difference in growth performance was reported.

Overall (d 0 to 31), ADG was greater ($P < 0.01$) for pigs fed the positive control diet and tended to be greater ($P < 0.07$) for pigs fed diets containing PSG2 compared with the negative control diet, with pigs fed PSG1 intermediate. There were no treatment differences in ADFI or feed efficiency. Pig BW differences generally matched observed ADG responses, with pigs fed the positive control diet heavier ($P < 0.02$) on d 7 and 21, whereas pigs fed PSG1 and PSG2 tended to be heavier ($P < 0.07$) on d 7 than negative controls. The weight differences were maintained through the end of the experiment, but pig BW differences were not found to be significant on d 35.

Altogether, the observed growth differences indicate that pigs fed diets containing PSG2 had greater performance than those fed the negative control diets, which did not include specialty protein sources, and performance similar to the positive control diets containing PepSoyGen and DPS 50. Numerically, pigs fed the PSG1 diet performed at a lower level than those fed the PSG2 diet but still exhibited better performance than pigs fed the negative control diet. It is unclear whether the lower CP and amino acid content in PSG1 may have contributed to its diminished growth response compared with pigs fed diets containing PSG2 or whether this result is a reflection of the difference in processing method. More research is needed to fully define the growth performance differences between pigs fed diets containing PSG1 and PSG2.

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

	Phase 1			Phase 2			Phase 3
Item	NC[2]	PC[3]	PSG[4]	NC	PC	PSG	Common
Ingredient, %							
Corn	30.1	34.8	34.8	42.3	47.0	46.9	60.9
Soybean meal, 46.5%	38.5	28.5	28.5	40.9	30.9	30.9	34.2
Spray-dried whey	25.0	25.0	25.0	10.0	10.0	10.0	-
Choice white grease	3.0	3.0	3.0	3.0	3.0	3.0	1.0
Monocalcium phosphate, 21% P	1.2	1.1	1.3	1.6	1.4	1.6	1.5
Limestone, ground	0.9	1.0	0.9	0.9	1.1	1.0	1.1
Sodium chloride	0.3	0.3	0.3	0.4	0.4	0.4	0.4
L-lysine HCl	0.1	0.2	0.2	0.1	0.3	0.3	0.3
DL-methionine	0.1	0.2	0.2	0.1	0.2	0.2	0.1
L-threonine	-	0.1	0.1	0.1	0.1	0.1	0.1
Trace mineral premix	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Vitamin premix	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Zinc oxide	0.4	0.4	0.4	0.3	0.3	0.3	0.0
DPS 50	-	4.0	-	-	4.0	-	-
PepSoyGen	-	1.0	5.0	-	1.0	5.0	-
Total	100	100	100	100	100	100	100
Calculated composition							
Standardized ileal digestible (SID) amino acids, %							
Lysine	1.35	1.35	1.35	1.35	1.35	1.35	1.25
Isoleucine:lysine	71	63	65	69	62	63	63
Leucine:lysine	130	121	126	131	122	128	128
Methionine:lysine	33	34	35	33	35	35	34
Met & Cys:lysine	58	58	58	58	58	58	58
Threonine:lysine	64	64	64	64	64	64	64
Tryptophan:lysine	21.8	18.8	19.1	21.1	18.2	18.5	18.8
Valine:lysine	73	70	70	73	70	70	68
Total lysine, %	1.50	1.50	1.50	1.51	1.51	1.51	1.40
ME, kcal/lb	1,542	1,544	1,552	1,535	1,547	1,545	1,496
SID lysine:ME, g/Mcal	3.97	3.94	3.95	3.99	3.96	3.96	3.97
CP, %	23.9	22.3	22.5	24.4	22.8	23.0	21.8
Ca, %	0.80	0.80	0.80	0.80	0.80	0.80	0.78
P, %	0.79	0.76	0.78	0.80	0.78	0.79	0.72
Available P, %	0.50	0.50	0.50	0.48	0.48	0.48	0.40

[1] Treatment diets were fed in two phases with a common Phase 3 diet. Phase 1 (d 0 to 7) diets were fed in pelleted form, and Phase 2 (d 7 to 21) and Phase 3 (d 21 to 31) diets were fed in meal form.
[2] Negative control (NC) diet formulated without fermented soybean meal.
[3] Positive control (PC) diet formulated with 4% DPS 50 (dried porcine solubles; Nutra-Flo, Sioux City, IA) and 1% PepSoyGen (Nutraferma, North Sioux City, SD).
[4] Fermented soybean meal (PSG) produced using 1 of 2 proprietary processing methods.

Table 2. Nutrient analysis of specialty protein ingredients (as-fed basis)[1]

Item	DPS 50/PepSoyGen[2]	PSG1[3]	PSG2[3]
Crude protein, %	53.00 (50.81)[4]	50.56 (54.07)	52.96 (54.07)
Crude fat, %	7.81 (8.06)	0.92 (2.30)	0.92 (2.30)
Ca, %	0.19 (0.11)	0.52 (0.37)	0.52 (0.37)
P, %	0.79 (1.28)	0.66 (0.78)	0.70 (0.78)
Amino acid content, %			
Lysine	3.66 (3.12)	2.91 (3.20)	3.14 (3.20)
Isoleucine	2.29 (1.88)	2.31 (2.21)	2.52 (2.21)
Leucine	4.09 (3.80)	3.88 (5.42)	4.17 (5.42)
Methionine	0.97 (0.86)	0.71 (0.71)	0.78 (0.71)
Cysteine	0.74 (0.87)	0.72 (0.97)	0.76 (0.97)
Threonine	2.09 (2.03)	1.85 (2.15)	2.03 (2.15)
Tryptophan	0.34 (0.38)	0.67 (0.49)	0.72 (0.49)
Valine	2.63 (2.38)	2.42 (2.32)	2.62 (2.32)

[1] Samples were analyzed at the University of Missouri Agricultural Experiment Station Chemical Laboratories in Columbia, MO.
[2] Provided at a ratio of 4 parts dried porcine solubles (DPS 50; Nutra-Flo, Sioux City, IA) to 1 part fermented soybean meal (PepSoyGen; Nutraferma, North Sioux City, SD).
[3] PSG (PepSoyGen; Nutraferma, North Sioux City, SD) produced using 1 of 2 proprietary processing methods.
[4] Values in parentheses indicate values used in diet formulation.

Table 3. Effects of PepSoyGen (PSG) processing method in diets on nursery pig growth performance[1,2]

Item	Negative control	Positive control (DPS 50 + PSG)[3]	PSG1[4]	PSG2[4]	SEM	*P* <
d 0 to 7						
ADG, lb	0.18[a,x]	0.27[b]	0.23[ab,y]	0.24[ab,y]	0.021	0.023
ADFI, lb	0.30	0.32	0.35	0.32	0.024	0.409
F/G	1.89[b]	1.14[a]	1.52[ab]	1.55[ab]	0.240	0.060
d 7 to 21						
ADG, lb	0.66	0.72	0.67	0.70	0.022	0.166
ADFI, lb	0.98	1.00	0.95	0.97	0.025	0.478
F/G	1.49	1.41	1.42	1.39	0.032	0.120
d 0 to 21						
ADG, lb	0.50[a]	0.57[b,y]	0.52[ab,x]	0.55[b]	0.018	0.029
ADFI, lb	0.75	0.78	0.75	0.76	0.021	0.749
F/G	1.51[b]	1.36[a]	1.43[a]	1.38[a]	0.038	0.002
d 21 to 31						
ADG, lb	1.04	1.10	1.09	1.07	0.058	0.428
ADFI, lb	1.67	1.82	1.79	1.74	0.065	0.157
F/G	1.60	1.65	1.64	1.62	0.043	0.588
Overall (d 0 to 31)						
ADG, lb	0.68[a,x]	0.75[b]	0.71[ab]	0.72[ab,y]	0.018	0.053
ADFI, lb	1.05	1.12	1.09	1.08	0.026	0.316
F/G	1.55	1.50	1.53	1.49	0.020	0.106
BW, lb						
d 0	13.3	13.3	13.3	13.3	0.03	0.909
d 7	14.5[a,x]	15.2[b]	14.9[ab,y]	14.9[ab,y]	0.15	0.027
d 21	23.9[a,x]	25.2[b]	24.4[ab]	24.8[ab,y]	0.37	0.091
d 31	34.5	36.3	35.4	35.7	0.63	0.144

[1] A total of 292 weanling pigs (initially 13.3 ± 2.4 lb BW) were used with 11 replicate pens per treatment and 6 or 7 pigs per pen.
[2] Treatment diets were fed in two phases with a common Phase 3 diet. Phase 1 (d 0 to 7) diets were fed in pelleted form, and Phase 2 (d 7 to 21) and Phase 3 (d 21 to 31) diets were fed in meal form.
[3] Positive control diets contained 4% dried porcine solubles (DPS 50, Nutra-Flo, Sioux City, IA) and 1% PepSoyGen (PSG; Nutra-ferma, North Sioux City, SD) during Phase 1 and 2.
[4] PSG1 and PSG2 diets contained fermented soybean meal processed using alternative methods compared with PepSoyGen. Both PSG1 and PSG2 were incorporated at 5% into Phase 1 and 2 diets.
[a,b] Within a row, means without a common superscript differ, $P < 0.05$.
[x,y] Within a row, means without a common superscript differ, $0.05 < P < 0.10$.

Evaluation of Fermented Soybean Meal Sources in Diets for Nursery Pigs[1]

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Summary

A total of 296 mixed-sex pigs (PIC 327 × 1050; 14.5 ± 3.0 lb BW and 21 d of age) were used in a 31-d experiment evaluating the effect of further processing methods for soybean meal on weanling pig growth performance. There were 11 replicate pens per treatment with 6 or 7 pigs per pen. At weaning, pigs were allotted to pens by initial weight to 1 of 4 treatments in a completely randomized design. Experimental treatments were: (1) negative control (NC: no specialty protein sources), (2) fermented soybean meal processing method 1 (FSBM 1), (3) fermented soybean meal processing method 2 (FSBM 2), and (4) enzymatically treated soybean meal (ETS). The specialty soybean meal protein sources were included in Phase 1 (d 0 to 7) and Phase 2 (d 7 to 20) diets at 5%, and diets were formulated to the same standardized ileal digestible (SID) amino acid level. All pigs were subsequently fed a common diet during Phase 3 (d 20 to 31). Phase 1 and 2 diets were fed in pellet form, whereas the Phase 3 common diet was fed in meal form. Nutrient analyses of specialty soybean meal ingredients were conducted and generally matched those used for diet formulation. From d 0 to 7, pigs fed FSBM 2 had increased ($P < 0.05$) ADG and BW compared with pigs fed ETS, whereas those fed NC and FSBM 1 were intermediate. No other differences were observed between treatments for growth or BW during the experimental period, common period, or overall. In summary, further processed soybean meal sources did not improve nursery pig growth compared with traditional soybean meal.

Key words: fermented soybean meal, nursery pig, protein sources

Introduction

Newly weaned pigs have limited ability to utilize plant protein sources because of their relatively immature digestive systems. This is why specialty animal protein sources are frequently used in diets as a source of readily available protein and amino acids; however, the high cost associated with the animal by-products creates a need for an economical plant-derived specialty protein source.

Traditional soybean meal contains high levels of intact proteins, which are not readily available to pigs' immature digestive system. Research has indicated that pigs fed fermented rather than solvent-extracted soybean meal have improved nutrient digestibility. Soybean meal fermented in the presence of *Aspergillus oryzae* and *Bacillus subtilis* (FSBM) may be used in diets fed to weanling pigs in place of specialty animal proteins without negatively affecting ME or NE of the diet or the standardized ileal digestibility

[1] Appreciation is expressed to Nutra-Flo (Sioux City, IA) for partial financial support.
[2] Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University.

(SID) of amino acids (Rojas and Stein, 2013[3]; Cervantes-Pahm 2010[4]). The fermentation process is thought to reduce trypsin inhibitors and some oligosaccharides that have been shown to decrease pig performance, but most research has indicated that soy proteins cannot fully replace animal protein sources postweaning and maintain equal pig growth performance (Jones et al., 2008[5]). Consequently, the objective of this study was to determine the impact of partially replacing conventional soybean meal with fermented or enzymatically treated soybean meal on nursery pig growth performance.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The trial was conducted at the K-State Swine Teaching and Research Center in Manhattan, KS.

A total of 296 mixed-sex pigs (PIC 327 × 1050; 14.5 ± 3.0 lb BW and 21 d of age) were used in a 31-d experiment. There were 11 replicate pens per treatment with 6 or 7 pigs per pen. At weaning, pigs were allotted to pens by initial weight to 1 of 4 dietary treatments in a completely randomized design. Each pen (4 ft × 5 ft) contained a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water.

The four dietary treatments were: (1) negative control (NC: no specialty protein sources), (2) fermented soybean meal processing method 1 (FSBM 1), (3) fermented soybean meal processing method 2 (FSBM 2), and (4) enzymatically treated soybean meal (ETS). Both FSBM products were manufactured using solid-state fermentation. FSBM processing methods differed from a previous experiment (see "Effects of PepSoyGen Processing Method on Nursery Pig Growth Performance," p. 27) because separate patented bacteria strains were utilized in the fermentation process. FSBM 1, FSBM 2, and ETS were included at 5% in the treatment diets. Nutrient profiles and SID amino acid digestibility coefficients for FSBM 1 and FSBM 2 were provided by the manufacturer. The SID amino acid coefficients for ETS were from NRC (2012[6]).

A three-phase diet (Table 1) series was used with treatment diets fed during Phase 1 (d 0 to 7) and Phase 2 (d 7 to 20), and a common diet was fed during Phase 3 (d 20 to 31). All diets were manufactured at the K-State O.H. Kruse Feed Technology Innovation Center. Phases 1 and 2 were fed in pelleted form, whereas the common diet was provided in meal form. Experimental protein sources were provided by Nutraferma (North Sioux City, SD) and shipped to Kansas State University prior to diet manufacturing. All specialty proteins were analyzed for amino acid profile and proximate analysis (Table 2) at the University of Missouri Agricultural Experiment Station Chemical Laboratories (Columbia, MO). Diet samples were collected from the feeders for each dietary phase and sent for proximate analysis (Table 3) at Ward Laboratories, Inc.

[3] Rojas, O.J., and H.H. Stein. 2013. Concentration of digestible, metabolizable, and net energy and digestibility of energy and nutrients in fermented soybean meal, conventional soybean meal, and fish meal fed to weanling pigs. J. Anim. Sci. 91:4397–4405.
[4] Cervantes-Pahm, S.K., and H.H. Stein. 2010. Ileal digestibility of amino acids in conventional, fermented and enzyme-treated soybean meal and in soy protein isolate, fish meal, and casein fed to weanling pigs. J. Anim. Sci. 88:2674–2683.
[5] Jones et al., Swine Day 2008. Report of Progress 1001, pp. 52–61.
[6] NRC, 2012. Nutrient Requirements of Swine, 11th ed. Natl. Acad. Press, Washington, DC.

(Kearney, NE). Average daily gain, ADFI, and F/G were calculated by weighing pigs and determining feed disappearance on d 0, 7, 14, 20, and 31 (Table 4).

Results were analyzed as a completely randomized design. One replicate pen from the NC treatment was determined to be an outlier (F/G > 2 SD from the mean) on d 7, and this data point was therefore removed from the dataset. Treatment means were analyzed using the LSMEANS statement with pen as the experimental unit. Least squares means were calculated for each independent variable, and means were considered significant at $P < 0.05$ and tendencies at $0.05 < P < 0.10$.

Results and Discussion

Nutrient analyses (Table 3) of experimental diets generally matched formulated levels for CP and amino acids. Given the similar nutrient content between FSBM 1 and FSBM 2, it is unlikely that any growth performance differences observed between processing methods are due to differences in essential amino acid concentrations.

For Phase 1 (d 0 to 7), pigs fed FSBM 2 had improved ($P < 0.05$; Table 4) ADG compared with ETS, whereas pigs fed the NC and FSBM 1 diets were intermediate. No differences in ADFI or feed efficiency were detected across treatments. Accordingly, pigs fed FSBM 2 were heavier ($P < 0.05$) than those fed ETS at d 7. During Phase 2 (d 7 to 20) and the common diet period (d 20 to 31), no growth performance differences were observed between treatment, and pig weights were similar on d 14, 20, and 31. Overall (d 0 to 31), there were no significant differences between treatments for ADG, ADFI, or feed efficiency.

Although the greater ADG seen for FSBM 2 compared with ETS in Phase 1 appears promising within treatments containing specialty proteins, the lack of a response in Phase 2 and overall appears to indicate a limited impact of processing method on overall nursery performance. Moreover, in the present study, pigs fed a negative control diet without specialty proteins performed similarly to those fed diets containing various further-processed soybean meal products. Many studies have demonstrated growth benefits when incorporating high-quality animal protein sources in early nursery diets. This benefit is thought to be the result of reducing the amount of soybean meal that may contain less digestible nutrients or anti-nutritional factors for the young pig; however, the present study failed to indicate any benefit of additional soybean meal processing to improve performance compared with pigs fed diets containing traditional soybean meal. Nevertheless, the postweaning period remains challenging for the young pig and warrants further investigation of plant-based protein source alternatives.

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

	Phase 1				Phase 2				Phase 3
Item	NC[2]	FSBM 1[3]	FSBM 2[3]	ETS[4]	NC[2]	FSBM 1[3]	FSBM 2[3]	ETS[4]	Common
Ingredient, %									
Corn	30.10	34.73	34.70	34.70	42.26	46.92	46.89	46.87	60.88
Soybean meal, 46.5%	38.50	28.50	28.50	28.50	40.92	30.89	30.92	30.90	34.20
Spray dried whey	25.00	25.00	25.00	25.00	10.00	10.00	10.00	10.00	-
Choice white grease	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00
Monocalcium phosphate	1.23	1.28	1.30	1.30	1.55	1.60	1.60	1.65	1.50
Limestone, ground	0.85	0.85	0.85	0.85	0.93	0.95	0.95	0.93	1.13
Sodium chloride	0.30	0.30	0.30	0.30	0.35	0.35	0.35	0.35	0.35
L-lysine HCl	0.09	0.24	0.23	0.24	0.14	0.30	0.29	0.29	0.30
DL-methionine	0.13	0.18	0.18	0.18	0.13	0.18	0.18	0.18	0.14
L-threonine	0.04	0.09	0.10	0.10	0.07	0.13	0.14	0.14	0.11
L-valine	-	0.04	0.04	0.04	-	0.04	0.04	0.04	-
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
Zinc oxide	0.40	0.40	0.40	0.40	0.26	0.26	0.26	0.26	-
FSBM 1	-	5.00	-	-	-	5.00	-	-	-
FSBM 2	-	-	5.00	-	-	-	5.00	-	-
ETS	-	-	-	5.00	-	-	-	5.00	-
Total	100	100	100	100	100	100	100	100	100
Calculated composition									
Standardized ileal digestible (SID) amino acids, %									
Lysine	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.25
Isoleucine:lysine	71	65	65	65	69	63	63	63	63
Methionine:lysine	33	35	35	35	33	35	35	35	34
Met & Cys:lysine	58	58	58	58	58	58	58	58	58
Threonine:lysine	64	64	64	64	64	64	64	64	62
Tryptophan:lysine	21.8	19.1	19.7	19.5	21.1	18.5	19.0	18.9	18.8
Valine:lysine	73	70	70	70	73	70	70	70	68
Total lysine, %	1.50	1.50	1.50	1.49	1.51	1.51	1.51	1.51	1.40
ME, kcal/lb	1,542	1,552	1,546	1,546	1,535	1,545	1,539	1,539	1,496
SID lysine:ME, g/Mcal	3.97	3.95	3.96	3.96	3.99	3.96	3.98	3.98	3.79
CP, %	23.9	22.5	22.5	22.5	24.4	23.0	23.0	23.0	21.8
Ca, %	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.78
P, %	0.79	0.78	0.78	0.78	0.80	0.79	0.79	0.80	0.72
Available P, %	0.50	0.51	0.51	0.51	0.48	0.49	0.49	0.49	0.40

[1] Experimental diets were fed in two phases with a common Phase 3 diet. Phase 1 (d 0 to 7) and Phase 2 (d 7 to 20) diets were fed in pelleted form, whereas Phase 3 (d 21 to 31) diets were in meal form.
[2] Negative control (NC) diet formulated without the addition of specialty proteins.
[3] Fermented soybean meal (FSBM) produced using 1 of 2 proprietary processing methods.
[4] Enzymatically treated soybean meal (ETS).

Table 2. Nutrient analysis of basal ingredients (as-fed basis)[1]

Item	FSBM 1[2]	FSBM 2[2]	ETS[3]
Crude protein, %	52.57 (54.07)[4]	53.95 (54.07)	51.09 (54.07)
Amino acid content, %			
Lysine	3.25 (3.20)	3.19 (3.36)	3.07 (3.10)
Isoleucine	2.41 (2.21)	2.43 (2.16)	2.31 (2.16)
Leucine	4.19 (5.42)	4.18 (5.42)	3.91 (5.42)
Methionine	0.73 (0.71)	0.72 (0.67)	0.67 (0.67)
Cysteine	0.74 (0.97)	0.78 (0.74)	0.70 (0.74)
Threonine	2.13 (2.15)	2.01 (1.85)	1.91 (1.85)
Tryptophan	0.73 (0.49)	0.69 (0.65)	0.70 (0.65)
Valine	2.50 (2.32)	2.52 (2.27)	2.41 (2.27)

[1] Samples were analyzed at the University of Missouri Agricultural Experiment Station Chemical Laboratories in Columbia, MO.
[2] Fermented soybean meal (Nutraferma) produced using 1 of 2 proprietary processing methods.
[3] Enzymatically treated soybean meal (ETS).
[4] Values in parentheses indicate those used for diet formulation.

Table 3. Nutrient analysis of experimental diets (as-fed basis)[1]

	Phase 1				Phase 2				Phase 3
Ingredient, %	Negative control	FSBM 1[2]	FSBM 2[2]	ETS[3]	Negative control	FSBM 1[2]	FSBM 2[2]	ETS[3]	Common
CP	24.0	22.9	22.7	22.5	24.4	23.3	22.9	23.5	22.0
Ca	0.85	0.87	0.84	0.79	0.79	0.84	0.90	0.79	0.69
P	0.76	0.75	0.76	0.75	0.73	0.74	0.77	0.77	0.58
Ash	7.06	6.98	6.85	6.81	6.35	6.28	6.42	6.26	5.01

[1] Samples were analyzed at Ward Laboratories, Inc. (Kearney, NE).
[2] Fermented soybean meal (Nutraferma, North Sioux City, SD) produced using 1 of 2 proprietary processing methods.
[3] Enzymatically treated soybean meal (ETS).

Table 4. Effects of soybean meal further processing method on nursery pig growth performance[1,2]

Item	Negative control	FSBM 1[3]	FSBM 2[3]	ETS[4]	SEM	Probability, *P*<
Phase 1 (d 0 to 7)						
ADG, lb	0.17[ab]	0.16[ab]	0.21[b]	0.14[a]	0.018	0.073
ADFI, lb	0.38	0.36	0.36	0.31	0.033	0.315
F/G[5]	2.31	2.30	1.75	2.59	1.123	0.417
Phase 2 (d 7 to 20)						
ADG, lb	0.84	0.85	0.83	0.88	0.025	0.425
ADFI, lb	1.11	1.10	1.09	1.10	0.031	0.969
F/G	1.32	1.28	1.32	1.23	0.041	0.155
Experimental period (d 0 to 20)						
ADG, lb	0.61	0.61	0.61	0.62	0.020	0.914
ADFI, lb	0.86	0.84	0.84	0.82	0.026	0.822
F/G	1.41	1.37	1.36	1.31	0.050	0.167
Common period (d 20 to 31)						
ADG, lb	1.12	1.06	1.12	1.07	0.063	0.301
ADFI, lb	1.81	1.75	1.77	1.77	0.085	0.838
F/G	1.61	1.66	1.58	1.65	0.028	0.159
Overall (d 0 to 31)						
ADG, lb	0.79	0.77	0.80	0.79	0.022	0.811
ADFI, lb	1.19	1.16	1.17	1.16	0.042	0.761
F/G	1.51	1.51	1.47	1.48	0.027	0.456
Pig BW, lb						
d 0	14.4	14.3	14.3	14.1	0.39	0.315
d 7	15.5[ab]	15.5[ab]	15.8[b]	15.1[a]	0.44	0.104
d 14	20.4	20.6	20.8	20.4	0.58	0.748
d 20	26.6	26.8	26.7	26.8	0.44	0.995
d 31	38.9	38.4	39.0	38.5	1.02	0.871

[1] A total of 296 barrows and gilts (PIC 327 × 1050; initially 14.5 ± 3.0 lb and 21 d of age) were used in a 31-d experiment with 11 replicate pens per treatment and 6 or 7 pigs per pen.
[2] Treatment diets were fed in two phases. Phase 1 (d 0 to 7) and Phase 2 (d 7 to 20) diets were fed in pelleted form, whereas diets were in meal form during Phase 3 (d 20 to 31).
[3] Fermented soybean meal 1 (FSBM 1) and fermented soybean meal 2 (FSBM 2) were incorporated at 5% into Phase 1 and 2 diets.
[4] Enzymatically treated soybean meal incorporated at 5% into Phase 1 and 2 diets.
[5] For feed efficiency from d 0 to 7, one outlier pen was removed from the dataset.
[a,b] Within a row, means without a common superscript differ, $P < 0.05$.

Evaluation of Different Oil Sources for Nursery Pigs[1]

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Summary

A total of 210 pigs (PIC 327 × 1050, initially 28.9 lb BW) were used in a 21-d trial to evaluate the effects of increasing oil sources on nursery pig growth performance. The 2 oil sources included a commercial source of soybean oil and a proprietary source of corn oil originating from the ethanol industry (Corn Oil ONE, Feed Energy Co., Pleasant Hill, IA). The 5 experimental diets included: a control diet without added oil, diets with 2.5 or 5% added soybean oil, or diets with 2.5 and 5% added corn oil. Diets were formulated with an identical standardized ileal digestible lysine:calorie ratio and were fed in meal form. There were 6 pens per treatment with 7 pigs per pen.

Overall, from d 0 to 21, no oil source × level interactions were observed. Increasing corn oil or soybean oil had no effect on ADG or final BW. Increasing corn oil or soybean oil decreased (linear, $P < 0.05$) ADFI, which resulted in improved (linear, $P < 0.01$) F/G. Caloric efficiency was not affected by oil source or level. Feed cost per pig tended to decrease (linear, $P = 0.066$) for pigs fed increasing levels of soy oil. Cost per pound of gain decreased for both Corn Oil ONE (linear, $P = 0.032$) and soybean oil (linear, $P = 0.008$) as oil level increased. Value of the weight gain and income over feed cost was similar for pigs fed diets with Corn Oil ONE and soybean oil ($P = 0.833$).

This study shows the benefits of adding a dietary oil source in late-phase nursery diets to achieve improved feed efficiency. Corn Oil ONE is a suitable alternative for soybean oil, and cost and availability should dictate which source is used.

Key words: corn oil, growth performance, nursery pig, soybean oil

Introduction

Soybean or corn oil can be added to nursery pig diets as highly digestible sources of energy. Because of the high price of soybean or corn oil, feed manufactures have often chosen to include other less expensive fat sources in swine diets, but the recent adoption of fat extraction from dried distillers grains with solubles (DDGS) at ethanol plants has made corn oil more available and economical.

Corn Oil ONE is a proprietary source of high-quality, refined corn oil supplied by Feed Energy Company (Pleasant Hill, IA) that has lower concentrations of free fatty acids and waxes than crude corn oil. Corn Oil ONE is typically a more economical source of energy than soy oil; however, no data are available to compare the impacts on growth performance of pigs fed diets containing increasing levels of soy oil compared with

[1] Appreciation is expressed to Feed Energy, Des Moines, IA, for partial financial support and for donating the specialty corn oil source.

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

Corn Oil ONE. Therefore, the objective of this study is to compare Corn Oil ONE and commercially available soy oil on nursery pig growth performance, caloric efficiency, and economics.

Procedures

The protocol for this experiment was approved by the Kansas State University Institutional Animal Care and Use Committee. This experiment was conducted in the nursery facility at the Kansas State University Swine Teaching and Research Center in Manhattan, KS. The facility is a totally enclosed, environmentally controlled, mechanically ventilated barn. Each pen contains a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water. Pens have wire-mesh floors and allow approximately 3 ft^2/pig.

A total of 210 pigs (PIC 327 × 1050, initially 28.9 lb BW) were used in a 21-d trial. Pigs were randomly allotted to 1 of 5 dietary treatments with 6 pens per treatment with 7 pigs per pen. Pigs were weaned from 18 to 25 d of age with weaning age balanced across treatments and were fed a common diet before the start of the experiment. Pig weight and feed disappearance were measured on d 7, 14, and 21 of the trial to determine ADG, ADFI, and F/G. In addition, caloric efficiency was calculated by using the Kcal of ME consumed divided by Kg of gain. The energy values used for soybean (ME = 3,889 kcal/kg; NE = 3,422) and corn oil (ME = 3,891; NE = 3,424) sources were used to calculate the caloric efficiency.

All dietary treatments were corn-soybean meal–based and fed in meal form (Table 1). The 5 experimental diets were: (1) no added fat control diet, diets with (2) 2.5 or (3) 5% added soybean oil, and diets with (4) 2.5 or (5) 5% added corn oil. Diet samples were collected and analyzed for DM, CP, Ca, P, and oil (Ward Laboratories, Inc., Kearney, NE). All diets were balanced with an identical standardized ileal digestible lysine:calorie ratio. Current ingredient prices at the time of the study were used in an economic comparison with soybean oil at $0.40/lb and corn oil at 0.39/lb.

Data were analyzed as a randomized complete block design using PROC MIXED in SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Weaning age was included in the model as a random effect. The effects of increasing oil within source were determined by linear and quadratic contrasts. In addition, a comparison was made between the diets containing added oil from either corn or soybean oil. Treatment differences were considered significant at $P \leq 0.05$ and a tendency from $P > 0.05$ to $P \leq 0.10$.

Results and Discussion

Quality attributes of the two oil sources (Table 2) were similar to expectations and did not differ meaningfully between sources. Complete diet analysis (Table 3) was similar to formulated expectations.

Overall (d 0 to 21), no oil source × level interactions were observed (Tables 4 and 5). Increasing soybean or corn oil had no effect on ADG or final BW. Average daily feed intake decreased (linear, $P < 0.03$) with increasing oil source, which resulted in an improvement (linear, $P < 0.01$) in F/G. Caloric efficiency was not influenced by oil

source or level, indicating that the energy values assigned to each oil source (NE = 3,422 kcal/lb and NE = 3,383 kcal/lb for soybean oil and corn oil, respectively) were accurate. Total feed cost per pig tended to decrease (linear, $P = 0.066$) for pigs fed increasing soybean oil, but cost per pound of gain decreased $P < 0.032$) for both oil sources. Value of the weight gain and income over feed cost was similar among pigs fed corn oil and soybean oil.

In conclusion, adding the dietary oil sources used in this study improved F/G. There were no differences in performance among pigs fed either soybean oil or corn oil. The source of corn oil (Corn Oil ONE) used in this study is a suitable alternative for soybean oil, and cost and availability should dictate its use.

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

Item	Control	2.5% Oil	5% Oil
Ingredient, %			
Corn	63.58	58.56	53.52
Soybean meal (47.5% CP)	32.65	35.20	37.75
Oil source[2]	--	2.50	5.00
Monocalcium phosphate	1.30	1.28	1.28
Limestone	1.08	1.08	1.05
Salt	0.35	0.35	0.35
L-lysine-HCl	0.32	0.31	0.30
DL-methionine	0.13	0.14	0.15
L-threonine	0.12	0.12	0.13
Trace mineral premix	0.15	0.15	0.15
Vitamin premix	0.25	0.25	0.25
Phytase[3]	0.08	0.08	0.08
Total	100.00	100.00	100.00
Calculated analysis			
Standardized ileal digestible (SID) amino acids, %			
Lysine	1.23	1.28	1.33
Isoleucine:lysine	62	63	63
Leucine:lysine	128	126	124
Methionine:lysine	34	34	34
Met & Cys:lysine	57	57	57
Threonine:lysine	63	63	63
Tryptophan:lysine	18.4	18.7	19.0
Valine:lysine	68	68	68
Total lysine, %	1.38	1.43	1.49
ME, kcal/lb	1,478	1,536	1,594
NE[4], kcal/lb	1,089	1,137	1,186
SID lysine:ME, g/Mcal	3.78	3.78	3.78
CP, %	21.3	22.1	22.9
Ca, %	0.73	0.73	0.73
P, %	0.68	0.68	0.68
Available P, %	0.45	0.45	0.45

[1] Experimental diets were fed for 21-d beginning approximately 42 d after weaning.
[2] Corn Oil ONE™, Feed Energy, Des Moines, Iowa.
[3] Natuphos 600 (BASF, Florham Park, NJ) provided 204.3 phytase units (FTU)/lb, with a release of 0.09% available P.
[4] NRC. 2012. Nutrient Requirements of Swine, 11th ed. Natl. Acad. Press, Washington, DC.

Table 2. Chemical analysis of oil sources[1]

Item	Soybean oil	Corn Oil ONE
Free fatty acids, %	0.46	1.29
Initial peroxide value (meq/kg)	14.0	16.9
Moisture, %	0.32	0.64
Insoluble impurities, %	0.18	0.04
Unsaponifiables, %	0.41	1.52

[1]Samples were analyzed by Midwest Laboratories, Inc. (Omaha, NE).

Table 3. Chemical analysis of experimental diets[1]

		Added oil, %			
	Control	Soybean oil		Corn Oil ONE	
Item	0	2.5	5	2.5	5
DM, %	89.59	89.64	90.52	89.97	90.05
CP, %	23.7	23.9	25.1	24.1	24.5
Ca, %	0.91	0.96	0.91	0.83	0.91
P, %	0.78	0.73	0.73	0.69	0.71
Oil, %	2.9	5.1	7.4	4.6	7.1

[1] Samples were collected, homogenized, and subsampled for analysis at Ward Laboratories, Inc. (Kearney, NE).

Table 4. Comparison of soybean oil vs. corn oil on nursery pig performance[1]

		Added oil, %					Probability, $P <$				
	Control	Soybean oil		Corn oil			Soybean oil		Corn oil		Soybean oil
Item	0	2.5	5.0	2.5	5.0	SEM	Linear	Quadratic	Linear	Quadratic	vs. corn oil
d 0 to 21											
ADG, lb	1.42	1.44	1.40	1.42	1.41	0.028	0.600	0.314	0.936	0.861	0.965
ADFI, lb	2.18	2.16	1.96	2.08	2.01	0.052	0.007	0.164	0.033	0.837	0.805
F/G	1.54	1.50	1.40	1.47	1.42	0.019	< 0.01	0.225	<0.01	0.574	0.711
BW, lb											
d 0	29.0	29.0	29.0	29.1	29.1	1.16	0.995	0.994	0.935	0.989	0.929
d 21	58.7	59.2	58.3	58.8	58.8	1.42	0.812	0.656	0.982	0.946	0.965
Caloric efficiency[2]	1,672	1,704	1,664	1,667	1,686	48.9	0.798	0.194	0.654	0.653	0.735
Feed cost,$/pig	11.54	11.65	10.77	11.22	11.04	0.282	0.066	0.159	0.223	0.840	0.766
Feed cost, $/lb gain	0.39	0.39	0.37	0.38	0.37	0.005	0.008	0.219	0.032	0.582	0.636
Gain value[3], $/pig	25.00	25.44	24.63	25.08	24.94	0.496	0.600	0.314	0.936	0.861	0.965
IOFC[4], $/pig	13.47	13.79	13.86	13.86	13.90	0.295	0.354	0.734	0.300	0.627	0.833

[1] A total of 210 pigs (PIC 327 × 1050) were used in a 21-d study with 7 pigs per pen and 6 pens per treatment.
[2] Caloric efficiency = Kcal of NE per pound of gain ((ADFI × NE/lb) /ADG).
[3] Gain value was calculated using (Final BW × $84.00/cwt) – (initial BW × $84.00/cwt).
[4] Income over feed cost = carcass gain value – feed cost.
[5] Ingredient cost, soybean oil $0.40/lb, Corn Oil ONE $0.39/lb, corn $0.14/lb, and soybean meal $0.25/lb.
[6] There were no significant source × level interactions.

Table 5. Main effects of oil source and level

	Oil source		Oil level, %				Probability, $P <$ Level	
Item	Soybean oil	Corn Oil ONE	0	2.5	5	SEM	Linear	Quadratic
d 0 to 21								
ADG, lb	1.42	1.42	1.42	1.43	1.41	0.020	0.727	0.437
ADFI, lb	2.06	2.05	2.18	2.12	1.99	0.036	0.006	0.430
F/G	1.45	1.44	1.54	1.48	1.41	0.014	< 0.01	0.663
CE[1]	1,684	1,676	1,671	1,685	1,675	34.641	0.912	0.570
BW, lb								
d 0	29.02	29.10	29.03	29.04	29.08	0.94	0.966	0.989
d 21	58.74	58.79	58.71	59.03	58.50	1.06	0.901	0.736
Feed cost, $/pig	11.21	11.13	11.54	11.44	10.90	0.199	0.079	0.422
$/lb gain	0.38	0.37	0.39	0.38	0.37	0.004	0.007	0.649
Gain value[2], $/pig	25.03	25.01	25.00	25.26	24.79	0.351	0.727	0.438
IOFC[3], $/pig	13.82	13.89	13.47	13.83	13.88	0.209	0.258	0.589

[1] Caloric efficiency = Kcal of NE per pound of gain ((ADFI × NE/lb) / ADG).
[2] Gain value was calculated using (Final BW × $84.00/cwt) – (initial BW × $84.00/cwt).
[3] Income over feed cost = carcass gain value – feed cost.

Comparison of Soybean Oil and Different Sources of Corn Oil on Nursery Pig Growth Performance

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Summary

A total of 350 pigs (PIC 1050; initially 26.45 ± 0.09 lb and 45 d of age) were used in a 21-d study to compare the effects of soy oil and 2 sources of corn oil on nursery pig growth performance. The 7 dietary treatments consisted of a corn-soybean meal–based control diet with no added oil or the control diet with 2.5 or 5% soybean oil (NE = 3,422 kcal/lb) or corn oil from 2 different sources (NE = 3,383 kcal/kg for both sources). There were 5 pigs per pen and 10 pens per treatment. Pig weight and feed disappearance were measured on day 0, 7, 14, and 21 of the trial to determine ADG, ADFI, and F/G.

Overall (d 0 to 21), increasing corn or soybean oil improved (linear; $P < 0.02$) ADG, F/G, and final (d-21) BW, but a source × level interaction was observed ($P < 0.05$) for ADG, F/G, and caloric efficiency (CE; caloric intake/total BW gain). For ADG, increasing soy oil or corn oil source 1 from 2.5 to 5% increased ADG, whereas increasing corn oil source 2 from 2.5 to 5% decreased ADG. Feed efficiency also improved at a greater rate for pigs fed increasing corn oil source 1 compared with the other oil sources. Caloric efficiency was not influenced by soy oil or corn oil source 2 but was improved (linear, $P < 0.05$) as corn oil source 1 increased in the diet. The improved CE for corn oil source 1 indicated that the energy value of this source was underestimated. In conclusion, soybean or corn oil improved ADG and F/G as expected; however, growth performance varied among the 3 oil sources. This study shows the benefits of adding an oil source in late-phase nursery pig diets to achieve improved ADG, F/G, and CE, but more research is needed to determine the cause of the varied responses between corn oil sources.

Key words: corn oil, growth performance, nursery pig, soybean oil

Introduction

Soybean oil can be added to nursery pig diets as a highly digestible source of energy, but feed manufactures often choose to include other sources of dietary energy because of the oil's high price. Corn oil is a more economical source of dietary fat than soybean oil because of increased oil extraction during the ethanol manufacturing process; however, few data are available to compare the impacts on growth performance of pigs fed diets containing soybean oil compared with corn oil. Furthermore, corn oil derived from different ethanol production facilities may influence pig growth performance differ-

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ently because of the oil extraction techniques utilized, but no data are available to test this assumption. Therefore, the objective of this study was to compare the influence of different corn oil sources and commercially available soybean oil on growth performance of nursery pigs.

Procedures

The protocol for this experiment was approved by the Kansas State University Institutional Animal Care and Use Committee. The study was conducted at the Kansas State University Segregated Early Weaning Facility in Manhattan, KS. The facility is a totally enclosed, environmentally controlled, mechanically ventilated barn. Each pen was equipped with a 4-hole stainless steel dry self-feeder and a cup waterer for ad libitum access to feed and water. Pens (4 × 4 ft) had wire-mesh floors and deep pits for manure storage.

A total of 350 pigs (PIC 1050; initially 26.45 ± 0.09 lb and 45 d of age) were used in a 21-d study. The 7 dietary treatments consisted of a corn-soybean meal–based control diet with no added oil or the control diet with 2.5 or 5% soybean oil (NE = 3,422 kcal/kg; NRC, 2012[2]) or corn oil from 2 sources (NE = 3,383 kcal/kg for both sources; NRC, 2012). Corn oil 1 was sourced from the Poet plant in Sioux Falls, SD, and corn oil 2 was from the Green Plains Renewable Energy plant in Shenandoah, IA. Commercially purchased soybean oil was from unknown sources. All diets were formulated to balance for the same lysine:ME ratio (Table 1). Diets were fed in meal form and were manufactured at the K-State O.H. Kruse Feed Technology Innovation Center. Pig weight and feed disappearance were measured on d 0, 7, 14, and 21 of the trial to determine ADG, ADFI, F/G, and caloric efficiency (caloric intake/total BW gain). There were 5 pigs per pen and 10 pens (replications) per treatment.

Samples of each oil source were collected at feed manufacturing and were analyzed for fatty acid profile; moisture, insoluble impurities and unsaponifiables (MIU); free fatty acids; and peroxide value. Samples were analyzed by NOVUS Laboratories, Inc. (St. Louis, MO). Multiple samples of each diet were collected from feeders, blended and subsampled, and submitted to Ward Laboratories, Inc. (Kearney, NE) for analysis of DM, CP, crude fat, Ca, and P (Table 2).

Data were analyzed as a randomized complete block design using PROC MIXED in SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Barn was used as a blocking factor, and block within barn was included in the model as a random effect. Results from the experiment were considered significant at $P < 0.05$ and a tendency between $P > 0.05$ and $P \leq 0.10$.

Results and Discussion

Complete diet analysis was similar to formulated nutrient levels. Quality characteristics of the 3 oil sources (Table 3) showed variation in some of the measurements. For free fatty acids, soybean oil, as expected, was very low, with corn oil having higher levels but not to the degree of concern for swine diets. In initial peroxide value, however, soybean oil had an elevated level that was much higher than general guidelines for fats for swine, and MIU exhibited minor differences among oil sources.

[2] NRC, 2012. Nutrient Requirements of Swine, 11th ed. Natl. Acad. Press, Washington DC.

For overall growth performance(d 0 to 21), increasing corn or soybean oil improved (linear; $P < 0.02$) ADG, F/G, and final (d 21) BW; however, a source × level interaction was observed ($P < 0.05$) for ADG, F/G, and caloric efficiency (Table 4). For ADG, increasing soybean oil or corn oil source 1 from 2.5 to 5% increased ADG, whereas increasing corn oil source 2 from 2.5 to 5% decreased ADG. The interaction for F/G was because F/G improved at a greater rate for pigs fed increasing levels of corn oil source 1 compared with the other oil sources. Caloric efficiency was not influenced by soy oil or corn oil source 2 but improved (linear, $P < 0.05$) as corn oil source 1 increased in the diet. The improved CE for corn oil source 1 indicated that the net energy value of this source was underestimated in diet formulation.

In conclusion, soybean or corn oil increased ADG and F/G as expected. Our data also suggest that there may be differences in corn oil sources, and additional research should be conducted to further define the impact of corn oil source on growth performance of pigs. Overall, this study confirms the benefits of adding an oil source in late-phase nursery pig diets to achieve improved ADG and F/G.

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

Ingredient, %	Control	2.5% oil	5% oil
Corn	63.58	58.56	53.52
Soybean meal (46.5% CP)	32.65	35.20	37.75
Oil source[2]	--	2.50	5.00
Monocalcium phosphate, (21% P)	1.30	1.28	1.28
Limestone	1.08	1.08	1.05
Salt	0.35	0.35	0.35
L-lysine-HCl	0.32	0.31	0.30
DL-methionine	0.13	0.14	0.15
L-threonine	0.12	0.12	0.13
Trace mineral premix	0.15	0.15	0.15
Vitamin premix	0.25	0.25	0.25
Phytase[3]	0.08	0.08	0.08
Total	100.00	100.00	100.00
Calculated analysis			
Standardized ileal digestible (SID) amino acids, %			
Lysine	1.23	1.28	1.33
Isoleucine:lysine	62	63	63
Leucine:lysine	128	126	124
Methionine:lysine	34	34	34
Met & Cys:lysine	57	57	57
Threonine:lysine	63	63	63
Tryptophan:lysine	18.4	18.7	19.0
Valine:lysine	68	68	68
Total lysine, %	1.38	1.43	1.49
ME, kcal/lb	1,478	1,536	1,594
NE NRC, kcal/lb	1,089	1,137	1,186
SID lysine:ME, g/Mcal	3.77	3.78	3.78
CP, %	21.3	22.1	22.9
Ca, %	0.73	0.73	0.73
P, %	0.68	0.68	0.68
Available P, %	0.45	0.45	0.45

[1] Experimental diets were fed for 21 d beginning approximately 42 d after weaning.
[2] Corn oil source 1 (Poet, Sioux Falls, SD), Corn oil source 2 (Green Plains Renewable Energy, Shenandoah, IA), and soybean oil were commercially contracted.
[3] Natuphos 600 (BASF, Florham Park, NJ) provided 204.3 phytase units (FTU)/lb, with a release of 0.09% available P.

Table 2. Chemical analysis of experimental diets[1]

		Added oil, %					
	Control	Soybean oil		Corn oil 1[2]		Corn oil 2[3]	
Item	0	2.5	5	2.5	5	2.5	5
DM, %	89.87	90.38	90.59	90.38	90.62	90.64	90.57
CP, %	21.90	22.80	23.70	21.60	23.40	22.50	23.20
Ca, %	1.05	0.90	0.89	1.03	1.06	0.92	0.98
P, %	0.69	0.64	0.70	0.67	0.71	0.65	0.65
Crude fat, %	2.80	4.90	7.20	4.90	7.70	4.40	5.70

[1] Multiple samples were collected from each diet throughout the study, homogenized, then subsampled for analysis at Ward Laboratories, Inc. (Kearney, NE).
[2] Corn oil source 1 (Poet, Sioux Falls, SD).
[3] Corn oil source 2 (Green Plains Renewable Energy, Shenandoah, IA).

Table 3. Chemical analysis of oil sources[1]

Item	Soybean oil	Corn oil 1[2]	Corn oil 2[3]
Free fatty acids, %	0.16	4.10	11.80
Initial peroxide value, (meq/kg)	47.60	1.00	5.60
Moisture, %	0.05	0.55	0.45
Insoluble impurities, %	0.03	0.07	0.02
Unsaponifiables, %	0.53	1.76	1.86

[1] Samples were analyzed by NOVUS Laboratories, Inc. (St. Louis, MO).
[2] Corn oil source 1 (Poet, Sioux Falls, SD).
[3] Corn oil source 2 (Green Plains Renewable Energy, Shenandoah, IA).

Table 4. Comparison of different levels and sources of oil on nursery pig performance[1]

		Added oil, %							Probability, $P <$					
	Control	Soybean oil		Corn oil 1[2]		Corn oil 2[3]			Soybean oil		Corn oil 1		Corn oil 2	
Item	0	2.5	5	2.5	5	2.5	5	SEM	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic
d 0 to 21														
ADG, lb[a]	1.39	1.50	1.53	1.46	1.48	1.46	1.44	0.028	<0.01	0.196	0.020	0.562	0.199	0.236
ADFI, lb[a,b]	2.23	2.26	2.22	2.16	2.08	2.16	2.08	0.045	0.939	0.482	0.020	0.959	0.025	0.898
F/G[b]	1.60	1.51	1.46	1.48	1.40	1.49	1.44	0.025	<0.01	0.347	<0.01	0.513	<0.01	0.152
BW, lb														
d 0	26.49	26.39	26.45	26.40	26.40	26.39	26.41	0.813	0.832	0.650	0.678	0.772	0.692	0.73
d 21[a]	55.78	58.28	58.48	56.99	57.69	56.97	56.70	0.824	0.005	0.149	0.045	0.745	0.330	0.360
CE[4bc]	1,740	1,712	1,726	1,682	1,663	1,689	1,714	63.930	0.645	0.428	0.013	0.446	0.381	0.143

[1] A total of 350 pigs (PIC 1050) were used in a 21-d study with 5 pigs per pen and 10 pens per treatment.
[2] Corn oil source 1 (Poet, Sioux Falls, SD).
[3] Corn oil source 2 (Green Plains Renewable Energy, Shenandoah, IA).
[4] Caloric efficiency = Kcal of NE per pound of gain ((ADFI × NE/lb) /ADG)).
[a] Source × level interaction (soybean oil × corn oil 1); $P < 0.05$.
[b] Source × level interaction (soybean oil × corn oil 2); $P < 0.05$.
[c] Source × level interaction (corn oil 1 × corn oil 2); $P < 0.10$.

Effects of an Algae-Modified Montmorillonite Clay on Growth Performance of Nursery Pigs Fed Diets Contaminated with Low Levels of Deoxynivalenol[1]

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Summary

A total of 360 barrows (PIC 1050; initially 25.1 lb and 45 d of age) were used in a 21-d growth trial to evaluate the effects of an algae-modified montmorillonite clay (AMMC) on nursery pig performance when fed diets contaminated with low levels of deoxynivalenol (DON). Pigs were allotted to pens by weight, and pens were randomly assigned to 1 of 9 dietary treatments arranged in a 3 × 3 factorial with main effects of DON (0, 1.5 ppm, or 3.0 ppm) and AMMC inclusion (0, 0.17%, or 0.50%). There were 5 pigs per pen and 8 pens per treatment. Mycotoxin analyses were conducted on the main ingredients at NDSU[3] and LDA Labs[4], and the results were used in diet formulation. Naturally contaminated wheat (6.03 ppm DON) was used to produce diets with desired DON levels. No significant DON × AMMC interactions were observed during the entire study. Overall (d 0 to 21), increasing DON concentration in the diet decreased (1.22 vs. 1.10 vs. 1.07 lb; linear, $P < 0.001$) ADG and d-21 BW as a result of decreased ADFI (2.13 vs. 2.05 vs. 2.11 lb; quadratic, $P < 0.01$) and poorer feed efficiency (1.49 vs. 1.50 vs. 1.64; linear, $P < 0.001$). As expected, DON-related growth reductions were most marked from d 0 to 7 (15 to 22% lower) and least distinct in the final period, d 14 to 21 (5 to 6% lower). Incorporating AMMC at increasing levels had no effect on ADG, ADFI, feed efficiency, or final BW. Overall, the results of this study reinforce prior research showing that even low levels of DON significantly reduce nursery pig growth, but the addition of AMMC does not offset the deleterious effects of DON.

Keywords: deoxynivalenol, montmorillonite clay, nursery pigs, vomitoxin

Introduction

Deoxynivalenol (DON), also known as vomitoxin, is a mycotoxin commonly found in wheat, corn, and other cereal grains. During wet, cool periods of the growing season, *Fusarium graminearum* forms a head blight, producing DON as a secondary metabolite. Because DON occurs frequently and at toxicologically relevant concentrations and pigs are the most susceptible livestock species, it is one of the most important mycotoxins for swine producers to be aware of. At low concentrations (<1 ppm), DON causes decreased feed intake and upregulation of the immune system; at high levels (>10 ppm), it can cause complete feed refusal and vomiting. Deoxynivalenol remains challenging

[1] Appreciation is expressed to Olmix N.A. (Black River Falls, WI) for partial financial support.
[2] Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University.
[3] North Dakota State University Veterinary Diagnostic Laboratory, Fargo, ND.
[4] LDA Labs, Ploufragan, France.

for livestock producers because commonly used detoxifying agents such as bentonite clay and activated aluminosilicates, which are known to be effective against aflatoxins, are largely ineffective against DON. These additives may be ineffective against DON because the DON molecule is too large to become trapped within the clay matrix. However, it is hypothesized that an algae-modified montmorillonite clay (AMMC), which uses a patented process (Amadeite; Olmix, Brehan, France) to incorporate algae polysaccharides and expand the layers of the clay, may alleviate the growth reductions associated with feeding DON-contaminated grains. Therefore, the objective of this study was to evaluate the effects of currently recommended levels of AMMC on the growth performance of nursery pigs fed diets containing low levels of DON.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The trial was conducted at the K-State Segregated Early Weaning Facility in Manhattan, KS. A total of 360 barrows (PIC 1050; 25.1 ± 0.5 lb and 45 d of age) were used in a 21-d experiment with 8 replicate pens per treatment and 5 pigs per pen.

Pigs were shipped to the facility immediately postweaning and placed in 2 identical nurseries, each containing 40 pens (5 ft × 5 ft). Upon arrival, pigs were placed in pens by weight and fed a common diet until approximately 25 lb.

On d 0, pigs were re-weighed and pens were randomly assigned to 1 of 9 dietary treatments in a 3 × 3 factorial arrangement with DON and AMMC inclusion as main effects (Table 1). The 9 dietary treatments consisted of 3 positive control (PC) diets without DON with 0, 0.17%, or 0.50% AMMC added, 3 low negative control (Low NC; 1.5 ppm DON) diets with 0, 0.17%, or 0.50% AMMC, and 3 high negative control (High NC; 3 ppm DON) diets with 0, 0.17%, or 0.50% AMMC. The AMMC that was supplied by Olmix N.A. (Black River Falls, WI) is typically recommended to be included at 0.17% and was added at the expense of corn in diet formulation. Diets exceeded NRC (2012[5]) nutrient requirements, and apart from the inclusion of DON and AMMC were formulated to be identical in nutrient composition.

Diets were manufactured in meal form at the K-State O. H. Kruse Feed Mill in Manhattan, KS. Hard red winter wheat naturally contaminated with DON was sourced (Table 2; 6.03 ppm DON) and incorporated into diets to achieve desired dietary DON levels. Prior to diet manufacturing, a total of 60 subsamples were collected from both a high-DON and DON-free wheat source. These samples were homogenized and split into duplicate samples, which were then sent for mycotoxin analysis at NDSU (North Dakota State University Veterinary Diagnostic Laboratory, Fargo, ND) and LDA Labs (Ploufragan, France). The lab at NDSU conducted an 18-component toxin screen using a combination of mass spectrometry, ELISA, and HPLC. LDA Labs performed a 43-component toxin screen using high-pressure liquid chromatography/mass spectrometry analyses. Due to concerns that high-DON wheat may also have a different amino acid profile than DON-free wheat, both wheat sources were analyzed for amino acid content (Table 3) at the University of Missouri Agricultural Experiment Station Chemical Laboratories (Columbia, MO), and diet formula-

[5] NRC. 2012. Nutrient Requirements of Swine. 11th ed. Natl. Acad. Press, Washington, DC.

tion was adjusted to account for the differences. Following final diet manufacturing, diet samples were sent to NDSU and the University of Missouri for mycotoxin (Table 4) and proximate analysis (Table 5).

Average daily gain, ADFI, and F/G were determined by weighing pigs and determining feed disappearance on d 0, 7, 14, and 21 (Tables 6 and 7). Each pen contained a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water.

Data were analyzed using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with the main effects and their interactions serving as fixed effects and barn as a random effect. Means were evaluated using preplanned linear and quadratic orthogonal contrasts. The coefficients for the unequally spaced linear and quadratic contrasts were derived using the IML procedure in SAS. Least squares means were calculated for each independent variable. Results were considered significant if *P*-values were ≤ 0.05 and tendencies if 0.05 > and $P \leq 0.10$.

Results and Discussion

Proximate and amino acid analysis of DON-contaminated wheat revealed protein and amino acid levels marginally but consistently higher than the DON-free wheat source. *Fusarium* pathogens are known to not only produce secondary metabolites such as mycotoxins but also alter the nutrient content of the affected grain source.[6] Because these alterations in nutrient content are inconsistent, it is critical to account for these differences in diet formulation to assess the true impact of mycotoxin contamination on animal performance.

In the present study, analyzed DON concentrations in the naturally DON-contaminated wheat differed between NDSU (8.4 ppm) and LDA Labs (6.03 ppm). Although very low levels of several other mycotoxins were detected in the DON-contaminated wheat source, the levels observed were below concentrations necessary to elicit reductions in animal performance due to individual toxin exposure; however, the impact of interactive effects between toxins cannot be completely excluded. To ensure that final diet DON levels were adequate to achieve a DON-associated reduction in performance, the analysis from LDA Labs was used as the basis for diet formulation. Analyzed DON in the final diets revealed levels that were within 20% of the targeted DON level, averaging 1.73 and 3.20 ppm for the 1.5 and 3.0 ppm targets, respectively. Furthermore, proximate analyses of the final diets were generally in line with formulated levels.

Regarding growth performance, a tendency for a DON × AMMC interaction (linear, $P < 0.10$) was observed for d 0 to 7, where increasing AMMC tended to improve ADG in PC and low-NC diets but tended to decrease ADG in high-NC diets. This interaction for ADG appeared to be driven by a tendency for a F/G interaction (linear, $P < 0.10$) in which increasing AMMC inclusion worsened feed efficiency in high-NC diets whereas feed efficiency remained similar in pigs fed PC and low-NC diets regardless of AMMC inclusion. Furthermore, a tendency for a DON × AMMC interaction for feed efficiency (quadratic, $P < 0.10$) was observed from d 14 to 21 and overall (d 0 to 21),

[6] Matthaus, K., S. Danicke, W. Vahjen, O. Simon, J. Wang, H. Valenta, K. Meyer, A. Strumpf, H. Ziesenib, and G. Flachowsky. 2004. Progression of mycotoxin and nutrient concentrations in wheat after inoculation with *Fusarium culmorum*. Arch. Anim. Nutr. 58:19–35.

where increasing AMMC in PC and low-NC diets worsened feed efficiency, whereas in high-NC diets increasing AMMC initially improved but subsequently worsened F/G at the 0.50% inclusion rate.

For the main effects of DON on nursery pig growth, results matched expected reductions in ADG, where pigs experienced the most deleterious effects of DON during the initial exposure period and seemed to attenuate somewhat over time. During d 0 to 7, ADG decreased (linear, $P < 0.001$) as DON was increased in diets, driven by both a decrease in feed intake (linear, $P < 0.001$) and a worsening of feed efficiency (linear, $P < 0.001$). These responses were expected because they are known to be associated with upregulation of the immune system during initial exposure. From d 7 to 14, reduced feed intake (quadratic, $P < 0.001$) continued to drive ADG lower (linear, $P < 0.001$) in pigs fed increasing concentrations of DON. However, increasing DON in the diets improved (quadratic, $P < 0.01$) feed efficiency, which may be attributed to improved nutrient utilization at such low feed intake. Nevertheless, from d 14 to 21, the previously observed negative effects of DON on nursery pig growth were less marked. Although there was a tendency for reduced ADG (linear, $P < 0.10$) as DON increased, ADFI and feed efficiency were similar across treatments. Overall (d 0 to 21), increasing DON concentration in nursery pig diets caused a reduction in ADG and BW (linear, $P < 0.001$), which was driven by lower ADFI (quadratic, $P < 0.01$) and poorer feed efficiency (quadratic, $P = 0.01$).

Although increasing DON in nursery pig diets resulted in the expected reductions in growth necessary to evaluate the potential effectiveness of a DON-detoxifying agent, the addition of AMMC at 0.17 and 0.50% did not affect ADG, ADFI, feed efficiency, or final pig BW during the experimental period.

In conclusion, although AMMC does not appear to offset the deleterious effects of low levels of DON in nursery pig diets, the results of this study indicate that minimizing DON contamination in swine diets is critical, because even low dietary levels (1.5 to 3.0 ppm) can result in growth performance reductions of 10% or greater. Correcting suboptimal field conditions to minimize DON concentration is impractical, so additional research is necessary to identify practical and effective methods to reduce the negative effects of deoxynivalenol postharvest.

Table 1. Formulated diet composition (as-fed basis)

	Positive control (0 ppm DON[1])			Low negative control (1.5 ppm DON)			High negative control (3.0 ppm DON)		
Item AMMC[2] level:	None	0.17%	0.50%	None	0.17%	0.50%	None	0.17%	0.50%
Ingredient, %									
Corn	15.07	14.89	14.53	15.35	15.17	14.81	15.63	15.45	15.09
Soybean meal (46.5% CP)	31.58	31.60	31.62	31.25	31.26	31.29	30.92	30.93	30.96
Hard red winter (HRW) wheat	50.00	50.00	50.00	25.00	25.00	25.00	-	-	-
High-DON[3] HRW wheat	-	-	-	25.00	25.00	25.00	50.00	50.00	50.00
Monocalcium P, 21% P	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Limestone	1.00	1.00	1.00	1.05	1.05	1.05	1.10	1.10	1.10
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
L-lysine HCl	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
DL-methionine	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
L-threonine	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Vitamin premix with phytase[4]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
AMMC	-	0.17	0.50	-	0.17	0.50	-	0.17	0.50
Total	100	100	100	100	100	100	100	100	100
Calculated composition, %									
Standardized ileal digestible (SID) amino acids, %									
Lysine	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28
Isoleucine:lysine	64	64	64	65	65	65	65	65	65
Leucine:lysine	118	118	117	118	118	118	117	117	117
Methionine:lysine	31	31	31	31	31	31	31	31	31
Met & Cys:lysine	57	57	57	57	57	57	57	57	57
Threonine:lysine	63	63	63	63	63	63	63	63	63
Tryptophan:lysine	21.2	21.2	21.2	20.7	20.7	20.7	20.3	20.3	20.2
Valine:lysine	68	68	68	69	69	69	70	70	70
Total lysine, %	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43
ME, kcal/lb	1,444	1,442	1,436	1,443	1,441	1,436	1,443	1,440	1,435
SID lysine:ME, g/Mcal	4.02	4.03	4.04	4.02	4.03	4.04	4.02	4.03	4.05
CP, %	22.7	22.7	22.6	22.6	22.6	22.6	22.6	22.6	22.6
Ca, %	0.68	0.68	0.68	0.69	0.69	0.69	0.71	0.71	0.71
P, %	0.68	0.68	0.68	0.69	0.69	0.69	0.71	0.71	0.70
Available P, %	0.50	0.50	0.50	0.51	0.51	0.51	0.51	0.51	0.51
DON, ppm	<0.5	<0.5	<0.5	1.5	1.5	1.5	3.0	3.0	3.0

[1] Deoxynivalenol (DON).
[2] AMMC algae-modified montmorillonite clay product (Olmix, Brehan, France).
[3] Analyzed DON concentration in wheat was 6.03 ppm at LDA Laboratories (Ploufragan, France).
[4] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 750 phytase units (FTU) phytase/kg and 0.13% available P released.

Table 2. Mycotoxin analysis of basal ingredients

		Hard red winter wheat	
Item, ppm	Ground corn	DON-free	High-DON[1]
NDSU[2]			
DON	<0.50	<0.50	8.40
LDA Labs[3]			
DON	---[4]	---	6.03
De-epoxy DON	---	---	0.02
15-O-Acetyl DON	---	---	0.07
3-Acetyl DON	---	---	0.03
Zearalenone	---	---	0.02
HT-2 Toxin	---	---	0.02
Ergocryptin	---	---	0.08
Ergosin	---	---	0.02
Tenuazonic acid	---	---	0.05

[1] Deoxynivalenol (DON).
[2] North Dakota State University Veterinary Diagnostic Laboratory (Fargo, ND). Samples were sent for 18-component mycotoxin analysis and analyzed using a variety of mass spectrometry, ELISA, and HPLC methods. Included in the table are mycotoxins found at levels above detection limits.
[3] LDA Labs (Ploufragan, France). Samples analyzed using a 43-component toxin screen using liquid chromatography/mass spectrometry analysis methods. Included in the table are mycotoxins found at levels above detection limits.
[4] (---) indicates samples were not tested.

Table 3. Nutrient analysis of basal ingredients (as-fed basis)[1]

	Hard red winter wheat	
Item, %	DON-free	High-DON[2]
Moisture	9.14	10.20
Crude protein	11.80	12.20
ADF	3.20	2.50
NDF	8.10	10.30
Crude fat	1.80	2.00
Ash	1.81	1.84
Ca	0.07	0.06
P	0.38	0.44
Amino acid analysis		
Lysine	0.40	0.44
Isoleucine	0.41	0.47
Leucine	0.84	0.87
Methionine	0.21	0.22
Cysteine	0.27	0.27
Threonine	0.36	0.38
Tryptophan	0.15	0.17
Valine	0.57	0.47

[1] Samples were analyzed at the University of Missouri Agricultural Experiment Station Chemical Laboratories (Columbia, MO).
[2] Deoxynivalenol (DON).

Table 4. Mycotoxin analysis of experimental diets (as-fed basis)[1]

	Positive control (0 ppm DON[2])			Low negative control (1.5 ppm DON)			High negative control (3.0 ppm)		
Item AMMC[3] level:	None	0.17%	0.50%	None	0.17%	0.50%	None	0.17%	0.50%
DON, ppm	<0.5	<0.5	<0.5	1.7	1.8	1.7	3.4	2.7	3.5

[1] Diet samples were analyzed at North Dakota State University Veterinary Diagnostic Laboratory (Fargo, ND). An 18-component mycotoxin analysis was conducted using a variety of mass spectrometry, ELISA, and HPLC methods. Included in the table are mycotoxins found at levels above detection limits.
[2] Deoxynivalenol (DON).
[3] AMMC. Algae-modified montmorillonite clay (Olmix, Brehan, France).

Table 5. Nutrient analysis of experimental diets (as-fed basis)[1]

	Positive control (0 ppm DON[2])			Low negative control (1.5 ppm DON)			High negative control (3.0 ppm)		
Item, % AMMC level[3]:	None	0.17%	0.50%	None	0.17%	0.50%	None	0.17%	0.50%
Moisture	9.77	9.60	9.93	10.04	9.77	9.89	9.97	9.66	9.75
Crude protein	24.9	23.8	24.2	23.4	23.2	23.3	23.5	23.7	23.5
ADF	2.6	2.4	2.1	2.7	3.5	2.2	2.5	2.6	2.6
NDF	7.6	7.0	7.5	7.6	8.0	7.4	6.8	7.2	7.2
Crude fat	2.4	2.6	2.5	2.6	2.9	2.6	2.6	2.8	2.7
Ash	5.14	5.31	5.53	5.53	5.61	5.57	5.65	5.73	5.96
Ca	0.71	0.81	0.82	0.86	0.83	0.76	0.87	0.83	0.89
P	0.74	0.67	0.68	0.69	0.69	0.71	0.69	0.71	0.74

[1] Samples were analyzed at the University of Missouri Agricultural Experiment Station Chemical Laboratories (Columbia, MO).
[2] Deoxynivalenol (DON).
[3] AMMC. Algae-modified montmorillonite clay (Olmix, Brehan, France).

Table 6. Effects of an algae-modified montmorillonite clay (AMMC) on growth performance of nursery pigs fed diets contaminated with low levels of deoxynivalenol (DON)[1]

DON level[2]:	Positive control (0 ppm DON)			Low negative control (1.5 ppm DON)			High negative control (3.0 ppm DON)				Probability, $P <$	
											DON × AMMC	
Item AMMC[3] level:	None	0.17%	0.50%	None	0.17%	0.50%	None	0.17%	0.50%	SEM	Linear	Quadratic
d 0 to 7												
ADG, lb	0.92	0.86	0.94	0.77	0.75	0.81	0.75	0.74	0.64	0.041	0.053	0.849
ADFI, lb	1.38	1.38	1.40	1.23	1.24	1.29	1.22	1.21	1.16	0.043	0.235	0.803
F/G	1.49	1.61	1.50	1.62	1.67	1.62	1.66	1.66	1.84	0.060	0.065	0.766
d 7 to 14												
ADG, lb	1.27	1.26	1.32	1.18	1.08	1.16	1.07	1.06	1.12	0.071	0.987	0.315
ADFI, lb	1.56	1.68	1.63	1.52	1.42	1.48	1.27	1.35	1.30	0.118	0.258	0.843
F/G	1.23	1.34	1.23	1.29	1.31	1.29	1.18	1.26	1.14	0.087	0.332	0.676
d 14 to 21												
ADG, lb	1.48	1.52	1.44	1.47	1.38	1.33	1.41	1.42	1.41	0.046	0.527	0.277
ADFI, lb	2.12	2.11	2.15	2.05	2.06	2.03	2.16	2.03	2.14	0.187	0.851	0.424
F/G	1.43	1.39	1.50	1.40	1.51	1.54	1.53	1.43	1.52	0.132	0.391	0.063
d 0 to 21												
ADG, lb	1.23	1.21	1.23	1.14	1.07	1.10	1.08	1.07	1.06	0.032	0.618	0.268
ADFI, lb	1.78	1.81	1.86	1.65	1.63	1.67	1.79	1.68	1.75	0.057	0.300	0.884
F/G	1.45	1.50	1.51	1.45	1.53	1.52	1.67	1.57	1.67	0.063	0.570	0.090
Pig weight, lb												
d 0	25.1	25.2	25.2	25.1	25.1	25.2	25.2	25.1	25.1	0.53	0.965	0.996
d 7	31.6	31.2	31.8	30.5	30.4	30.8	30.4	30.3	29.6	0.68	0.415	0.936
d 14	40.5	40.0	41.0	38.8	37.9	39.0	37.9	37.7	37.4	0.86	0.523	0.662
d 21	50.8	50.6	51.1	49.1	47.5	48.3	47.7	47.6	47.3	1.05	0.740	0.488

[1] A total of 360 barrows (PIC 1050; initially 25.1 lb and approximately 45 d of age) were used in a 21-d experiment with 8 replicate pens per treatment and 5 pigs per pen. All diets were fed in meal form.
[2] Denotes formulated levels. Wheat naturally contaminated with DON (6.03 ppm) was used to incorporate DON into diets at desired concentrations.
[3] AMMC. Algae-modified montmorillonite clay (Olmix, Brehan, France).

Table 7. Main effects of deoxynivalenol (DON) and algae-modified montmorillonite clay (AMMC) on nursery pig performance[1]

	Formulated DON level[2], ppm				AMMC[3] level, %				Probability, $P <$			
									DON		AMMC	
Item	0	1.5	3.0	SEM	None	0.17%	0.50%	SEM	Linear	Quadratic	Linear	Quadratic
d 0 to 7												
ADG, lb	0.91	0.77	0.71	0.026	0.81	0.78	0.80	0.026	<0.001	0.188	0.747	0.353
ADFI, lb	1.39	1.25	1.19	0.021	1.27	1.28	1.28	0.021	<0.001	0.181	0.789	0.979
F/G	1.53	1.63	1.72	0.057	1.59	1.65	1.65	0.057	<0.001	0.848	0.261	0.396
d 7 to 14												
ADG, lb	1.28	1.14	1.08	0.060	1.17	1.13	1.20	0.060	<0.001	0.218	0.747	0.148
ADFI, lb	1.62	1.48	1.30	0.091	1.45	1.48	1.47	0.091	0.764	<0.001	0.650	0.293
F/G	1.26	1.30	1.20	0.050	1.23	1.30	1.22	0.050	<0.001	<0.01	0.616	0.916
d 14 to 21												
ADG, lb	1.48	1.39	1.41	0.027	1.45	1.44	1.39	0.027	0.087	0.103	0.652	0.935
ADFI, lb	2.13	2.05	2.11	0.178	2.11	2.06	2.11	0.178	0.754	0.166	0.545	0.370
F/G	1.44	1.48	1.49	0.126	1.46	1.44	1.52	0.126	0.199	0.592	0.741	0.310
d 0 to 21												
ADG, lb	1.22	1.10	1.07	0.020	1.15	1.12	1.13	0.020	<0.001	0.053	0.644	0.292
ADFI, lb	1.82	1.65	1.74	0.038	1.74	1.71	1.76	0.038	0.357	<0.01	0.629	0.233
F/G	1.49	1.50	1.64	0.050	1.52	1.53	1.57	0.050	<0.001	0.010	0.120	0.790
Pig weight, lb												
d 0	25.1	25.1	25.1	2.55	25.1	25.1	25.2	2.55	0.999	0.979	0.968	0.998
d 7	31.5	30.6	30.1	3.23	30.8	30.6	30.7	3.23	0.013	0.583	0.922	0.709
d 14	40.5	38.5	37.7	4.35	39.0	38.5	39.1	4.35	<0.001	0.376	0.772	0.406
d 21	50.8	48.3	47.6	5.38	49.2	48.6	48.9	5.38	<0.001	0.220	0.789	0.510

[1] A total of 360 barrows (PIC 1050; initially 25.1 lb and approximately 45 d of age) were used in a 21-d experiment with 24 replicate pens per treatment and 5 pigs per pen. All diets were fed in meal form.
[2] Denotes formulated levels. Wheat naturally contaminated with DON (6.03 ppm) was used to incorporate DON into diets at desired concentrations.
[3] AMMC. Algae-modified montmorillonite clay (Olmix, Brehan, France).

Effects of Algae-Derived β-Glucans with Zinc on Nursery Pig Growth Performance and Immune Response Under Commercial Conditions[1,2]

M.A.D. Goncalves[3], S.S. Dritz[3], J.M. DeRouchey, M.D. Tokach, R.D. Goodband, and J.C. Woodworth

Summary

An experiment was conducted to determine the impact of increasing levels of Algamune ZPC (Algal Scientific Corporation, Plymouth, MI) on growth performance and porcine circovirus type 2 (PCV2)-specific immune response of nursery pigs housed under commercial conditions. Algamune ZPC is a polysaccharide-zinc complex feed additive composed of 35% β-1,3-glucan extracted from algae and 10% zinc. A total of 2,484 pigs (PIC 337 × 1050, initially 15.7 lb) were used in a 40-d trial. After feeding a common pelleted diet for 7 d after weaning, pigs were allotted to 1 of 6 dietary treatments in a randomized complete block design with 14 or 16 replicate pens and 27 pigs per pen. All pigs were vaccinated with PCV2 and *M. hyopneumoniae* vaccines (1 mL Fostera PCV and 1 mL Respisure-One; Zoetis, Florham Park, NJ) at d 3 after birth and at weaning. Blood samples of 72 pigs (12 pens per treatment) were collected on d 2, 18, and 38. The 6 experimental diets were fed in two phases (d 0 to 12 and 12 to 40). Dietary treatments included: a negative control diet fed in both phases (1,910 and 110 ppm of zinc oxide in Phase 1 and 2, respectively); the negative control diet with 104, 208, 423, and 625 ppm added Algamune ZPC for both Phase 1 and Phase 2; and a negative control diet with 423 ppm added Algamune ZPC fed during phase Phase 1 followed by the negative control in Phase 2.

From d 0 to 40, increasing Algamune ZPC tended to decrease then increase (quadratic, $P = 0.09$) ADG and increase (linear, $P = 0.10$) ADFI. No differences were observed in F/G. There were no differences ($P > 0.54$) in ADG, ADFI or F/G in pigs fed 423 ppm Algamune ZPC in both phases compared with pigs fed 423 ppm Algamune ZPC only in Phase 1 and the negative control diet fed in Phase 2. The lowest removal rates were observed among pigs assigned to 423 ppm Algamune ZPC only in Phase 1 or in both phases (0 and 0.27%, respectively). No evidence of differences was detected in PCV2-neutralizing antibody titers on d 16, but the titers decreased on d 38 (linear, $P = 0.04$) with increasing Algamune ZPC.

In conclusion, including up to 625 ppm of Algamune ZPC in nursery pig diets from 16 to 56 lb had minimal impact on growth performance. Also, modulation of the specific immune response to PCV2 on d 38 after weaning was negatively related to increasing Algamune ZPC under commercial conditions.

Key words: β-glucans, immune response, nursery

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[2] Appreciation is expressed to New Horizon Farms for use of pigs and facilities and to Lanny Bosma, Shannon Paulson, and Marty Heintz for technical assistance.
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Introduction

Feed additives that could modulate the immune response of nursery pigs may serve as an alternative to growth-promoting antimicrobials. β-glucans are polysaccharides containing only glucose and are found as cellulose in plants; cell walls of yeast, fungi, or bacteria; and bran of cereal grains. Research has shown that dietary inclusion of 0.025% of yeast-derived β-glucans in nursery pig diets increased ADG, ADFI, and pig BW on d 28 after weaning (Dritz et al., 1995[4]). In addition, pigs fed 0.025% β-glucans had an increased mortality rate compared with pigs fed the negative control or 0.05% β-glucans, but Li et al. (2006[5]) observed an improvement in the immune system of pigs fed yeast-derived β-glucans. Most research has been performed with β-glucans extracted from specific yeast cell wall components. A new product, Algamune ZPC (Algal Scientific Corporation, Plymouth, MI), contains β-glucans extracted from algae and is a polysaccharide-zinc complex (35% β-1,3-glucan and 10% zinc).

Therefore, the objective of this experiment was to determine the impact of Algamune ZPC on growth performance, removal rate, and PCV2-specific immune response of nursery pigs housed under commercial conditions.

Procedures

The protocol for this experiment was approved by the Kansas State University Institutional Animal Care and Use Committee.

The study was conducted at a commercial research nursery in southwestern Minnesota. The facility was totally enclosed, environmentally controlled, and mechanically ventilated. Pens were distributed across 2 rooms and had completely slatted flooring and deep pits for manure storage. Each pen was equipped with a 5-hole stainless steel dry self-feeder and a pan waterer for ad libitum access to feed and water. Daily feed additions to each pen were accomplished through a robotic feeding system (FeedPro; Feedlogic Corp., Willmar, MN) capable of providing and measuring feed amounts for individual pens. A total of 2,484 pigs (PIC 337 × 1050, initially 15.7 lb BW) were used in a 40-d trial. Pigs were weaned at 19 d of age and were initially fed a common pelleted diet for 7 d before the start of the experiment. On d 7 after weaning, pigs were weighed and pens of pigs were allotted to 1 of 6 dietary treatments in a randomized complete block design. Each treatment had 14 or 16 replicate pens and 27 pigs per pen, with each pen containing a mix of barrows and gilts.

All pigs were vaccinated with porcine circovirus type 2 (PCV2) and *M. hyopneumoniae* vaccines (1 mL Fostera PCV and 1 mL Respisure-One; Zoetis, Florham Park, NJ) on d 3 after birth and at weaning. Blood samples of 72 pigs (12 pens per treatment, 1 pig per pen) were collected on d 2, 18, and 38 of the trial and were submitted to the Kansas State Veterinary Diagnostic Laboratory to measure PCV2 antibody titers using indirect immunofluorescence (IFA) assay.

[4] Dritz, S.S., J. Shi, T.L. Kielian, R.D. Goodband, J.L. Nelssen, M.D. Tokach, M.M. Chengappa, J.E. Smith, and F. Blecha. 1995. Influence of dietary beta-glucan on growth performance, nonspecific immunity, and resistance to *Streptococcus suis* infection in weanling pigs. J. Anim. Sci. 73:3341–3350.
[5] Li, J., D.F. Li, J.J. Xing, Z.B. Cheng, and C.H. Lai. 2006. Effects of β-glucans extracted from *Saccharomyces cerevisiae* on growth performance, and immunological and somatotropic responses of pigs challenged with *Escherichia coli* lipopolysaccharide. J. Anim. Sci. 84:2374–2381.

All dietary treatments were corn-soybean meal–based with 5% select menhaden fish meal, 10% spray-dried whey, and 10% dried distillers grains with solubles (DDGS) in Phase 1 and 20% DDGS in Phase 2 (Table 1). Phase 1 diets were fed for 12 days, and Phase 2 diets were fed for 28 days. Algamune ZPC was added at the expense of corn. The 6 experimental diets included a negative control diet fed in both phases (1,910 and 110 ppm of zinc oxide in Phases 1 and 2, respectively); or the negative control diets with 104, 208, 423, or 625 ppm added Algamune ZPC for both Phase 1 and Phase 2; and the negative control diet with 423 ppm added Algamune ZPC fed during phase Phase 1, followed by the negative control diet without any added Algamune ZPC fed in Phase 2. To provide the diets with intermediate levels of β-glucans, the negative control diet and the 625 ppm Algamune ZPC were blended using the robotic feeding system. Diets were fed in meal form and were manufactured at the New Horizon Farms Feed Mill (Pipestone, MN). Pig weight and feed disappearance were measured on d 0, 7, 12, 20, 26, 33, and 40 of the trial to determine ADG, ADFI, and F/G. Pig inventory was continually monitored to determine removal rate and mortality.

Diet samples were taken from 6 feeders per dietary treatment on each weigh day and combined to form a composite sample within each phase. Samples of the diets were submitted to Ward Laboratories, Inc. (Kearney, NE) for analysis of DM, CP, Ca, P, ash, and crude fat.

Data were analyzed as a randomized complete block design using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. For statistical analysis of growth performance, the fixed effect was the dietary treatment, and room and weight block within room were included in the model as a random effects. The effects of increasing dietary Algamune ZPC on performance criteria were determined by linear and quadratic polynomial contrasts with coefficients adjusted for unequally spaced inclusions. A single degree of freedom contrast was used to compare performance of pigs fed 423 ppm in both phases with pigs fed 423 ppm in Phase 1 and the negative control diet in Phase 2. Results for treatment criteria were considered significant at $P \leq 0.05$ and tendencies from $P > 0.05$ to $P \leq 0.10$.

For the immune response analysis, PCV2 antibody titers were transformed by obtaining the log base 2 of the reciprocal of the highest dilution antibody detected in the sample. PCV2 antibody titer results were then analyzed using repeated measures to determine the effects of Algamune ZPC level on response criteria over time and the treatment × time interactions. The fixed effects used were dietary treatment, serum sampling period, and treatment × period interaction. Log-transformed PCV2 neutralizing antibody titers at day 2 were included as a covariate. Weight block within serum sampling period and pen within dietary treatment were included in the model as random effects.

Results and Discussion

Chemical analyses of the complete diets (Table 2) showed that, as expected, DM, CP, Ca, P, ash, and crude fat levels were similar across dietary treatments.

From d 0 to 40, increasing Algamune ZPC tended to decrease then increase (quadratic, $P = 0.09$) ADG and increased (linear, $P = 0.10$) ADFI (Table 3). No differences were observed in F/G. There were no differences in ADG, ADFI, or F/G in pigs fed 423 ppm

Algamune ZPC in both phases compared with pigs fed 423 ppm Algamune ZPC only in Phase 1 and the negative control diet in Phase 2. Hiss and Sauerwein (2003[6]) also observed a tendency for increased ADFI without changing feed efficiency when feeding β-glucans.

Although removal rates were low across all treatments compared with industry standards, the numerically lowest removal rates were in pigs assigned to the dietary treatment of 423 ppm Algamune ZPC only in Phase 1 or in both phases (0.0 and 0.27%, respectively).

No statistical differences were detected in PCV2-neutralizing antibody titers on d 16, but titers decreased on d 38 (linear, $P = 0.04$) with increasing Algamune ZPC. The mean of all bleeding periods showed a tendency (linear, $P = 0.07$) toward decreased PCV2-neutralizing antibody titers as Algamune ZPC concentration increased. This result was unexpected, because increasing β-glucans was expected to increase specific immune response, but these results agree with the study conducted by Hiss and Sauerwein (2003[6]), in which no modulation of specific immune response was observed. Cheng et al. (2004[7]) found evidence of higher activity of cell-mediated immune response in poultry when feeding β-glucans compared with control pigs. In a study conducted in weaned pigs by Li et al. (2005[8]), a modulation of both humoral and cellular immunity was observed when feeding β-glucans. This result indicates that β-glucans can improve immunity of pigs. There was no difference in PCV2-neutralizing antibody titers between pigs fed 423 ppm in both phases and pigs fed 423 ppm in Phase 1 and the negative control diet in Phase 2.

In conclusion, adding up to 625 ppm of Algamune ZPC in nursery pig diets from d 7 to 40 after weaning (16 to 56 lb BW) had minimal impact on growth performance, and modulation of the specific immune response to PCV2 on d 38 after weaning was negatively related to increasing Algamune ZPC in diets under commercial conditions. Further research is needed to evaluate the effects of Algamune ZPC on nursery pig performance and immune response in herds with a higher degree of pathogen challenge than used in this study.

[6] Hiss, S., and H. Sauerwein. 2003. Influence of dietary β-glucan on growth performance, lymphocyte proliferation, specific immune response and haptoglobin plasma concentrations in pigs. J. Anim. Phys. Anim. Nutr. 87:2–11.

[7] Cheng, Y.H., D.N. Lee, C.M. Wen, and C.F. Weng. 2004. Effects of ß-glucan supplementation on lymphocyte proliferation, macrophage chemotaxis and specific immune responses in broilers. Asian-Aust. J. Anim. Sci., 17:1145–1149.

[8] Li, J., J. Xing, D. Li, X. Wang, L. Zhao, S. Lv, and D. Huang. 2005. Effects of β-glucan extracted from *Saccharomyces cerevisiae* on humoral and cellular immunity in weaned piglets. Arch. Anim. Nutr., 59:303–312.

Table 1. Diet composition (as fed basis)

Item	Phase 1[1]		Phase 2[2]	
	Negative control	Algamune ZPC 625 ppm	Negative control	Algamune ZPC 625 ppm
Corn	44.73	44.66	45.73	45.67
Soybean meal (46.5% CP)	28.05	28.05	31.41	31.41
Dried distillers grains with solubles	10.00	10.00	20.00	20.00
Select menhaden fish meal	5.00	5.00	--	--
Spray-dried whey	10.00	10.00	--	--
Dicalcium phosphate (18.5 % P)	0.25	0.25	0.55	0.55
Limestone	0.78	0.78	1.15	1.15
Salt	0.30	0.30	0.35	0.35
L-lysine	0.28	0.28	0.45	0.45
DL-methionine	0.065	0.065	0.053	0.053
L-threonine	0.04	0.04	0.06	0.06
Zinc oxide	0.25	0.25	--	--
Trace mineral premix	0.100	0.100	0.100	0.100
Vitamin premix	0.125	0.125	0.125	0.125
Algamune ZPC[3]	--	0.0625	--	0.0625
Phytase[4]	0.038	0.038	0.025	0.025
Total	100.00	100.00	100.00	100.00
Calculated analysis				
Standardized ileal digestible (SID) amino acids, %				
Lysine	1.30	1.30	1.25	1.25
Isoleucine:lysine	68	68	69	69
Leucine:lysine	141	141	155	155
Methionine:lysine	33	33	31	31
Met & cys:lysine	57	57	57	57
Threonine:lysine	63	63	63	63
Tryptophan:lysine	19.1	19.1	19.2	19.2
Valine:lysine	75	75	77	77
Total lysine, %	1.49	1.49	1.45	1.45
ME, kcal/lb	1,504	1,503	1,492	1,491
SID Lysine:ME, g/Mcal	3.92	3.92	3.80	3.80
CP, %	24.4	24.4	24.6	24.6
Ca, %	0.73	0.73	0.67	0.67
P, %	0.64	0.64	0.56	0.56
Available P, %	0.50	0.50	0.40	0.40

[1]A common diet was fed for the first 7 d after weaning and followed by the Phase 1 diet fed from d 0 to 12 of the study.
[2] Phase 2 was fed from d 12 to 40 of the study.
[3] Algamune ZPC (Algal Scientific Corporation, Plymouth, MI) is a zinc metal polysaccharide complex that contains β-1,3-glucan from algae.
[4] OptiPhos 2000 (Huvepharma, Sheridan, IN) provided phytase at 853 and 569 phytase units (FTU)/lb with a release of 0.14% and 0.13% of available P for Phase 1 and Phase 2 diets, respectively.

Table 2. Chemical analysis of diets containing Algamune ZPC (as fed-basis)[1,2]

	Phase 1						Phase 2					
	Negative	Algamune ZPC, ppm					Negative	Algamune ZPC, ppm				
Item, %	control	104	208	423	625	423/0[3]	control	104	208	423	625	423/0[3]
DM	89.8	89.6	90.0	89.4	89.7	89.3	90.0	89.6	89.3	89.3	89.6	89.6
CP	24.5	24.7	24.5	23.9	23.5	24.0	24.0	25.0	25.4	25.5	24.5	24.5
Ca	0.82	0.85	0.83	0.83	0.79	0.86	0.79	0.80	0.78	0.83	0.83	0.83
P	0.63	0.60	0.60	0.64	0.62	0.62	0.54	0.52	0.54	0.55	0.55	0.55
Fat	3.8	3.7	3.5	3.5	3.9	3.7	3.9	3.8	3.8	3.7	4.0	4.0
Ash	5.8	6.1	6.0	6.0	5.9	6.0	5.3	5.3	5.2	5.4	5.3	5.3

[1] A composite sample consisting of 6 subsamples was performed a proximate analysis by Ward Laboratories, Inc. (Kearney, NE).
[2] Phase 1 and 2 diets were fed from d 0 to 12 and from d 12 to 40 of the study, respectively.
[3] 423 ppm of Algamune ZPC (Algal Scientific Corporation, Plymouth, MI) was fed in Phase 1 followed by the negative control diet in Phase 2.

Table 3. Effects of Algamune ZPC on nursery pig growth performance and immune response under commercial conditions[1,2]

								Probability, *P*<		
	Negative	Algamune ZPC, ppm						Algamune ZPC[3]		423 ppm entire
	control	104	208	423	625	423/0[5]	SEM	Linear	Quadratic	× only in Phase 1
d 0 to 40										
ADG, lb	1.01	0.99	0.99	1.00	1.02	1.01	0.03	0.21	0.09	0.65
ADFI, lb	1.52	1.49	1.51	1.51	1.55	1.53	0.06	0.10	0.13	0.54
F/G	1.51	1.51	1.52	1.52	1.53	1.52	0.01	0.32	0.80	0.67
BW, lb										
d 0	15.8	15.8	15.7	15.7	15.6	15.7	0.27	0.18	0.74	0.97
d 40	56.7	55.8	56.0	56.2	56.9	56.5	2.63	0.39	0.09	0.67
Removal rate, %										
d 40	0.50%	0.70%	0.47%	0.27%	0.47%	0.00%	--	--	--	--
Log-transformed PCV2-neutralizing antibody titers[4], log_2										
d 16	6.7	7.2	6.9	6.8	6.2	6.6	0.65	0.38	0.49	0.79
d 38	7.0	8.0	7.5	6.8	5.9	7.1	0.66	0.04	0.18	0.75
Overall	6.9	7.6	7.2	6.8	6.0	6.8	0.52	0.07	0.21	0.98

[1] A total of 2,484 nursery pigs (PIC 337 x 1050, initially 15.7 lb BW) with 27 pigs per pen and 14 or 16 pens per treatment.
[2] Algamune ZPC (Algal Scientific Corporation, Plymouth, MI) is a zinc metal polysaccharide complex that contains β-1,3-glucan from algae.
[3] Contrasts were determined using negative control and the different levels of Algamune ZPC inclusion.
[4] A total of 72 pigs (12 pens per treatment, 1 pig per pen) were sampled. An increase in the log-transformed PCV2-neutralizing antibody titer indicates an increased concentration of neutralizing antibody.
[5] 423 ppm of Algamune ZPC was fed in Phase 1 followed by the negative control diet in Phase 2.

Effects of a Novel Protease Enzyme (CIBENZA DP100) on Finishing Pig Growth Performance and Carcass Characteristics[1]

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Summary

A total of 1,170 pigs (PIC 337 × 1050; initial BW 56.3 lb) were used in a 131-d study to determine the effects of a protease enzyme on growth performance and carcass characteristics of finishing pigs. Dietary treatments consisted of: (1) a positive control diet formulated to provide 90% of the standardized ileal digestible (SID) lysine requirement for these pigs; (2) a negative control diet formulated to provide 90% of the SID lysine requirement minus the expected nutrient release (both amino acids and dietary energy) from the protease enzyme (CIBENZA DP100, Novus International, Inc., St. Charles, MO), and (3) the negative control diet with the addition of 0.05% CIBENZA DP100. The diets were formulated such that the negative control diet containing the protease enzyme had calculated nutrient concentrations similar to the positive control. Pens of pigs were randomly allotted to 1 of 3 treatments with 26 pigs per pen and 15 replicates per treatment.

Overall (d 0 to 131), pigs fed the positive control diet had increased ($P < 0.05$) ADG compared with pigs fed the negative control diet. Pigs fed the negative control diet plus CIBENZA DP100 had improved ($P < 0.05$) ADFI and a tendency for improved ($P = 0.09$) ADG compared with pigs fed the negative control diet without the enzyme. No differences were observed in ADG, ADFI, or F/G between pigs fed the positive control diet and those fed the negative control diet plus the protease enzyme, which suggests that the release values attributed to the enzyme are accurate. The only observed effect on carcass characteristics was for yield, in which the pigs fed the negative control diet with the enzyme had lower ($P < 0.05$) carcass yield than pigs fed the negative control diet without the enzyme.

Although differences did exist in feed cost per pig and feed cost per pound of gain, no differences were observed for income over feed cost (IOFC) between treatments. These data suggest that the protease enzyme CIBENZA DP100 will elicit improved growth performance when added to diets formulated at 90% of the pig's estimated SID lysine requirement.

Key words: finishing pig, carcass characteristics, protease enzyme

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[1] Appreciation is expressed to Novus International (St. Charles, MO) for providing the protease enzyme and partial financial support, New Horizon Farms (Pipestone, MN) for providing the animals and research facilities, and to Richard Brobjorg, Scott Heidebrink, Marty Heintz, Craig Steck, and Marc Brown.

[2] Novus International (St. Charles, MO).

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Introduction

With ever-increasing feed prices, the swine industry continues to search for alternatives to reduce feed cost and extract more nutrients from feed ingredients. Proteases are endogenous enzymes that are required for the digestion and utilization of dietary proteins. Recently it has been suggested that supplemental protease enzymes can be added to diets to improve protein utilization. Preliminary results indicate that a new protease enzyme (CIBENZA DP100, Novus International, Inc., St. Charles, MO) may be able to increase digestibility of dietary protein and increase dietary energy utilization, consequently eliciting improved growth performance. Although research has been conducted with nursery pigs, none is available to verify this response in finishing pigs housed in commercial research facilities.

Therefore, the objective of this study was to determine if the addition of CIBENZA DP100 could improve growth performance, carcass characteristics, and economic return of finishing pigs housed in a commercial setting.

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 barn was naturally ventilated and double-curtain-sided. Each pen was equipped with a 5-hole stainless steel feeder and bowl waterer for ad libitum access to feed and water. Feed additions to each individual pen were made and recorded by a robotic feeding system (FeedPro; Feedlogic Corp., Wilmar, MN).

A total of 1,170 mixed sex pigs (PIC 337 × 1050; initial BW 56.3 lb) were used in a 131-d study. Pens were blocked by BW and were randomly assigned to diets with 15 pens per treatment and 26 pigs per pen. Dietary treatments consisted of: (1) a positive control diet formulated to provide 90% of the standardized ileal digestible (SID) lysine requirement for these pigs; (2) a negative control diet formulated to provide 90% of the SID lysine requirement minus the expected nutrient release (both amino acids and dietary energy) from the protease enzyme (CIBENZA DP100), and (3) the negative control diet with the addition of 0.05% CIBENZA DP100 (Tables 1 and 2). The diets were formulated such that the negative control diet containing the protease enzyme had calculated nutrient concentrations similar to the positive control. Samples of the complete feed were taken from the feeder at the beginning and end of each phase and proximate analysis was conducted (Ward Laboratories, Inc., Kearney, NE) on each diet (Tables 3 and 4).

Pens of pigs were weighed and feeder measurements were recorded on d 0, 12, 26, 45, 63, 81, 94, 108, and 131 to calculate ADG, ADFI, F/G, and caloric efficiency. On d 108, 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 d 131, 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 also calculated by dividing the individual HCW at the plant by the pig's pen average final live weight at the farm.

An economic analysis was completed at the conclusion of the trial to determine the financial impact of the protease addition. 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. Value of the gain was calculated by multiplying the final live weight by an assumed live value of $78.00/cwt then subtracting an initial pig cost, which was determined by multiplying the initial weight by an assumed cost of $78.00/cwt. To calculate income over feed cost (IOFC), total feed cost was subtracted from the value of the gain.

The experimental data were analyzed as a randomized complete block design using the MIXED procedure of SAS (SAS Institute, Cary, NC) with pen as the experimental unit and initial BW as a blocking factor. Hot carcass weight served as a covariate for the analysis of backfat, loin depth, and lean percentage. LSMEANS was used to analyze the data, with $P \leq 0.05$ being a significant difference and a tendency being recorded between $P > 0.05$ and $P \leq 0.10$.

Results and Discussion

Analysis of diets revealed that nutrients were similar to calculated values considering normal analytical variation (Tables 3 and 4).

Overall (d 0 to 131), pigs fed the positive control diet had increased ($P < 0.05$) ADG compared with pigs fed the negative control diet, which illustrates that we were, in fact, below the estimated SID lysine requirement of the pigs (Table 4). Pigs fed the negative control diet plus CIBENZA DP100 had increased ($P < 0.05$) ADFI, which led to a tendency for improved ($P < 0.10$) ADG compared with pigs fed the negative control diet without the enzyme (Table 5). Final BW was greater ($P < 0.05$) for pigs fed the positive control diet compared with those fed the negative control diet, with the pigs fed the negative control diet plus enzyme being intermediate. Overall feed and caloric efficiency were unaffected by treatments. The only impact on carcass characteristics that was observed was for yield, in which the pigs fed the negative control diet with the enzyme had lower ($P < 0.05$) yield than pigs fed the negative control diet without the enzyme.

Total feed cost per pig and feed cost per pound of gain were lower ($P < 0.05$) for pigs fed the negative control diet compared to either of the other treatments. Gain value was higher ($P < 0.05$) for pigs fed the positive control diet than for pigs fed the negative control diet, with pigs fed the negative control diet with enzyme being intermediate. No differences were observed between treatments for IOFC.

In summary, our data confirm the importance of not under-formulating the dietary SID lysine level if maximum growth performance is desired. The addition of CIBENZA DP100 to a nutrient deficient diet increased ADFI and tended to increase ADG, which supports the hypothesis that the enzyme allowed for better nutrient utilization. Additional research should be conducted to determine if a similar improvement in growth performance will be observed when pigs are fed diets formulated closer to their nutrient requirement estimates.

Table 1. Phase 1, 2, and 3 diet composition (as-fed basis)[1]

	Phase 1			Phase 2			Phase 3		
Item	PC[2]	NC+DP100	NC	PC	NC+DP100	NC	PC	NC+DP100	NC
Ingredient, %									
Corn	45.22	49.91	49.96	49.38	52.20	52.25	52.33	55.01	55.06
Soybean meal, (46.5% CP)	19.58	15.50	15.50	15.49	13.30	13.30	12.61	10.50	10.50
DDGS[3]	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
Beef tallow	3.00	2.20	2.20	3.00	2.25	2.25	3.00	2.30	2.30
Limestone	1.40	1.40	1.40	1.35	1.35	1.35	1.30	1.30	1.30
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
L-threonine	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
L-lysine sulfate[4]	0.26	0.34	0.34	0.24	0.27	0.27	0.23	0.25	0.25
Dicalcium P (18% P)	0.00	0.05	0.05	0.00	0.05	0.05	0.00	0.05	0.05
Phytase[5]	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Vitamin premix	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Trace mineral premix	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Enzyme[6]	0.00	0.05	0.00	0.00	0.05	0.00	0.00	0.05	0.00
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

continued

Table 1. Phase 1, 2, and 3 diet composition (as-fed basis)[1]

	Phase 1			Phase 2			Phase 3		
Item	PC[2]	NC+DP100	NC	PC	NC+DP100	NC	PC	NC+DP100	NC
Calculated analysis									
Standard ileal digestible (SID) amino acids, %									
Lysine	0.99	0.99	0.95	0.76	0.75	0.74	0.77	0.77	0.76
Isoleucine:lysine	0.74	0.71	0.70	1.97	1.97	2.00	2.09	2.09	2.12
Leucine:lysine	1.84	1.80	1.83	0.35	0.35	0.35	0.37	0.37	0.37
Methionine:lysine	0.33	0.32	0.32	0.67	0.67	0.67	0.70	0.71	0.71
Met & Cys:lysine	0.63	0.62	0.62	0.69	0.71	0.68	0.71	0.73	0.70
Threonine:lysine	0.66	0.67	0.64	0.19	0.18	0.18	0.18	0.18	0.18
Tryptophan:lysine	0.19	0.17	0.17	0.85	0.87	0.84	0.88	0.90	0.87
Valine:lysine	0.81	0.81	0.78	0.74	0.76	0.70	0.69	0.71	0.66
SID lysine:ME, g/Mcal	2.90	2.91	2.82	2.55	2.56	2.48	2.31	2.32	2.23
ME, kcal/lb	1542	1543	1529	1545	1545	1544	1547	1546	1534
CP, %	22.2	21.6	20.8	20.5	20.4	19.7	19.3	19.2	18.5
Ca, %	0.60	0.60	0.60	0.57	0.58	0.58	0.54	0.55	0.55
P, %	0.47	0.47	0.47	0.45	0.45	0.46	0.44	0.44	0.44
Available P, %	0.31	0.31	0.21	0.20	0.21	0.21	0.30	0.31	0.31
Standard digestible P, %	0.30	0.30	0.30	0.30	0.30	0.30	0.29	0.30	0.30

[1] Phase 1, 2, and 3 diets were fed from d 0 to 26, d 26 to 45, and d 45 to 63, respectively.
[2] Treatments were designed as follows: PC (positive control) = 90% of SID lysine requirement of pigs in each phase; NC + DP100 = negative control plus nutrient release expected from CIBENZA DP100 to meet the nutrient contribution of the positive control; and negative control.
[3] Dried distillers grains with solubles.
[4] L-lysine sulfate provided by Biolys (Evonik Corporation, Kennesaw, GA).
[5] Optiphos 2000 (Enzyvia LLC, Sheridan, IN) provided 227 phytase units (FTU)/lb, with a release of 0.07% available P.
[6] CIBENZA DP100 (Novus International, St. Charles, MO).

Table 2. Phase 4 and 5 diet composition (as-fed basis)[1]

	Phase 4			Phase 5		
Item	PC[2]	NC+DP100	NC	PC	NC+DP100	NC
Ingredient, %						
Corn	55.22	57.07	57.12	58.14	59.74	59.79
Soybean meal, (46.5% CP)	9.78	8.50	8.50	6.88	5.80	5.80
DDGS[3]	30.00	30.00	30.00	30.00	30.00	30.00
Beef tallow	3.00	2.35	2.35	3.00	2.40	2.40
Limestone	1.25	1.25	1.25	1.25	1.25	1.25
Salt	0.35	0.35	0.35	0.35	0.35	0.35
L-threonine	0.00	0.00	0.00	0.00	0.00	0.00
L-lysine sulfate[4]	0.21	0.22	0.22	0.20	0.20	0.20
Dicalcium P, (18% P)	0.00	0.03	0.03	0.00	0.03	0.03
Phytase[5]	0.01	0.01	0.01	0.01	0.01	0.01
Vitamin premix	0.08	0.08	0.08	0.08	0.08	0.08
Trace mineral premix	0.10	0.10	0.10	0.10	0.10	0.10
Enzyme[6]	0.00	0.05	0.00	0.00	0.05	0.00
Total	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis						
Standard ileal digestible (SID) amino acids, %						
Lysine	0.71	0.71	0.68	0.62	0.62	0.59
Isoleucine:lysine	0.79	0.80	0.80	0.82	0.83	0.83
Leucine:lysine	2.24	2.25	2.29	2.43	2.45	2.51
Methionine:lysine	0.39	0.40	0.40	0.42	0.43	0.44
Met & Cys:lysine	0.75	0.76	0.76	0.80	0.82	0.82
Threonine:lysine	0.73	0.77	0.74	0.77	0.81	0.78
Tryptophan:lysine	0.18	0.18	0.18	0.18	0.18	0.18
Valine:lysine	0.91	0.96	0.93	0.96	1.02	0.98
SID lysine:ME, g/Mcal	2.06	2.08	2.00	1.82	1.83	1.75
ME, kcal/lb	1549	1548	1536	1550	1549	1539
CP, %	18.2	18.3	17.7	17.0	17.2	16.6
Ca, %	0.52	0.52	0.52	0.51	0.51	0.51
P, %	0.43	0.43	0.43	0.42	0.42	0.42
Available P, %	0.29	0.30	0.30	0.29	0.30	0.30
Standard digestible P, %	0.29	0.29	0.29	0.28	0.29	0.29

[1] Phase 4 and 5 diets were fed from d 63 to 94 and d 94 to 131, respectively.
[2] Treatments were designed as follows: PC (positive control) = 90% of SID lysine requirement of pigs in each phase; NC + DP100 = negative control plus nutrient release expected from CIBENZA DP100 to meet the nutrient contribution of the positive control; and negative control.
[3] Dried distillers grains with solubles.
[4] L-lysine sulfate provided by Biolys (Evonik Corporation, Kennesaw, GA).
[5] Optiphos 2000 (Enzyvia LLC, Sheridan, IN) provided 227 phytase units (FTU)/lb, with a release of 0.07% available P.
[6] CIBENZA DP100 (Novus International, St. Charles, MO).

Table 3. Proximate analysis of diets (as-fed basis)[1]

	Phase 1[2]			Phase 2[2]			Phase 3[2]		
Item, %[3]	PC	NC+DP100	NC	PC	NC+DP100	NC	PC	NC+DP100	NC
DM	89.32	89.20	89.25	88.31	88.63	88.19	88.80	88.80	88.53
CP	20.5	19.2	20.2	19.6	18.3	16.9	18.9	18.2	17.9
ADF	4.9	5.2	5.1	4.3	4.6	4.4	5.2	4.8	5.4
NDF	11.7	12.0	12.7	12.5	12.0	11.8	13.3	12.1	12.4
Crude fiber	3.6	3.6	3.6	3.4	3.2	2.9	3.8	3.4	3.8
Nitrogen Free Extract	54.2	55.7	54.2	55.1	56.8	58.8	54.5	56.3	56.3
Fat	6.5	6.0	6.3	5.8	5.4	4.9	7.1	6.4	6.4
Ash	4.22	4.15	4.41	4.42	4.37	4.07	4.10	4.11	3.64

[1] Phase 1, 2, and 3 diets were fed from d 0 to 26, d 26 to 45, d 45 to 63, respectively.
[2] PC = positive control, NC + DP100 = negative control with the addition of CIBENZA DP100, NC = negative control.
[3] Values represent the mean of samples collected from feeders, then pooled and subsampled, and one composite sample of each diet was finally analyzed.

Table 4. Proximate analysis of diets (as-fed basis)[1]

	Phase 4[2]			Phase 5[2]		
Item, %[3]	PC	NC+DP100	NC	PC	NC+DP100	NC
DM	89.11	89.07	89.16	89.06	88.78	89.00
CP	17.8	17.6	17.2	17.3	17.3	16.7
ADF	4.9	5.1	5.5	5.7	5.4	5.1
NDF	11.6	12.1	13.5	13.2	11.7	12.8
Crude Fiber	4.0	4.3	3.9	3.5	3.0	3.4
Nitrogen Free Extract	53.4	55.7	55.7	56.7	56.2	57.6
Fat	9.6	7.9	7.9	6.9	6.7	6.8
Ash	4.40	3.84	3.95	3.65	4.25	3.78

[1] Phase 4 and 5 diets were fed from d 63 to 94 and d 94 to 131, respectively.
[2] PC = positive control, NC + DP100 = negative control with the addition of CIBENZA DP100, NC = negative control.
[3] Values represent the mean of samples collected from feeders, then pooled and subsampled, and one composite sample of each diet was finally analyzed.

Table 5. The effects of CIBENZA DP100 on finishing pig growth performance[1,2]

					Probability, $P <$			
Item	PC[3]	NC+DP100	NC	SEM	Treatment	PC vs. DP100	PC vs. NC	NC vs. DP100
BW, lb								
d 0	56.3	56.3	56.2	1.052	0.988	0.961	0.882	0.921
d 131	294.0	292.3	287.0	2.763	0.090	0.598	0.036	0.107
d 0 to 131								
ADG, lb	1.83	1.82	1.79	0.014	0.074	0.612	0.031	0.088
ADFI, lb	4.82	4.87	4.73	0.046	0.090	0.391	0.172	0.031
F:G	2.63	2.67	2.65	0.048	0.478	0.228	0.549	0.537
Caloric efficiency								
ME	4,979	4,976	4,961	52.485	0.968	0.973	0.812	0.838
Carcass characteristics								
HCW, lb	216.9	214.8	213.45	1.991	0.277	0.330	0.115	0.530
Yield, %	73.8	73.5	74.4	0.258	0.052	0.420	0.101	0.018
Backfat, in.[4]	0.76	0.75	0.75	0.012	0.796	0.751	0.504	0.718
Loin depth, in.[4]	2.63	2.65	2.63	0.035	0.849	0.608	0.961	0.642
Lean, %[4]	55.1	55.3	55.3	0.260	0.859	0.664	0.612	0.937
Economics, $/pig								
Feed cost[5]	63.89	63.42	60.34	0.608	0.001	0.531	0.001	0.001
Feed cost/lb gain	0.266	0.266	0.258	0.002	0.022	0.854	0.013	0.012
Gain value[6]	185.39	184.07	179.95	1.740	0.088	0.597	0.036	0.105
IOFC	121.49	120.65	119.61	1.491	0.675	0.692	0.380	0.628

[1] A total of 1,170 (PIC 337 × 1050) were used with 26 pigs per pen and 15 replications per treatment.
[2] Treatments were designed as follows: Positive control = 90% of SID lysine requirement of pigs in each phase; negative control + DP100 = negative control plus nutrient release expected from CIBENZA DP100 to meet the nutrient contribution of the positive control; and negative control.
[3] PC = positive control, NC + DP100 = negative control with the addition of CIBENZA DP100, NC = negative control.
[4] HCW was used as a covariate.
[5] Corn was valued at $4.17/bushel, soybean meal at $457.64/ton, DDGS at $146.25/ton, beef tallow at $0.32/lb, and CIBENZA DP100 at $4.92/lb.
[6] Gain value was calculated using (Final wt. x $78.00/cwt) – (initial wt. × $78.00/cwt).

Effects of Increasing Crystalline Amino Acids in Sorghum- or Corn-Based Diets on Nursery Pig Growth Performance[1]

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Summary

A total of 300 pigs (PIC 1050; initially 23.3 lb BW) were used in a 21-d study to compare the effects of increasing crystalline amino acids in sorghum- and corn-based diets on nursery pig growth performance. Treatments with 5 pigs per pen and 10 pens per treatment were arranged in a 2 × 3 factorial with main effects of grain source (sorghum vs. corn) and crystalline amino acid supplementation (low, medium, or high). Amino acid ratios to lysine as well as standardized ileal digestibility coefficients used were set by NRC (2012[3]). Because replacing increasing amounts of soybean meal with crystalline amino acids changes the NE of the diet, all diets were formulated to the same Lys:NE ratio. The lysine concentration in the diets was formulated at 95% of the pig's estimated requirement to ensure that the other amino acids, on a ratio to lysine, would not be underestimated. The grain sources and soybean meal were analyzed for amino acid profile and diets formulated from these concentrations. The low amino acid fortification contained L-lysine HCl and DL-methionine. The medium amino acid fortification contained L-lysine HCl, DL-methionine, and L-threonine, and the high amino acid fortification contained L-lysine HCl, DL-methionine, L-threonine, and L-valine.

Overall, no main or interactive effects ($P > 0.05$) of grain source or added amino acids were detected for any response criteria. This suggests that balancing to the third, fourth, or fifth limiting amino acids is possible in both sorghum- and corn-based diets with the use of crystalline amino acids without detrimental effects on growth performance.

Key words: corn, crystalline amino acid, nursery pig, sorghum

Introduction

To lower feed costs, crystalline amino acids are used routinely in swine diets to replace a portion of the soybean meal. The amino acids that are currently economical to add to swine diets include lysine, threonine, methionine, tryptophan, and valine. The increased availability of economical sources of crystalline amino acids has created the opportunity to formulate either sorghum- or corn-based diets to the fifth or sixth limiting amino acids. If this can be accomplished without negatively affecting pig growth performance, it will result in greater economic return; however, in some cases, low-protein, amino

[1] Appreciation is expressed to the United Sorghum Checkoff Program (Lubbock, TX) for partial financial support and Ajinomoto-Heartland Inc. (Chicago, IL) for amino acid analysis and providing the amino acids used in this study.

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[3] NRC. 2012. Nutrient Requirements of Swine. 11th rev. ed. Natl. Acad. Press, Washington, DC.

acid–fortified diets have not provided growth performance similar to grain-soybean meal–based diets.

The objective of this study was to determine the effects of feeding high levels of crystalline amino acids in sorghum- or corn-based diets on growth performance of nursery pigs.

Procedures

The protocol for this experiment was approved by the Kansas State University Institutional Animal Care and Use Committee. The study was conducted at the Kansas State University Segregated Early Weaning Facility in Manhattan, KS. The facility is a totally enclosed, environmentally controlled, mechanically ventilated barn. Each pen was equipped with a 4-hole stainless steel dry self-feeder and a cup waterer for ad libitum access to feed and water. Pens (4 ft × 4 ft) had wire-mesh floors and deep pits for manure storage.

A total of 300 pigs (PIC 1050; initially 23.3 lb BW) were used in a 21-d study. The experimental treatments with 5 pigs per pen and 10 replications per treatment were arranged in a 2 × 3 factorial with main effects of grain source (grain sorghum vs. corn) and crystalline amino acid level (low, medium, or high). Amino acid to lysine ratios, as well as standardized ileal digestibility coefficients used, were set by NRC (2012). The lysine concentration in the diets was formulated at 95% of the pig's estimated requirement to ensure that the other amino acids, in ratio with lysine, would not be underestimated. Furthermore, because replacing soybean meal with crystalline amino acids increases the NE of the diet, all diets were formulated to a constant lysine:NE ratio. The grain sources and soybean meal were analyzed for amino acid profile and diets formulated from these concentrations (Table 1). The low amino acid fortification contained L-lysine HCl and DL-methionine. The medium amino acid fortification contained L-lysine HCl, DL-methionine, and L-threonine, and the high amino acid fortification contained L-lysine HCl, DL-methionine, L-threonine, and L-valine (Table 2). Pig weight and feed disappearance were measured on day 0, 7, 14, and 21 of the trial to determine ADG, ADFI, and F/G. Experimental diets were fed in meal form and were manufactured at the K-State O.H. Kruse Feed Technology Innovation Center.

Multiple samples of each diet were collected from feeders, blended and subsampled, and submitted to Ward Laboratories, Inc. (Kearney, NE) for analysis of DM, CP, Ca, and P. Amino acid analysis was conducted by Ajinomoto Heartland, Inc. (Chicago IL; Table 3).

Data were analyzed as a randomized complete block design using PROC MIXED in SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit and barn as a random effect. Results from the experiment were considered significant $P \leq 0.05$ and a tendency between $P > 0.05$ and ≤ 0.10.

Results and Discussion

The amino acid profiles of the ingredients varied somewhat from values published by the NRC (2012). As a result, the order of limiting amino acids was different than expected. Based on the amino acid analysis, in both sorghum and corn, the limiting

amino acids were lysine, methionine and cysteine, threonine, and valine. The diets were then co-limiting on tryptophan and isoleucine. The variation of these amino acid profiles for these grain sources confirms the need to evaluate sources routinely and update amino acid profiles when formulating and manufacturing diets. As expected, the analyzed CP content of the experimental diets decreased as soybean meal was replaced by the crystalline amino acids (Table 3).

Overall, no main or interactive effects ($P > 0.05$) of grain source or added crystalline amino acid level were detected for any response criteria measured (Tables 4 and 5). Pigs fed sorghum-based diets had similar growth performance and feed efficiency to those fed corn-based diets. Sorghum is typically thought to have approximately 96% the energy value of corn, resulting in slightly poorer feed efficiency than pigs fed corn-based diets, but this was not the case in our study. Furthermore, we saw no negative responses to increasing crystalline amino acid concentrations in place of soybean meal in the diets. This suggests that balancing to the third, fourth, or fifth limiting amino acid is possible in both sorghum- or corn-based diets with the use of crystalline amino acids without detrimental effects on growth performance.

Table 1. Analyzed amino acid concentration of sorghum, corn, and soybean meal (%, as-fed basis)[1]

Item	Sorghum	Corn	Soybean meal
Arginine	0.29	0.36	3.33
Histidine	0.16	0.23	1.19
Isoleucine	0.26	0.28	2.12
Leucine	0.82	0.98	3.47
Lysine	0.17	0.23	2.86
Methionine	0.13	0.17	0.65
Phenylalanine	0.34	0.37	2.33
Threonine	0.23	0.28	1.82
Tryptophan	0.08	0.06	0.68
Valine	0.33	0.36	2.13

[1] Values represent the mean of 3 samples analyzed in duplicate by Ajinomoto Heartland, Inc., Chicago, IL.

Table 2. Diet composition (as-fed basis)[1]

	Sorghum			Corn		
Ingredient, %	Low	Medium	High	Low	Medium	High
Corn	--	--	--	61.59	67.37	70.73
Milo	61.11	67.10	72.68	--	--	--
Soybean meal (46.5% CP)	35.86	29.41	23.24	35.33	29.07	25.36
Monocalcium phosphate	1.10	1.15	1.23	1.18	1.25	1.3
Limestone	1.03	1.05	1.08	1.00	1.04	1.05
Salt	0.35	0.35	0.35	0.35	0.35	0.35
L-lysine HCl	0.16	0.37	0.59	0.18	0.39	0.52
DL-methionine	0.08	0.15	0.22	0.05	0.12	0.16
L-threonine	--	0.10	0.20	--	0.10	0.15
L-valine	--	--	0.11	--	--	0.07
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15
Vitamin premix	0.15	0.15	0.15	0.15	0.15	0.15
Phytase[2]	0.02	0.02	0.02	0.02	0.02	0.02
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis						
Standardized ileal digestible (SID) lysine:NE, g/Mcal	5.04	5.04	5.04	5.04	5.04	5.04
SID amino acids, %						
Lysine	1.11	1.13	1.14	1.15	1.16	1.17
Isoleucine:lysine	72	61	51.2	71	60	55
Leucine:lysine	136	120	105	140	126	117
Methionine:lysine	31.7	34.8	37.7	30.4	33.2	34.8
Met & Cys:lysine	55.3	55.3	55.3	55.3	55.3	55.3
Threonine:lysine	59.4	59.4	59.4	59.4	59.4	59.4
Tryptophan:lysine	23.2	19.7	16.3	21.7	18.2	16.3
Valine:lysine	73.7	63.4	63.4	73.1	63.4	63.4
Total lysine, %	1.25	1.25	1.25	1.29	1.29	1.30
NE NRC, kcal/lb	1,054	1,069	1,084	1,085	1,101	1,112
CP, %	22.3	19.9	17.7	22.7	20.4	19.1
Ca, %	0.70	0.70	0.70	0.7	0.7	0.7
P, %	0.63	0.61	0.60	0.64	0.63	0.62
Available P, %	0.43	0.43	0.44	0.43	0.44	0.45

[1] Experimental diets were fed for 21 d beginning approximately 18 d after weaning.
[2] Ronozyme HiPhos (GT) 2700 (DSM Nutritional Products, Parsippany, NJ) provided 216.0 phytase units (FTU)/lb with a release of 0.10% available P.

Table 3. Chemical analysis of experimental diets (as-fed basis)[1]

	Grain source					
	Sorghum			Corn		
Item Crystalline amino acids:	Low	Medium	High	Low	Medium	High
DM, %	89.15	89.34	89.26	89.99	89.72	89.71
CP, %	23.3	20.5	18.1	23.3	21.5	20.0
Ca, %	0.66	0.82	0.70	0.83	0.74	0.76
P, %	0.53	0.68	0.54	0.62	0.71	0.62
Amino acids						
Arginine	1.43	1.26	1.07	1.51	1.39	1.28
Histidine	0.55	0.49	0.43	0.59	0.55	0.52
Isoleucine	0.95	0.87	0.70	0.98	0.91	0.79
Leucine	1.89	1.75	1.50	1.98	1.86	1.74
Lysine	1.30	1.33	1.34	1.40	1.44	1.46
Methionine	0.39	0.42	0.47	0.40	0.42	0.44
Threonine	0.83	0.80	0.85	0.89	0.90	0.88
Tryptophan	0.27	0.25	0.21	0.28	0.23	0.21
Valine	1.01	0.95	0.92	1.06	1.00	0.94

[1] Multiple samples were collected from each diet throughout the study, homogenized, then subsampled for analysis at Ward Laboratories, Inc. (Kearney, NE) and Ajinomoto Heartland, Inc. (Chicago, IL).

Table 4. Interactive effects of grain source and crystalline amino acid level on growth performance of pigs[1]

	Grain source								
	Sorghum			Corn				Probability, $P <$ [3]	
Crystalline amino acids[2]:	Low	Medium	High	Low	Medium	High	SEM	Grain source	Amino acid level
d 0 to 21									
ADG, lb	1.07	1.04	1.03	1.04	1.06	1.05	0.044	0.973	0.721
ADFI, lb	1.64	1.59	1.63	1.61	1.61	1.63	0.074	0.803	0.603
F/G	1.52	1.52	1.57	1.53	1.51	1.54	0.023	0.449	0.954
BW, lb									
d 0	23.29	23.38	23.32	23.35	23.35	23.34	0.793	0.939	0.895
d 21	45.87	45.36	45.09	45.30	45.62	45.51	1.691	0.952	0.804

[1]A total of 300 pigs (PIC 1050) were used in a 21-d study with 5 pigs per pen and 10 pens per treatment.
[2] The low amino acid fortification contained L-lysine HCl and DL-methionine. The medium amino acid fortification contained L-lysine HCl, DL-methionine, and L-threonine, and the high amino acid fortification contained L-lysine HCl, DL-methionine, L-threonine, and L-valine.
[3] No grain source × amino acid level interactions were detected ($P > 0.10$).

Table 5. Main effects of grain source and crystalline amino acid on growth performance of nursery pigs[1]

							Probability, $P <$		
	Grain source		Added crystalline amino acids[2]					Crystalline amino acids	
Item	Milo	Corn	Low	Medium	High	SEM	Grain source	Linear	Quadratic
d 0 to 21									
ADG, lb	1.05	1.05	1.06	1.05	1.04	0.04	0.973	0.633	0.994
ADFI, lb	1.62	1.61	1.62	1.60	1.63	0.07	0.803	0.871	0.410
F/G	1.54	1.53	1.53	1.51	1.55	0.02	0.449	0.116	0.089
BW, lb									
d 0	23.33	23.35	23.32	23.36	23.33	0.77	0.939	0.967	0.870
d 21	45.44	45.48	45.59	45.49	45.30	1.60	0.952	0.706	0.942

[1]A total of 300 pigs (PIC 1050) were used in a 21-d study with 5 pigs per pen and 30 pens for grain source or 20 pens for added crystalline amino acid.
[2] The low amino acid fortification contained L-lysine HCl and DL-methionine. The medium amino acid fortification contained L-lysine HCl, DL-methionine, and L-threonine, and the high amino acid fortification contained L-lysine HCl, DL-methionine, L-threonine, and L-valine.

Validating a Dietary Approach to Determine Amino Acid:Lysine Ratios for Pigs[1,2]

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Summary

Standardized ileal digestible (SID) amino acid:lysine (AA:Lys) ratio experiments are commonly conducted to estimate the AA requirement of pigs relative to lysine (Lys) and allow for accurate diet formulation. The objective of the studies herein was to validate a dietary approach to determine the optimal SID AA:Lys ratio for pigs using tryptophan (Trp) as a model. Four 21-d experiments were conducted in which pigs (337 × 1050; PIC) were fed corn-soybean meal–based diets with 30% corn dried distillers grains with solubles (DDGS). A total of 1,188, 1,232, 1,204, and 1,183 pigs with initial BW of 28.5 ± 0.4, 50.1 ± 1.3, 127.0 ± 2.5, and 192.5 ± 2.6 lb were used in experiments 1, 2, 3, and 4, respectively. Each experiment had 11 pens per treatment with 24 to 28 pigs per pen. In Experiment 1, each pen housed the same number of barrows and gilts, whereas in Experiments 2 to 4 only gilts were used. Dietary treatments were: (1) High CP, High Lys, and High Trp:Lys ratio (HHH); (2) Low CP, High Lys, and High Trp:Lys ratio (LHH); (3) Low CP, Low Lys, and High Trp:Lys ratio (LLH); and (4) Low CP, Low Lys, and Low Trp:Lys ratio (LLL). The SID Trp concentrations used were 14.5 vs. 20% of Lys, CP was at least 3 percentage units different, and SID Lys levels were 0.01 percentage unit above the estimated requirement at the expected initial BW and 0.10 or 0.05 percentage units below requirement at the expected final BW of the Experiment 1 (nursery) and Experiments 2, 3, and 4 (finishing), respectively. In Experiment 1, decreasing CP (HHH vs. LHH) did not influence ADG but increased ($P < 0.05$) F/G. Decreasing Lys (LHH vs. LLH) and decreasing the SID Trp:Lys ratio (LLH vs. LLL) reduced ($P < 0.05$) ADG and increased ($P < 0.05$) F/G. In Experiment 2, decreasing CP (HHH vs. LHH) did not affect ADG but increased ($P < 0.05$) F/G. Decreasing Lys (LHH vs. LLH) and the SID Trp:Lys ratio (LLH vs. LLL) decreased ($P < 0.05$) ADG and increased ($P < 0.05$) F/G. In Experiment 3, decreasing CP (HHH vs. LHH) or Lys (LHH vs. LLH) did not influence ADG or F/G. Decreasing the SID Trp:Lys ratio (LLH vs. LLL) reduced ($P < 0.05$) ADG and increased ($P < 0.05$) F/G. In Experiment 4, decreasing CP (HHH vs. LHH) did not influence ADG but increased ($P < 0.05$) F/G. Decreasing Lys (LHH vs. LLH) had no effect on performance, but decreasing the SID Trp:Lys ratio (LLH vs. LLL) reduced ($P < 0.05$) ADG and increased ($P < 0.05$) F/G.

In conclusion, low-CP diets formulated 0.10 and 0.05 percentage units below the SID Lys requirement at the end of the experiment's weight range appear to ensure pigs are

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[4] Ajinomoto Heartland Inc., Chicago, IL.

below their Lys requirement when determining the optimal SID Trp:Lys ratio for 29- to 52-lb and 50- to 80-lb pigs, respectively. For pigs heavier than 80 lb, formulating diets at 0.05 percentage units below the SID Lys requirement at the end of the experiment's weight range can limit the ability to provide statistical evidence that pigs are under their lysine requirement.

Key words: amino acid ratio, lysine, tryptophan

Introduction

Low-CP, amino acid (AA)-fortified diets are commonly fed in the swine industry due to the increased availability and decreased cost of feed-grade AA. Pigs fed low-CP diets have similar performance to pigs fed high-CP diets as long as essential AA are supplemented to meet the pigs' requirements. The tryptophan (Trp) requirement can be expressed in different ways; however, the standardized ileal digestible (SID) Trp requirement expressed as a ratio to lysine (Trp:Lys) is considered a practical approach for diet formulation. Lysine is the first limiting AA in most of the cereal grain diets used in swine. Because the Lys requirement when reported as a percentage of the diet decreases as BW increases, if the experimental diet is not limiting in Lys at the end of the experiment's BW range, the ratio of other AA to Lys will be underestimated; therefore, Lys must be the second limiting AA throughout the experiment. The objective of these studies was to validate a dietary approach to determining the optimal SID AA:Lys ratio for pigs using Trp as a model.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The studies were conducted at 2 commercial research barns in southwestern Minnesota. The nursery barn in which Experiment 1 was conducted was totally enclosed, environmentally controlled, and mechanically ventilated. Each pen (3.7 × 2.3 m) was equipped with a 6-hole stainless steel dry self-feeder (SDI Industries, Alexandria, SD) and a pan waterer. The finishing barn was naturally ventilated and double-curtain-sided. Each pen (5.5 × 3.0 m) was equipped with a 4-hole stainless steel dry self-feeder (Thorp Equipment, Thorp, WI) and a cup waterer. Both barns had completely slatted flooring and deep pits for manure storage. Each facility was equipped with a computerized feeding system (FeedPro; Feedlogic Corp., Willmar, MN) that delivered and recorded daily feed additions and diets as specified. Pigs had ad libitum access to feed and water.

Four 21-d growth experiments were conducted with two groups of pigs. Experiment 1 was conducted with a group of nursery pigs, and Experiments 2, 3, and 4 were conducted with a group of finishing pigs. A total of 1,188, 1,232, 1,204, and 1,183 pigs (337 × 1050; PIC Hendersonville, TN) with initial BW of 28.5 ± 0.4, 50.1 ± 1.3, 127.0 ± 2.5, and 192.5 ± 2.6 lb were used in Experiments 1, 2, 3, and 4, respectively. Each experiment had 11 pens per treatment with 24 to 28 pigs per pen. In Experiment 1, each pen housed the same number of barrows and gilts, whereas only gilts were used in Experiments 2 to 4. Dietary treatments (Tables 1, 2, 3, and 4) were: (1) High CP, High Lys, and High Trp:Lys ratio (HHH); (2) Low CP, High Lys, and High Trp:Lys ratio (LHH); (3) Low CP, Low Lys, and High Trp:Lys ratio (LLH); and (4) Low CP, Low Lys, and Low Trp:Lys ratio (LLL). Corn-soybean meal–based diets with 30%

DDGS were used with different SID Trp:Lys ratios (14.5% vs. 20%), CP (at least 3 percentage units difference), and SID Lys levels (0.01 percentage unit above requirement at the expected initial BW and 0.10 or 0.05 percentage units below requirement at the expected final BW of the nursery and finishing, respectively). Lysine requirements were estimated using the NRC (2012[5]) model for mixed gender pens of pigs for the nursery phase and for gilts only for the finishing phase. Diets were balanced to have the same NE and Ca:standardized total tract digestible (STTD) P ratio.

Five representative samples of corn, soybean meal, and DDGS were collected each week for 5 wk and analyzed in duplicate for total AA and CP by Ajinomoto Heartland Inc. (Chicago, IL), and values were used in diet formulation. Other nutrients and SID AA digestibility coefficient values used for diet formulation were obtained from NRC (2012).

Pens of pigs were weighed and feed disappearance was measured at the beginning and at d 21 of each experiment to determine ADG, ADFI, and F/G. There were 21-d periods between the finishing experiments, in which pigs were fed a common diet that met or exceeded NRC (2012) nutrient requirements and contained 20% SID Trp:Lys. Caloric efficiency was calculated on a pen basis by multiplying total pen feed intake by the dietary energy level (kcal/lb) and dividing by total pen gain.

Diet samples were taken from 6 feeders per dietary treatment 3 d after the beginning and 3 d before the end of each experiment and stored at -20°C, then total Trp, other AA, and CP analysis were conducted on composite samples from each dietary treatment by Ajinomoto Heartland, Inc. Diet samples were also submitted to Ward Laboratories, Inc. (Kearney, NE) for analysis of DM, crude fiber, ash, crude fat, Ca, and P.

Data were analyzed using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) as a randomized complete block design. Pen was the experimental unit for all data analysis. The model included terms for the fixed effects of dietary treatment with the block (initial average pen BW) as a random effect. In addition, for Experiments 3 and 4, dietary treatment from the previous experiment (2 and 3, respectively) was also considered a random effect. Treatment means were separated using pairwise comparisons of means performed using the DIFFS option from the LSMEANS statement of SAS. Results were considered significant at $P \leq 0.05$ and a tendency at $P > 0.05$ and $P \leq 0.10$.

Results and Discussion

The nutrient and total AA analysis of the diets (Tables 5, 6, 7, and 8) were reasonably within the expected variation reported by Cromwell et al. (1999[6]). The analyzed total Trp for the LLL treatment in Experiment 1 was higher than expected, but due to the reduction in growth performance when comparing the LLH vs. LLL treatments observed in that experiment and because the analysis of free L-Trp agrees with formu-

[5] NRC. 2012. Nutrient Requirements of Swine. 11th ed. Natl. Acad. Press, Washington, DC.

[6] Cromwell, G.L., C.C. Calvert, T.R. Cline, J.D. Crenshaw, T.D. Crenshaw, R.A. Easter, R.C. Ewan, C.R. Hamilton, G.M. Hill, A.J. Lewis, D.C. Mahan, E.R. Miller, J.L. Nelssen, J.E. Pettigrew, L.F. Tribble, T.L. Veum, and J.T. Yen. 1999. Variability among sources and laboratories in nutrient analyses of corn and soybean meal. NCR-42 Committee on Swine Nutrition. North Central Regional-42. J. Anim. Sci. 77:3262–3273.

lated values, the researchers believe that this variation could be due to the analytical procedure.

In Experiment 1, decreasing CP (Table 9; HHH vs. LHH) did not influence ($P > 0.05$) ADG and final BW but increased ($P < 0.05$) ADFI and, consequently, F/G and caloric efficiency. Decreasing Lys (LHH vs. LLH) and decreasing the SID Trp:Lys ratio (LLH vs. LLL) reduced ($P < 0.05$) ADG, ADFI, and final BW but increased ($P < 0.05$) F/G and caloric efficiency. In Experiment 2, decreasing CP (HHH vs. LHH) did not influence ADG and final BW but increased ($P < 0.05$) ADFI and consequently increased F/G and caloric efficiency. Decreasing Lys (LHH vs. LLH) reduced ($P < 0.05$) ADG and final BW but increased ($P < 0.05$) F/G and caloric efficiency, with no change in ADFI. Decreasing the SID Trp:Lys ratio (LLH vs. LLL) reduced ($P < 0.05$) ADG, ADFI, and final BW; however, F/G and caloric efficiency were increased ($P < 0.05$). In Experiment 3, decreasing CP (HHH vs. LHH) did not influence ($P > 0.05$) ADG, F/G, caloric efficiency, or final BW but increased ($P < 0.05$) ADFI. Decreasing Lys (LHH vs. LLH) had no effect on pig performance. Decreasing the SID Trp:Lys ratio (LLH vs. LLL) decreased ($P < 0.05$) ADG, ADFI, and final BW but increased ($P < 0.05$) F/G and caloric efficiency. In Experiment 4, decreasing CP (HHH vs. LHH) did not influence ADG, ADFI, or final BW ($P > 0.05$) but increased ($P < 0.05$) F/G and caloric efficiency. Decreasing Lys (LHH vs. LLH) had no effect ($P > 0.05$) on pig performance. Decreasing the SID Trp:Lys ratio (LLH vs. LLL) reduced ($P < 0.05$) ADG and final BW, whereas ADFI was not affected ($P > 0.05$), so F/G and caloric efficiency were increased ($P < 0.05$).

Low-CP, AA-fortified diets did not influence ADG or final BW in any experiment compared with pigs fed the high-CP diets with increased soybean meal. Pigs fed low-CP, AA-fortified diets in Experiments 1, 2, and 3 had increased ADFI and consequently increased NE intake compared with those fed high-CP diets. In addition, F/G was increased in Experiments 1, 2, and 4 in pigs fed low-CP diets, which suggests that the NE used for corn was overestimated or that NE values used for soybean meal and added fat sources were underestimated.

The SID Lys concentrations used in diet formulation were 92, 95, 94, and 93% of SID Lys requirement estimates suggested by NRC (2012) at the end of the BW range for Experiments 1, 2, 3, and 4, respectively. Using diets with 92 and 95% of the estimated SID Lys requirement at the end of the BW range for 29- to 52-lb and 50- to 80-lb pigs was sufficient to statistically reduce growth performance (LHH vs. LLH); however, for 127- to 162-lb and 193- to 237-lb pigs, using diets with 94 and 93% of SID Lys requirement at the end of the BW range resulted in only a numerical increase in F/G and reduction in ADG and final BW between the LHH and LLH diets. This result suggests that one should formulate SID Lys to be less than 93% of the NRC (2012) requirement estimate of the final BW of the experiment when determining AA:Lys in pigs heavier than 80 lb.

In all experiments, pigs fed diets with 14.5% SID Trp:Lys had decreased performance compared with pigs fed diets with 20% SID Trp:Lys, which indicates that Trp was definitely the first limiting AA in the LLL diet. Also, in Trp:Lys ratio studies, a Trp ratio of 14.5% of Lys may be a good starting point for observing a response to increasing Trp.

We recommend the following procedures as critical to successful characterization of AA:Lys ratios:

- Analyze dietary ingredients before formulation and use analyzed AA concentrations in the diet formulation.
- Ensure that diets are formulated to be below the SID Lys requirement for the entire feeding period using the NRC (2012) for the specific weight range, energy level, and gender. Based on the results of these studies, formulating diets with 0.05 percentage units below the SID Lys requirement estimate at the final BW of the experiment is enough for pigs under 80 lb, but for pigs heavier than that, it only numerically increased F/G and reduced ADG and final BW.
- Conduct experiments with a short length (e.g., 3 to 4 wk) to ensure Lys is below the requirement for the entire period.
- To ensure that diets were indeed formulated below the SID Lys requirement, conduct a preliminary experiment or include a dietary treatment in which Lys is above pigs' requirement.
- Ensure that all other AA are high enough to decrease the probability that another essential AA is deficient (e.g., SID ratios of 65% and 68% for Thr in early and late finishing phases, respectively; 70% Valine:Lys; 55% Isoleucine:Lys; 60% Methionine & Cysteine:Lys; 100% Leucine:Lys; 32% Histidine:Lys).
- Analyze diets after formulation to determine actual Lys and other AA levels that were fed.
- In conclusion, low-CP diets formulated 0.10 and 0.05 percentage units below the SID Lys requirement at the end of the experiment's weight range appear to ensure pigs are below their Lys requirement when determining the optimal SID Trp:Lys ratio for 29- to 52-lb and 50- to 80-lb pigs, respectively. For pigs heavier than 80 lb, formulating diets at 0.05 percentage units below the SID Lys requirement at the end of the experiment's weight range can limit the ability to provide statistical evidence that pigs are under their Lys requirement.

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

Item	HHH[2]	LHH	LLH	LLL
Ingredient, %				
Corn	31.48	41.59	55.10	55.16
Soybean meal (46% CP)	32.79	23.09	10.91	10.91
DDGS	30.00	30.00	30.00	30.00
Corn oil	3.00	1.80	0.50	0.50
Calcium phosphate (dicalcium)	0.15	0.30	0.50	0.50
Limestone	1.50	1.49	1.48	1.48
Salt	0.35	0.35	0.35	0.35
Trace mineral premix[3]	0.100	0.100	0.100	0.100
Vitamin premix[4]	0.125	0.125	0.125	0.125
L-lysine-HCL	0.340	0.625	0.575	0.575
DL-methionine	0.075	0.160	0.070	0.070
L-threonine	0.065	0.190	0.140	0.140
L-tryptophan	---	0.053	0.054	---
L-valine	---	0.105	0.060	0.060
L-isoleucine	---	---	0.010	0.010
Phytase[5]	0.025	0.025	0.025	0.025
Total	100	100	100	100

continued

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

Item	HHH[2]	LHH	LLH	LLL
Calculated analysis				
Standardized ileal digestible (SID) amino acids, %				
Lysine	1.29	1.29	0.97	0.97
Isoleucine:lysine	67	55	55	55
Leucine:lysine	152	135	153	153
Methionine:lysine	34	37	35	35
Met & Cys:lysine	60	60	60	60
Threonine:lysine	65	65	65	65
Tryptophan:lysine	20.0	20.0	20.0	14.5
Valine:lysine	73	70	70	70
Histidine:lysine	43	37	38	38
Total lysine, %	1.51	1.48	1.13	1.13
ME, kcal/lb	1,563	1,541	1,512	1,511
NE, kcal/lb	1,121	1,121	1,122	1,121
SID lysine:ME, g/Mcal	3.74	3.80	2.91	2.91
SID lysine:NE, g/Mcal	5.22	5.22	3.92	3.92
CP, %	26.1	22.9	18.2	18.1
Ca, %	0.71	0.71	0.71	0.71
P, %	0.52	0.51	0.49	0.49
Available P, %	0.37	0.38	0.40	0.40
STTD P[6] with phytase, %	0.40	0.40	0.40	0.40
Ca:P	1.36	1.39	1.44	1.44
Ca:P (STTD P with phytase)	1.79	1.79	1.79	1.79

[1] Diets were fed from 28.5 to 51.9 lb BW. Corn, dried distillers grains with solubles (DDGS) and soybean meal were analyzed for total amino acid content, and NRC (2012) SID digestibility values were used in the diet formulation.

[2] HHH: high CP, high SID Lys, and high SID Trp:Lys; LHH: low CP, high SID Lys, and high SID Trp:Lys; LLH: low CP, low SID Lys, and high Trp:Lys; LLL: low CP, low SID Lys, and low SID Trp:Lys.

[3] Provided per pound of diet: 33 ppm Mn from manganese oxide, 110 ppm Fe from iron sulfate, 110 ppm Zn from zinc oxide, 16.5 ppm Cu from copper sulfate, 0.33 ppm I from ethylenediamin dihydroiodide, and 0.30 ppm Se from sodium selenite.

[4] Provided per pound of diet: 4,000 IU vitamin A, 625 IU vitamin D_3, 20 IU vitamin E, 2.0 mg vitamin K, 12.5 mg pantothenic acid, 22.5 mg niacin, 3.5 mg riboflavin, and 15 µg vitamin B_{12}.

[5] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN) provided 568 phytase units (FTU) per pound of diet.

[6] Standardized total tract digestible phosphorus.

Table 2. Diet composition, Experiment 2 (as-fed basis)[1]

Item	HHH[2]	LHH	LLH	LLL
Ingredient, %				
Corn	39.59	49.60	57.14	57.20
Soybean meal (46% CP)	25.32	16.10	9.56	9.55
DDGS	30.00	30.00	30.00	30.00
Choice white grease	2.70	1.35	0.50	0.50
Limestone	1.49	1.45	1.43	1.43
Salt	0.35	0.35	0.35	0.35
Trace mineral premix[3]	0.100	0.100	0.100	0.100
Vitamin premix[4]	0.075	0.075	0.075	0.075
L-lysine-HCL	0.305	0.575	0.550	0.550
DL-methionine	0.020	0.100	0.050	0.050
L-threonine	0.035	0.150	0.125	0.125
L-tryptophan	---	0.050	0.051	---
L-valine	---	0.070	0.050	0.050
Phytase[5]	0.025	0.025	0.025	0.025
Total	100	100	100	100

continued

Table 2. Diet composition, Experiment 2 (as-fed basis)[1]

Item	HHH[2]	LHH	LLH	LLL
Calculated analysis				
Standardized ileal digestible (SID) amino acids, %				
Lysine	1.09	1.09	0.92	0.92
Isoleucine:lysine	68	55	55	55
Leucine:lysine	165	147	159	159
Methionine:lysine	32	36	34	34
Met & Cys:lysine	60	60	60	60
Threonine:lysine	65	65	65	65
Tryptophan:lysine	20.0	20.0	20.0	14.5
Valine:lysine	76	70	70	70
Histidine:lysine	45	38	39	39
Total lysine, %	1.29	1.26	1.08	1.08
ME, kcal/lb	1,557	1,536	1,520	1,520
NE, kcal/lb	1,131	1,131	1,131	1,131
SID lysine:ME, g/Mcal	3.18	3.22	2.75	2.75
SID lysine:NE, g/Mcal	4.37	4.37	3.69	3.69
CP, %	23.2	20.2	17.6	17.6
Ca, %	0.65	0.61	0.58	0.58
P, %	0.46	0.42	0.40	0.40
Available P, %	0.33	0.32	0.31	0.31
STTD P[6] with phytase, %	0.36	0.33	0.32	0.32
Ca:P	1.40	1.44	1.46	1.46
Ca:P (STTD P with phytase)	1.82	1.82	1.82	1.82

[1] Diets were fed from 50.1 to 80.3 lb BW. Corn, dried distillers grains with solubles (DDGS) and soybean meal were analyzed for total amino acid content and NRC (2012) SID digestibility values were used in the diet formulation.

[2] HHH: high CP, high SID Lys, and high SID Trp:Lys; LHH: low CP, high SID Lys, and high SID Trp:Lys; LLH: low CP, low SID Lys, and high Trp:Lys; LLL: low CP, low SID Lys, and low SID Trp:Lys.

[3] Provided per pound of diet: 33 ppm Mn from manganese oxide, 110 ppm Fe from iron sulfate, 110 ppm Zn from zinc oxide, 16.5 ppm Cu from copper sulfate, 0.33 ppm I from ethylenediamin dihydroiodide, and 0.30 ppm Se from sodium selenite.

[4] Provided per pound of diet: 2,400 IU vitamin A, 375 IU vitamin D_3, 12 IU vitamin E, 1.2 mg vitamin K, 7.5 mg pantothenic acid, 13.5 mg niacin, 2.1 mg riboflavin, and 9 µg vitamin B_{12}.

[5] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN) provided 568 phytase units (FTU) per pound of diet.

[6] Standardized total tract digestible phosphorus.

Table 3. Diet composition, Experiment 3 (as-fed basis)[1]

Item	HHH[2]	LHH	LLH	LLL
Ingredient, %				
Corn	46.84	57.00	60.82	60.87
Soybean meal (46% CP)	18.95	9.52	6.23	6.23
DDGS	30.00	30.00	30.00	30.00
Corn oil	2.10	0.85	0.50	0.50
Limestone	1.28	1.26	1.25	1.25
Salt	0.35	0.35	0.35	0.35
Trace mineral premix[3]	0.100	0.100	0.100	0.100
Vitamin premix[4]	0.075	0.075	0.075	0.075
L-lysine-HCL	0.275	0.552	0.495	0.495
DL-methionine	---	0.050	0.005	0.005
L-threonine	0.005	0.125	0.090	0.090
L-tryptophan	---	0.052	0.045	---
L-valine	---	0.045	0.010	0.010
Phytase[5]	0.025	0.025	0.025	0.025
Total	100	100	100	100

continued

Table 3. Diet composition, Experiment 3 (as-fed basis)[1]

Item	HHH[2]	LHH	LLH	LLL
Calculated analysis				
Standardized ileal digestible (SID) amino acids, %				
Lysine	0.92	0.92	0.80	0.80
Isoleucine:lysine	70	55	56	56
Leucine:lysine	181	159	174	174
Methionine:lysine	33	34	32	32
Met & Cys:lysine	63	60	60	60
Threonine:lysine	65	65	65	65
Tryptophan:lysine	20.0	20.0	20.0	14.5
Valine:lysine	80	70	70	70
Histidine:lysine	48	39	41	41
Total lysine, %	1.10	1.08	0.95	0.95
ME, kcal/lb	1,554	1,532	1,524	1,524
NE, kcal/lb	1,142	1,142	1,142	1,142
SID lysine:ME, g/Mcal	2.69	2.72	2.38	2.38
SID lysine:NE, g/Mcal	3.65	3.65	3.18	3.18
CP, %	20.7	17.6	16.3	16.2
Ca, %	0.55	0.52	0.51	0.51
P, %	0.44	0.40	0.38	0.38
Available P, %	0.32	0.31	0.30	0.30
STTD P[6] with phytase, %	0.34	0.32	0.31	0.31
Ca:P	1.27	1.31	1.32	1.32
Ca:P (STTD P with phytase)	1.63	1.63	1.63	1.63

[1] Diets were fed from 127.0 to 162.1 lb BW. Corn, dried distillers grains with solubles (DDGS), and soybean meal were analyzed for total amino acid content, and NRC (2012) SID digestibility values were used in the diet formulation.

[2] HHH: high CP, high SID Lys, and high SID Trp:Lys; LHH: low CP, high SID Lys, and high SID Trp:Lys; LLH: low CP, low SID Lys, and high Trp:Lys; LLL: low CP, low SID Lys, and low SID Trp:Lys.

[3] Provided per pound of diet: 33 ppm Mn from manganese oxide, 110 ppm Fe from iron sulfate, 110 ppm Zn from zinc oxide, 16.5 ppm Cu from copper sulfate, 0.33 ppm I from ethylenediamin dihydroiodide, and 0.30 ppm Se from sodium selenite.

[4] Provided per pound of diet: 2,400 IU vitamin A, 375 IU vitamin D_3, 12 IU vitamin E, 1.2 mg vitamin K, 7.5 mg pantothenic acid, 13.5 mg niacin, 2.1 mg riboflavin, and 9 µg vitamin B_{12}.

[5] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN) provided 568 phytase units (FTU) per pound of diet.

[6] Standardized total tract digestible phosphorus.

Table 4. Diet composition, Experiment 4 (as-fed basis)[1]

Item	HHH[2]	LHH	LLH	LLL
Ingredient, %				
Corn	51.86	61.19	65.19	65.23
Soybean meal (46% CP)	14.19	5.65	2.21	2.21
DDGS	30.00	30.00	30.00	30.00
Choice white grease	2.10	0.90	0.50	0.50
Limestone	1.12	1.11	1.10	1.10
Salt	0.35	0.35	0.35	0.35
Trace mineral premix[3]	0.050	0.050	0.050	0.050
Vitamin premix[4]	0.050	0.050	0.050	0.050
L-lysine-HCL	0.250	0.500	0.423	0.423
DL-methionine	---	0.005	---	---
L-threonine	0.005	0.115	0.065	0.065
L-tryptophan	---	0.046	0.036	---
L-valine	---	0.015	---	---
Phytase[5]	0.025	0.025	0.025	0.025
Total	100	100	100	100

continued

Table 4. Diet composition, Experiment 4 (as-fed basis)[1]

Item	HHH[2]	LHH	LLH	LLL
Calculated analysis				
Standardized ileal digestible (SID) amino acids, %				
Lysine	0.79	0.79	0.65	0.65
Isoleucine:lysine	73	56	60	60
Leucine:lysine	198	174	201	201
Methionine:lysine	36	32	36	36
Met & Cys:lysine	68	60	67	67
Threonine:lysine	68	68	68	68
Tryptophan:lysine	20.0	20.0	20.0	14.5
Valine:lysine	84	70	75	75
Histidine:lysine	50	41	45	45
Total lysine, %	0.96	0.94	0.79	0.79
ME, kcal/lb	1,555	1,536	1,528	1,528
NE, kcal/lb	1,154	1,154	1,154	1,154
SID lysine:ME, g/Mcal	2.30	2.33	1.93	1.93
SID lysine:NE, g/Mcal	3.11	3.11	2.55	2.56
CP, %	18.9	16.0	14.6	14.6
Ca, %	0.48	0.45	0.44	0.44
P, %	0.42	0.38	0.37	0.37
Available P, %	0.31	0.30	0.30	0.30
STTD P[6] with phytase, %	0.33	0.31	0.30	0.30
Ca:P	1.16	1.20	1.20	1.20
Ca:P (STTD P with phytase)	1.47	1.47	1.47	1.47

[1] Diets were fed from 192.5 to 237.4 lb BW. Corn, dried distillers grains with solubles (DDGS), and soybean meal were analyzed for total amino acid content, and NRC (2012) SID digestibility values were used in the diet formulation.

[2] HHH: high CP, high SID Lys, and high SID Trp:Lys; LHH: low CP, high SID Lys, and high SID Trp:Lys; LLH: low CP, low SID Lys, and high Trp:Lys; LLL: low CP, low SID Lys, and low SID Trp:Lys.

[3] Provided per pound of diet: 16.5 ppm Mn from manganese oxide, 55 ppm Fe from iron sulfate, 55 ppm Zn from zinc oxide, 8.3 ppm Cu from copper sulfate, 0.17 ppm I from ethylenediamin dihydroiodide, and 0.15 ppm Se from sodium selenite.

[4] Provided per pound of diet: 1,600 IU vitamin A, 250 IU vitamin D_3, 8 IU vitamin E, 0.80 mg vitamin K, 5.0 mg pantothenic acid, 9.0 mg niacin, 1.4 mg riboflavin, and 6 µg vitamin B_{12}.

[5] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN) provided 568 phytase units (FTU) per pound of diet.

[6] Standardized total tract digestible phosphorus.

Table 5. Chemical analysis of the diets, Experiment 1 (as-fed basis)[1,2]

Item	HHH	LHH	LLH	LLL
Proximate analysis, %				
DM	91.28 (82.06)	91.11 (82.26)	90.79 (83.23)	90.8 (83.28)
CP	27.6 (26.1)	23.9 (22.9)	20.2 (18.2)	20.1 (18.1)
Crude fiber	4.3 (4.6)	3.9 (4.4)	3.6 (4.2)	3.4 (4.2)
Ca	0.87 (0.71)	1.05 (0.71)	0.74 (0.71)	0.88 (0.71)
P	0.52 (0.52)	0.51 (0.51)	0.51 (0.49)	0.50 (0.49)
Fat	7.1 (7.2)	6.0 (6.2)	4.7 (5.2)	4.6 (5.2)
Ash	5.57 (3.68)	5.32 (3.20)	4.28 (2.61)	4.71 (2.61)
Total amino acids, %				
Lysine	1.48 (1.51)	1.52 (1.48)	1.21 (1.13)	1.14 (1.13)
Isoleucine	1.07 (1.01)	0.96 (0.85)	0.76 (0.65)	0.76 (0.65)
Leucine	2.38 (2.27)	2.21 (2.03)	1.94 (1.74)	1.95 (1.74)
Methionine	0.51 (0.50)	0.57 (0.54)	0.41 (0.39)	0.42 (0.39)
Methionine & Cysteine	0.95 (0.91)	0.97 (0.90)	0.76 (0.70)	0.76 (0.70)
Threonine	1.03 (1.03)	1.08 (1.01)	0.86 (0.78)	0.87 (0.78)
Tryptophan	0.29 (0.30)	0.29 (0.30)	0.22 (0.23)	0.27 (0.17)
Valine	1.23 (1.14)	1.18 (1.08)	0.97 (0.83)	0.98 (0.83)
Histidine	0.67 (0.65)	0.60 (0.56)	0.49 (0.44)	0.49 (0.44)
Phenylalanine	1.29 (1.22)	1.18 (1.04)	0.93 (0.81)	0.94 (0.81)
Free lysine	0.26 (0.34)	0.45 (0.63)	0.49 (0.58)	0.44 (0.58)
Free threonine	0.09 (0.07)	0.22 (0.19)	0.18 (0.14)	0.20 (0.14)
Free tryptophan	0.02 (---)	0.04 (0.05)	0.04 (0.05)	0.01 (---)

[1] Values in parentheses indicate those used in diet formulation and are from NRC (2012), with the exception of CP and total amino acid content from corn, soybean meal, and dried distillers grains with solubles, which were analyzed prior to diet formulation by Ajinomoto Heartland Inc. (Chicago, IL).

[2] Diet samples were collected from feeders, stored at -20°C, and submitted to Ward Laboratories, Inc. (Kearney, NE) for proximate analysis, with the exception of CP and total amino acids, which were analyzed by Ajinomoto Heartland, Inc. (Chicago, IL).

Table 6. Chemical analysis of the diets, Experiment 2 (as-fed basis)[1,2]

Item	HHH	LHH	LLH	LLL
Proximate analysis, %				
DM	91.16 (86.94)	91.10 (88.04)	90.79 (88.67)	90.97 (88.66)
CP	24.0 (23.2)	20.7 (20.2)	20.5 (17.6)	18.9 (17.6)
Crude fiber	4.2 (4.4)	3.6 (4.3)	3.2 (4.2)	3.6 (4.2)
Ca	0.78 (0.65)	0.84 (0.61)	0.74 (0.58)	0.64 (0.58)
P	0.44 (0.46)	0.40 (0.42)	0.39 (0.40)	0.40 (0.40)
Fat	6.0 (7.1)	5.2 (6.0)	4.7 (5.3)	4.9 (5.3)
Ash	4.87 (4.92)	4.71 (4.44)	4.53 (4.10)	4.15 (4.10)
Total amino acids, %				
Lysine	1.30 (1.29)	1.23 (1.26)	1.16 (1.08)	1.08 (1.08)
Isoleucine	0.93 (0.89)	0.81 (0.73)	0.77 (0.62)	0.72 (0.62)
Leucine	2.19 (2.09)	2.04 (1.86)	1.96 (1.71)	1.91 (1.71)
Methionine	0.42 (0.41)	0.48 (0.45)	0.39 (0.37)	0.40 (0.37)
Methionine & Cysteine	0.82 (0.79)	0.83 (0.78)	0.73 (0.67)	0.75 (0.67)
Threonine	0.91 (0.89)	0.89 (0.86)	0.81 (0.74)	0.78 (0.74)
Tryptophan	0.26 (0.26)	0.24 (0.25)	0.23 (0.22)	0.17 (0.17)
Valine	1.08 (1.01)	1.02 (0.92)	0.94 (0.80)	0.92 (0.80)
Histidine	0.60 (0.58)	0.53 (0.49)	0.50 (0.43)	0.47 (0.43)
Phenylalanine	1.15 (1.08)	1.01 (0.91)	0.96 (0.79)	0.90 (0.79)
Free lysine	0.23 (0.31)	0.37 (0.58)	0.37 (0.55)	0.38 (0.55)
Free threonine	0.06 (0.04)	0.15 (0.15)	0.12 (0.13)	0.13 (0.13)
Free tryptophan	0.01 (---)	0.03 (0.05)	0.02 (0.05)	0.01 (---)

[1] Values in parentheses indicate those used in diet formulation and are from NRC (2012), with the exception of CP and total amino acid content from corn, soybean meal, and DDGS, which were analyzed prior to diet formulation by Ajinomoto Heartland, Inc. (Chicago, IL).
[2] Diet samples were collected from feeders, stored at -20°C, and submitted to Ward Laboratories, Inc. (Kearney, NE) for proximate analysis, with the exception of CP and total amino acids, which were analyzed by Ajinomoto Heartland, Inc. (Chicago, IL).

Table 7. Chemical analysis of the diets, Experiment 3 (as-fed basis)[1,2]

Item	HHH	LHH	LLH	LLL
Proximate analysis, %				
DM	91.44 (87.33)	90.86 (88.34)	90.35 (88.57)	90.77 (88.57)
CP	21.5 (20.7)	19.1 (17.6)	17.2 (16.3)	17.6 (16.2)
Crude fiber	3.9 (4.3)	3.1 (4.2)	3.1 (4.1)	3.2 (4.1)
Ca	0.77 (0.55)	0.64 (0.52)	0.62 (0.51)	0.56 (0.51)
P	0.49 (0.44)	0.42 (0.40)	0.4 (0.38)	0.42 (0.38)
Fat	7.2 (6.6)	5.4 (5.6)	4.9 (5.4)	5.1 (5.4)
Ash	4.54 (4.41)	3.74 (3.93)	3.57 (3.77)	3.40 (3.77)
Total amino acids, %				
Lysine	1.23 (1.10)	1.37 (1.08)	1.03 (0.95)	1.11 (0.95)
Isoleucine	0.86 (0.78)	0.71 (0.62)	0.65 (0.56)	0.65 (0.56)
Leucine	2.10 (1.94)	1.95 (1.71)	1.85 (1.63)	1.85 (1.63)
Methionine	0.39 (0.36)	0.40 (0.37)	0.33 (0.31)	0.34 (0.31)
Methionine & Cysteine	0.77 (0.71)	0.74 (0.67)	0.65 (0.59)	0.66 (0.59)
Threonine	0.84 (0.76)	0.80 (0.74)	0.71 (0.66)	0.74 (0.66)
Tryptophan	0.21 (0.22)	0.20 (0.22)	0.18 (0.19)	0.16 (0.15)
Valine	1.02 (0.90)	0.89 (0.79)	0.80 (0.70)	0.81 (0.70)
Histidine	0.55 (0.52)	0.49 (0.43)	0.45 (0.40)	0.46 (0.40)
Phenylalanine	1.06 (0.96)	0.91 (0.79)	0.84 (0.73)	0.85 (0.73)
Free lysine	0.31 (0.28)	0.68 (0.55)	0.43 (0.50)	0.47 (0.50)
Free threonine	0.05 (0.01)	0.12 (0.13)	0.10 (0.09)	0.13 (0.09)
Free tryptophan	0.02 (---)	0.04 (0.05)	0.03 (0.05)	0.01 (---)

[1] Values in parentheses indicate those used in diet formulation and are from NRC (2012), with the exception of CP and total amino acid content from corn, soybean meal, and DDGS, which were analyzed prior to diet formulation by Ajinomoto Heartland, Inc. (Chicago, IL).
[2] Diet samples were collected from feeders, stored at -20°C, and submitted to Ward Laboratories, Inc. (Kearney, NE) for proximate analysis, with the exception of CP and total amino acids, which were analyzed by Ajinomoto Heartland Inc.

Table 8. Chemical analysis of the diets, Experiment 4 (as-fed basis)[1,2]

Item	HHH	LHH	LLH	LLL
Proximate analysis, %				
DM	90.43 (87.31)	89.92 (88.21)	89.79 (88.46)	89.83 (88.46)
CP	20.9 (18.9)	17.3 (16.0)	15.7 (14.6)	15.9 (14.6)
Crude fiber	3.7 (4.3)	3.8 (4.1)	3.3 (4.1)	3.8 (4.1)
Ca	0.86 (0.48)	0.65 (0.45)	0.66 (0.44)	0.52 (0.44)
P	0.42 (0.42)	0.40 (0.38)	0.39 (0.37)	0.38 (0.37)
Crude fat	6.4 (6.6)	5.7 (5.7)	5.0 (5.5)	5.4 (5.5)
Ash	4.70 (3.96)	3.87 (3.54)	3.45 (3.36)	3.48 (3.36)
Amino acids, %				
Lysine	1.00 (0.96)	0.93 (0.94)	0.84 (0.79)	0.81 (0.79)
Isoleucine	0.81 (0.70)	0.65 (0.55)	0.58 (0.49)	0.56 (0.49)
Leucine	2.05 (1.82)	1.81 (1.61)	1.75 (1.53)	1.75 (1.53)
Methionine	0.37 (0.34)	0.33 (0.30)	0.31 (0.28)	0.31 (0.28)
Methionine & Cysteine	0.74 (0.66)	0.65 (0.59)	0.61 (0.55)	0.60 (0.55)
Threonine	0.77 (0.69)	0.72 (0.67)	0.64 (0.57)	0.64 (0.57)
Tryptophan	0.21 (0.19)	0.18 (0.19)	0.16 (0.16)	0.13 (0.12)
Valine	0.96 (0.82)	0.81 (0.70)	0.71 (0.62)	0.71 (0.62)
Histidine	0.52 (0.48)	0.43 (0.39)	0.41 (0.36)	0.41 (0.36)
Phenylalanine	1.00 (0.87)	0.82 (0.72)	0.76 (0.65)	0.77 (0.65)
Free lysine	0.17 (0.25)	0.32 (0.50)	0.30 (0.42)	0.31 (0.42)
Free threonine	0.04 (0.01)	0.12 (0.12)	0.08 (0.07)	0.08 (0.07)
Free tryptophan	0.01 (---)	0.02 (0.05)	0.02 (0.04)	0.01 (---)

[1] Values in parentheses indicate those used in diet formulation and are from NRC (2012), with the exception of CP and total amino acid content from corn, soybean meal, and DDGS, which were analyzed prior to diet formulation by Ajinomoto Heartland, Inc. (Chicago, IL).
[2] Diet samples were collected from feeders, stored at -20°C, and submitted to Ward Laboratories, Inc. (Kearney, NE) for proximate analysis, with the exception of CP and total amino acids, which were analyzed by Ajinomoto Heartland, Inc.

Table 9. Effects of different standardized ileal digestible (SID) tryptophan:lysine ratios, CP, and SID lysine levels on pig performance[1]

Item	HHH[2]	LHH	LLH	LLL	SEM	Probability, $P <$
Exp. 1						
d 0 BW, lb	28.5	28.5	28.5	28.5	0.37	0.976
ADG, lb	1.23^{a}	1.26^{a}	1.04^{b}	0.89^{c}	0.02	0.001
ADFI, lb	1.69^{b}	1.82^{a}	1.73^{b}	1.59^{c}	0.03	0.001
F/G	1.38^{a}	1.45^{b}	1.67^{c}	1.78^{d}	0.03	0.001
NE caloric efficiency[3]	1,547^{a}	1,620^{b}	1,873^{c}	1,996^{d}	31.1	0.001
d 21 BW, lb	54.4^{a}	55.3^{a}	50.5^{b}	47.3^{c}	0.61	0.001
Exp. 2						
d 0 BW, lb	50.2	50.1	50.1	50.1	1.3	0.988
ADG, lb	1.57^{a}	1.60^{a}	1.44^{c}	1.08^{b}	0.03	0.001
ADFI, lb	2.55^{a}	2.75^{b}	2.78^{b}	2.23^{c}	0.08	0.001
F/G	1.62^{a}	1.71^{b}	1.93^{d}	2.06^{c}	0.03	0.001
NE caloric efficiency	1,838^{a}	1,940^{b}	2,178^{c}	2,326^{d}	34.9	0.001
d 21 BW, lb	83.2^{a}	83.8^{a}	80.9^{c}	73.1^{b}	1.8	0.001
Exp. 3						
d 0 BW, lb	126.8	126.9	127.1	127.1	2.5	0.967
ADG, lb	1.67^{b}	1.72^{b}	1.66^{b}	1.46^{a}	0.04	0.001
ADFI, lb	4.03^{a}	4.24^{b}	4.26^{b}	4.02^{a}	0.06	0.001
F/G	2.43^{a}	2.48^{a}	2.57^{a}	2.77^{b}	0.10	0.007
NE caloric efficiency	2,777^{a}	2,831^{a}	2,934^{a}	3,167^{b}	77.5	0.007
d 21 BW, lb	163.6^{b}	164.1^{b}	162.6^{b}	158.2^{a}	1.2	0.001
Exp. 4						
d 0 BW, lb	192.5	192.5	192.5	192.6	2.6	0.999
ADG, lb	2.28^{c}	2.17^{bc}	2.13^{b}	1.91^{a}	0.04	0.001
ADFI, lb	5.90	5.87	5.90	5.64	0.10	0.163
F/G	2.59^{a}	2.70^{b}	2.78^{b}	2.95^{c}	0.03	0.001
NE caloric efficiency	2992^{a}	3121^{b}	3210^{b}	3410^{c}	42.9	0.001
d 21 BW, lb	240.5^{c}	238.6^{bc}	237.6^{b}	233.0^{a}	2.6	0.001

[1]A total of 1,188, 1,232, 1,204, and 1,183 pigs (PIC 337 × 1050) were used for Experiments 1, 2, 3 and 4, respectively, in 21-d growth trials. Each treatment had 11 replications with 24 to 28 pigs per pen.

[2] Dietary treatments were HHH (High CP, High Lys, and High Trp), LHH (Low CP, High Lys, and High Trp), LLH (Low CP, Low Lys, and High Trp), LLL (Low CP, Low Lys, and Low Trp).

[3] Caloric efficiency is expressed as kcal/lb of gain.

[a,b,c,d] Means in same row with different superscripts differ ($P < 0.05$).

Effects of Standardized Ileal Digestible Tryptophan:Lysine Ratio on Growth Performance and Economics of 25- to 45-lb Nursery Pigs[1,2]

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Summary

The use of feed-grade tryptophan (Trp) in swine diets has become more economical recently due to the increased cost of soybean meal and the increased usage of dried distillers grains with solubles (DDGS). Therefore, the objectives of this study were to estimate the effects of the standardized ileal digestible (SID) tryptophan:lysine (Trp:Lys) ratio on growth performance and economics of 25- to 45-lb nursery pigs housed in a commercial environment. A total of 1,088 pigs (PIC 337 × 1050; initially 24.8 ± 1.2 lb BW) were used in a 21-d growth trial. Pigs were weaned at 16 d of age and grouped into pens of 27 pigs (14 gilts and 13 barrows). Pigs were fed common diets until d 28 after weaning. On d 28, pens of pigs were weighed and blocked by average BW, then randomly assigned to 1 of 7 dietary treatments in a randomized complete block design with 6 pens per treatment. Dietary treatments contained 30% DDGS and were 14.5, 16.5, 18.0, 19.5, 21.0, 22.5, and 24.5% SID Trp:Lys ratio. The SID Trp:Lys ratio was increased by adding crystalline L-Trp to the control diet at the expense of corn. The SID Lys requirement was 1.07% and was reduced by 0.10 percentage points below the estimated requirement to ensure that lysine was the second limiting amino acid throughout the experiment.

Increasing SID Trp:Lys ratio increased (quadratic, $P < 0.002$) ADG, ADFI, and final BW through the 21.0% SID Trp:Lys ratio with no change thereafter. Consequently, F/G, caloric efficiency, and income over feed cost (IOFC) also improved as the SID Trp:Lys ratio increased from 14.5 to 21.0% of Lys. For ADG, pigs fed the 18% SID Trp:Lys ratio were at 97% of maximum response, whereas for IOFC, pigs fed 18% SID Trp:Lys were at 98% of the maximum. Risk of reduced performance and profitability was much greater when SID Trp:Lys was formulated below 18% than when formulated above 18%. In conclusion, formulating nursery diets below 18% SID Trp:Lys reduced feed intake and, consequently, growth performance.

Key words: amino acid ratio, economics, nursery, tryptophan

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Introduction

Tryptophan (Trp) is an essential amino acid in swine diets and is important for increasing feed intake. Wide availability of feed-grade lysine, threonine, and methionine in swine diets increases the importance of Trp, because it is often the next limiting amino acid. As the economical availability of feed-grade Trp has improved, interest has grown in using it as a replacement for protein sources in swine diets. However, the requirement for Trp has not been well characterized in the late nursery phase using diets with high inclusion of dried distillers grains with solubles (DDGS). Although the optimum Trp requirement in swine diets can be expressed in different ways, using a standardized ileal digestible (SID) Trp requirement expressed as a ratio to lysine (Trp:Lys) is considered a practical approach for diet formulation. As a ratio to Lys, NRC (2012[6]) suggests that the SID Trp requirement is at 16.5% of Lys for 25- to 45-lb pigs, but from a practical perspective, it is important to determine not only the growth performance but also the economic impact of different SID Trp:Lys ratios. Therefore, the objectives of these studies were to estimate the effects of SID Trp:Lys ratio on growth performance and economics of 25- to 45-lb nursery pigs housed in a commercial environment.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. This study was conducted at a commercial research nursery barn in southwestern Minnesota. The facility was totally enclosed, environmentally controlled, and mechanically ventilated. Pens had completely slatted flooring and deep pits for manure storage. Each pen (12 × 7.5 ft) was equipped with a 6-hole stainless steel dry self-feeder (SDI Industries, Alexandria, SD) and a pan waterer for ad libitum access to feed and water.

Five representative samples of corn, soybean meal, and DDGS were collected each week for 5 wk before the start of the experiment and were analyzed in duplicate for total amino acids and CP by Ajinomoto Heartland, Inc. (Chicago, IL). These values, along with standardized digestibility coefficients from NRC (2012) for corn, soybean meal, and DDGS, were used in diet formulation. Diets were balanced on a NE basis using NRC (2012) values.

A total of 1,088 pigs (PIC 337 × 1050; initial BW of 24.8 ± 1.2 lb, final BW of 44.7 ± 1.9 lb, respectively) were used in a 21-d growth trial. Pigs were weaned at 16 d of age and grouped into pens of 27 pigs (14 gilts and 13 barrows). After weaning, pigs were fed a common pelleted diet for 7 d, followed by common diets fed in meal form containing 10 and 20% DDGS from d 7 to 14 and 14 to 28 after weaning, respectively, both formulated to contain a minimum 20% SID Trp:Lys ratio. On d 28 after weaning, pigs were weighed in pens, and pens were ranked by average BW and randomly assigned to dietary treatments in a randomized complete block design based on BW. There were 6 pens per treatment, and d 28 after weaning was considered d 0 of the trial.

Daily feed additions to each pen were accomplished through a robotic feeding system (FeedPro; Feedlogic Corp., Willmar, MN) capable of providing and measuring feed amounts for individual pens. This system is capable of feeding each individual pen any of the individual diets as well as a blend of two diets.

[6] NRC. 2012. Nutrient Requirements of Swine. 11th ed. Natl. Acad. Press, Washington, DC.

Two experimental corn-soybean meal–based diets with 30% DDGS were formulated (Table 1) to contain 14.5 and 24.5% SID Trp:Lys ratios and then were blended using the robotic feeding system to achieve intermediate SID Trp:Lys ratios. The SID Trp:Lys ratio was increased by adding crystalline L-Trp to the control diet at the expense of corn. The percentage of low and high SID Trp:Lys blended to create the treatment diets were 100:0, 80:20, 65:35, 50:50, 35:65, 20:80, and 0:100 to achieve 14.5, 16.5, 18.0, 19.5, 21.0, 22.5, and 24.5% SID Trp:Lys ratios, respectively. The NRC (2012) model was used to estimate the SID Lys requirement of pigs fed diets with 1,120 kcal NE/lb at the expected BW at the end of the experiment (50.0 lb). The SID Lys requirement (1.07%) was reduced by 0.10 percentage points (i.e., 0.97%) below the requirement at the end of the experiment for diet formulation to ensure that lysine was the second limiting amino acid throughout the experiment. Diets were fed in meal form and were manufactured at the New Horizon Farms Feed Mill (Pipestone, MN). A preliminary experiment was conducted prior to this experiment in the same facility and with pigs of same BW to validate that diets were indeed limiting in Lys, as described by Goncalves et al. (see "Validating a Dietary Approach to Determine Amino Acid:Lysine Ratios for Pigs," p. 83).

Pig BW and feed disappearance were measured on d 0 and 21 to calculate ADG, ADFI, F/G, and grams of SID Trp intake per kilogram of gain. Caloric efficiency was calculated on a pen basis by multiplying total pen feed intake by the dietary energy level (kcal/lb) and dividing by total pen gain. The total grams of SID Trp intake based on formulated values were divided by total BW gain to calculate the grams of SID Trp intake per kilogram of gain.

Diet samples were taken from 6 feeders per dietary treatment 3 d after the beginning and 3 d before the end of the experiment and stored at -4°F, then total amino acids and CP analyses were conducted on composite samples from each dietary treatment by Ajinomoto Heartland, Inc. Diet samples were also submitted to Ward Laboratories, Inc. (Kearney, NE) for analysis of DM, crude fiber, ash, crude fat, Ca, and P.

For the economic evaluation, total feed cost per pig, cost per pound of gain, revenue, and income over feed cost (IOFC) were calculated. The total feed cost per pig was calculated by multiplying the ADFI by diet cost and the number of days it was fed. Note that since experimental diets were formulated by adding different levels of L-tryptophan, diet cost was not optimized on a least-cost basis. Cost per pound of gain was calculated by dividing the total feed cost per pig by overall pounds gained. Revenue per pig was calculated by multiplying the ADG times the total days in the trial times an assumed live price of $68.00 per cwt. To calculate IOFC, total feed cost was subtracted from pig revenue. For all economic evaluations, price of ingredients during fall of 2013 were used; therefore, corn was valued at $6.19/bu ($221/ton), DDGS at $220/ton, soybean meal at $440/ton, L-tryptophan at $10.00/lb, and L-valine at $7.00/lb.

Responses measured at the pen level were analyzed using a general linear mixed model. The model included the fixed effect of dietary treatment and average pen BW block as a random effect. Pen was the experimental unit. Linear and quadratic orthogonal polynomial contrasts were built to evaluate the functional form of the dose response to increasing dietary SID Trp:Lys ratio on ADG, ADFI, F/G, NE caloric efficiency, BW, g of SID Trp intake per kilogram of gain, feed cost/pig, feed cost/lb of gain, total revenue/pig, and IOFC. Polynomial contrast coefficients were adjusted for unequally spaced

treatment intervals. Statistical models were fitted using the MIXED procedure in SAS (SAS Institute Inc., Cary, NC). Results were considered significant at $P \leq 0.05$.

Results and Discussion

The analyzed total amino acids, DM, CP, crude fiber, Ca, P, fat and ash contents of experimental diets (Table 2) were reasonably consistent with formulated estimates.

Increasing the SID Trp:Lys ratio quadratically increased (Table 3; $P < 0.002$) ADG, ADFI, and final BW through the 21.0% SID Trp:Lys ratio, with no evidence for further improvement in performance for pigs fed the 2 higher SID Trp:Lys ratios. On the contrary, larger SID Trp:Lys ratios seemed to have a detrimental effect on growth performance; consequently, F/G and caloric efficiency improved for pigs fed 14.5 to 21.0% SID Trp:Lys ratios. Similarly, the amount in grams of SID Trp intake per kilogram of gain increased in a quadratic manner with increasing SID Trp:Lys ratio (quadratic, $P < 0.001$). The grams of SID Trp intake per kilogram of gain was 3.5 at 21.0% SID Trp:Lys, which is higher than NRC (2012) requirement estimates of 2.5 to 2.9 g per kilogram of gain.

Feed cost per pig increased through the 22.5% SID Trp:Lys diet (quadratic, $P < 0.002$). Feed cost per pound of gain, in turn, was reduced quadratically with an estimated lowest at 16.5% SID Trp:Lys ratio ($P < 0.001$). Feed cost per pound of gain decreased quadratically when SID Trp:Lys ratio increased from 14.5 to 16.5% due to the low ADG of pigs fed 14.5% SID Trp:Lys ratio. Above 16.5% SID Trp:Lys, feed cost per pound of gain increased with increasing SID Trp:Lys ratio. Total revenue per pig increased quadratically ($P < 0.001$) up to 21.0% SID Trp:Lys ratio, with no evidence for improvement thereafter. On the contrary, larger SID Trp:Lys ratios seemed to have a detrimental effect on total revenue. The IOFC increased through the 21.0% SID Trp:Lys ratio.

The percentage of the maximum response was plotted against the SID Trp:Lys level for ADG, F/G, and IOFC (Figure 1). Note that the lowest F/G is considered the maximum pigs' response. The best performance was obtained when pigs were fed the 21% SID Trp:Lys ratio. Also, it is important to note that for pigs fed the 18% SID Trp:Lys ratio, ADG was 97% of maximum. For IOFC, pigs fed 18% SID Trp:Lys were at 98% of the maximum. In addition, when SID Trp:Lys was at 22.5%, ADG, F/G, and IOFC were at 99% of their maximum response.

Overall, growth and economic variables improved in a quadratic fashion with increasing SID Trp:Lys ratios. Although feed cost increased with the increasing Trp:Lys ratio, the increased incremental value of the increased growth negated the increased diet cost. This result suggests that increasing the margin of safety above the 16.5 to 18% range that is typically used in the U.S. diet formulation can be accomplished with little cost to economic performance. Also, the diets fed below 18.0% SID Trp:Lys were more detrimental to economic return than those fed above this range. In conclusion, formulating nursery diets below 18% SID Trp:Lys reduced feed intake and, consequently, growth performance.

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

	Standardized ileal digestible tryptophan:lysine	
Item	Low (14.5%)	High (24.5%)
Ingredient, %		
Corn	55.16	55.06
Soybean meal (46% CP)	10.91	10.92
DDGS[2]	30.00	30.00
Beef tallow	0.50	0.50
Dicalcium phosphate (18.5% P)	0.50	0.50
Limestone	1.48	1.48
Salt	0.35	0.35
Trace mineral premix[3]	0.100	0.100
Vitamin premix[4]	0.125	0.125
L-lysine HCL	0.575	0.575
DL-methionine	0.070	0.070
L-threonine	0.140	0.140
L-tryptophan	---	0.098
L-isoleucine	0.010	0.010
L-valine	0.060	0.060
Phytase[5]	0.025	0.025
Total	100	100

continued

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

	Standardized ileal digestible tryptophan:lysine	
Item	Low (14.5%)	High (24.5%)
Calculated analysis		
Standardized ileal digestible (SID) amino acids, %		
Lysine	0.97	0.97
Isoleucine:lysine	55	55
Leucine:lysine	153	153
Methionine:lysine	35	35
Met & Cys:lysine	60	60
Threonine:lysine	65	65
Tryptophan:lysine	14.5	24.5
Valine:lysine	70	70
Histidine:lysine	38	38
Tryptophan:BCAA[6]	3.9	6.6
Tryptophan:LNAA[7]	2.8	4.8
ME, kcal/lb	1,510	1,511
NE, kcal/lb	1,120	1,121
SID lysine:ME, g/Mcal	2.91	2.91
SID lysine:NE, g/Mcal	3.93	3.93
CP, %	18.1	18.2
Ca, %	0.71	0.71
P, %	0.49	0.49
Available P, %	0.40	0.40

[1] Diets were fed from 24.8 to 44.7 lb BW. Corn, dried distillers grains with solubles (DDGS), and soybean meal were analyzed for CP and total amino acid concentrations and NRC (2012) SID digestibility values were used in the diet formulation.
[2] Dried distillers grains with solubles.
[3] Provided per pound of diet: 33 ppm Mn from manganese oxide, 110 ppm Fe from iron sulfate, 110 ppm Zn from zinc oxide, 16.5 ppm Cu from copper sulfate, 0.33 ppm I from ethylenediamin dihydroiodide, and 0.30 ppm Se from sodium selenite.
[4] Provided per pound of diet: 4,000 IU vitamin A; 625 IU vitamin D3; 20 IU vitamin E; 2.0 mg vitamin K; 12.5 mg pantothenic acid; 22.5 mg niacin; 3.5 mg riboflavin and 15 µg vitamin B12.
[5] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN) provided 568 phytase units (FTU) per pound of diet.
[6] Amount of tryptophan in the diet as a ratio to branched-chain SID amino acid (BCAA; Ile, Leu, Val).
[7] Amount of tryptophan in the diet as a ratio to large neutral amino acid (LNAA; Ile, Leu, Val, Phe, and Tyr) on SID basis.

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

	Standardized ileal digestible tryptophan:lysine, %						
Item	14.5	16.5	18.0	19.5	21.0	22.5	24.5
Proximate analysis, %							
DM	90.48 (88.26)[2]	90.06 (88.27)	90.21 (88.27)	90.25 (88.27)	90.35 (88.27)	89.91 (88.27)	89.78 (88.28)
CP	19.0 (18.1)	19.4 (18.2)	18.8 (18.2)	18.7 (18.2)	18.9 (18.2)	19.1 (18.2)	18.2 (18.2)
Crude fiber	3.8 (4.2)	3.8 (4.2)	4 (4.2)	3.9 (4.2)	3.5 (4.2)	3.8 (4.2)	4.0 (4.2)
Ca	0.88 (0.71)	0.93 (0.71)	0.97 (0.71)	1.11 (0.71)	1.04 (0.71)	1.10 (0.71)	1.25 (0.71)
P	0.52 (0.49)	0.52 (0.49)	0.55 (0.49)	0.54 (0.49)	0.52 (0.49)	0.53 (0.49)	0.54 (0.49)
Fat	4.8 (5.2)	4.7 (5.2)	4.9 (5.2)	4.9 (5.2)	4.7 (5.2)	4.7 (5.2)	4.7 (5.2)
Ash	4.89 (4.73)	4.75 (4.73)	4.82 (4.73)	5.39 (4.72)	5.35 (4.72)	5.18 (4.72)	5.57 (4.72)
Amino acids, %							
Lysine	1.19 (1.13)	1.18 (1.13)	1.22 (1.13)	1.22 (1.13)	1.17 (1.13)	1.16 (1.13)	1.19 (1.13)
Isoleucine	0.73 (0.65)	0.75 (0.65)	0.75 (0.65)	0.75 (0.65)	0.74 (0.65)	0.76 (0.65)	0.77 (0.65)
Leucine	1.82 (1.74)	1.86 (1.74)	1.86 (1.74)	1.87 (1.74)	1.85 (1.74)	1.90 (1.74)	1.89 (1.74)
Methionine	0.40 (0.39)	0.39 (0.39)	0.40 (0.39)	0.40 (0.39)	0.40 (0.39)	0.39 (0.39)	0.40 (0.39)
Met & Cys	0.70 (0.70)	0.71 (0.70)	0.72 (0.70)	0.71 (0.70)	0.72 (0.70)	0.72 (0.70)	0.73 (0.70)
Threonine	0.82 (0.78)	0.81 (0.78)	0.83 (0.78)	0.81 (0.78)	0.83 (0.78)	0.80 (0.77)	0.81 (0.77)
Tryptophan	0.19 (0.17)	0.19 (0.19)	0.19 (0.21)	0.20 (0.22)	0.23 (0.24)	0.23 (0.25)	0.24 (0.27)
Valine	0.93 (0.83)	0.96 (0.83)	0.96 (0.83)	0.96 (0.83)	0.95 (0.83)	0.96 (0.83)	0.96 (0.83)
Histidine	0.47 (0.44)	0.48 (0.44)	0.48 (0.44)	0.48 (0.44)	0.47 (0.44)	0.49 (0.44)	0.49 (0.44)
Phenylalanine	0.88 (0.81)	0.91 (0.81)	0.90 (0.81)	0.91 (0.81)	0.90 (0.81)	0.93 (0.81)	0.93 (0.81)

[1] Diet samples were taken from 6 feeders per dietary treatment 3 d after the beginning of the trial and 3 d prior to the end of the trial and stored at -20°C, then CP and amino acid analysis was conducted on composite samples by Ajinomoto Heartland, Inc. (Chicago, IL). Samples of the diets were also submitted to Ward Laboratories, Inc. (Kearney, NE) for analysis of DM, crude fiber, Ca, P, ash, and crude fat.
[2] Values in parentheses indicate those calculated from diet formulation and are based on values from NRC (2012) with the exception of CP and total amino acid content from corn, soybean meal, and dried distillers grains with solubles, which were analyzed prior to diet formulation by Ajinomoto Heartland, Inc.

Table 3. Least square mean estimates (and corresponding SEM) for growth performance and economics of 25- to 45-lb nursery pigs subjected to dietary treatments of standardized ileal digestible tryptophan:lysine (SID Trp:Lys) ratio ranging from 14.5 to 24.5%[1,2]

	SID Trp:Lys ratio, %								Probability, *P* <	
	14.5	16.5	18.0	19.5	21.0	22.5	24.5	SEM	Linear	Quadratic
d 0 to 21										
ADG, lb	0.81	0.94	0.97	0.95	1.00	0.99	0.96	0.04	0.001	0.001
ADFI, lb	1.50	1.62	1.67	1.65	1.69	1.70	1.65	0.07	0.001	0.002
F/G	1.84	1.72	1.72	1.73	1.70	1.71	1.73	0.02	0.001	0.001
NE caloric efficiency[3]	2,066	1,927	1,925	1,940	1,900	1,919	1,935	20.8	0.001	0.001
BW, lb										
d 0	24.8	24.8	24.7	24.8	24.8	24.8	24.7	1.2	0.844	0.952
d 21	41.8	44.5	45.5	44.8	45.7	45.6	45.0	1.9	0.001	0.001
SID Trp, g/kg gain	2.6	2.8	3.0	3.3	3.5	3.7	4.1	0.04	0.001	0.001
Economics, $										
Feed cost/pig	3.55	3.88	4.05	4.04	4.18	4.24	4.18	0.18	0.001	0.002
Feed cost/lb gain[4]	0.208	0.196	0.198	0.202	0.199	0.203	0.208	0.002	0.158	0.001
Total revenue/pig[5,6]	10.63	12.31	12.72	12.44	13.04	12.97	12.51	0.52	0.001	0.001
IOFC[7]	7.08	8.43	8.67	8.41	8.86	8.73	8.33	0.35	0.001	0.001

[1] A total of 1,088 pigs (PIC 337 ×1050; initially 24.8 lb BW and 28 d postweaning) were used in a 21-d growth trial with 24 to 27 pigs per pen and 6 pens per treatment.
[2] The NRC (2012) model was used to determine the lysine requirement of mixed gender pens of pigs at the end of expected the phase range (50.0 lb), and that value was reduced by 0.10 percentage point.
[3] Caloric efficiency is expressed as kcal/lb of gain.
[4] Feed cost/lb gain = total feed cost divided by total gain per pig.
[5] One pound of live gain was considered to be worth $0.68.
[6] Total revenue/pig = total gain/pig × $0.68.
[7] Income over feed cost = total revenue/pig – feed cost/pig.

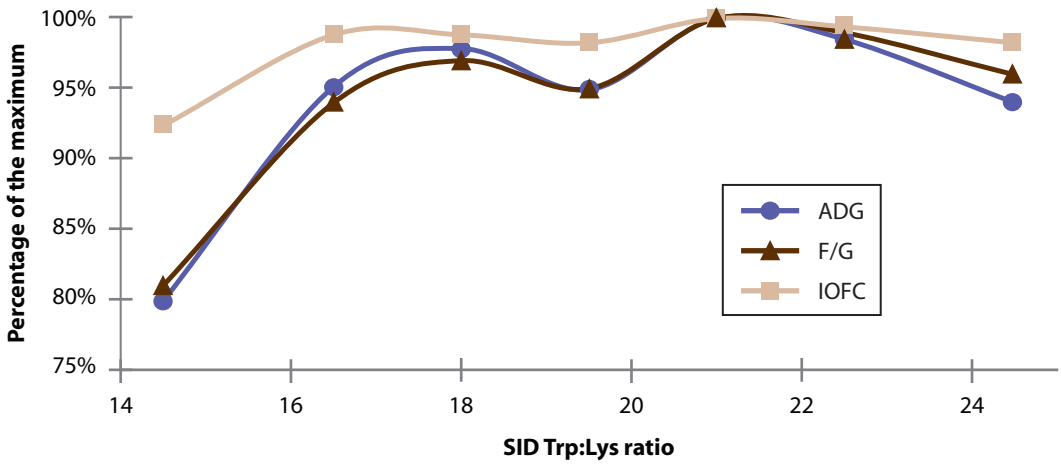

Figure 1. Effects of standardized ileal digestible tryptophan:lysine (SID Trp:Lys) ratio on ADG, F/G, and income over feed cost (IOFC) as a percentage of the maximum response observed in this experiment. (Note that the lowest F/G is considered the maximum pig response.)

Effects of Standardized Ileal Digestible Tryptophan:Lysine Ratio on Growth Performance and Economics of Finishing Pigs[1,2]

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Summary

The high usage of dried distillers grains with solubles (DDGS) in swine diets and the economical availability of feed-grade tryptophan have allowed swine nutritionists to include L-tryptophan in practical diet formulations. The objective of these experiments was to determine the effects of different standardized ileal digestible tryptophan:lysine (SID Trp:Lys) ratios on growth performance and economics in finishing pigs. Three 21-d growth experiments with a total of 1,166, 1,099, and 1,132 gilts (337 × 1050; PIC, Hendersonville, TN) and initial BW of 66.0 ± 1.8, 122.2 ± 4.3, and 156.9 ± 2.8 lb were used in Experiments 1, 2, and 3, respectively. At the beginning of each experiment, pigs were weighed in pens, and pens were ranked by average BW and randomly assigned dietary treatments in a randomized complete block design based on BW. Each experiment had 6 pens per treatment with 23 to 28 pigs per pen. Dietary treatments contained 30% DDGS and were 14.5, 16.5, 18.0, 19.5, 21.0, 22.5, and 24.5% SID Trp:Lys ratio. The SID Trp:Lys ratio was increased by adding crystalline L-Trp to the control diet at the expense of corn. Diets were formulated to ensure that lysine was the second limiting amino acid throughout the experiment.

From 66.0 to 100.6 lb, ADG increased up to 19.5% SID Trp:Lys ratio then had marginal changes at higher ratios (quadratic, $P < 0.02$), whereas F/G improved through 21.0% SID Trp:Lys ratio then also had marginal changes at higher ratios (quadratic, $P < 0.004$). Income over feed cost (IOFC) increased quadratically ($P < 0.02$) up to 24.5% SID Trp:Lys ratio. From 122.2 to 165.2 lb, pigs fed increasing SID Trp:Lys ratio had increased ADG (linear, $P < 0.03$); however, the higher magnitude of improvement in ADG was through the 18% SID Trp:Lys ratio, with a subtle increase up to the highest SID Trp:Lys ratio. Feed efficiency and IOFC were not statistically different between treatments. From 156.9 to 200.8 lb, ADG, F/G, and IOFC improved (quadratic, $P < 0.04$) through 21.0% SID Trp:Lys ratio, then was poorer for pigs fed the 2 highest SID Trp:Lys ratios.

In conclusion, these studies provide good evidence to formulate diets for finishing pigs with at least 18.0% SID Trp:Lys ratio because the growth and economic risk of formulating diets below that ratio is considerably greater than formulating diets above that ratio.

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Key words: amino acid ratio, tryptophan, finishing pig

Introduction

Tryptophan is typically considered the fourth limiting amino acid in corn-soybean meal–based diets for growing pigs; however, the increased usage of dried distillers grains with solubles (DDGS) has resulted in tryptophan (Trp) becoming the second limiting amino acid after lysine (Lys). Tryptophan plays a role in a wide range of functions besides protein synthesis, and limiting dietary tryptophan levels will cause amino acid imbalance at the brain level because of the relative excess of large neutral amino acids compared with tryptophan. This is important because reductions in feed intake will consequently reduce growth rate.

The amino acid requirements of pigs can be expressed in several different ways; however, the most practical approach for diet formulation is the expression of the standardized ileal digestible (SID) Trp requirement as a ratio to Lys (Trp:Lys). Based on NRC (2012[6]), the SID Trp:Lys ratio requirement for finishing pigs below 165 lb BW is 17.2%, and above 165 lb BW the ratio is 17.7%. To accurately determine the SID Trp:Lys ratio requirement, Lys must be limiting; otherwise, the SID Trp:Lys ratio requirement may be underestimated. The current body of literature lacks experiments in which pigs are below their Lys requirement and that encompass the different stages of the finishing phase to estimate the optimum SID Trp:Lys ratios for the different response variables. Therefore, the objective of this series of experiments was to determine the effects of different SID Trp:Lys ratios on growth performance and economics of finishing pigs.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in these experiments. The studies were conducted at a commercial research-finishing barn in southwestern Minnesota. The barn was naturally ventilated and double-curtain-sided. Pens had completely slatted flooring and deep pits for manure storage. Each pen (18 × 10 ft) was equipped with a 4-hole stainless steel dry self-feeder (Thorp Equipment, Thorp, WI) and a cup waterer. The facility was equipped with a computerized feeding system (FeedPro; Feedlogic Corp., Willmar, MN) that delivered and recorded daily feed additions and diets as specified. Pigs had ad libitum access to feed and water.

Five representative samples of corn, soybean meal, and DDGS were collected each week for 5 wk and analyzed in duplicate for total amino acids and CP by Ajinomoto Heartland, Inc. (Chicago, IL), and values were used in diet formulation. Other nutrients and SID amino acid digestibility coefficient values used for diet formulation were obtained from NRC (2012).

Three 21-d growth experiments were conducted with two groups of pigs. Experiments 1 and 3 were conducted with one group of pigs, and Experiment 2 was conducted with a different group of pigs. A total of 1,166, 1,099, and 1,132 gilts (337 × 1050; PIC, Hendersonville, TN) with initial BW of 66.0 ± 1.8, 122.2 ± 4.3, and 156.9 ± 2.8 lb, and final BW of 100.6 ± 2.6, 165.2 ± 4.6, and 200.8 ± 3.2 lb were used in Experiments

[6] NRC. 2012. Nutrient Requirements of Swine. 11th ed. Natl. Acad. Press, Washington, DC.

1, 2, and 3, respectively. At the beginning of each experiment, pigs were weighed in pens and pens were ranked by average BW and randomly assigned dietary treatments in a randomized complete block design based on average pen BW. Each experiment had 6 pens per treatment with 23 to 28 pigs per pen.

Two experimental corn-soybean meal–based diets with 30% DDGS were formulated (Table 1) to have either a 14.5 or 24.5% SID Trp:Lys ratio, then blended using the robotic feeding system to achieve intermediate SID Trp:Lys ratios. The SID Trp:Lys ratio was increased by adding crystalline L-Trp to the control diet at the expense of corn. The percentage of low and high SID Trp:Lys blended to create the treatment diets were 100:0, 80:20, 65:35, 50:50, 35:65, 20:80, and 0:100 to achieve 14.5, 16.5, 18.0, 19.5, 21.0, 22.5, and 24.5% SID Trp:Lys ratios, respectively. The NRC (2012) model was used to estimate the Lys requirement of pigs at the expected BW at the end of each experiment. The SID Lys percentage used in diet formulation was 0.05 percentage points below the SID Lys requirement at the expected BW at the end of Experiments 1 and 3 and 0.10 percentage points below the SID Lys requirement at the expected BW at the end of Experiment 2 to ensure that Lys was the second limiting amino acid throughout the experiments. These reductions in SID Lys were based on a preliminary study conducted by Goncalves et al. (see "Validating a Dietary Approach to Determine Amino Acid:Lysine Ratios for Pigs, p. 83) in the same commercial research barn. Diets were fed in meal form and were manufactured at the New Horizon Farms Feed Mill (Pipestone, MN).

Pens of pigs were weighed and feed disappearance measured at the beginning and at d 21 of each experiment to determine ADG, ADFI, and F/G. There was a 21-d period between Experiments 1 and 3 during which pigs were fed a common diet that met or exceeded NRC (2012) requirements and contained 20% SID Trp:Lys. Caloric efficiency was calculated on a pen basis by multiplying total pen feed intake by the dietary energy level (kcal/lb) and dividing by total pen gain. The total grams of SID Trp intake based on formulated values was divided by total BW gain to calculate the grams of SID Trp intake per kilogram of gain.

Diet samples were taken from 6 feeders per dietary treatment 3 d after the beginning and 3 d before the end of each experiment and stored at -20°C, then CP and total amino acid analysis was conducted on composite samples from each treatment by Ajinomoto Heartland, Inc. Diet samples were also submitted to Ward Laboratories, Inc. (Kearney, NE) for analysis of DM, crude fiber, ash, crude fat, Ca, and P.

For the economic evaluation, total feed cost per pig, cost per pound of gain, revenue, and income over feed cost (IOFC) were calculated. The total feed cost per pig was calculated by multiplying the ADFI by the cost per pound of feed and the number of days. Note that because experimental diets were formulated by adding different levels of L-Trp, diet cost was not optimized on a least-cost basis. Cost per pound of gain was calculated by dividing the total feed cost per pig by the amount of pounds gained overall. Revenue per pig was calculated by multiplying the ADG times the total days in the trial times an assumed live price of $68.00 per cwt. To calculate IOFC, total feed cost was subtracted from pig revenue. Ingredient prices during the fall of 2013 were used for all economic evaluations; therefore, corn was valued at $6.19/bu ($221/ton), DDGS at $220/ton, soybean meal at $440/ton, L-Trp at $10.00/lb, and L-Valine at $7.00/lb.

Data corresponding to Experiments 1, 2, and 3 were analyzed separately. Within each experiment, responses measured at the pen level were analyzed using a general linear mixed model. The model included the fixed effect of dietary treatment and average pen BW block as a random effect. Pen was the experimental unit. Linear and quadratic orthogonal polynomial contrasts were built to evaluate the functional form of the dose response to increasing dietary SID Trp:Lys ratio on ADG, ADFI, F/G, NE caloric efficiency, BW, grams of SID Trp intake per kilogram of gain, feed cost/pig, feed cost/lb of gain, total revenue/pig, and IOFC. Polynomial contrast coefficients were adjusted for unequally spaced treatment intervals. In addition, for Experiment 3, dietary treatment from the previous experiment (Experiment 1) was also considered a random effect. Statistical models were fitted using the MIXED procedure of SAS (SAS Institute Inc., Cary, NC). Results were considered significant at $P \leq 0.05$.

Results and Discussion

The analyzed total amino acids, DM, CP, crude fiber, Ca, P, fat, and ash contents of experimental diets (Tables 2, 3, and 4) were reasonably consistent with formulated estimates. From 66.0 to 100.6 lb, ADG and final BW increased quadratically (Table 5; $P < 0.02$) with increasing SID Trp:Lys ratio, but the rate of increase progressively diminished, particularly above the 19.5% SID Trp:Lys ratio. Feed intake increased quadratically ($P < 0.02$) up to 19.5% SID Trp:Lys ratio with no improvements thereafter. In addition, F/G and caloric efficiency improved quadratically ($P < 0.004$) as the SID Trp:Lys ratio increased, with the greatest rate of change up to 21%, but the best F/G was observed at the 24.5% SID Trp:Lys ratio. The grams of SID Trp intake per kilogram of gain increased linearly ($P < 0.001$).

From 122.2 to 165.2 lb, ADG, ADFI, and final BW increased linearly ($P < 0.03$) with increasing SID Trp:Lys ratio. Feed efficiency and caloric efficiency were not statistically different among treatments. Similar to Experiment 1, grams of SID Trp intake per kilogram of gain increased linearly ($P < 0.001$).

From 156.9 to 200.8 lb, ADG increased quadratically ($P < 0.04$) through 21.0% SID Trp:Lys ratio and then was reduced for pigs fed the 2 highest SID Trp:Lys ratios. Final BW increased in a linear manner ($P < 0.02$) with increasing SID Trp:Lys ratio, although the highest final BW was for pigs fed the 21% SID Trp:Lys ratio. No evidence for differences in ADFI was observed among dietary treatments. Feed efficiency and caloric efficiency improved quadratically ($P < 0.02$) through 21% SID Trp:Lys ratio and then was poorer for pigs fed the 2 highest ratios. In contrast to Experiments 1 and 2, the grams of SID Trp intake per kilogram of gain in Experiment 3 increased quadratically ($P < 0.03$) with increasing SID Trp:Lys ratio.

Overall, the grams of SID Trp intake per kilogram of gain where performance reached a point of diminishing returns in response to increased SID Trp:Lys ratio ranged from 3.3 to 3.7 g, which is on the higher end of the NRC (2012) requirement estimates of 2.3 to 3.6 g per kilogram of gain for finishing pigs.

From 66.0 to 100.6 lb, feed cost per pig, total revenue per pig, and IOFC increased quadratically (Table 6; $P < 0.02$) up to 24.5% SID Trp:Lys ratio. Feed cost per pound of gain was reduced (quadratic, $P < 0.005$) for pigs fed the 16.5% SID Trp:Lys ratio,

with a plateau thereafter for pigs fed higher doses. From 122.2 to 165.2 lb, feed cost per pig, feed cost per pound of gain, and total revenue per pig increased linearly ($P < 0.001$) with increasing SID Trp:Lys ratio; consequently, IOFC was not statistically different among treatments. From 156.9 to 200.8 lb, feed cost per pig increased linearly ($P < 0.001$) with increasing SID Trp:Lys ratios. Feed cost per pound of gain was reduced (quadratic, $P < 0.03$) for pigs fed up to 21% SID Trp:Lys ratio and then increased for pigs fed the 2 highest SID Trp:Lys ratios. Conversely, total revenue per pig and IOFC increased (quadratic, $P < 0.03$) up to 21% SID Trp:Lys ratio and then was reduced thereafter.

The percentage of the response compared with the maximum ADG and IOFC and to the optimum F/G was plotted against the SID Trp:Lys ratio (Figures 1, 2, and 3, respectively) for each of the experiments. Note that the lowest F/G is considered the optimum pig response. The ADG was at least at 95% of maximum response at 19.5, 18.0, and 19.5% SID Trp:Lys ratios for Experiments 1, 2, and 3, respectively. Feed efficiency was at least at 95% of its optimum response at 16.5% for all experiments. Finally, IOFC was at least at 95% of maximum response at 19.5, 16.5, and 19.5% SID Trp:Lys ratios for Experiments 1, 2, and 3, respectively.

The 16.5% SID Trp:Lys ratio for finishing pigs was enough to improve F/G to 97% of its optimum; however, pigs fed the 16.5% SID Trp:Lys ratio were only at 92% of their maximum for ADG and IOFC. In contrast, pigs fed a higher ratio of 21% SID Trp:Lys were at 98% of maximum ADG and 96% of maximum IOFC. This illustrates that different response criteria will result in a different estimate of the requirement. In addition, although diets with increased SID Trp:Lys ratios were more expensive, the cost was offset by the improvement in growth performance. In conclusion, these studies provide good evidence to formulate diets for finishing pigs with at least an 18.0% SID Trp:Lys ratio because the growth and economic risk of formulating diets below that ratio is considerably greater than formulating diets above that ratio.

Table 1. Diet composition, Experiments 1, 2, and 3 (as-fed basis)[1]

	Exp. 1		Exp. 2		Exp. 3	
	Standardized ileal digestible (SID) tryptophan:lysine					
Item	Low (14.5%)	High (24.5%)	Low (14.5%)	High (24.5%)	Low (14.5%)	High (24.5%)
Ingredient, %						
Corn	57.77	57.67	62.69	62.61	63.07	62.99
Soybean meal (46% CP)	9.03	9.03	4.51	4.51	4.13	4.14
DDGS	30.00	30.00	30.00	30.00	30.00	30.00
Corn oil	0.50	0.50	-	-	-	-
Beef tallow	-	-	0.50	0.50	-	-
Choice white grease	-	-	-	-	0.50	0.50
Limestone	1.40	1.40	1.28	1.28	1.20	1.20
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Trace mineral premix[2]	0.100	0.100	0.100	0.100	0.100	0.100
Vitamin premix[3]	0.075	0.075	0.075	0.075	0.075	0.075
L-lysine HCL	0.540	0.540	0.431	0.431	0.455	0.455
DL-methionine	0.045	0.045	-	-	-	-
L-threonine	0.125	0.125	0.045	0.045	0.090	0.090
L-tryptophan	-	0.091	-	0.076	-	0.073
L-valine	0.045	0.045	-	-	-	-
Phytase[4]	0.025	0.025	0.025	0.025	0.025	0.025
Total	100	100	100	100	100	100

continued

Table 1. Diet composition, Experiments 1, 2, and 3 (as-fed basis)[1]

	Exp. 1		Exp. 2		Exp. 3	
	Standardized ileal digestible (SID) tryptophan:lysine					
Item	Low (14.5%)	High (24.5%)	Low (14.5%)	High (24.5%)	Low (14.5%)	High (24.5%)
Calculated analysis						
SID amino acids, %						
Lysine	0.90	0.90	0.75	0.75	0.72	0.72
Isoleucine:lysine	55	55	63	63	58	58
Leucine:lysine	161	161	196	195	187	187
Methionine:lysine	34	34	34	34	34	34
Methionine & Cys:lysine	60	60	64	64	63	63
Threonine:lysine	65	65	65	65	68	68
Tryptophan:lysine	14.5	24.5	14.5	24.5	14.5	24.5
Valine:lysine	70	70	76	76	72	72
Histidine:lysine	39	39	46	46	43	43
Tryptophan:BCAA[5]	5.8	9.8	4.3	7.3	3.0	5.1
Tryptophan:LNAA[6]	4.7	7.9	3.1	5.3	2.2	3.7
ME, kcal/lb	1,521	1,522	1,522	1,523	1,524	1,525
NE, kcal/lb	1,133	1,134	1,144	1,145	1,147	1,147
SID lysine:ME, g/Mcal	3.60	3.60	2.23	2.23	2.14	2.14
SID lysine:NE, g/Mcal	2.68	2.68	2.97	2.97	2.85	2.85
CP, %	17.4	17.5	16.4	16.5	15.4	15.4
Ca, %	0.57	0.57	0.51	0.51	0.48	0.48
P, %	0.39	0.39	0.38	0.37	0.37	0.37
Available P, %	0.31	0.31	0.30	0.30	0.30	0.30

[1] Diets were fed from 66.0 to 100.6, 122.2 to 165.2, and 156.9 to 200.8 lb BW in Experiments 1, 2, and 3, respectively. Corn, dried distillers grains with solubles (DDGS), and soybean meal were analyzed for CP and total amino acid content, and NRC (2012) SID digestibility values were used in the diet formulation.

[2] Provided: 33 ppm Mn from manganese oxide, 110 ppm Fe from iron sulfate, 110 ppm Zn from zinc oxide, 16.5 ppm Cu from copper sulfate, 0.33 ppm I from ethylenediamin dihydroiodide, and 0.30 ppm Se from sodium selenite.

[3] Provided per pound of diet: 2,400 IU vitamin A; 375 IU vitamin D3; 12.0 IU vitamin E; 1.20 mg vitamin K; 7.5 mg pantothenic acid; 13.5 mg niacin; 2.1 mg riboflavin and 9 µg vitamin B12.

[4] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN) provided 568 phytase units (FTU) per pound of diet and a release of 0.14% in available P was considered.

[5] Dietary tryptophan as a ratio to branched-chain amino acids (BCAA; isoleucine, leucine, valine) on SID basis.

[6] Dietary tryptophan as a ratio to large neutral amino acids (LNAA; isoleucine, leucine, valine, phenylalanine, and tyrosine) on SID basis.

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

	Standardized ileal digestible tryptophan:lysine, %						
Item	14.5	16.5	18.0	19.5	21.0	22.5	24.5
Proximate analysis, %							
DM	90.77 (88.65)[2]	90.91 (88.65)	90.68 (88.65)	90.81 (88.65)	90.84 (88.65)	90.73 (88.66)	90.66 (88.66)
CP	19.7 (17.4)	19.6 (17.4)	19.4 (17.4)	18.4 (17.4)	19.5 (17.4)	18.7 (17.5)	18.9 (17.5)
Crude fiber	3.8 (4.2)	3.9 (4.2)	3.5 (4.2)	3.6 (4.2)	3.4 (4.2)	3.4 (4.2)	3.3 (4.2)
Ca	0.74 (0.57)	0.87 (0.57)	0.72 (0.57)	0.78 (0.57)	0.85 (0.57)	0.77 (0.57)	0.78 (0.57)
P	0.45 (0.39)	0.46 (0.39)	0.44 (0.39)	0.44 (0.39)	0.45 (0.39)	0.42 (0.39)	0.45 (0.39)
Fat	5.6 (5.3)	5.9 (5.3)	6.0 (5.3)	5.9 (5.3)	5.9 (5.3)	5.3 (5.3)	5.4 (5.3)
Ash	4.44 (2.53)	4.79 (2.53)	4.33 (2.53)	4.2 (2.53)	4.44 (2.53)	3.95 (2.53)	4.10 (2.53)
Amino acids, %							
Lysine	1.13 (1.06)	1.16 (1.06)	1.15 (1.06)	1.11 (1.06)	1.13 (1.06)	1.11 (1.06)	1.10 (1.06)
Isoleucine	0.70 (0.67)	0.69 (0.67)	0.70 (0.67)	0.70 (0.67)	0.72 (0.67)	0.69 (0.67)	0.69 (0.67)
Leucine	1.92 (1.92)	1.84 (1.92)	1.89 (1.92)	1.89 (1.92)	1.91 (1.92)	1.90 (1.92)	1.89 (1.92)
Methionine	0.38 (0.36)	0.38 (0.36)	0.39 (0.36)	0.40 (0.36)	0.39 (0.36)	0.38 (0.36)	0.37 (0.36)
Met & Cys	0.72 (0.67)	0.70 (0.67)	0.72 (0.67)	0.73 (0.67)	0.73 (0.67)	0.70 (0.67)	0.71 (0.67)
Threonine	0.79 (0.75)	0.82 (0.75)	0.81 (0.75)	0.78 (0.75)	0.80 (0.75)	0.80 (0.75)	0.78 (0.75)
Tryptophan	0.18 (0.16)	0.21 (0.18)	0.22 (0.19)	0.21 (0.21)	0.22 (0.22)	0.23 (0.23)	0.23 (0.25)
Valine	0.89 (0.85)	0.85 (0.85)	0.87 (0.85)	0.86 (0.85)	0.88 (0.85)	0.86 (0.85)	0.86 (0.85)
Histidine	0.48 (0.44)	0.47 (0.44)	0.48 (0.44)	0.48 (0.44)	0.49 (0.44)	0.48 (0.44)	0.48 (0.44)
Phenylalanine	0.91 (0.87)	0.88 (0.87)	0.90 (0.87)	0.90 (0.87)	0.92 (0.87)	0.90 (0.87)	0.89 (0.87)

[1] Diet samples were taken from 6 feeders per dietary treatment 3 d after the beginning of the trial and 3 d prior to the end of the trial and stored at -20°C, then CP and amino acid analysis was conducted on composite samples by Ajinomoto Heartland, Inc. (Chicago, IL). Samples of the diets were also submitted to Ward Laboratories, Inc. (Kearney, NE) for analysis of DM, crude fiber, Ca, P, ash, and crude fat.
[2] Values in parentheses indicate those calculated from diet formulation and are based on values from NRC (2012), with the exception of CP and total amino acid content from corn, soybean meal, and dried distillers grains with solubles, which were analyzed prior to diet formulation by Ajinomoto Heartland, Inc.

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

	Standardized ileal digestible tryptophan:lysine, %						
Item	14.5	16.5	18.0	19.5	21.0	22.5	24.5
Proximate analysis, %							
DM	89.97 (88.52)[2]	89.47 (88.53)	89.77 (88.53)	90.17 (88.53)	90.02 (88.53)	89.6 (88.53)	90.08 (88.53)
CP	16.7 (16.4)	16.6 (16.4)	15.5 (16.5)	15.9 (16.5)	16.8 (16.5)	16.6 (16.5)	16.7 (16.5)
Crude fiber	3.5 (4.1)	3.7 (4.1)	3.5 (4.1)	3.3 (4.1)	3.3 (4.1)	3.5 (4.1)	3.7 (4.1)
Ca	0.74 (0.51)	0.61 (0.51)	0.75 (0.51)	0.69 (0.51)	0.72 (0.51)	0.79 (0.51)	0.62 (0.51)
P	0.41 (0.38)	0.40 (0.38)	0.40 (0.38)	0.40 (0.38)	0.41 (0.38)	0.41 (0.38)	0.42 (0.37)
Fat	5.2 (5.4)	5.4 (5.4)	5.3 (5.4)	5.2 (5.4)	5.3 (5.4)	5.0 (5.4)	5.5 (5.4)
Ash	4.22 (3.71)	3.98 (3.71)	4.34 (3.71)	4.06 (3.71)	4.25 (3.71)	4.33 (3.71)	3.98 (3.71)
Amino acids, %							
Lysine	0.94 (0.93)	0.92 (0.93)	0.92 (0.93)	0.91 (0.93)	0.90 (0.93)	0.93 (0.93)	0.95 (0.93)
Isoleucine	0.72 (0.60)	0.66 (0.60)	0.69 (0.60)	0.72 (0.60)	0.67 (0.60)	0.68 (0.60)	0.76 (0.60)
Leucine	1.71 (1.73)	1.68 (1.72)	1.67 (1.72)	1.69 (1.72)	1.67 (1.72)	1.68 (1.72)	1.76 (1.72)
Methionine	0.30 (0.31)	0.31 (0.31)	0.29 (0.31)	0.29 (0.31)	0.30 (0.31)	0.29 (0.31)	0.32 (0.31)
Met & Cys	0.60 (0.61)	0.60 (0.61)	0.57 (0.61)	0.58 (0.61)	0.60 (0.61)	0.58 (0.61)	0.62 (0.61)
Threonine	0.62 (0.67)	0.64 (0.67)	0.63 (0.67)	0.64 (0.67)	0.63 (0.67)	0.63 (0.67)	0.67 (0.67)
Tryptophan	0.16 (0.14)	0.16 (0.16)	0.17 (0.17)	0.17 (0.18)	0.19 (0.19)	0.20 (0.20)	0.21 (0.22)
Valine	0.78 (0.73)	0.78 (0.73)	0.76 (0.73)	0.77 (0.73)	0.76 (0.73)	0.78 (0.73)	0.82 (0.73)
Histidine	0.41 (0.43)	0.42 (0.43)	0.40 (0.43)	0.41 (0.43)	0.42 (0.43)	0.41 (0.43)	0.44 (0.43)
Phenylalanine	0.78 (0.76)	0.80 (0.76)	0.77 (0.76)	0.78 (0.76)	0.80 (0.76)	0.78 (0.76)	0.83 (0.76)

[1] Diet samples were taken from 6 feeders per dietary treatment 3 d after the beginning of the trial and 3 d prior to the end of the trial and stored at -20°C, then CP and amino acid analysis was conducted on composite samples by Ajinomoto Heartland, Inc. (Chicago, IL). Samples of the diets were also submitted to Ward Laboratories, Inc. (Kearney, NE) for analysis of DM, crude fiber, Ca, P, ash, and crude fat.
[2] Values in parentheses indicate those calculated from diet formulation and are based on values from NRC (2012), with the exception of CP and total amino acid content from corn, soybean meal, and dried distillers grains with solubles, which were analyzed prior to diet formulation by Ajinomoto Heartland, Inc.

Table 4. Chemical analysis of the diets, Experiment 3 (as-fed-basis)[1]

	Standardized ileal digestible tryptophan:lysine, %						
Item	14.5	16.5	18.0	19.5	21.0	22.5	24.5
Proximate analysis, %							
DM	89.74 (88.52)[2]	90.49 (88.52)	90.12 (88.52)	90.54 (88.52)	90.61 (88.52)	90.85 (88.52)	90.45 (88.53)
CP	16.2 (15.4)	16.7 (15.4)	16.3 (15.4)	16.8 (15.4)	17.1 (15.4)	16.4 (15.4)	16.2 (15.4)
Crude fiber	3.8 (4.1)	4.0 (4.1)	4.1 (4.1)	3.9 (4.1)	3.9 (4.1)	3.9 (4.1)	3.9 (4.1)
Ca	1.10 (0.48)	0.62 (0.48)	0.73 (0.48)	0.75 (0.48)	0.73 (0.48)	0.76 (0.48)	0.81 (0.48)
P	0.40 (0.37)	0.37 (0.37)	0.37 (0.37)	0.35 (0.37)	0.38 (0.37)	0.36 (0.37)	0.37 (0.37)
Fat	4.9 (5.4)	5.2 (5.4)	5.0 (5.4)	5.0 (5.4)	5.0 (5.4)	5.1 (5.4)	4.9 (5.4)
Ash	4.63 (2.29)	3.62 (2.29)	4.02 (2.29)	4.03 (2.29)	3.90 (2.29)	4.01 (2.29)	4.02 (2.29)
Amino acids, %							
Lysine	0.87 (0.87)	0.87 (0.87)	0.88 (0.87)	0.93 (0.87)	0.90 (0.87)	0.91 (0.87)	0.90 (0.87)
Isoleucine	0.59 (0.60)	0.61 (0.60)	0.60 (0.60)	0.62 (0.60)	0.61 (0.60)	0.60 (0.60)	0.59 (0.60)
Leucine	1.73 (1.82)	1.78 (1.82)	1.79 (1.82)	1.83 (1.82)	1.80 (1.82)	1.76 (1.82)	1.75 (1.82)
Methionine	0.31 (0.29)	0.32 (0.29)	0.32 (0.29)	0.33 (0.29)	0.33 (0.29)	0.32 (0.29)	0.31 (0.29)
Met & Cys	0.60 (0.58)	0.61 (0.58)	0.63 (0.58)	0.64 (0.58)	0.62 (0.58)	0.62 (0.58)	0.61 (0.58)
Threonine	0.66 (0.65)	0.68 (0.65)	0.68 (0.65)	0.68 (0.65)	0.70 (0.65)	0.68 (0.65)	0.67 (0.65)
Tryptophan	0.13 (0.14)	0.16 (0.15)	0.17 (0.16)	0.18 (0.17)	0.18 (0.18)	0.19 (0.19)	0.19 (0.21)
Valine	0.71 (0.74)	0.73 (0.74)	0.74 (0.74)	0.76 (0.74)	0.75 (0.74)	0.73 (0.74)	0.72 (0.74)
Histidine	0.41 (0.39)	0.42 (0.39)	0.43 (0.39)	0.44 (0.39)	0.43 (0.39)	0.42 (0.39)	0.42 (0.39)
Phenylalanine	0.77 (0.78)	0.80 (0.78)	0.79 (0.78)	0.81 (0.78)	0.8 (0.78)	0.78 (0.78)	0.78 (0.78)

[1] Diet samples were taken from 6 feeders per dietary treatment 3 d after the beginning of the trial and 3 d prior to the end of the trial and stored at -20°C, then CP and amino acid analysis was conducted on composite samples by Ajinomoto Heartland, Inc. (Chicago, IL). Samples of the diets were also submitted to Ward Laboratories, Inc. (Kearney, NE) for analysis of DM, crude fiber, Ca, P, ash, and crude fat.
[2] Values in parentheses indicate those calculated from diet formulation and are based on values from NRC (2012), with the exception of CP and total amino acid content from corn, soybean meal, and dried distillers grains with solubles, which were analyzed prior to diet formulation by Ajinomoto Heartland, Inc.

Table 5. Least squares mean estimates (and corresponding SEM) for growth performance of finishing pigs subjected to dietary treatments of standardized ileal digestible tryptophan:lysine (SID Trp:Lys) ratio ranging from 14.5 to 24.5%[1,2]

	SID Trp:Lys, %								Probability, $P <$	
	14.5	16.5	18.0	19.5	21.0	22.5	24.5	SEM	Linear	Quadratic
Exp. 1										
d 0 BW, lb	66.0	65.9	65.9	66.0	66.0	65.9	66.0	1.8	0.994	0.922
ADG, lb	1.38	1.58	1.64	1.68	1.69	1.72	1.74	0.04	0.001	0.001
ADFI, lb	2.95	3.12	3.20	3.30	3.25	3.30	3.30	0.10	0.001	0.017
F/G	2.13	1.98	1.95	1.96	1.92	1.92	1.90	0.03	0.001	0.004
d 21 BW, lb	95.4	99.2	100.4	101.3	101.6	103.0	103.0	2.6	0.001	0.017
NE caloric efficiency[3]	2,420	2,247	2,215	2,224	2,183	2,181	2,149	31.0	0.001	0.004
SID Trp, g/kg gain	2.78	2.94	3.16	3.44	3.64	3.89	4.18	0.05	0.001	0.099
Exp. 2										
d 0 BW, lb	122.3	122.3	122.2	122.3	122.2	122.2	122.2	4.3	0.902	0.976
ADG, lb	1.94	1.98	2.07	2.02	2.06	2.06	2.12	0.03	0.001	0.647
ADFI, lb	5.09	4.88	5.08	5.29	5.40	5.55	5.38	0.15	0.001	0.822
F/G	2.62	2.46	2.45	2.63	2.63	2.69	2.54	0.06	0.221	0.897
d 21 BW, lb	163.3	164.1	165.7	165.2	165.4	165.6	166.8	4.6	0.030	0.737
NE caloric efficiency	3,002	2,819	2,809	3,006	3,006	3,081	2,903	67.1	0.221	0.897
SID Trp, g/kg gain	2.85	3.04	3.31	3.84	4.14	4.54	4.66	0.09	0.001	0.791
Exp. 3										
d 0 BW, lb	157.0	156.8	156.9	156.8	157.0	157.0	156.9	2.8	0.956	0.938
ADG, lb	1.96	2.05	2.03	2.11	2.20	2.10	2.12	0.04	0.001	0.034
ADFI, lb	5.30	5.27	5.25	5.26	5.33	5.24	5.35	0.09	0.651	0.496
F/G	2.69	2.57	2.58	2.50	2.43	2.50	2.53	0.05	0.003	0.020
d 21 BW, lb	198.5	200.1	199.6	201.3	203.3	201.0	201.7	3.2	0.021	0.241
NE caloric efficiency	3,090	2,950	2,965	2,872	2,786	2,863	2,899	58.1	0.003	0.020
SID Trp, g/kg gain	2.81	3.06	3.35	3.52	3.67	4.04	4.46	0.07	0.001	0.034

[1] A total of 1,166, 1,099, and 1,132 gilts (PIC 337 x 1050) with initial BW of 66.0 ± 1.8, 122.2 ± 4.3, and 156.9 ± 2.8 lb were used in Experiments 1, 2, and 3, respectively, with 23 to 28 pigs per pen and 6 pens per treatment.

[2] The NRC (2012) model was used to determine the lysine requirement of gilts at the end of expected the phase range of each experiment, and that value was reduced by 0.05 percentage point for Experiments 1 and 3, and by 0.10 percentage point for Experiment 2.

[3] Caloric efficiency is expressed as kcal/lb of gain.

Table 6. Least squares mean estimates (and corresponding SEM) for economics of finishing pigs subjected to dietary treatments of standardized ileal digestible tryptophan:lysine (SID Trp:Lys) ratio ranging from 14.5 to 24.5%[1,2]

	SID Trp:Lys, %								Probability, $P <$	
	14.5	16.5	18.0	19.5	21.0	22.5	24.5	SEM	Linear	Quadratic
Exp. 1										
Feed cost/pig, $	11.65	12.43	12.84	13.34	13.21	13.52	13.65	0.36	0.001	0.019
Feed cost/lb gain[3], $	0.401	0.376	0.373	0.377	0.373	0.375	0.373	0.005	0.001	0.005
Total revenue/pig[4,5], $	19.78	22.52	23.43	24.06	24.10	24.54	24.91	0.57	0.001	0.001
IOFC[6], $	8.12	10.09	10.60	10.72	10.89	11.01	11.26	0.31	0.001	0.001
Exp. 2										
Feed cost/pig, $	13.02	12.58	13.25	13.93	14.37	14.87	14.57	0.38	0.001	0.838
Feed cost/lb gain, $	0.319	0.303	0.305	0.329	0.332	0.343	0.327	0.007	0.001	0.646
Total revenue/pig, $	27.73	28.32	29.53	28.80	29.39	29.46	30.29	0.42	0.001	0.933
IOFC, $	14.74	15.72	16.28	14.88	15.03	14.59	15.71	0.37	0.886	0.728
Exp. 3										
Feed cost/pig, $	13.49	13.59	13.66	13.80	14.11	13.97	14.43	0.22	0.001	0.487
Feed cost/lb gain, $	0.325	0.316	0.319	0.313	0.307	0.315	0.325	0.007	0.630	0.030
Total revenue/pig, $	28.05	29.24	29.05	30.22	31.39	30.07	30.26	0.63	0.001	0.034
IOFC, $	14.57	15.67	15.40	16.41	17.27	16.07	15.84	0.55	0.012	0.012

[1] A total of 1,166, 1,099, and 1,132 gilts (PIC 337 x 1050) with initial BW of 66.0 ± 1.8, 122.2 ± 4.3, and 156.9 ± 2.8 lb were used in Experiments 1, 2, and 3, respectively, with 23 to 28 pigs per pen and 6 pens per treatment.

[2] The NRC (2012) model was used to determine the lysine requirement of gilts at the end of expected the phase range of each experiment, and that value was reduced by 0.05 percentage point for Experiments 1 and 3, and by 0.10 percentage point for Experiment 2.

[3] Feed cost/lb gain = total feed cost divided by total gain per pig.

[4] One pound of live gain was considered to be worth $0.68.

[5] Total revenue/pig = total gain/pig × $0.68.

[6] Income over feed cost = total revenue/pig – feed cost/pig.

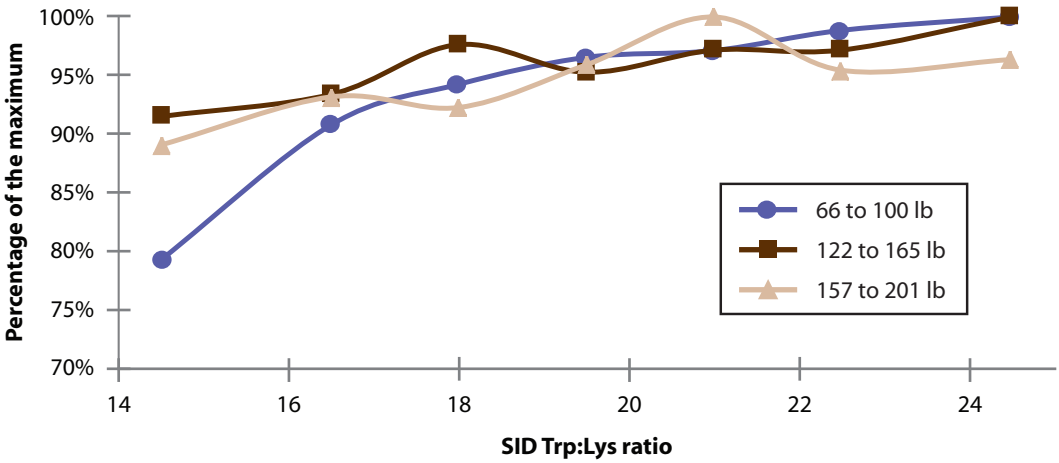

Figure 1. Effects of different standardized ileal digestible tryptophan:lysine (SID Trp:Lys) ratios on ADG of finishing pigs as a percentage of the maximum response.

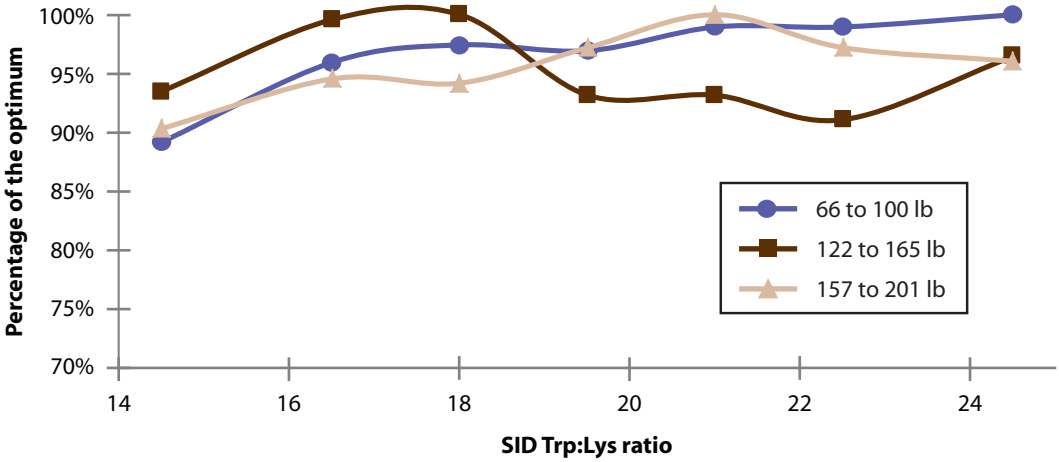

Figure 2. Effects of different standardized ileal digestible tryptophan:lysine (SID Trp:Lys) ratios on F/G of finishing pigs as a percentage of the optimum response (note that the lowest F/G is considered the optimum response).

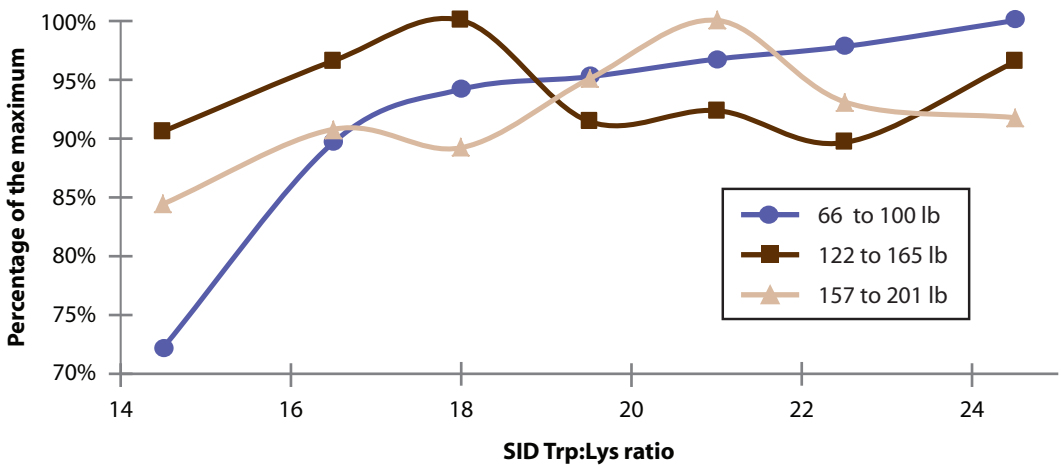

Figure 3. Effects of different standardized ileal digestible tryptophan:lysine (SID Trp:Lys) ratios on income over feed cost of finishing pigs as a percentage of the maximum response.

Effects of Standardized Ileal Digestible Lysine Level and Added Tribasic Copper Chloride on Growth Performance, Carcass Characteristics, and Economics in Finishing Pigs[1]

K.F. Coble, S.S. Dritz[2], J. Usry[3], M.D. Tokach, J.M. DeRouchey, R.D. Goodband, and J.C. Woodworth.

Summary

A total of 1,267 pigs (PIC 337 × 1050; initially 58.3 lb) were used in a 120-d study. Before initiating the trial, pigs were fed a common diet for 9 d containing 188 ppm Cu from tribasic copper chloride (TBCC). On d 0, pens of pigs were allotted to 1 of 8 dietary treatments in a randomized complete block design with 26 to 27 pigs (similar number of barrows and gilts) per pen and 6 pens per treatment. Treatments were arranged in a split-plot design. Whole-plot treatments were 2 levels of the estimated standardized ileal digestible lysine (SID Lys) requirement (92.5 or 100%). Within each level of Lys, there was a 2 × 2 factorial arrangement of treatments with either 0 or 150 ppm Cu from TBCC with two feeding durations (60 or 120 d). All diets were corn-soybean meal–based with 30% dried distillers grains with solubles (DDGS) and contained 17 ppm of Cu from copper sulfate ($CuSO_4$) provided by the trace mineral premix. Overall (d 0 to 120), no TBCC × SID Lys interactions were observed for growth performance, final BW, or caloric efficiency. Pigs fed 100% of the SID Lys requirement had increased ($P < 0.05$) ADG and final BW as well as improved F/G, compared with those fed 92.5% of the estimated requirement. The improvements in F/G also led to improvements in caloric efficiency on both an ME and NE basis. For carcass characteristics, a significant TBCC × SID Lys interaction ($P < 0.05$) was observed for carcass yield and backfat depth. Hot carcass weight and ADG were improved ($P < 0.05$) in pigs fed 100% SID Lys compared with those fed 92.5% and tended ($P < 0.10$) to improve in pigs fed TBCC compared with those not fed TBCC.

Economically, pigs fed 92.5% of their SID Lys requirement had lower ($P < 0.05$) total feed cost, cost per pound of gain, and value of the weight gained during the experiment (gain value) compared with those fed 100% SID Lys. Despite the increased feed cost, income over feed cost (IOFC) was greater ($P < 0.05$) for pigs fed 100% compared with those fed 92.5% of the estimated Lys requirement. When economics were calculated on a constant weight basis, pigs fed 92.5% SID Lys had poorer ($P < 0.05$) adjusted F/G. The lower ADG for pigs fed 92.5% of their SID Lys requirement resulted in an increase ($P < 0.05$) in facility cost compared with those fed 100% of their SID Lys requirement because of the increased time required for those pigs to reach the assumed market weight of 275 lb.

[1] Appreciation is expressed to New Horizon Farms for use of pigs and facilities, to Richard Brobjorg and Marty Heintz for their technical assistance, and to Micronutrients (Indianapolis, IN) for partial funding.
[2] Department of Diagnostic Medicine/Pathology, College of Veterinary Medicine, Kansas State University.
[3] Micronutrients, Indianapolis, IN.

In conclusion, increasing SID Lys from 92.5 to 100% resulted in increased ADG, HCW, HCW ADG, and improved F/G. There were no differences among pigs fed different TBCC feeding strategies, but pigs fed 150 ppm Cu from TBCC had increased yield and HCW, which led to an increase in HCW ADG and improved HCW F/G.

Key words: copper, finishing pig, lysine

Introduction

Past experiments have suggested that feeding supplemental copper (Cu) in the form of copper sulfate ($CuSO_4$) did not provide growth benefits beyond 135 lb (Hastad et al., 2001[4]). A more recent study suggested that supplementing Cu in the form of tri-basic copper chloride (TBCC; Intellibond C, Micronutrients, Indianapolis, IN) during the finishing period can influence growth much longer than previously reported (Coble et al., 2013[5]). Supplementing finishing diets with 150 ppm of Cu from TBCC increased feed intake and consequently gain, even after the pigs had reached 195 lb. These diets were formulated 0.05% below the estimated standardized ileal digestible (SID) lysine (Lys) level requirement, because previous work in poultry has suggested that when TBCC was added to diets containing marginal levels of Lys, growth performance of broilers was similar to those fed diets adequate in Lys with no additional Cu.

A second, more recent study (see "Effects of Standardized Ileal Digestible Lysine Level in Diets Containing Tribasic Copper Chloride on Finishing Pig Growth Performance, Carcass Characteristics, and Fat Quality," p. 138) further investigated the response to Cu in diets differing in SID lysine content by investigating the effects of feeding diets to finishing pigs that contained 100, 92.5, or 85% of the estimated SID Lys requirement with or without 150 ppm Cu from TBCC. In this study, the response to TBCC again increased ADG and final BW. Pigs fed increasing levels of SID Lys also had higher ADG with similar ADFI, which resulted in improved F/G. However, the growth rates of the pigs in this study were lower than in previous studies; as a result, the understanding of how nutrient density can affect the response to TBCC is unclear. Therefore, the objectives of this study were (1) to understand how a limited SID Lys diet affects the growth performance of pigs fed Cu from TBCC, and (2) to understand the effects of feeding TBCC during only early finishing or late finishing or for the entire finishing period.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted in a commercial research finishing barn in southwest Minnesota. The barn was 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 1,267 pigs (PIC 337 × 1050; initially 58.3 lb) were used in a 120-d study. Before initiating the trial, pigs were fed a common diet containing 188 ppm added

[4] Hastad et al., Swine Day 2001, Report of Progress 880, pp. 111–117.
[5] Coble et al., Swine Day 2013, Report of Progress 1092, pp. 168–180.

Cu from TBCC. On d 0, pens of pigs were allotted to 1 of 8 dietary treatments in a randomized complete block design with 26 to 27 pigs (similar number of barrows and gilts) per pen and 6 replications per treatment. Treatments were arranged in a split-plot design. Whole-plot treatments were 2 levels of the estimated SID Lys requirement (92.5 or 100%). Within each level of Lys, there was a 2 × 2 factorial arrangement of treatments with either 0 or 150 ppm Cu from TBCC with two feeding durations (60 or 120 d). All diets were corn-soybean meal–based with 30% dried distillers grains with solubles (DDGS) and contained 17 ppm of Cu from copper sulfate ($CuSO_4$) provided by the trace mineral premix. Treatment diets were fed in 5 phases (Tables 1, 2, and 3). 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 change to form a composite sample and was analyzed for Cu (Table 4).

Pens of pigs were weighed and feed disappearance was recorded on d 21, 38, 60, 95, 101, and 120 to determine ADG, ADFI, and F/G. Caloric efficiency on both an ME and NE basis were calculated for each treatment by dividing the sum of total feed intake and dietary energy (kcal) by total gain. On d 101, the 5 heaviest pigs in each pen were visually selected, 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 d 120, final pen weights were taken and pigs were transported to a commercial packing plant in southwestern Minnesota (JBS Swift and Company, Worthington, MN) for processing and carcass data collection. Carcass measurements included HCW, loin depth, backfat depth, and percentage lean. Percentage carcass yield was calculated by dividing the average pen HCW by the average final live weight at the farm. Hot carcass weight ADG was calculated by subtracting the assumed initial HCW (d-0 wt × an estimated 75% yield) from HCW, then dividing the value by 120 d. Carcass F/G was calculated by dividing ADFI by HCW ADG.

At the conclusion of the study, an economic analysis was calculated on both a constant days on feed or constant market weight basis to determine the value of feeding TBCC and two levels of SID Lys in two scenarios. For calculating on a constant days on feed basis, economics were determined using the treatment means from the trial. To determine the economics on a constant weight basis, feed efficiency was adjusted to a common final BW by a factor of 0.005 per pound of final weight. The actual ADG and adjusted F/G were then used to determine the difference in total number of days and feed need to reach a common weight of 275 lb.

For the constant days on feed and constant weight economic evaluation, total feed cost per pig, cost per pound of gain, gain value, and income over feed cost (IOFC) were calculated. Feed cost was calculated by multiplying 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 calculated the total feed cost per pig. Cost per pound of gain was calculated by dividing the total feed cost per pig by the total pounds gained overall. The value of the weight gained during the experiment (gain value) was calculated by subtracting the product of initial pig weight times the assumed carcass price of $110.34 per cwt from final pig weight times $110.34 per cwt. Income over feed cost was calculated by subtracting total feed cost from gain value. The income over feed and facilities cost

(IOFFC) was calculated for the constant market weight evaluation because pigs with faster growth rates will reach 275 lb sooner, therefore decreasing the cost of housing the pigs. Facility cost was calculated by multiplying the number of overall days the pigs need to reach 275 lb based on their respective growth rate by $0.10 per-day facility cost.

Experimental data were analyzed in a randomized complete block design using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen serving as the experimental unit and initial BW serving as the blocking factor. The random effect of block was included in the model. The 3-way interaction of Early TBCC × Late TBCC × SID Lys (Treatments B, C, F, and G vs. A, D, E, and H), and 2-way interactions of Early TBCC × SID Lys (Treatments A, C, F, and H vs. B, D, E, and G), Late TBCC × SID Lys (Treatments C, D, E, and F vs. A, B, G, and H), and Early TBCC × Late TBCC (Treatments B and F vs. C and G) were tested, and no interactions were observed. Treatments A, D, E, and H were used to test the interaction of TBCC × SID Lys, the main effect of TBCC, and the main effect of SID Lys for the overall period. Hot carcass weight served as a covariate for the analysis of backfat, loin depth, and lean percentage. Results from the experiment were considered significant at $P < 0.05$ and a tendency between $P > 0.05$ and $P \leq 0.10$.

Results and Discussion

All diets from each phase were analyzed for Cu, except for Phase 5 diets, which were not available for analysis (Table 4). Considering the Cu originating from both the trace mineral premix and the ingredients used in formulation, these results were similar to expected values.

For any of the measured responses, no 3-way interactions for early TBCC × late TBCC × SID Lys or 2-way interactions for early TBCC × SID Lys, late TBCC × SID Lys, or early TBCC × late TBCC were observed (Table 5).

For growth performance during the early finishing period (d 0 to 60), there was a TBCC × SID Lys interaction ($P < 0.05$; treatments A and H vs. D and E) for ADFI and a tendency ($P < 0.10$) for F/G. These were the result of pigs fed 100% of the estimated SID Lys requirement having an increase in ADFI with added Cu from TBCC, whereas those fed 92.5% had a decrease in ADFI. Without a significant interaction for ADG, this led to pigs fed 100% of the estimated SID Lys requirement having worse F/G when Cu from TBCC was added to the diet, whereas those fed 92.5% had an improvement in F/G with added Cu. Pigs fed 100% of the SID Lys requirement had increased ($P < 0.05$; Treatments A and D vs. E and H) ADG and BW on d 60, as well as an improvement in F/G, compared with those fed 92.5% of their requirement. These results are similar for the late finishing period (d 60 to 120), as pigs fed 100% SID Lys also had increased ($P < 0.05$) ADG, BW on d 120, and improved F/G.

Overall (d 0 to 120), no TBCC × SID Lys interactions were observed for growth performance, final BW, or caloric efficiency; however, pigs fed 100% SID Lys had an increase ($P < 0.05$) in ADG and final BW, as well as an improvement in F/G, compared with those fed 92.5% of their SID Lys requirement. The improvements ($P < 0.05$) in F/G also led to improvements in caloric efficiency on both an ME and NE basis.

For carcass characteristics, there was a TBCC × SID Lys interaction ($P < 0.05$) for carcass yield and backfat depth and a tendency for an interaction ($P < 0.10$) for HCW F/G (Table 6). These were the result of pigs fed 92.5% SID Lys having increased carcass yield and reduced backfat depth with added TBCC, whereas those fed 100% SID Lys requirement had decreased carcass yield and increased backfat depth when TBCC was added to the diet. Hot carcass weight and HCW ADG improved ($P < 0.05$) when pigs were fed 100% of their SID Lys requirement compared with 92.5% and tended ($P < 0.10$) to improve in pigs fed TBCC compared with those not fed TBCC (Treatments A and E vs. D and H).

For any of the calculated economics, no TBCC × SID Lys interactions were observed. For economics calculated on a constant days on feed basis, pigs fed 92.5% of their SID Lys requirement had lower ($P < 0.05$) total feed cost, cost per pound of gain, and value of the weight gained during the experiment (gain value) compared with those fed 100% SID Lys (Table 7). Despite the increased feed cost, IOFC was greater ($P < 0.05$) for pigs fed 100% compared with those fed 92.5% of the estimated Lys requirement. When the economics were calculated on a constant weight basis, pigs fed 92.5% of their SID Lys requirement had worse ($P < 0.05$) adjusted F/G. The lower ADG for pigs fed 92.5% of their SID Lys requirement resulted in an increase ($P < 0.05$) in facility cost compared with those fed 100% of their SID Lys requirement because of increased time required for those pigs to reach the assumed market weight of 275 lb.

In conclusion, there were no differences in overall growth performance, carcass characteristics, or economics among pigs fed different TBCC feeding strategies, but there was a TBCC × Lys interaction for carcass yield, backfat, and HCW F/G. Increasing SID Lys from 92.5 to 100% of their estimated requirement resulted in increased ADG, HCW, and HCW ADG and improved F/G. Poorer performance among pigs fed the reduced SID Lys diets also led to a reduction in IOFC. There were no improvements in overall growth performance in pigs supplemented with Cu from TBCC, which is not consistent with previous trials completed in the same facility; however, pigs fed 150 ppm Cu from TBCC had an increase in yield and HCW, which led to an increase in HCW ADG and improved HCW F/G.

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

	Phase 1		Phase 2	
SID Lys,[2] %:	92.5	100.0	92.5	100.0
Ingredient, %				
Corn	56.06	52.94	59.94	57.20
Soybean meal, 46.5 CP	11.23	14.33	7.56	10.29
DDGS[3]	30.00	30.00	30.00	30.00
Limestone	1.60	1.60	1.45	1.45
Salt	0.35	0.35	0.35	0.35
L-lysine HCl	0.48	0.48	0.45	0.45
DL-methionine	0.01	0.01	0.04	0.03
L-threonine	0.05	0.05	0.03	0.04
L-tryptophan	0.04	0.04	0.04	0.04
Phytase[4]	0.01	0.01	0.01	0.01
Vitamin premix	0.08	0.08	0.08	0.08
Trace mineral premix[5]	0.10	0.10	0.10	0.10
Added Cu[6]	---	---	---	---
Total	100.0	100.0	100.0	100.0

continued

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

	Phase 1		Phase 2	
SID Lys,[2] %:	92.5	100.0	92.5	100.0
Calculated SID Lys requirement[2], %	1.03	1.03	0.91	0.91
Calculated analysis				
SID amino acids, %				
Lysine	0.95	1.03	0.84	0.91
Isoleucine:lysine	62	62	63	63
Leucine:lysine	171	166	184	177
Methionine:lysine	31	32	32	31
Met & Cys:lysine	58	58	61	59
Threonine:lysine	62	62	62	62
Tryptophan:lysine	19.0	19.0	19.0	19.0
Valine:lysine	71	70	73	73
Total lysine, %	1.14	1.22	1.02	1.09
ME, kcal/lb	1,505	1,503	1,509	1,507
NE, kcal/lb	1,114	1,105	1,125	1,118
SID lysine:ME, g/Mcal	2.87	3.11	2.53	2.74
CP, %	19.3	20.5	17.7	18.8
Ca, %	0.65	0.66	0.58	0.59
P, %	0.42	0.42	0.39	0.40
Available P, %	0.28	0.28	0.26	0.27
Diet cost,[7] $/ton	215.72	225.70	203.20	211.61

[1] Phase 1 diets were fed from d 0 to 21 (58.3 to 94.8 lb); Phase 2 diets were fed from d 21 to 38 (94.8 to 130.8 lb).
[2] Standardized ileal digestible lysine values were based on 100% of the estimated SID Lys requirement for finishing pigs within this production system.
[3] Dried distillers grains with solubles (Valero, Aurora, SD).
[4] Optiphos 2000 (Huvepharma, Inc, Peachtree City, GA) provided 1,816,000 phytase units (FTU)/lb, with a release of 0.10% available P.
[5] Trace mineral premix provided 17 ppm Cu in the form of $CuSO_4$ to each diet.
[6] Supplemental copper provided in the form of tri-basic copper chloride (TBCC; Intellibond C; Micronutrients, Indianapolis, IN) at 150 ppm at the expense of corn.
[7] Cost of corn = $4.26/bushel; soybean meal = $465/ton; DDGS = $164/ton; L-Lys = $0.62 /lb; TBCC = $3.85/lb.

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

	Phase 3		Phase 4	
SID Lys,[2] %:	92.5	100.0	92.5	100.0
Ingredient, %				
Corn	62.61	60.20	64.14	61.98
Soybean meal, 46.5 CP	5.04	7.45	3.65	5.81
DDGS[3]	30.00	30.00	30.00	30.00
Limestone	1.38	1.38	1.30	1.30
Salt	0.35	0.35	0.35	0.35
L-lysine HCl	0.40	0.40	0.35	0.35
L-threonine	---	0.01	---	---
L-tryptophan	0.04	0.04	0.03	0.03
Phytase[4]	0.01	0.01	0.01	0.01
Vitamin premix	0.08	0.08	0.08	0.08
Trace mineral premix[5]	0.10	0.10	0.10	0.10
Added Cu[6]	---	---	---	---
Total	100.0	100.0	100.0	100.0

continued

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

	Phase 3		Phase 4	
SID Lys,[2] %:	92.5	100.0	92.5	100.0
Calculated SID Lys requirement[2], %	0.80	0.80	0.72	0.72
Calculated analysis				
SID amino acids, %				
Lysine	0.74	0.80	0.67	0.72
Isoleucine:lysine	65	66	69	69
Leucine:lysine	201	193	218	209
Methionine:lysine	35	34	38	36
Met & Cys:lysine	66	64	71	69
Threonine:lysine	62	62	66	65
Tryptophan:lysine	19.5	19.5	19.5	19.5
Valine:lysine	78	77	83	82
Total lysine, %	0.91	0.97	0.83	0.89
ME, kcal/lb	1,511	1,510	1,512	1,511
NE, kcal/lb	1,132	1,126	1,137	1,131
SID lysine:ME, g/Mcal	2.22	2.40	2.00	2.16
CP, %	16.7	17.6	16.0	16.9
Ca, %	0.55	0.55	0.52	0.52
P, %	0.38	0.39	0.37	0.38
Available P, %	0.25	0.25	0.23	0.24
Diet cost,[7] $/ton	193.75	201.26	187.89	194.53

[1] Phase 3 diets were fed from d 38 to 60 (130.8 to 173.8 lb); Phase 4 were diets fed from d 60 to 95 (173.8 to 244.1 lb).
[2] Standardized ileal digestible lysine values were based on 100% of the estimated SID Lys requirement for finishing pigs within this productions system.
[3] Dried distillers grains with solubles (Valero, Aurora, SD).
[4] Optiphos 2000 (Huvepharma, Inc, Peachtree City, GA) provided 1,816,000 phytase units (FTU)/lb, with a release of 0.10% available P.
[5] Trace mineral premix provided 17 ppm Cu in the form of $CuSO_4$ to each diet.
[6] Supplemental copper provided in the form of tri-basic copper chloride (TBCC; Intellibond C; Micronutrients, Indianapolis, IN) at 150 ppm at the expense of corn.
[7] Cost of corn = $4.26/bushel; soybean meal = $465/ton; DDGS = $164/ton; L-Lys = $0.62 /lb; TBCC = $3.85/lb.

Table 3. Diet composition for Phase 5 (as-fed basis)[1]

	Phase 5	
SID Lys,[2] %:	92.5	100.0
Ingredient, %		
Corn	60.63	57.92
Soybean meal, 46.5 CP	7.16	9.87
DDGS[3]	30.00	30.00
Limestone	1.10	1.10
Salt	0.35	0.35
L-lysine HCl	0.45	0.45
L-threonine	0.06	0.06
L-tryptophan	0.05	0.04
Ractopamine HCl[4]	0.03	0.03
Phytase[5]	0.01	0.01
Vitamin premix	0.08	0.08
Trace mineral premix[6]	0.10	0.10
Added Cu[7]	---	---
Total	100.00	100.00

continued

Table 3. Diet composition for Phase 5 (as-fed basis)[1]

	Phase 5	
SID Lys,[2] %:	92.5	100.0
Calculated SID Lys requirement.[2], %	0.90	0.90
Calculated analysis		
SID amino acids, %		
Lysine	0.83	0.90
Isoleucine:lysine	63	63
Leucine:lysine	185	178
Methionine:lysine	32	31
Met & Cys:lysine	61	59
Threonine:lysine	65	65
Tryptophan:lysine	19.5	19.5
Valine:lysine	73	73
Total lysine, %	1.01	1.08
ME, kcal/lb	1,514	1,513
NE, kcal/lb	1,130	1,123
SID lysine:ME, g/Mcal	2.49	2.70
CP, %	17.6	18.7
Ca, %	0.46	0.46
P, %	0.39	0.40
Available P, %	0.23	0.24
Diet cost,[8] $/ton	221.80	230.24

[1] Phase 5 diets were fed from d 95 to 120 (244.1 to 289.2 lb).
[2] Standardized ileal digestible lysine values were based on 100% of the estimated SID Lys requirement for finishing pigs within this production system.
[3] Dried distillers grains with solubles (Valero, Aurora, SD).
[4] Paylean, 9 g/lb (Elanco Animal Health, Indianapolis, IN).
[5] Optiphos 2000 (Huvepharma, Inc., Peachtree City, GA) provided 1,816,000 phytase units (FTU)/lb, with a release of 0.10% available P.
[6] Trace mineral premix provided 17 ppm Cu in the form of $CuSO_4$ to each diet.
[7] Supplemental copper provided in the form of tri-basic copper chloride (TBCC; Intellibond C; Micronutrients, Indianapolis, IN) at 150 ppm at the expense of corn.
[8] Cost of corn = $4.26/bushel; soybean meal = $465/ton; DDGS = $164/ton; L-Lys = $0.62 /lb; TBCC = $3.85/lb.

Table 4. Copper analysis of complete diets (ppm, as-fed)[1]

	TBCC,[2] ppm:			
	0		150	
SID lysine,[3] %:	92.5	100.0	92.5	100.0
Total Cu, ppm				
Phase 1	37	31	249	201
Phase 2	31	28	272	214
Phase 3	38	42	246	210
Phase 4	34	32	246	219
Phase 5[4]	---	---	---	---

[1] Values represent means from one composite sample, analyzed in duplicate.
[2] Copper from tri-basic copper chloride (Intellibond C; Micronutrients, Indianapolis, IN).
[3] Standardized ileal digestible (SID) lysine values were based on 100% of the estimated SID Lys requirement finishing pigs within this production system.
[4] Phase 5 diets were not available for analysis.

Table 5. Effects of standardized ileal digestible lysine (SID Lys) and duration of feeding copper on growth performance of finishing pigs[1]

SID Lys,[2] %	92.5				100.0							
Early TBCC[3]:	-	+	-	+	-	+	-	+				
Late TBCC[4]:	-	-	+	+	-	-	+	+		Probability, [5]*P* <		
Treatment:	A	B	C	D	E	F	G	H	SEM	TBCC × SID Lys[6]	TBCC[7]	SID Lys[8]
Weight, lb												
d 0	58.3	58.2	58.3	58.3	58.3	58.3	58.3	58.3	1.46	0.913	0.998	0.987
d 60	172.2	173.1	172.3	172.6	174.4	175.6	174.4	175.3	2.21	0.833	0.567	0.031
d 120	285.2	286.2	288.3	284.9	291.6	291.8	291.2	294.2	2.65	0.428	0.527	0.001
d 0 to 60												
ADG, lb	1.90	1.90	1.89	1.89	1.93	1.95	1.92	1.95	0.019	0.463	0.681	0.018
ADFI, lb	4.59	4.67	4.55	4.52	4.52	4.55	4.59	4.67	0.068	0.023	0.391	0.461
F/G	2.42	2.45	2.40	2.39	2.34	2.34	2.39	2.40	0.027	0.088	0.609	0.097
d 60 to 120												
ADG, lb	1.99	2.02	2.03	1.99	2.06	2.05	2.07	2.06	0.023	0.951	0.931	0.007
ADFI, lb	6.11	6.12	6.11	6.14	6.22	6.07	6.23	6.13	0.055	0.283	0.576	0.326
F/G, lb	3.07	3.04	3.02	3.08	3.03	2.97	3.00	2.98	0.033	0.332	0.608	0.034
d 0 to 120												
ADG, lb	1.94	1.96	1.96	1.94	1.99	2.00	1.99	2.00	0.015	0.566	0.732	0.001
ADFI, lb	5.33	5.36	5.30	5.30	5.34	5.28	5.38	5.38	0.049	0.365	0.900	0.235
F/G	2.74	2.74	2.71	2.73	2.68	2.65	2.70	2.69	0.020	0.755	0.865	0.009
Caloric efficiency[9]												
ME	4142	4142	4091	4126	4049	3994	4072	4052	30.6	0.754	0.832	0.007
NE	3098	3099	3059	3086	3014	2972	3031	3016	22.8	0.740	0.829	0.001

[1] A total of 1,267 pigs (PIC 337 × 1050; initially 58.3 lb) were used in a 120-d experiment with 26 to 27 pigs per pen and 6 replications per treatment.
[2] Standardized ileal digestible lysine (SID Lys) values were based on 100% of estimated SID Lys requirement finishing pigs within this production system.
[3] 150 ppm copper from tri-basic copper chloride (TBCC; Intellibond C; Micronutrients, Indianapolis, IN) fed from d 0 to 60.
[4] 150 ppm copper from TBCC fed from d 60 to 120.
[5] No Early TBCC × Late TBCC × SID Lys, Early TBCC × SID Ly, Late TBCC × SID Lys, or Early TBCC × Late TBCC interactions were observed.
[6] Contrast between Treatments A and H vs. D and E.
[7] Contrast between Treatments A and E vs. D and H.
[8] Contrast between Treatments A and D vs. E and H.
[9] Caloric efficiency is expressed as kcal per pound of live weight gain.

Table 6. Effects of standardized ileal digestible lysine (SID Lys) and duration of feeding copper on carcass characteristics of finishing pigs[1]

SID Lys,[2] %	92.5				100.0							
Early TBCC[3]:	-	+	-	+	-	+	-	+				
Late TBCC[4]:	-	-	+	+	-	-	+	+		Probability,[5] $P <$		
Treatment:	A	B	C	D	E	F	G	H	SEM	TBCC × SID Lys[6]	TBCC[7]	SID Lys[8]
Carcass characteristics												
HCW, lb	215.5	218.5	220.2	221.2	221.7	222.3	220.9	222.9	2.19	0.244	0.076	0.043
Yield, %	75.06	76.11	75.74	76.74	75.89	75.35	75.60	75.76	0.383	0.022	0.048	0.847
Backfat,[9] in.	0.74	0.71	0.68	0.68	0.66	0.67	0.72	0.71	0.019	0.011	0.780	0.279
Loin depth,[9] in.	2.20	2.19	2.23	2.23	2.24	2.22	2.18	2.22	0.018	0.117	0.953	0.289
Lean,[9] %	55.78	55.56	56.53	56.51	56.97	56.26	55.42	56.29	0.450	0.115	0.953	0.286
Carcass performance												
HCW ADG, lb	1.43	1.46	1.47	1.48	1.48	1.49	1.48	1.49	0.015	0.232	0.064	0.035
HCW F/G	3.72	3.68	3.60	3.59	3.60	3.55	3.64	3.60	0.038	0.062	0.074	0.174

[1] 1,267 pigs (PIC 337 × 1050; initially 58.3 lb) were used in a 120-d experiment with 26 to 27 pigs per pen and 6 replications per treatment.
[2] SID Lys alues were based on 100% of estimated SID Lys requirement for finishing pigs within this production system.
[3] 150 ppm copper from tri-basic copper chloride (TBCC; Intellibond C; Micronutrients, Indianapolis, IN) fed from d 0 to 60.
[4] 150 ppm copper from TBCC fed from d 60 to 120.
[5] No Early TBCC × Late TBCC × SID Lys, Early TBCC × SID Lys, Late TBCC × SID Lys, or Early TBCC × Late TBCC interactions were observed.
[6] Contrast between Treatments A and H vs. D and E.
[7] Contrast between Treatments A and E vs. D and H.
[8] Contrast between Treatments A and D vs. E and H.
[9] HCW was used as a covariate.

Table 7. Effects of standardized ileal digestible lysine (SID Lys) and duration of feeding copper on economics of finishing pigs[1]

SID Lys,[2] %	92.5				100.0							
Early TBCC[3]:	-	+	-	+	-	+	-	+				
Late TBCC[4]:	-	-	+	+	-	-	+	+		Probability, [5]*P* <		
Treatment:	A	B	C	D	E	F	G	H	SEM	TBCC × SID Lys[6]	TBCC[7]	SID Lys[8]
Constant days, $/pig												
Feed cost	64.91	65.75	65.12	65.33	67.68	67.27	68.55	68.68	0.589	0.552	0.147	0.001
Cost/lb gain	0.278	0.280	0.277	0.281	0.283	0.281	0.287	0.286	0.002	0.972	0.254	0.022
Gain value[9]	250.35	251.53	253.74	249.98	257.35	257.62	256.91	260.27	2.109	0.408	0.520	0.001
IOFC[10]	185.45	185.77	188.62	184.65	189.66	190.35	188.36	191.58	1.803	0.444	0.751	0.003
Constant weight,[11] $/pig												
Adjusted F/G[12]	2.69	2.69	2.64	2.68	2.60	2.56	2.62	2.59	0.023	0.957	0.691	0.001
Feed cost	58.90	59.08	58.20	59.31	59.13	58.52	59.81	59.44	0.507	0.922	0.484	0.727
Cost/lb gain	0.272	0.273	0.269	0.274	0.273	0.270	0.276	0.274	0.002	0.922	0.484	0.727
Gain value[9]	239.11	239.11	239.11	239.11	239.11	239.11	239.11	239.11	---	---	---	---
IOFC[10]	180.21	180.02	180.90	179.80	179.98	180.59	179.30	179.67	0.507	0.922	0.484	0.727
Facility cost[13]	11.49	11.44	11.34	11.51	11.18	11.16	11.22	11.07	0.130	0.469	0.620	0.001
IOFFC[14]	168.72	168.59	169.57	168.30	168.80	169.43	168.08	168.60	0.574	0.846	0.586	0.739

[1] 1,267 pigs (PIC 337 × 1050; initially 58.3 lb) were used in a 120-d experiment with 26 to 27 pigs per pen and 6 replications per treatment.
[2] SID Lys values were based on 100% of estimated SID Lys requirement for finishing pigs within this production system.
[3] 150 ppm copper from tri-basic copper chloride (TBCC; Intellibond C; Micronutrients, Indianapolis, IN) fed from d 0 to 60.
[4] 150 ppm copper from TBCC fed from d 60 to 120.
[5] No Early TBCC × Late TBCC × SID Lys, Early TBCC × SID Ly, Late TBCC × SID Lys, or Early TBCC × Late TBCC interactions were observed.
[6] Contrast between Treatments A and H vs. D and E.
[7] Contrast between Treatments A and E vs. D and H.
[8] Contrast between Treatments A and D vs. E and H.
[9] Gain value calculated using (Final wt × $110.34/cwt) – (initial wt. × $110.34/cwt).
[10] Income over feed cost = carcass gain value – feed cost.
[11] Adjusted to constant final weight of 275 lb.
[12] Adjusted using a factor of 0.005 for 1 lb change in live weight.
[13] Facility cost at $0.10/hd/day.
[14] Income over feed and facility cost = IOFC – facility cost.

Effects of Standardized Ileal Digestible Lysine Level in Diets Containing Tribasic Copper Chloride on Finishing Pig Growth Performance, Carcass Characteristics, and Fat Quality[1,2]

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Summary

A total of 1,248 pigs (PIC 337 × 1050; initially 63.8 lb) were used in a 120-d experiment to study the effects of increasing standardized ileal digestible lysine (SID Lys) in diets with or without 150 ppm added Cu from tri-basic copper chloride (TBCC) on growth performance, carcass characteristics, and fat quality. Pens of pigs were allotted to 1 of 6 dietary treatments in a randomized complete block design with 26 pigs (similar number of barrows and gilts) per pen and 8 replications per treatment. Treatments were arranged in a 2 × 3 factorial with main effects of added TBCC (0 or 150 ppm of Cu) and SID Lys (85, 92.5, and 100% of the pig's estimated requirement). Diets were corn-soybean meal–based with 30% dried distillers grains with solubles and 15% bakery meal. Overall (d 0 to 120), no TBCC × Lys interactions ($P > 0.10$) were observed for growth performance. Adding dietary TBCC tended ($P < 0.10$) to increase ADG and improve F/G. As SID Lys increased, ADG increased and F/G improved (linear; $P < 0.05$). Final BW increased (linear; $P < 0.05$) as SID Lys increased, and if pigs were fed diets containing TBCC ($P < 0.05$); however, only HCW increased with increasing SID Lys (linear; $P < 0.05$).

Backfat iodine value (IV) was not affected by treatment; however, increasing the SID Lys level tended to increase jowl fat IV only in pigs fed TBCC (TBCC × Lys linear; $P < 0.10$). Feeding TBCC decreased ($P < 0.02$) liver a* values, resulting in decreased redness of the liver and increased ($P < 0.01$) liver Cu concentrations.

Feed cost per pig, cost per pound of gain, and gain value all increased (linear; $P < 0.05$) as SID Lys increased when calculated on a constant days basis. As a result, IOFC was $2.19 lower (linear; $P < 0.02$) when pigs were fed only 85% of their estimated SID Lys requirement compared with those fed 100% of their requirement. The value of the weight gained during the experiment tended to increase ($P < 0.10$) for pigs fed diets containing TBCC. When calculating cost on a constant weight basis, adjusted F/G was improved ($P < 0.05$), and facility costs tended to be lower ($P < 0.10$) for pigs fed TBCC. Facility cost decreased (linear; $P < 0.01$) as SID Lys increased.

[1] Appreciation is expressed to New Horizon Farms for use of pigs and facilities, to Richard Brobjorg and Marty Heintz for their technical assistance, and to Micronutrients (Indianapolis, IN) for partial funding.
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[4] Department of Animal Science, Michigan State University.

In conclusion, feeding 150 ppm Cu from TBCC tended to increase ADG and F/G. More importantly, these results suggest that 100% of the estimated SID Lys requirement should be fed to achieve the highest net return when pigs are fed for a constant number of days and that TBCC cannot compensate for deficient SID Lys concentrations in finishing pig diets.

Key words: copper, finishing pig, lysine, tribasic copper chloride

Introduction

Copper (Cu) is an essential trace mineral that is included in all swine diets through trace mineral premix and endogenously by feed ingredients. In addition to the dietary Cu needed to meet the pig's basal requirements (approximately 3 to 6 ppm[5]), it is sometimes added up to 250 ppm in the nursery and early finishing periods to enhance growth performance. A recent experiment by Coble et al. (2013[6]) suggested that high levels of Cu may provide benefits for a longer duration in the finishing period than previously thought. In that experiment, adding 150 ppm of Cu from tribasic copper chloride (TBCC) in finishing diets formulated 0.05% below the pig's standardized ileal digestible lysine (SID Lys) estimated requirement resulted in a linear increase ($P < 0.01$) in overall ADG and ADFI. This improvement in ADG resulted in an 8.3-lb heavier carcass.

Formulating diets 0.05% below the pig's estimated SID Lys requirement was done because previous work in poultry suggested that when TBCC was added to diets containing marginal levels of Lys, growth performance of broilers was similar to those fed diets adequate in Lys with no additional Cu. Although many experiments have been completed to better understand the SID Lys requirement of growing pigs, previous research has not investigated the effects of SID Lys level in diets supplemented with Cu. Our study sought to replicate the poultry data and investigate whether SID Lys levels could be decreased below the pig's estimated requirement in diets containing Cu from TBCC. Therefore, this study was designed to investigate the effects of limiting SID Lys in diets with or without 150 ppm added Cu from TBCC on growth performance, carcass characteristics, and fat quality. In addition, liver Cu concentrations and color, carcass fat IV, and the economics of added Cu were addressed.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted in a commercial research-finishing barn in southwest Minnesota. The barn was 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 1,248 pigs (PIC 337 × 1050; initially 63.8 lb) were used in a 120-d study. Before initiating the trial, pigs were fed a common diet containing 205 ppm Cu from TBCC (Intellibond C; Micronutrients, Inc., Indianapolis, IN). Pens of pigs were allot-

[5] NRC. 2012. Nutrient Requirements of Swine. 11th ed. Natl. Acad. Press, Washington, DC.
[6] Coble et al. Swine Day 2013. Report of Progress 1092, pp. 168-180.

ted to 1 of 6 dietary treatments in a randomized complete block design with 26 pigs (similar number of barrows and gilts) per pen and 8 replications per treatment. Treatments were arranged in a 2 × 3 factorial with main effects of added Cu from TBCC (0 or 150 ppm) and SID Lys (85, 92.5, and 100% of the estimated requirement based on previous studies; Main et al., 2008[7]). All diets were corn-soybean meal–based with 30% dried distiller's grains and 15% bakery meal and contained 17 ppm of Cu from copper sulfate ($CuSO_4$) provided by the trace mineral premix. Treatment diets were fed in 5 phases (Tables 1 through 3). During the last phase, all diets contained 9 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 change to form a composite sample and analyzed for Cu (Table 4).

Pens of pigs were weighed and feed disappearance was recorded at d 23, 38, 70, 97, and 120 to determine ADG, ADFI, and F/G. Caloric efficiency on both an ME and NE basis were calculated for each treatment by dividing the sum of total feed intake and dietary energy (kcal) by total gain. On d 97, 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 d 120, final pen weights were taken and 3 individual pigs were visually identified as representatives of the mean individual pig weight of the pen and transported to a small commercial packing plant in northwestern Iowa (Natural Foods Holdings Inc.; Sioux City, IA) for measuring liver mineral concentrations and color, and collecting backfat and jowl fat samples. All other pigs were transported to a commercial packing plant in southwestern Minnesota (JBS Swift and Company, Worthington, MN) for processing and carcass data collection. Carcass measurements there included HCW, loin depth, backfat, and percentage lean. Percentage carcass yield was calculated by dividing the average pen HCW by the average final live weight at the farm. Hot carcass weight ADG was calculated by subtracting the assumed initial HCW (d 0 wt × an estimated 75% yield) from HCW, then dividing the value by 120 d. Carcass F/G was calculated by dividing ADFI by HCW ADG. Carcass data between the two plants was combined for the analysis

Pigs transported to the packing plant in northwestern Iowa were used to collect liver and carcass fat samples. Individual livers were collected on the production line to determine an objective liver color score. Using a MiniScan EZ (Model 4500L; Hunter Associates Laboratory, Reston, VA) L*, a*, and b* color values were obtained that indicate lightness, redness, and yellowness, respectively, by taking three scans from each liver and obtaining an average for each color value. From these values, the hue angle and chroma were calculated. Hue angle describes the blemish or taint of the color, and chroma describes the color saturation. Approximately 1-lb samples of each liver were taken from the ascending right lobe and sent to Michigan State University for analysis of total Cu, Fe, and Zn. Fat samples were taken from both the jowl and 10th-rib backfat (all 3 layers) and sent to the University of Georgia for complete fatty acid profile analysis.

At the conclusion of the study, an economic analysis was calculated on both a constant days on feed or constant market weight basis to determine the value of feeding TBCC

[7] Main, R.G, S.S. Dritz, M.D. Tokach, R.D. Goodband, J.L. Nelssen, and J.M. DeRouchey. 2008. Effects of feeding growing pig's less or more than their estimated lysine requirement in early and late finishing on overall performance. PAS 24:76–87.

and varying levels of SID Lys in two scenarios. For calculating on a constant days on feed basis, economics were determined using the treatment means from the trial. To determine the economics on a constant weight basis, feed efficiency was adjusted to a common final BW by a factor of 0.005 per pound of final weight. The actual ADG and adjusted F/G were then used to determine the difference in total number of days and total amount of feed needed to reach a common weight of 275 lb. For the constant days on feed and constant weight economic evaluation, total feed cost per pig, cost per pound of gain, gain value, and income over feed cost (IOFC) were calculated. Feed cost was calculated by multiplying 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 calculated the total feed cost per pig. Cost per pound of gain was calculated by dividing the total feed cost per pig by the total pounds gained overall. The value of the weight gained during the experiment (gain value) was calculated by subtracting the product of initial pig weight times the assumed live price of $68.83 per cwt from final pig weight times $68.83 per cwt. Income over feed cost was calculated by subtracting total feed cost from gain value. Income over feed and facilities cost (IOFFC) was calculated for the constant market weight evaluation because pigs with faster growth rates will reach 275 lb sooner, thus decreasing the cost of housing the pigs. Facility cost was calculated by multiplying the number of overall days the pigs need to reach 275 lb based on their respective growth rate by $0.10 per-day facility cost.

The experimental data were analyzed using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) as a randomized complete block design with pen serving as the experimental unit and initial weight as the blocking factor. Linear and quadratic contrasts were tested to determine if SID Lys affected the response to TBCC. If the interaction was significant, pairwise comparisons for TBCC within SID Lys were determined to describe the interaction. The main effect of TBCC and linear and quadratic effects of SID Lys were also tested. Hot carcass weight served as a covariate for the analysis of backfat, loin depth, and lean percentage. Results from the experiment were considered significant at $P \leq 0.05$ and considered a tendency between $P > 0.05$ and ≤ 0.10.

Results and Discussion

All diets from each phase were analyzed for Cu (Table 4). Considering the Cu originating from both the trace mineral premix and the ingredients used in formulation, these results are similar to expected values.

During the early finishing period from d 0 to 70, SID Lys affected the response to TBCC (TBCC × Lys linear interaction; $P < 0.05$; Table 5). This was due to the significant increase ($P < 0.05$) in ADG with added Cu from TBCC when pigs were fed 100% of the estimated SID Lys requirement and the lack of Cu response within the 85 or 92.5% SID Lys treatments. As a result, pigs fed added Cu from TBCC and 100% SID Lys tended to have a 5-lb increase in BW by d 70 (TBCC × Lys linear interaction; $P < 0.10$). Similar to ADG, SID Lys tended to affect the ADFI response to TBCC (TBCC × Lys quadratic interaction; $P < 0.10$) because pigs fed added Cu from TBCC and 100% SID Lys had increased ($P < 0.05$) ADFI, whereas pigs in other treatments did not. As expected, F/G improved as SID Lys increased (Lys linear; $P < 0.05$), but

added Cu from TBCC had no effect. During the late finishing period from d 70 to 120, neither TBCC nor SID Lys level affected ADG, ADFI, or F/G.

Overall, (d 0 to 120), no TBCC × Lys interactions were detected for growth performance. Adding 150 ppm Cu from TBCC to the diet tended ($P < 0.10$) to increase ADG and improve F/G. This was due to the response in gain and efficiency to TBCC within the 100% SID Lys level. Average daily gain increased and F/G improved as SID Lys increased (linear; $P < 0.01$). These differences also led to an increase in final BW with added Cu from TBCC ($P < 0.05$) and as SID Lys increased (linear; $P < 0.01$). Caloric efficiency on both an ME and NE basis tended to improve when Cu from TBCC was added to the diet ($P < 0.10$) and significantly improved as SID Lys increased ($P < 0.01$).

For carcass characteristics, increasing SID Lys increased ($P < 0.01$) HCW by over 5 lb, or almost 3%, in pigs fed 100% of their estimated SID Lys requirement compared with those fed only 85% (Table 6). The TBCC response for increasing loin depth tended to be influenced by SID Lys (TBCC × Lys linear; $P < 0.10$) because pigs fed 100% SID Lys with added Cu from TBCC tended to have increased ($P < 0.10$) loin depth, whereas pigs not fed supplemental TBCC did not. Standardized ileal digestible Lys also tended to affect percentage lean only when TBCC was included in the diet (TBCC × Lys quadratic; $P < 0.10$), specifically within the 92.5% SID Lys treatment ($P < 0.10$). Evaluating performance on a HCW basis showed that HCW ADG increased and HCW F/G improved ($P < 0.05$) as the SID Lys level increased. Added Cu from TBCC did not affect HCW ADG or F/G.

No interactions were detected between SID Lys and TBCC for any of the calculated economic criteria (Table 7). When values were calculated on a constant days basis, feed cost per pig, cost per pound of gain, and gain value all increased (linear; $P < 0.05$) as SID Lys increased. This resulted in increased (linear; $P < 0.05$) IOFC by $2.19 when pigs were fed 100% of their estimated SID Lys requirement compared with those fed only 85% of the requirement. Value of the weight gained during the experiment (gain value) tended to increase ($P < 0.10$) for those fed diets containing 150 ppm TBCC. When the economics were calculated on a constant weight basis, the adjusted F/G was improved ($P < 0.05$) for pigs fed 150 ppm TBCC because they were heavier at the end of the experiment. Also, similar to the treatment means, adjusted F/G improved (linear; $P < 0.05$) as SID Lys increased. Facility cost tended to be reduced ($P < 0.10$) when pigs were fed diets with TBCC because they would achieve 275 lb quicker. Facility cost decreased (linear; $P < 0.05$) as SID Lys increased. Although statistically not significant, pigs fed added TBCC with 100% SID Lys had an increase in IOFC of $2.54 per pig on a constant days basis and $1.89 per pig on a constant weight basis compared with those fed 100% SID Lys without added Cu.

No interactions were found between TBCC and SID Lys on liver color (Table 8); however, the main effect of TBCC led to a decrease ($P < 0.05$) in a*, suggesting that TBCC decreased the redness of the liver. The a* value also tended ($P < 0.10$) to decrease as SID Lys increased. Furthermore, TBCC tended to decrease ($P < 0.10$) chroma, or the intensity of the liver color. Although these slight differences were statistically significant, these color changes would not be visibly discernable.

Analysis of liver Cu, Fe, and Zn did not result in any TBCC × Lys interactions (Table 9). The main effect of 150 ppm added Cu from TBCC increased ($P < 0.05$) liver Cu concentrations by only 19 ppm. This is consistent with previous research that demonstrated liver Cu concentration increased only when dietary Cu supplementation was greater than 150 ppm (Cromwell et al., 1989[8]). However, liver Zn concentrations tended ($P < 0.10$) to decrease when pigs were fed diets with added Cu from TBCC compared with those not fed TBCC. Liver Cu concentrations tended (quadratic; $P < 0.10$) to increase then decrease, whereas Zn tended to increase as SID Lys increased.

For backfat fatty acid profile, SID Lys × TBCC interactions were observed for gadoleic acid (C20:1) and eicosatrienoic acid (C20:3n-3); however, both these fatty acids represent less than 1% of the fatty acid composition (Table 10). Increasing SID Lys levels influenced ($P < 0.10$) the percentage of heptadecanoic acid (C17:0), α-linoleic acid (C18:3n-3), eicosadienoic acid (C20:2), and other fatty acids, although when the percentages for these fatty acids are combined, they equate to less than 3% of the total fatty acid composition. These small but significant differences did not influence the iodine value (IV) for backfat.

In the jowl, as SID Lys increased in diets containing TBCC, the percentage of steric acid (C18:0) and palmitoleic acid (C16:1) increased (Table 11). These changes caused the percentage of total SFA to decrease and UFA:SFA to increase (TBCC × Lys interaction; linear $P < 0.05$), but PUFA:SFA and jowl IV only tended to increase (TBCC × Lys interaction; linear $P < 0.10$) with increasing SID Lys in diets containing TBCC.

In conclusion, results from this study differed from our initial hypothesis. Based on previous work by Coble et al. (2013), it was expected that TBCC would increase feed intake and allow the pigs fed the lower SID Lys diets to compensate for the deficiency in Lys. This did not occur, even though TBCC tended to increase ADG and improve F/G. Results from this study confirmed that 100% of the estimated SID Lys requirement should be fed to achieve the highest net return when pigs are fed for a constant number of days. Although not statistically significant, pigs fed added TBCC within 100% SID Lys had a numeric increase in IOFC of $2.54 per pig on a constant days basis and $1.89 per pig on a constant weight basis compared with those not fed added Cu from TBCC.

[8] Cromwell, G.L., T.S. Stahly, and H.J. Monegue. 1989. Effects of source and level of copper on performance and liver copper stores in weanling pigs. J. Anim. Sci. 67:2996–3002.

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

	Phase 1			Phase 2		
SID Lys,[2] %:	85.0	92.5	100.0	85.0	92.5	100.0
Ingredient, %						
Corn	39.42	36.82	34.23	43.31	41.07	38.82
Soybean meal, 46.5% CP	13.02	15.59	18.15	9.42	11.64	13.86
Bakery meal	15.00	15.00	15.00	15.00	15.00	15.00
DDGS[3]	30.00	30.00	30.00	30.00	30.00	30.00
Dicalcium P, 18.5%	---	---	---	0.13	0.13	0.13
Monocalcium P, 21.5%	0.25	0.25	0.25	---	---	---
Limestone	1.25	1.25	1.25	1.15	1.15	1.15
Salt	0.35	0.35	0.35	0.35	0.35	0.35
L-threonine	0.03	0.03	0.03	0.00	0.00	0.00
Lysine sulfate[4]	0.51	0.54	0.57	0.46	0.49	0.52
Phytase[5]	0.01	0.01	0.01	0.01	0.01	0.01
Vitamin premix	0.08	0.08	0.08	0.08	0.08	0.08
Trace mineral premix[6]	0.10	0.10	0.10	0.10	0.10	0.10
Added Cu[7]	---	---	---	---	---	---
Total	100.0	100.0	100.0	100.0	100.0	100.0
Calculated SID Lys requirement[2], %	1.04	1.04	1.04	0.91	0.91	0.91
Calculated analysis						
SID amino acids, %						
Lysine	0.88	0.96	1.04	0.77	0.84	0.91
Isoleucine:lysine	74	72	71	77	75	73
Leucine:lysine	191	181	174	207	197	188
Methionine:lysine	34	33	31	37	35	34
Met & Cys:lysine	63	61	58	69	65	63
Threonine:lysine	65	63	62	64	63	61
Tryptophan:lysine	18.2	18.2	18.2	18.2	18.2	18.2
Valine:lysine	87	84	82	91	88	86
Total lysine, %	1.07	1.16	1.24	0.95	1.03	1.10
ME, kcal, lb	1,536	1,535	1,534	1,541	1,540	1,539
SID lysine:ME, g/Mcal	2.61	2.84	3.08	2.28	2.48	2.68
CP, %	19.9	20.9	22.0	18.5	19.4	20.3
Ca, %	0.59	0.59	0.60	0.53	0.53	0.54
P, %	0.47	0.48	0.49	0.42	0.43	0.44
Available P, %	0.32	0.32	0.33	0.28	0.28	0.29

[1] Phase 1 diets were fed from d 0 to 23 (63.8 to 102.8 lb); Phase 2 diets were fed from d 23 to 38 (102.8 to 132.8 lb).
[2] Standardized ileal digestible lysine values were based on 100% of the estimated SID Lys requirement for these pigs in this environment and production stage.
[3] Dried distillers grains with solubles (Valero, Aurora, SD).
[4] Biolys (Evonik, Inc., Kennesaw, GA).
[5] Optiphos 2000 (Huvepharma, Inc., Peachtree City, GA) provided 1,816,000 phytase units (FTU)/lb, with a release of 0.10% available P.
[6] Trace mineral premix provided 17 ppm Cu in the form of $CuSO_4$ to each diet.
[7] Supplemental copper provided in the form of tri-basic copper chloride (TBCC; Intellibond C; Micronutrients, Inc., Indianapolis, IN) at 150 ppm at the expense of corn.

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

	Phase 3			Phase 4		
SID Lys,[2] %:	85.0	92.5	100.0	85.0	92.5	100.0
Ingredient, %						
Corn	46.59	44.58	42.57	48.80	46.98	45.17
Soybean meal, 46.5 CP	6.31	8.30	10.28	4.15	5.95	7.74
Bakery meal	15.00	15.00	15.00	15.00	15.00	15.00
DDGS[3]	30.00	30.00	30.00	30.00	30.00	30.00
Limestone	1.15	1.15	1.15	1.13	1.13	1.13
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Lysine sulfate[4]	0.43	0.45	0.47	0.40	0.42	0.44
Phytase[5]	0.01	0.01	0.01	0.01	0.01	0.01
Vitamin premix	0.08	0.08	0.08	0.08	0.08	0.08
Trace mineral premix[6]	0.10	0.10	0.10	0.10	0.10	0.10
Added Cu[7]	---	---	---	---	---	---
Total	100.0	100.0	100.0	100.0	100.0	100.0
Calculated SID Lys requirement[2], %	0.80	0.80	0.80	0.72	0.72	0.72
Calculated analysis						
SID amino acids, %						
Lysine	0.68	0.74	0.80	0.68	0.74	0.80
Isoleucine:lysine	80	78	76	83	81	79
Leucine:lysine	225	213	203	242	229	217
Methionine:lysine	40	38	36	43	41	39
Met & Cys:lysine	74	70	67	79	75	72
Threonine:lysine	67	65	64	70	68	66
Tryptophan:lysine	18.2	18.2	18.2	18.3	18.3	18.3
Valine:lysine	97	93	90	102	98	95
Total lysine, %	0.85	0.92	0.98	0.85	0.92	0.98
ME, kcal, lb	1,544	1,544	1,543	1,546	1,545	1,544
SID lysine:ME, g/Mcal	2.00	2.17	2.35	1.80	1.96	2.12
CP, %	17.2	18.0	18.8	16.4	17.1	17.8
Ca, %	0.49	0.49	0.50	0.47	0.48	0.48
P, %	0.38	0.39	0.40	0.37	0.38	0.39
Available P, %	0.25	0.26	0.26	0.25	0.25	0.26

[1] Phase 3 diets were fed from d 38 to 70 (132.8 lb to 189.9 lb); Phase 4 diets were fed from d 70 to 97 (189.9 to 239.1 lb).
[2] Standardized ileal digestible lysine values were based on 100% of the estimated SID Lys requirement for these pigs in this environment and production stage.
[3] Dried distillers grains with solubles (Valero, Aurora, SD).
[4] Biolys (Evonik, Inc., Kennesaw, GA).
[5] Optiphos 2000 (Huvepharma, Inc, Peachtree City, GA) provided 1,816,000 phytase units (FTU)/lb, with a release of 0.10% available P.
[6] Trace mineral premix provided 17 ppm Cu in the form of $CuSO_4$ to each diet.
[7] Supplemental copper provided in the form of tri-basic copper chloride (TBCC; Intellibond C; Micronutrients, Inc., Indianapolis, IN) at 150 ppm at the expense of corn.

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

	Phase 5		
SID Lys,[2] %:	85.0	92.5	100.0
Ingredient, %			
Corn	41.81	39.39	36.97
Soybean meal, 46.5 CP	11.04	13.40	15.79
Bakery meal	15.00	15.00	15.00
DDGS[3]	30.00	30.00	30.00
Limestone	1.15	1.15	1.15
Salt	0.35	0.35	0.35
L-threonine	0.03	0.03	0.03
Lysine sulfate[4]	0.45	0.48	0.50
Ractopamine HCl,[5] 9 g/ton	0.03	0.03	0.03
Phytase[6]	0.10	0.10	0.10
Vitamin premix	0.08	0.08	0.08
Trace mineral premix[7]	0.10	0.10	0.10
Added Cu[8]	---	---	---
Total	100.0	100.0	100.0

continued

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

	Phase 5		
SID Lys,[2] %:	85.0	92.5	100.0
Calculated SID Lys requirement[2], %	0.65	0.65	0.65
Calculated analysis			
SID amino acids, %			
Lysine	0.81	0.88	0.95
Isoleucine:lysine	77	75	74
Leucine:lysine	203	193	185
Methionine:lysine	36	35	33
Met & Cys:lysine	67	64	62
Threonine:lysine	68	66	65
Tryptophan:lysine	18.6	18.6	18.6
Valine:lysine	91	88	85
Total lysine, %	0.99	1.07	1.14
ME, kcal, lb	1,542	1,541	1,540
SID lysine:ME, g/Mcal	2.38	2.59	2.80
CP, %	19.1	20.1	21.0
Ca, %	0.50	0.51	0.52
P, %	0.41	0.42	0.43
Available P, %	0.26	0.27	0.28

[1] Phase 5 diets were fed from d 97 to 120 (239.1 to 276.6 lb).
[2] Standardized ileal digestible lysine values were based on 100% of the estimated SID Lys requirement for these pigs in this environment and production stage.
[3] Dried distillers grains with solubles (Valero, Aurora, SD).
[4] Biolys (Evonik, Inc., Kennesaw, GA).
[5] Ractopamine HCl (Elanco Animal Health, Inc., Greenfield, IN).
[6] Optiphos 2000 (Huvepharma, Inc, Peachtree City, GA) provided 1,816,000 phytase units (FTU)/lb, with a release of 0.10% available P.
[7] Trace mineral premix provided 17 ppm Cu in the form of $CuSO_4$ to each diet.
[8] Supplemental copper provided in the form of tri-basic copper chloride (TBCC; Intellibond C; Micronutrients, Inc., Indianapolis, IN) at 150 ppm at the expense of corn.

Table 4. Copper analysis of complete diets (ppm, as-fed)[1]

	TBCC,[2] ppm:					
	0			150		
SID Lys,[3] %:	85.0	92.5	100.0	85.0	92.5	100.0
Total Cu, ppm						
Phase 1	45	38	28	217	218	218
Phase 2	34	25	29	188	178	215
Phase 3	30	29	41	182	219	196
Phase 4	42	39	56	222	246	232
Phase 5	34	39	33	187	225	221

[1] Values represent means from one composite sample, analyzed in duplicate.
[2] Tri-basic copper chloride (Intellibond C; Micronutrients, Indianapolis, IN).
[3] Standardized ileal digestible lysine values were based on 100% of the estimated SID Lys requirement for these pigs in this environment and production stage.

Table 5. Effects of standardized ileal digestible lysine (SID Lys) and added copper on growth performance of finishing pigs[1]

	TBCC,[2] ppm							Probability, $P <$				
	0			150				TBCC × Lys			SID Lys	
SID Lys,[3] %:	85.0	92.5	100.0	85.0	92.5	100.0	SEM	Linear	Quadratic	TBCC	Linear	Quadratic
BW, lb												
d 0	63.8	63.8	63.9	63.9	63.8	63.9	2.06	0.896	0.940	0.915	0.930	0.840
d 70	185.6	190.8	190.8	186.3	190.4	195.6	3.31	0.089[7]	0.124	0.089	0.001	0.325
d 120	270.6	276.5	278.1	272.6	277.4	284.4	3.05	0.110	0.169	0.006	0.001	0.636
d 0 to 70[4]												
ADG, lb	1.74	1.80	1.80	1.74	1.81	1.88	0.022	0.034[8]	0.222	0.057	0.001	0.236
ADFI, lb	4.32	4.41	4.35	4.35	4.37	4.49	0.087	0.172	0.095[9]	0.184	0.053	0.765
F/G	2.49	2.44	2.41	2.50	2.42	2.39	0.029	0.398	0.537	0.516	0.001	0.266
d 70 to 120[5]												
ADG, lb	1.79	1.78	1.81	1.80	1.80	1.83	0.027	0.772	0.956	0.514	0.339	0.519
ADFI, lb	5.55	5.54	5.56	5.54	5.51	5.53	0.069	0.897	0.997	0.599	0.979	0.752
F/G	3.11	3.11	3.08	3.09	3.07	3.02	0.040	0.562	0.915	0.121	0.156	0.596
d 0 to 120												
ADG, lb	1.76	1.80	1.80	1.76	1.80	1.86	0.016	0.109	0.414	0.095	0.001	0.740
ADFI, lb	4.82	4.86	4.83	4.82	4.83	4.91	0.070	0.414	0.333	0.654	0.227	0.949
F/G	2.74	2.71	2.68	2.74	2.68	2.64	0.028	0.279	0.838	0.097	0.001	0.542
Caloric efficiency[6]												
ME	4,228	4,170	4,130	4,223	4,127	4,068	42.9	0.278	0.837	0.087	0.001	0.541
NE	3,144	3,087	3,044	3,139	3,055	2,998	31.7	0.276	0.831	0.085	0.001	0.535

[1] A total of 1,248 (PIC 337 × 1050; initial BW 63.8 lb) pigs were used in a 120 d study with 6 treatments and 8 replications per treatment.
[2] Tri-basic copper chloride (Intellibond C; Micronutrients, Indianapolis, IN).
[3] SID Lys values were based on 100% of the estimated SID Lys requirement for these pigs in this environment and production stage.
[4] Phase 1, 2, and 3 diets were fed from d 0 to 70.
[5] Phase 4 and 5 diets were fed from d 70 to 120.
[6] Caloric efficiency is expressed as kcal per pound of live weight gain.
[7] Main effect of TBCC within 100 % SID Lys: $P < 0.007$.
[8] Main effect of TBCC within 100% SID Lys: $P < 0.003$.
[9] Main effect of TBCC within 100% SID Lys: $P < 0.019$.

Table 6. Effects of standardized ileal digestible lysine (SID Lys) and added copper on carcass characteristics of finishing pigs[1]

	TBCC,[2] ppm							Probability, $P <$				
	0			150				TBCC × Lys			SID Lys	
SID Lys,[3] %:	85.0	92.5	100.0	85.0	92.5	100.0	SEM	Linear	Quadratic	TBCC	Linear	Quadratic
Carcass characteristics[4]												
HCW, lb	204.2	208.7	207.9	205.8	208.5	213.2	2.54	0.346	0.290	0.170	0.007	0.619
Farm yield, %	75.45	75.51	74.76	75.47	75.16	74.97	0.464	0.838	0.557	0.921	0.203	0.666
Backfat, [5]in.	0.64	0.66	0.62	0.63	0.64	0.63	0.017	0.745	0.509	0.765	0.553	0.215
Loin depth, [5]in.	2.74	2.71	2.71	2.71	2.74	2.78	0.026	0.068[6]	0.930	0.260	0.340	0.601
Lean,[5] %	57.42	57.31	58.12	57.59	58.04	57.87	0.222	0.342	0.057[7]	0.249	0.040	0.696
Carcass performance												
HCW ADG, lb	1.30	1.34	1.33	1.32	1.34	1.38	0.016	0.321	0.276	0.151	0.006	0.591
HCW F/G	3.70	3.63	3.63	3.67	3.61	3.56	0.051	0.599	0.593	0.141	0.012	0.428

[1] A total of 1,248 (PIC 337 × 1050; initial BW 63.8 lb) pigs were used in a 120-d study with 6 treatments and 8 replications per treatment.
[2] Tri-basic copper chloride (Intellibond C; Micronutrients, Indianapolis, IN).
[3] SID Lys values were based on 100% of the estimated SID Lys requirement for these pigs in this environment and production stage.
[4] 1,069 pigs (19 to 23 pigs/pen) were transported to a commercial packing plant for processing and data collection (Swift and Company, Worthington, MN) and 144 pigs (3 pigs/pen) visually assumed to represent the mean live weight of the pen were subsampled and shipped to a separate processing facility for further carcass measurements (Natural Foods Holdings, Inc., Sioux Center, IA). The weighted average of the two plants were used for HCW, farm yield, and backfat.
[5] HCW was used as a covariate.
[6] Main effect of TBCC within 100% SID Lys: $P < 0.063$.
[7] Main effect of TBCC within 92.5% SID Lys: $P < 0.062$.

Table 7. Effects of standardized ileal digestible lysine (SID Lys) and added copper on economics of finishing pigs[1]

	TBCC,[2] ppm							Probability, $P <$				
	0			150				TBCC × Lys			SID Lys	
SID Lys,[3] %:	85.0	92.5	100.0	85.0	92.5	100.0	SEM	Linear	Quadratic	TBCC	Linear	Quadratic
Constant days												
Feed cost, $/pig	79.20	81.65	83.10	80.00	81.79	84.90	1.180	0.502	0.372	0.136	0.001	0.900
$/lb gain	0.376	0.379	0.384	0.379	0.378	0.381	0.004	0.188	0.888	0.879	0.029	0.537
Gain value,[4] $/pig	142.34	146.38	147.43	143.68	147.06	151.77	1.412	0.296	0.383	0.074	0.001	0.740
IOFC,[5] $/pig	63.14	64.73	64.33	63.68	65.26	66.87	0.991	0.302	0.545	0.131	0.028	0.558
Constant weight[6]												
Adjusted F/G[7]	2.76	2.70	2.66	2.75	2.67	2.59	0.023	0.192	0.794	0.037	0.001	0.543
Feed cost, $/pig	79.65	79.47	80.26	79.86	79.15	78.73	0.678	0.187	0.764	0.309	0.686	0.578
Feed cost, $/lb gain	0.377	0.376	0.380	0.378	0.375	0.373	0.003	0.187	0.764	0.309	0.686	0.578
Gain value,[4] $/pig	145.37	145.37	145.37	145.37	145.37	145.37	---	---	---	---	---	---
IOFC,[5] $/pig	65.72	65.90	65.11	65.51	66.22	66.64	0.678	0.187	0.764	0.309	0.686	0.578
Facility cost,[8] $/pig	12.24	11.91	11.84	12.12	11.87	11.48	0.188	0.312	0.306	0.075	0.001	0.758
IOFFC,[9] $/pig	53.48	53.99	53.27	53.39	54.35	55.16	0.712	0.173	0.660	0.225	0.278	0.578

[1] A total of 1,248 (PIC 337 ×1050; initial BW 63.8 lb) pigs were used in a 120-d study with 6 treatments and 8 replications per treatment.
[2] Tri-basic copper chloride (Intellibond C; Micronutrients, Indianapolis, IN).
[3] SID Lys values were based on 100% of the estimated SID Lys requirement for these pigs in this environment and production stage.
[4] Gain value calculated using (final wt. x $68.83/cwt) – (initial wt. × $68.83/cwt).
[5] Income over feed cost = carcass gain value – feed cost.
[6] Adjusted to constant final weight of 275 lb.
[7] Adjusted using a factor of 0.005 for 1 lb change in live weight.
[8] Facility cost at $0.10/hd/day.
[9] Income over feed and facility cost = IOFC – facility cost.

Table 8. Effects of standardized ileal digestible lysine (SID Lys) and added copper on liver color of finishing pigs[1]

	TBCC,[2] ppm							Probability, *P* <				
	0			150				TBCC × Lys			SID Lys	
SID Lys,[3] %:	85.0	92.5	100.0	85.0	92.5	100.0	SEM	Linear	Quadratic	TBCC	Linear	Quadratic
Liver color												
L*[4]	32.55	31.18	32.24	31.48	31.05	32.08	0.594	0.431	0.888	0.160	0.800	0.191
a*[5]	14.86	15.01	14.71	14.77	14.09	13.71	0.359	0.206	0.537	0.027	0.097	0.912
b*[6]	6.42	5.59	6.19	6.75	5.61	5.68	0.461	0.357	0.271	0.303	0.163	0.695
Hue Angle,[7] °	0.399	0.409	0.389	0.424	0.370	0.379	0.199	0.376	0.186	0.647	0.170	0.639
Chroma[8]	16.24	16.43	16.02	16.28	15.23	14.98	0.488	0.266	0.404	0.071	0.125	0.908

[1] 144 pigs (PIC 337 ×1050) were used (3 pigs/pen) to determine liver color scores in a 120-d study with 6 treatments and 8 replications per treatment.
[2] Tri-basic copper chloride (Intellibond C; Micronutrients, Indianapolis, IN).
[3] SID Lys values were based on 100% of the estimated SID Lys requirement for these pigs in this environment and production stage.
[4] L*, 0 = black, 100 = white.
[5] a* – values = green; + values = red.
[6] b* – values = blue; + values = yellow.
[7] Hue angle = $\tan^{-1}(b^*/a^*)$.
[8] Chroma = $(\sqrt{a^* + b^*}) / L^*$.

Table 9. Effects of standardized ileal digestible lysine (SID Lys) and added copper on liver mineral concentrations (DM basis) of finishing pigs[1]

	TBCC, [2]ppm							Probability, *P* <				
	0			150				TBCC × Lys			SID Lys	
SID Lys,[3] %:	100.0	92.5	85.0	100.0	92.5	85.0	SEM	Linear	Quadratic	TBCC	Linear	Quadratic
Cu, ppm	12	13	13	26	39	33	3.27	0.393	0.105	0.001	0.182	0.092
Fe, ppm	211	221	196	205	203	200	11.43	0.654	0.368	0.437	0.344	0.322
Zn, ppm	59	59	62	55	57	59	2.29	0.566	0.806	0.095	0.099	0.841

[1] 144 pigs (PIC 337 ×1050) were used (3 pigs/pen) to determine liver mineral concentrations in a 120-d study with 6 treatments and 8 replications per treatment.
[2] Tri-basic copper chloride (Intellibond C; Micronutrients, Indianapolis, IN).
[3] SID Lys values were based on 100% of the estimated SID Lys requirement for these pigs in this environment and production stage.

Table 10. Effects of standardized ileal digestible lysine (SID Lys) and added copper on backfat fatty acid analysis (DM basis) of finishing pigs[1]

	TBCC,[2] ppm							Probability, $P <$				
	0			150				TBCC × Lys			SID Lys	
SID Lys,[3] %:	85.0	92.5	100.0	85.0	92.5	100.0	SEM	Linear	Quad.	TBCC	Linear	Quad.
Myristic acid (C14:0). %	1.11	1.14	1.13	1.12	1.14	1.09	0.027	0.419	0.664	0.597	0.909	0.277
Palmitic acid (C16:0), %	19.82	20.22	20.07	19.75	19.80	19.63	0.262	0.469	0.725	0.145	0.797	0.382
Palmitoleic acid (C16:1), %	1.88	1.91	1.87	1.83	1.95	1.87	0.071	0.731	0.597	0.880	0.842	0.280
Heptadecanoic acid (C17:0), %	0.41	0.41	0.47	0.40	0.40	0.47	0.021	0.786	0.953	0.486	0.004	0.089
Stearic acid (C18:0), %	9.97	10.37	10.17	10.38	10.05	10.17	0.266	0.455	0.272	0.896	0.975	0.859
Oleic acid (C18:1 *cis*-9), %	37.25	36.57	36.46	36.82	37.20	36.19	0.420	0.851	0.190	0.946	0.101	0.574
Linoleic acid (C18:2n-6), %	25.70	25.54	25.87	25.99	25.56	26.58	0.618	0.738	0.658	0.508	0.545	0.374
α-linoleic acid (C18:3n-3), %	0.92	0.93	0.94	0.93	0.95	0.98	0.021	0.402	0.688	0.235	0.098	0.945
γ-linoleic acid (C18:3n-6), %	0.10	0.10	0.10	0.10	0.11	0.10	0.007	0.630	0.593	0.617	0.448	0.822
Conjugated linoleic acid (*c9, t*11), %	0.14	0.14	0.12	0.15	0.16	0.14	0.009	0.539	0.870	0.064	0.224	0.113
Arachidic acid (C20:0), %	0.17	0.18	0.17	0.16	0.17	0.18	0.007	0.163	0.726	0.642	0.141	0.544
Gadoleic acid (C20:1), %	0.72	0.71	0.79	0.67	0.72	0.74	0.016	0.887	0.028[11]	0.018	0.001	0.302
Eicosadienoic acid (C20:2), %	0.94	0.95	1.01	0.93	0.96	1.01	0.026	0.803	0.647	0.845	0.005	0.487
Eicosatrienoic acid (C20:3n-3), %	0.12	0.12	0.11	0.11	0.12	0.12	0.005	0.054[10]	0.589	0.683	0.213	0.681
Dihomo-γ-linoleic acid (C20:3n-6), %	0.12	0.13	0.12	0.11	0.12	0.13	0.005	0.255	0.749	0.589	0.143	0.358
Arachidonic acid (C20:4n-6), %	0.34	0.31	0.30	0.33	0.32	0.33	0.015	0.100	0.837	0.510	0.100	0.711
Other fatty acids, %	0.28	0.27	0.29	0.26	0.27	0.29	0.010	0.303	0.224	0.309	0.081	0.309
Total SFA,[4] %	31.49	32.31	32.01	31.79	31.57	31.53	0.474	0.405	0.422	0.427	0.786	0.566
Total MUFA,[5] %	39.85	39.20	39.13	39.32	39.87	38.80	0.472	0.823	0.187	0.869	0.198	0.531
Total PUFA,[6] %	28.37	28.22	28.57	28.63	28.29	29.38	0.671	0.684	0.691	0.494	0.484	0.410
UFA:SFA ratio[7]	2.18	2.09	2.14	2.15	2.18	2.17	0.047	0.461	0.323	0.465	0.810	0.561
PUFA:SFA ratio[8]	0.91	0.88	0.91	0.91	0.90	0.94	0.032	0.592	0.829	0.494	0.651	0.394
Iodine value,[9] g/100 g	82.63	81.75	82.21	82.64	82.44	83.36	0.901	0.530	0.942	0.406	0.869	0.433

[1] 144 pigs (PIC 337 ×1050) were used (3 pigs/pen) to determine fatty acid concentrations in a 120-d study with 6 treatments and 8 replications per treatment.
[2] Tri-basic copper chloride (Intellibond C; Micronutrients, Indianapolis, IN).
[3] SID Lys values were based on 100% of the estimated SID Lys requirement for these pigs in this environment and production stage.
[4] Total SFA = ([C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0]); brackets indicate concentration.
[5] Total MUFA = ([C16:1] + [C18:1*cis*-9] + [C20:1]); brackets indicate concentration.
[6] Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [*c*9,*t*11] + [C20:2] + [C20:3n-3] + [C20:3n-6] + [C20:4n-6]); brackets indicate concentration.
[7] UFA:SFA = (total MUFA+PUFA)/ total SFA.
[8] PUFA:SFA = total PUFA/ total SFA.
[9] Calculated as IV = [C16:1] × 0.950 + [C18:1] × 0.860 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C20:4] × 3.201 + [C22:1] × 0.723 + [C22:5] × 3.697 + [C22:6] × 4.463; brackets indicate concentration.
[10] Main effect of TBCC within 100% SID Lys: $P < 0.030$; within 85% SID Lys: $P < 0.012$.
[11] Main effect of TBCC within 100% SID Lys: $P < 0.070$.

Table 11. Effects of standardized ileal digestible (SID) lysine and added copper on jowl fatty acid analysis (DM Basis) of finishing pigs[1]

	TBCC,[2] ppm							Probability, $P <$				
	0			150				TBCC × Lys			SID Lys	
SID Lys, [3]%:	85.0	92.5	100.0	85.0	92.5	100.0	SEM	Linear	Quad.	TBCC	Linear	Quad.
Myristic acid (C14:0). %	1.10	1.16	1.19	1.12	1.16	1.14	0.032	0.305	0.803	0.687	0.092	0.446
Palmitic acid (C16:0), %	18.63	18.22	19.00	19.00	18.80	18.51	0.377	0.218	0.282	0.573	0.858	0.358
Palmitoleic acid (C16:1), %	2.52	2.35	2.64	2.39	2.66	2.59	0.116	0.678	0.032[10]	0.628	0.129	0.744
Heptadecanoic acid (C17:0), %	0.41	0.44	0.43	0.40	0.41	0.42	0.026	0.924	0.760	0.446	0.496	0.733
Stearic acid (C18:0), %	8.07	8.55	8.10	8.91	7.95	7.67	0.289	0.024[11]	0.092	0.781	0.030	0.795
Oleic acid (C18:1 *cis*-9), %	40.70	40.07	40.23	40.19	40.98	39.98	0.568	0.811	0.174	0.911	0.537	0.605
Linoleic acid (C18:2n-6), %	24.52	25.12	24.34	24.08	24.01	25.45	0.630	0.211	0.176	0.776	0.332	0.950
α-linoleic acid (C18:3n-3), %	0.89	0.94	0.90	0.87	0.89	0.96	0.025	0.123	0.086[12]	0.946	0.044	0.771
γ-linoleic acid (C18:3n-6), %	0.10	0.10	0.10	0.09	0.09	0.10	0.005	0.660	0.774	0.100	0.515	0.907
Conjugated linoleic acid (*c*9, *t*11), %	0.16	0.15	0.14	0.16	0.17	0.18	0.008	0.047[13]	0.701	0.013	0.952	0.580
Arachidic acid (C20:0), %	0.13	0.14	0.13	0.13	0.14	0.14	0.006	0.878	0.266	0.882	0.746	0.156
Gadoleic acid (C20:1), %	0.80	0.78	0.80	0.76	0.80	0.80	0.019	0.245	0.281	0.692	0.261	0.974
Eicosadienoic acid (C20:2), %	1.02	1.04	1.03	1.00	1.02	1.08	0.026	0.178	0.463	0.891	0.109	0.798
Eicosatrienoic acid (C20:3n-3), %	0.13	0.13	0.13	0.12	0.13	0.14	0.005	0.154	0.450	0.443	0.152	0.704
Dihomo-γ-linoleic acid (C20:3n-6), %	0.13	0.15	0.14	0.12	0.14	0.14	0.005	0.492	0.637	0.090	0.017	0.259
Arachidonic acid (C20:4n-6), %	0.36	0.35	0.35	0.34	0.34	0.37	0.012	0.196	0.505	0.492	0.409	0.247
Other fatty acids, %	0.34	0.34	0.36	0.30	0.32	0.34	0.014	0.451	0.789	0.043	0.049	0.846
Total SFA,[4] %	28.35	28.49	28.85	29.56	28.45	27.87	0.501	0.019[14]	0.837	0.854	0.191	0.635
Total MUFA,[5] %	44.02	43.20	43.67	43.34	44.44	43.38	0.644	0.752	0.109	0.864	0.803	0.687
Total PUFA,[6] %	27.30	27.97	27.13	26.79	26.78	28.41	0.687	0.188	0.175	0.800	0.285	0.951
UFA:SFA ratio[7]	2.54	2.54	2.47	2.40	2.52	2.59	0.066	0.032[15]	0.941	0.756	0.294	0.562
PUFA:SFA ratio[8]	0.97	1.00	0.95	0.91	0.95	1.03	0.037	0.073[16]	0.339	0.672	0.233	0.835
Iodine value,[9] g/100 g	84.20	84.62	83.61	82.73	83.61	85.48	0.861	0.052[17]	0.402	0.769	0.202	0.882

[1] 144 pigs (PIC 337 x 1050) were used (3 pigs/pen) to determine fatty acid concentrations in a 120-d study with 6 treatments and 8 replications per treatment.
[2] Tri-basic copper chloride (Intellibond C; Micronutrients, Indianapolis, IN).
[3] SID Lys values were based on 100% of the estimated SID Lys requirement for these pigs in this environment and production stage.
[4] Total SFA = ([C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0]); brackets indicate concentration.
[5] Total MUFA = ([C16:1] + [C18:1*cis*-9] + [C20:1]); brackets indicate concentration.
[6] Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [*c*9, *t*11] + [C20:2] + [C20:3n-3] + [C20:3n-6] + [C20:4n-6]); brackets indicate concentration.
[7] UFA:SFA = (total MUFA+PUFA)/total SFA.
[8] PUFA:SFA = total PUFA/total SFA.
[9] Calculated as IV = [C16:1] × 0.950 + [C18:1] × 0.860 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C20:4] × 3.201 + [C22:1] × 0.723 + [C22:5] × 3.697 + [C22:6] × 4.463; brackets indicate concentration.
[10] Main effect of TBCC within 92.5% SID Lys: $P < 0.042$.
[11] Main effect of TBCC within 85% SID Lys: $P < 0.031$.
[12] Main effect of TBCC within 100% SID Lys: $P < 0.07$.
[13] Main effect of TBCC within 100% SID Lys: $P < 0.004$.
[14] Main effect of TBCC within 85% SID Lys: $P < 0.059$.
[15] Main effect of TBCC within 85% SID Lys: $P < 0.089$.
[16] Main effect of TBCC within 100% SID Lys: $P < 0.160$.
[17] Main effect of TBCC within 100% SID Lys: $P < 0.125$.

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.
[2] Appreciation is expressed to Novus International, Inc. (St. Charles, MO) for funding of this experiment.
[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.

Effects of Added Zinc During the Grower and/or Finisher Phase 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 1,197 pigs (PIC 337 × 1050) were used in a 72-d study to determine the effects of added zinc from zinc oxide (ZnO) fed in grower (d 0 to 45; initially 129.6 lb) and finisher (d 45 to 72; initially 218.3 lb) pig diets with or without ractopamine HCl (RAC; Paylean; Elanco Animal Health, Greenfield, IN) on growth performance and carcass characteristics. Pens were randomly assigned to a 2 × 2 × 2 factorial arrangement in a split-plot design. The whole plot consisted of diets with or without 75 ppm added Zn from d 0 to 45, and the subplots were diets with or without 75 ppm added Zn and with or without 10 ppm RAC from d 45 to 72. All diets contained 50 ppm Zn supplied from the premix. No interactions were observed. Addition of 75 ppm Zn during either period or both periods did not influence overall pig growth performance or carcass characteristics. Pigs fed RAC had improved ($P < 0.03$) ADG, F/G, final BW, HCW, loin depth, and fat-free lean index compared with pigs fed the control diet. In conclusion, feeding RAC improved the performance of growing-finishing pigs, but additional Zn did not.

Key words: finishing pig, ractopamine HCl, zinc

Introduction

Ractopamine HCl (RAC; Paylean; Elanco Animal Health, Greenfield, IN) is frequently added to finishing pig diets to improve growth performance and carcass leanness. Previous research suggests that when adding RAC to finishing diets, amino acid concentrations need to be increased approximately 30% to maximize growth and carcass leanness, but little research has been conducted to determine if other nutrients (such as trace minerals) also should be increased. Some recent studies have indicated that added Zn above that contained in the standard trace mineral premix can further increase the response of RAC (Akey, 2011[3]; Paulk et al., 2012[4]).

One consequence of feeding higher levels of zinc if not utilized by the pig is increased excretion and the associated environmental impact. Increasing dietary Zn levels above

[1] Appreciation is expressed to New Horizon Farms for use of pigs and facilities and to Richard Brobjorg, Scott Heidebrink, and Marty Heintz for technical assistance.
[2] Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University.
[3] Akey. 2011. Effects of zinc source and level in Paylean diets on pig performance and carcass characteristics. Akey Swine Newsletter.
[4] Paulk et al., Swine Day 2012, Report of Progress 1074, pp. 348–356.

the requirement results in increased Zn excreted in swine waste (Creech et al., 2004[5]), so it is important to define the duration of feeding added Zn to maximize performance while minimizing Zn excretion.

The objective of this study was to determine if added Zn had to be fed throughout the grower period, and with or without RAC in the finishing period, to achieve an improvement in growth performance, and the influence of added Zn on plasma and fecal Zn concentrations.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The experiment was conducted at a commercial research-finishing barn. The barn was naturally ventilated and double-curtain-sided with completely slatted flooring and a deep pit for manure storage. Each pen was equipped with a 4-hole stainless steel dry self-feeder and a cup waterer for ad libitum access to feed and water. Daily feed additions to each pen were accomplished through a robotic feeding system (FeedPro; Feedlogic Corp., Willmar, MN) capable of providing and measuring feed amounts for individual pens.

A total of 1,197 pigs (Line 337 × 1050: PIC Hendersonville, TN; initially 129.6 lb) were used in a 72-d study to determine the effects of added Zn from ZnO fed during the grower (d 0 to 45) and finisher (d 45 to 72) phase in diets with or without RAC on growth performance, carcass characteristics, and plasma and fecal Zn concentrations. Pens were randomly assigned to a 2 × 2 × 2 factorial arrangement in a split-plot design. The whole plot consisted of diets with or without 75 ppm added Zn from ZnO from d 0 to 45, and the subplots were diets with or without 75 ppm added Zn from ZnO and with or without 10 ppm RAC from d 45 to 72. All diets contained 50 ppm Zn supplied from the premix. All experimental diets were in meal form and were prepared at a commercial feed mill. A subsample of experimental diets was collected and analyzed for dietary Zn (Ward Laboratories, Inc., Kearney, NE). There were 25 pigs per a pen and a total of 24 pens per treatment for the whole plot and 12 pens per treatment for the subplot.

Pigs and feeders were weighed on d 0, 23, 45, 52, 57, 65, and 72 to determine ADG, ADFI, and F/G. Subsamples of 1, 2, 4, and 4 pigs were bled from each pen on d 0, 45, 52, and 63, respectively. On d 0, the median weight barrow from each pen was ear tagged to allow for bleeding on subsequent collection dates. On day 52 and 63, four median weight barrows, including the previously selected pig, were selected from each pen for blood collection. Samples were collected via jugular venipuncture into heparinized (143 USP units of NA heparin) vacutainer tubes (Tyco Healthcare Group LP, Mansfield, MA), inverted, and immediately placed on ice until samples were processed. On d 45 and 63, fecal grab samples were collected on 3 random pigs per pen for determination of Zn concentrations. On d 57, the 6 heaviest pigs from each pen (determined visually), and on d 72, the remaining pigs were tattooed by pen and transported 1 h to a USDA-inspected processing plant (JBS Swift and Company, Worthington, MN)

[5] Creech, B.L., J.W. Spears, W.L. Flowers, G.M. Hill, K.E. Lloyd, T.A. Armstrong, and T.E. Engle. Effect of dietary trace mineral concentration and source (inorganic vs. chelated) on performance, mineral status, and fecal mineral excretion in pigs from weaning through finishing. J. Anim. Sci. 82:2140–2147.

for processing and carcass data collection. Hot carcass weight was collected immediately following evisceration, and carcass measurements including backfat depth and loin depth were collected using a Fat-O-Meter probe (SFK, Herlev, Denmark). Using the data collected at the farm and commercial abattoir, carcass yield, percentage lean, and carcass IOFC were calculated. Percentage carcass yield was calculated by dividing HCW at the packing plant by the live weight obtained at the farm. Percentage lean was calculated by dividing the standardized fat-free lean (SFFL) by HCW. The following equation was used for calculation of SFFL (NPPC, 2001[6]):

SFFL, lb = 15.31 – (31.277 × backfat depth, in.) + (3.813 × loin muscle depth, in.) + (0.51 × HCW, lb)

Income over feed cost, a method to measure economic value, was also calculated assuming that other costs, such as utility and labor, are equal across treatments, and the only variables are carcass ADG and feed usage for the experimental period. Corn was valued at $152/ton, soybean meal at $420/ton, dried distillers grains with solubles at $164/ton, L-lysine sulfate at $0.61/lb, phytase at $1.65/lb, RAC at $35.26/lb, ZnO at $0.86/lb, and live and carcass weight were priced at $84.24/cwt and $115.40/cwt, respectively.

For plasma Zn analysis, whole blood was centrifuged (2000 × *g*, 15 min, 4°C), plasma was removed, and blood was frozen at -20°C. Plasma was deproteinized by diluting 1:4 in 12.5% trichloroacetic acid followed by centrifugation at 2,000 × *g* for 15 min (GS-6KR, Beckman-Coulter, Brea, CA) and collection of the supernatant for analysis. The ashed fecal samples were placed in 10 mL of 6N HCl and boiled for 10 min (AOAC, 1995[7]). Zinc concentrations were determined by flame atomic absorption spectrophotometry (Perkin Elmer 3110 AA Spectrometer, PerkinElmer, Waltham, MA).

Data were analyzed as a split-plot design using the MIXED procedure of SAS (SAS Institute Inc., Cary, NC), with dietary grower treatment (0 or 75 ppm added Zn from d 0 to 45) as the whole plot and dietary finisher treatment (diets with or without RAC × 0 or 75 ppm added Zn from d 45 to 72) as the subplot. Pen served as the experimental unit. For plasma Zn concentration analysis, the statistical structure was the same except day of bleeding, and treatment × day of bleeding served as a fixed effects in addition to dietary treatment. Day of bleeding also served as the repeated measure, with animal as the subject. The covariance structure compound symmetry was used. Hot carcass weight was used as a covariate for analyses of backfat thickness, loin depth, and percentage lean. Statistical significance was determined at $P < 0.05$ and trends at $P < 0.10$.

Results and Discussion

From d 0 to 45, there were no differences in ADG or ADFI but a tendency for increased ($P < 0.10$) F/G and caloric efficiency on both an ME and NE basis in pigs fed diets containing added Zn compared with pigs fed the control diet (Table 2). For the finisher phase (d 45 to 72), there were no interactive effects of Zn grower × Zn finisher × RAC or Zn grower × Zn finisher for growth performance and carcass characteristics. There

[6] NPPC. 2001. Procedures for Estimating Pork Carcass Composition. Natl. Pork Prod. Counc., Des Moines, IA.

[7] AOAC. 1995. Official methods of analysis. 16th ed. Assoc. Off. Anal. Chem., Gaithersburg, MD.

was an added Zn during the grower phase × RAC interaction ($P = 0.034$) for ADG of finishing pigs. This resulted from pigs fed RAC and diets with added Zn during the grower phase having increased ADG compared with pigs fed RAC diets without added Zn during the grower phase. Added Zn during the grower phase did not influence ADG of pigs fed the control diet without RAC during the finisher phase. There was a tendency for an added Zn during the finisher phase × RAC interaction ($P = 0.066$) for ADG of finishing pigs. This resulted from pigs fed control diets with added Zn during the finisher phase having decreased ADG compared with pigs fed control diets without added Zn. Pigs fed RAC diets with or without added Zn had similar ADG. There was an added Zn during the finisher phase × RAC interaction ($P = 0.025$) for ADFI. Pigs fed RAC diets with added Zn during the finisher phase had increased ADFI compared with those fed added Zn diets without RAC; however, pigs fed RAC diets without added Zn during the finishing phase had ADFI similar to pigs fed control diets without added Zn. Pigs fed RAC diets had improved ($P < 0.05$) ADG, F/G, IOFC, and caloric efficiency on both an ME and NE basis compared with those fed diets without RAC for the 27-d finishing period. Pigs fed diets with added Zn during the finisher phase had poorer ($P < 0.05$) ADG, F/G, IOFC, and caloric efficiency on both an ME and NE basis compared with those fed diets without. Overall (d 0 to 72), there were no dietary treatment interactions for growth performance and carcass characteristics. Pigs fed RAC for the last 27 d of the experiment had improved ($P < 0.05$) ADG, F/G, IOFC, caloric efficiency on an ME and NE basis, final BW, HCW, loin depth, and percentage lean; a tendency for improved ($P = 0.064$) IOFC on a carcass basis; and reduced ($P = 0.001$) backfat thickness compared with pigs fed diets without RAC. Added Zn did not influence overall growth performance or carcass characteristics of pigs.

From d 0 to 45, pigs fed diets with added Zn had increased ($P = 0.001$) average daily Zn intake (Table 3). From d 45 to 72, there was an added Zn during the finisher phase × RAC interaction ($P = 0.004$). Either added Zn during the finishing period or RAC caused an increase in average daily Zn intake; however, average daily Zn intakes were further increased when both added Zn during the finisher period and RAC were fed to pigs.

For plasma Zn concentrations, there were no 4, 3, or 2-way interactions among dietary treatment and day. Added Zn during the grower phase did not influence plasma Zn concentrations on d 45, but pigs fed diets with 75 ppm added Zn during the finisher phase had increased ($P < 0.05$) plasma Zn levels on d 52 and 63 compared with those fed diets without added Zn during the finisher phase. There was no effect of the RAC diet on plasma Zn concentration. For fecal analysis, pigs fed added Zn during the grower period had increased ($P < 0.05$) fecal Zn concentrations on d 45 compared with those fed diets without added Zn. For d-63 fecal Zn concentrations, there was an added Zn during the finishing period × RAC interaction ($P = 0.032$). Either added Zn during the finishing period or RAC caused an increase in d-63 fecal Zn concentration; however, concentrations were further increased when both added Zn during the finisher period and RAC were fed to pigs.

As expected, pigs fed RAC diets had improved growth performance and carcass characteristics, but added Zn with RAC did not. However, additional Zn in diets of growing pigs may increase the ADG response to RAC fed during the finishing phase. In addition, pigs fed diets with 75 ppm added Zn during the finisher phase had increased

plasma Zn levels. Pigs fed added Zn during the grower and finisher period and pigs fed RAC diets during the finisher phase had increased fecal Zn concentrations, but concentrations were further increased when both added Zn during the finisher period and RAC were fed to pigs.

Table 1. Diet composition (as-fed basis)[1,2]

	Phase 1	Phase 2	Phase 3	
Item	Control	Control	Control	RAC[3]
Ingredient, %				
Corn	54.60	58.10	72.50	62.76
Soybean meal, 46.5% CP	12.95	9.78	10.58	20.26
DDGS[4]	30.00	30.00	15.00	15.00
Monocalcium phosphate, 21 % P	0.20	---	0.05	---
Limestone	1.33	1.25	1.08	1.03
Salt	0.35	0.35	0.35	0.35
Vitamin premix	0.08	0.08	0.05	0.05
Trace mineral premix[5]	0.05	0.05	0.05	0.05
L-lysine sulfate	0.44	0.40	0.33	0.33
Methionine hydroxy	---	---	---	0.09
L-threonine	---	---	---	0.03
Phytase[6]	0.005	0.004	0.010	0.010
Ractopamine HCl[7]	---	---	---	0.05
Total	100	100	100	100
Calculated analysis, %				
ME, kcal/lb	1,505	1,510	1,512	1,509
NE, kcal/lb	1,087	1,096	1,110	1,119
Standardized ileal digestible (SID) lysine, %	0.83	0.73	0.66	0.90
Total lysine, %	1.01	0.90	0.79	1.06
SID lysine:ME, g/Mcal	2.50	2.19	1.98	2.70
Ca, %	0.59	0.52	0.46	0.46
Total P, %	0.46	0.40	0.37	0.40
Available P, %	0.28	0.22	0.21	0.21

[1] Diets were fed in meal form from d 0 to 72. Basal diets for all 3 phases contained 55 ppm zinc from zinc oxide provided by the trace mineral premix.
[2] Dietary treatments were obtained by replacing corn to achieve 75 ppm of added Zn from ZnO. Analyzed total Zn concentrations were 88 and 131 ppm in the phase 2 control and added Zn diet diets, respectively, and 96, 155, 117, and 180 for the control, control + added Zn, RAC, and RAC + added Zn diets, respectively.
[3] Ractopamine HCl (RAC; Paylean; Elanco Animal Health, Greenfield, IN).
[4] Dried distillers grains with solubles.
[5] Trace mineral premix provided 50 ppm Zn from ZnO.
[6] OptiPhos 2000 (Enzyvla LLC, Sheridan, NJ) provided 250, 200, and 500 phytase units (FTU) per kilogram of diet for phases 1, 2, and 3, respectively.
[7] Provided 10 ppm of ractopamine HCl (Paylean; Elanco Animal Health, Greenfield, IN).

Table 2. Effects of added zinc during the grower and/or finisher phase on growth performance and carcass characteristics of finishing pigs fed diets with or without ractopamine HCl (RAC)[1]

Added Zn, d 0 to 45:	-	-	-	-	+	+	+	+		Probability[2], *P* <				
Added Zn, d 45 to 72:	-	+	-	+	-	+	-	+						
Added RAC, d 45 to 72:	-	-	+	+	-	-	+	+	SEM	Zn grower × RAC	Zn finisher × RAC	Zn grower	Zn finisher	RAC
d 0 to 45														
ADG, lb	1.96	---	---	---	1.96	---	---	---	0.029	---	---	0.900	---	---
ADFI, lb	5.50	---	---	---	5.70	---	---	---	0.12	---	---	0.206	---	---
F/G	2.81	---	---	---	2.91	---	---	---	0.050	---	---	0.086	---	---
IOFC,[3] $/pig	48.95	---	---	---	48.16	---	---	---	0.91	---	---	0.2450	---	---
Caloric efficiency[4]														
ME	4,243	---	---	---	4,385	---	---	---	76	---	---	0.086	---	---
NE	3,140	---	---	---	3,245	---	---	---	56	---	---	0.086	---	---
d 45 to 72														
ADG, lb	1.98	1.89	2.35	2.36	1.98	1.88	2.46	2.43	0.03	0.034	0.066	0.134	0.015	0.001
ADFI, lb	6.39	6.27	6.22	6.36	6.41	6.30	6.42	6.60	0.11	0.103	0.025	0.299	0.647	0.305
F/G	3.23	3.31	2.65	2.70	3.23	3.36	2.61	2.72	0.05	0.595	0.737	0.927	0.003	0.001
IOFC, $/pig	27.90	26.27	31.38	31.01	27.97	25.84	33.18	31.72	0.61	0.102	0.267	0.242	0.003	0.001
Caloric efficiency														
ME	4,880	5,007	3,999	4,077	4,885	5,078	3,943	4,109	68	0.586	0.681	0.825	0.004	0.001
NE	3,689	3,785	2,965	3,024	3,693	3,839	2,924	3,047	51	0.586	0.661	0.822	0.004	0.001

continued

Table 2. Effects of added zinc during the grower and/or finisher phase on growth performance and carcass characteristics of finishing pigs fed diets with or without ractopamine HCl (RAC)[1]

Added Zn, d 0 to 45:	-	-	-	-	+	+	+	+		Probability[2], *P* <				
Added Zn, d 45 to 72:	-	+	-	+	-	+	-	+						
Added RAC, d 45 to 72:	-	-	+	+	-	-	+	+	SEM	Zn grower × RAC	Zn finisher × RAC	Zn grower	Zn finisher	RAC
d 0 to 72														
ADG, lb	1.96	1.94	2.09	2.09	1.97	1.94	2.13	2.11	0.03	0.450	0.698	0.549	0.293	0.001
ADFI, lb	5.84	5.74	5.73	5.80	5.93	5.90	5.96	5.99	0.10	0.301	0.164	0.225	0.879	0.565
F/G	2.98	2.96	2.74	2.77	3.02	3.05	2.80	2.84	0.04	0.793	0.439	0.174	0.338	0.001
IOFC, $/pig	76.29	76.00	80.39	79.79	76.19	74.61	80.94	79.22	1.22	0.669	0.895	0.682	0.229	0.001
Caloric efficiency														
ME	4,502	4,464	4,132	4,184	4,551	4,596	4,225	4,285	61	0.928	0.440	0.167	0.388	0.001
NE	3,358	3,329	3,060	3,098	3,394	3,428	3,128	3,173	45	0.934	0.443	0.168	0.390	0.001
BW, lb														
d 0	58.7	---	---	---	58.7	---	---	---	---	---	---	0.996	---	---
d 45	218.2	218.0	218.0	218.2	218.4	218.4	218.5	218.4	5.5	0.985	0.946	0.966	0.989	0.972
d 72	243.1	240.9	249.0	248.8	242.4	240.6	250.7	249.9	5.7	0.754	0.400	0.865	0.700	0.001
Carcass characteristics														
HCW, lb	189.7	189.6	194.4	198.3	188.2	192.0	195.6	197.3	4.9	0.950	0.873	0.960	0.404	0.026
Yield,[5] %	74.09	74.64	74.12	75.35	73.09	73.98	75.52	74.08	1.35	0.534	0.657	0.719	0.383	0.740
Backfat thickness,[6] in.	0.66	0.62	0.54	0.59	0.64	0.64	0.56	0.54	0.025	0.565	0.345	0.720	0.785	0.001
Loin depth,[6] in.	2.47	2.43	2.54	2.49	2.44	2.43	2.58	2.60	0.044	0.158	0.898	0.386	0.485	0.002
Lean,[6,7] %	53.13	55.13	53.69	55.13	53.52	55.01	53.33	55.94	0.57	0.644	0.697	0.737	0.375	0.001
IOFC, $/pig	75.53	75.93	78.25	79.46	73.72	75.88	78.34	77.71	2.33	0.977	0.766	0.604	0.638	0.064

[1]A total of 1,197 pigs (Line 337 × 1050: PIC Hendersonville, TN) were used in a 72-d study with 25 pigs per pen and 6 pens per treatment.
[2]No interactive effects ($P > 0.154$) of Zn grower × Zn finisher × RAC or Zn grower × Zn finisher.
[3]Income over feed cost. Corn was valued at $152/ton, soybean meal at $420/ton, dried distillers grains with solubles at $164/ton, L-lysine sulfate at $0.61/lb, phytase at $1.65/lb, RAC at $35.26/lb, zinc oxide at $0.86/lb, and live and carcass weights were priced at $84.24/cwt and $115.40/cwt, respectively.
[4]Caloric efficiency is expressed as kcal/lb gain.
[5]Calculated by dividing HCW by live weight obtained at the farm.
[6]Adjusted using HCW as a covariate.
[7]Calculated using NPPC (2001) equation.

Table 3. Effects of added zinc during the grower and/or finisher phase on plasma and fecal Zn concentrations of finishing pigs fed diets with or without ractopamine HCl (RAC)[1]

Added Zn, d 0 to 45:	-	-	-	-	+	+	+	+		Probability[2,3,4], *P* <			
Added Zn, d 45 to 72:	-	-	+	+	-	-	+	+					
Added RAC, d 45 to 72:	-	+	-	+	-	+	-	+	SEM	Zn finisher × RAC	Zn grower	Zn finisher	RAC
Zn intake, mg/d													
d 0 to 45	252	---	---	---	382	---	---	---	4.0	---	0.001	---	---
d 45 to 72	278	330	441	520	279	341	443	539	6.8	0.002	0.281	0.001	0.001
d 0 to 72	263	279	321	354	343	366	400	447	5.9	0.004	0.001	0.001	0.001
Plasma Zn, µg/mL													
d 0	1.33	---	---	---	1.38	---	---	---	0.043	---	0.422	---	---
d 45	1.34	---	---	---	1.34	---	---	---	0.029	---	0.980	---	---
d 52	1.23	1.29	1.36	1.31	1.22	1.25	1.25	1.33	0.038	0.571	0.254	0.013	0.204
d 63	1.25	1.34	1.37	1.34	1.34	1.32	1.39	1.41	0.037	0.428	0.269	0.011	0.560
Fecal Zn, ppm													
d 45	591	---	---	---	1,038	---	---	---	17.7	---	0.001	---	---
d 63	854	988	1,197	1,460	922	941	1,262	1,533	59.1	0.032	0.371	0.001	0.001

[1] A total of 1,197 pigs (PIC 337 × 1050) were used in a 72-d study with 25 pigs per pen and 6 pens per treatment. On d 0 and 45 the median weight barrow from each pen was ear tagged to allow for bleeding on subsequent collection dates. On day 52 and 63, four median weight barrows, including the previously selected pig were selected from each pen for blood collection. On d 45 and 63, fecal grab samples were collected on 3 random pigs per pen.

[2] For Zn intake, no interactive effects ($P > 0.073$) of Zn grower × Zn finisher × RAC, Zn grower × Zn finisher, or Zn grower × RAC.

[3] For plasma Zn, no interactive effects ($P > 0.083$) of Zn grower × Zn finisher × RAC, Zn grower × Zn finisher, or Zn grower × RAC.

[4] For fecal Zn, no interactive effects ($P > 0.477$) of Zn grower × Zn finisher × RAC, Zn grower × Zn finisher, or Zn grower × RAC.

Effects of High Levels of Dietary Niacin from Nicotinic Acid on Growth and Meat Quality of Finishing Pigs Raised During Summer[1]

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Summary

A total of 1,232 pigs (PIC 337 × 1050; initially 59.4 lb) were used in a 98-d study to evaluate the influence of increasing dietary niacin supplementation on growth, body temperatures, and meat quality of pigs raised in a commercial facility during the summer. There were 28 pigs per pen and 11 pens per treatment. Basal diets contained corn, soybean meal, and dried distillers grains with solubles (DDGS). The four dietary treatments were formed by adding increasing levels of nicotinic acid as the source of niacin (Lonza, Allendale, NJ) at 14, 172, 331, and 490 mg/lb of complete feed. On d 57, 58, and 59, rectal temperatures and skin temperatures on the top of the shoulder and rump were collected from 2 pigs per pen (1 barrow and 1 gilt). On d 98, 2 pigs per pen (1 barrow and 1 gilt) were visually selected as the heaviest pigs in the pen and were harvested for carcass and meat quality data. Carcass traits, pH decline, and subjective loin color and marbling scores were measured at a commercial abattoir. Afterward, a 15.7-in. segment of the loin was used for meat quality analysis, including measurements of ultimate pH and purge loss. Boneless chops (1 in. thick) were cut from the loin segment and were used to determine 24-h drip loss, subjective color and marbling, objective lean color values (L*, lightness; a*, redness; and b*, yellowness), and muscle niacin concentrations.

Average daily temperatures within the barn ranged from 63.8 to 85.5°F throughout the length of the study, with daily low temperatures from 59.9 to 81.0°F and daily high temperatures from 66.1 to 93.3°F. Overall, temperature was cooler than expected for the facility compared with normal seasonal increases associated with the summer months.

Time × day interactions ($P < 0.01$) were observed for rectal, shoulder, and rump temperatures; however, body temperature was not consistently influenced by dietary niacin concentrations during the collection period.

Overall (d 0 to 98), increasing dietary niacin did not influence ADG or F/G, but it tended (linear; $P = 0.07$) to increase ADFI. Increasing niacin supplementation did not influence carcass traits; however, for meat quality, it did increase (linear; $P < 0.01$) pH decline at 45 min and 21 h postmortem. Increases (linear; $P < 0.05$) in a* and b* were observed for chops from pigs fed increasing niacin, but subjective chop color scores were not affected by increasing niacin supplementation. In summary, dietary niacin above the animal's requirement estimate did not consistently influence rectal or skin tempera-

[1] Appreciation is expressed to the National Pork Board for funding this trial as project number 13-093.
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tures and had negligible influences on growth performance, carcass traits, and meat quality parameters.

Key words: heat stress, niacin, nicotinic acid, finishing pig

Introduction

Niacin is a component of the coenzymes nicotinamide-adenine dinucleotide (NAD) and nicotinamide-adenine dinucleotide phosphate (NADP). These coenzymes are required for the normal metabolism of carbohydrates, proteins, and fats due to their redoxing and oxidizing abilities. Two main forms of niacin are available for use as supplements in swine diets; these are nicotinamide and nicotinic acid. Both forms act as exogenous precursors for the metabolically active forms of the vitamin (NAD and NADP); however, nicotinic acid is also known for other functions in the body. In human medicine, pharmacological doses of nicotinic acid are commonly used to help reduce circulating lipid concentrations by reducing LDL and vLDL cholesterol and increasing HDL cholesterol. One of the largest side effects associated with pharmacological dosing of nicotinic acid is an increase in skin vasodilation known as flushing. Although it is seen as a negative side effect in humans, this increase in vasodilation could act as a mediator of seasonal heat stress in swine by increasing blood circulation to the periphery of the body, thus allowing for increased heat abatement by the animal.

Heat stress is a major contributor to seasonal losses experienced in pig production. Economic losses were estimated to total approximately $200 million dollars (St. Pierre et al., 2003[3]) in the grower and finishing pig sector in the form of decreased performance, lowered market weights, increased days on feed, and mortality of finishing pigs. Previous research by Zimbelman et al. (2010[4]) in dairy cows concluded that niacin was successful at reducing heat stress in milking cows during periods of high temperatures in the form of reduced rectal and vaginal temperatures and increased evaporative heat loss. No research has examined the influence of pharmacological doses of nicotinic acid on growing and finishing pig performance during seasonal heat stress.

Other interests associated with niacin supplementation in finishing pigs are potential influences on carcass meat quality. Real et al. (2002[5]) examined the influence of nicotinic acid supplementation on meat quality of commercially reared pigs and concluded that increasing nicotinic acid supplementation from 0 to 249 mg/lb of complete feed increased 24-h pH and improved meat color. The objectives of this study were to examine the influence of pharmacological doses of nicotinic acid on growth performance, body temperature, and meat quality of pigs raised in a commercial setting during summer months.

[3] St. Pierre, N.R., B. Cobanov, and G. Schnitkey. 2003. Economic losses from heat stress by US livestock industries. J. Dairy Sci. 86(E-suppl.):E52–E77.
[4] Zimbelman, R.B., L.H. Baumgard, and R.J. Collier. 2010. Effects of encapsulated niacin on evaporative heat loss and body temperature in moderately heat-stressed lactating Holstein cows. J. Dairy Sci. 93:2387–2394.
[5] Real, D.E., J.L. Nelssen, J.A. Unruh, M.D. Tokach, R.D. Goodband, S.S. Dritz, J.M. DeRouchey, and E. Alonso. 2002. Effects of increasing dietary niacin on growth performance and meat quality in finishing pigs reared in two different environments. J. Anim. Sci. 80:3203–3210.

Procedures

Experimental procedures and animal care were approved by the Kansas State University Institutional Animal Care and Use Committee. This experiment was conducted in a commercial research-finishing barn in southwestern Minnesota. The barn was naturally ventilated and double-curtain-sided with completely slatted flooring and a deep pit for manure storage. Pens were equipped with a cup waterer and 4-hole stainless steel dry feeder (56 in. wide) manufactured by Thorp Equipment, Inc. (Thorp, WI) to provide ad libitum access to feed and water. Daily feed additions to each pen were accomplished through a robotic feeding system (FeedPro; Feedlogic Corp., Willmar, MN) capable of providing and measuring feed deliveries on an individual pen basis.

Three temperature loggers (LogTag Recorders, New Zealand) were placed in the barn to collect daily ambient temperature and relative humidity. Readings were recorded hourly throughout the day on each logger, and average hourly temperature and humidity were determined. Hourly data were used to calculate daily high, low, and average values (Figure 1).

A total of 1,232 pigs (PIC 337 × 1050; initially 59.4 lb) were used in a 98-d study to evaluate the influence of pharmacological doses of nicotinic acid on growth, body temperatures, and meat quality. At initiation of the study, pens were allotted to treatments in a randomized complete block design with location within barn as the blocking factor. There were 4 dietary treatments with 11 pens per treatment.

The 4 dietary treatments were increasing levels of nicotinic acid (Lonza, Allendale, NJ) at 14, 172, 331 and 490 mg/lb (Table 1). Diets were formulated such that the first diet met the pig's estimated requirement (14 mg/lb) for niacin, with further additions exceeding the niacin requirement. The basal diet was corn-soybean meal–based and contained 10% dried distillers grains with solubles (DDGS). Diets were formulated to meet or exceed the nutrient requirements of the pigs as defined by NRC (2012[6]). These diets were fed in 4 phases from approximately 60 to 90, 90 to 150, 150 to 215, and 215 to 245 lb BW. Experimental diets were subsampled and samples were sent to a commercial laboratory (Ward Laboratories Inc., Kearney, NE) for analysis (DM, CP, fat, ash, Ca, and P), and subsamples were also shipped to another commercial laboratory (AIB International, Manhattan, KS) for dietary niacin concentrations.

Pigs and feeders were weighed approximately every 14 d to determine ADG, ADFI, and F/G. On d 57, 58, and 59 (August 8, 9, and 10, respectively), a randomly selected barrow and gilt within each pen were used to determine pig rectal and body temperatures throughout the day. On each collection day, rectal temperatures were collected using electronic thermometers (SureTemp Plus 692; Welch Allyn, San Diego, CA), and skin temperatures were taken on the top of the shoulder and rump using an infrared dual laser thermometer (Model 42512; Extech Instruments Corporation, Waltham, MA). Temperatures were collected from the same pigs within each pen at 6:00 and 9:00 a.m. and 12:00, 3:00, and 6:00 p.m. during the three consecutive collection days.

On d 98, the heaviest barrow and gilt (determined visually) from each pen were marketed following normal farm procedures. Pigs were tattooed by gender and pen and

[6] NRC. 2012. Nutrient Requirements of Swine. 11th ed. Natl. Acad. Press, Washington, DC.

transported to JBS Swift and Company (Worthington, MN) for processing and carcass data collection. Hot carcass weights were measured immediately after evisceration, and each carcass was evaluated for percentage yield, backfat, and loin depth. Percentage yield was calculated by dividing HCW by live weight obtained at the farm before transport to the abattoir. Fat depth and loin depth were measured with an optical probe (SFK; Herlev, Denmark) inserted between the 3rd and 4th ribs located anterior to the last rib at a distance approximately 2.8 in. from the dorsal midline. Fat-free lean index (FFLI) was calculated using NPPC (20007) guidelines for carcasses measured with the optical probe such that FFLI = ((15.31 + (0.51 × HCW, lb) – (31.277 × last-rib fat thickness, in.) + (3.813 × loin muscle depth, in.))/HCW, lb.

All meat quality was performed using the left side of the carcass. All pH measurements were collected using a pH meter (Model 9025, Hanna Instruments, Smithfield, RI) with a glass-tip probe. The pH measurements were taken at three time points to evaluate the pH decline post-slaughter at 45 min, 3 h, and 21 h. At the 45-min and 3-h time points, the probe was inserted into the longissimus dorsi (LD) between the 10th and 11th rib. Approximately 20.5 h postmortem, carcasses were fabricated for sample collection and additional analysis. A 15.7-in. section of the LD was removed from the posterior end of the loin, individually labeled, and allowed to bloom for 30 min. After blooming, subjective color and marbling scores were determined by a trained evaluator using the 1 to 6 scoring system for color and the 1 to 5 scoring system for marbling (NPPC, 2001). In addition, the 21-h pH was recorded by again placing the probe into the LD at a central position across the sirloin face. The LD was subsequently vacuum-packaged and transported on ice to the Kansas State University Meats Laboratory for subsequent analysis. Samples were stored at 39.2°F and aged for 10 d post-slaughter.

After aging, purge loss was measured by initially weighing the packaged LD, then removing the packaging and pat-drying both the package and the LD sample. After weighing the dried package and LD sample, purge loss was calculated as a percentage of the original LD weight. Ultimate pH was then recorded by placing the probe into the LD at a central position across the sirloin face. Afterward, 3 1-in.-thick boneless chops were fabricated from the anterior end of the loin. The first chop was trimmed to approximately 100 g of lean to estimate 24-h drip loss; these samples were bagged individually and stored at 39.2°F for 24 h, after which samples were pat-dried and reweighed to calculate 24-h drip loss as a percentage of original sample weight. The second LD chop was placed on a 1 S polystyrene tray (Dyne-A-Pak Inc., LAVAL, QC, Canada) and was overwrapped with a polyvinylchloride film (23,250 mL of O_2/m^2/24 h oxygen permeability/flow rate). The packages were placed in an open-top retail display case (unit model DMF8, Tyler Refrigeration Corp., Niles, MI) at 35.6°F ± 3.6°F and were allowed to bloom for 45 min. After blooming, subjective color and marbling score were determined by 3 trained evaluators using the previously discussed scoring systems (NPPC, 2000[7]). Objective color measurements of lean color were then determined using a HunterLab Miniscan XE Plus spectrophotometer (Model 45/0 LAV, 2.54-cm-diameter aperture, 10° standard observer, Illuminant D65, Hunter Associates Laboratory, Inc., Reston, VA) to measure CIE L* (lightness), a* (redness), and b* (yellowness). The spectrophotometer was calibrated against a standard white tile

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

(Hunter Associates Laboratory), and 2 locations of the lean surface of each sample were measured and averaged to determine the CIE L*, a*, and b* values. The third chop was frozen at -4°F until subsampling; these subsamples were individually flash-frozen using liquid nitrogen and then pulverized. Afterward, 0.5 g of pulverized sample was weighed and niacin was extracted in solution using an acid hydrolysis technique discussed by the European Committee for Standardization (2009[8]). These extracted samples were analyzed in duplicate using high-performance liquid chromatography (HPLC) analysis. Final loin niacin concentrations are expressed as mg/lb of tissue.

Data were analyzed as a randomized complete block design using PROC MIXED in SAS (SAS Institute, Inc., Cary, NC). Linear and quadratic polynomial contrasts were used to determine the effects of increasing nicotinic acid. Pen served as the experimental unit for growth performance. Carcass data were analyzed as a split plot design with pig as the experimental unit to evaluate the effects of gender. Temperature data were also analyzed as a split plot design to evaluate the effects of gender using repeated measures, with time × day interactions as the repeated variable and pig as the subject. In addition, a Toeplitz covariance model was used for the temperature analysis. This covariance structure assumes that pairs of within-subject errors separated by a common lag share the same correlation, and it provided the best fit of the temperature data (as measured by smaller AIC, AICC, and BIC values).

Results

Daily average temperatures within the barn ranged from 63.8 to 85.5°F (Figure 1) throughout the length of the study; meanwhile, daily low temperatures were 59.9 to 81.0°F, and daily high temperatures were 66.1 to 93.3°F. Daily average humidity ranged from 44.9 to 85.5% relative humidity, with low daily humidity measurements from 26.3 to 76.0% and daily high humidity from 58.2 to 91.4%. In general, temperature was cooler than expected for the facility compared with previous seasonal increases associated with summer months, and humidity was variable throughout the length of the study. As a result, the degree of seasonal heat stress observed during this study was less than anticipated.

Experiment diets were analyzed for niacin content at a commercial laboratory (AIB International, Manhattan, KS). Diets formulated to contain 14, 172, 331, and 490 mg/lb were determined to contain niacin concentrations of 18, 117, 256, and 564 mg/lb (Table 2), respectively.

Average daily gain and F/G from d 0 to 98 were not influenced by increasing dietary niacin ($P > 0.17$; Table 3), but ADFI tended to increase with increasing dietary niacin (linear; $P = 0.07$). The current study suggests that additional supplementation of niacin above the animal's requirement does not influence ADG or F/G. However, the study was designed to test the influence of increasing niacin during heat stress, and unfortunately heat stress was minimal during the study. Nevertheless, our data are in agreement with that of Real et al. (2001), who concluded that 6 to 24 mg/lb of added niacin are needed to maximize gain and feed efficiency.

[8] European Committee for Standardization. 2009. Foodstuffs – Determination of niacin by HPLC. Tech. Bull. No. 15652. British Standards Institution, United Kingdom.

No dietary niacin × gender interactions were observed for carcass trait data. Carcass traits were not influenced ($P > 0.05$; Table 4) by dietary niacin; however, barrows had heavier final live weights, HCW, and increased yield percentages ($P < 0.03$) than gilts. Gilts had lower body fat, increased loin depth, and higher FFLI ($P = 0.01$) than barrows.

Increased dietary niacin reduced 45-min pH (linear; $P = 0.01$). A dietary niacin × gender interaction ($P = 0.01$; Table 5) was observed for the 3-h pH measurement because barrows fed 14 and 331 mg/lb niacin had lower pH values than gilts fed the same diets, whereas barrows fed 172 and 490 mg/lb had higher pH values than gilts fed the same diets. This was the only interaction observed for meat quality data. Increasing dietary niacin reduced 21-h pH (linear; $P = 0.01$). Ultimate pH was not altered ($P > 0.11$) by dietary niacin, but barrows ($P = 0.02$) had higher ultimate pH than gilts. Subjective color and marbling scores of loins and boneless chops were not influenced ($P > 0.22$) by dietary niacin. Barrows had higher ($P = 0.04$) boneless chop color and marbling scores and tended ($P = 0.08$) to have higher loin marbling scores than gilts. Purge loss and 24-h drip loss did not differ ($P > 0.18$) among dietary niacin treatments or genders. In terms of objective lean color scores, increasing dietary niacin increased (linear; $P < 0.05$) a* and b* values. Boneless chop niacin concentrations were not influenced ($P > 0.56$) by dietary niacin treatments or gender.

Overall, the current study suggests that supplementation of niacin from 14 to 490 mg/lb does not drastically affect pork quality. This contrasts with previous meat quality research by Real et al. (2001), who observed improved color and pH with increasing niacin supplementation up to 227 mg/lb. One reason for the difference in results may be that carcasses in the current study underwent chilling in a blast chiller, which may have mitigated some effects on meat quality that were previously observed during a longer chilling period. In a recent study, Khan et al. (2013[9]) concluded that feeding 340 mg/lb nicotinic acid to intact boars resulted in an increase in muscle fiber switching from glycolytic type II fibers to oxidative type I fibers. The authors hypothesized that this may lead to an increase in dark, firm, and dry pork. The current study would be in difference with that conclusion given that subjective color was not different among niacin treatments and that pH decline was actually increased by niacin supplementation.

A time × day interaction ($P < 0.01$; Figure 2) was observed for rectal temperatures, but no dietary niacin × gender interactions were found within specific time × day collection points. At 6:00 a.m. on d 1, increasing dietary niacin increased (linear; $P = 0.02$) rectal temperature; however, at 12:00 on d 1, increasing niacin decreased (quadratic; $P = 0.03$) rectal temperatures, with pigs fed 172 mg/lb having the lowest temperatures. In addition, barrows had higher rectal temperatures at 3:00 and 6:00 p.m. on d 1 and at 3:00 p.m. on d 3. Overall, the inconsistent differences in rectal temperatures across dietary treatments suggest that dietary niacin supplementation did not biologically affect core body temperatures during the collection period. This conclusion disagrees with previous research conducted in dairy cows that concluded supplementing high doses of niacin reduced rectal and vaginal temperatures and increased evaporative heat loss.

[9] Khan, M., R. Ringseis, F. Mooren, K. Kruger, E. Most, and K. Eder. 2013. Niacin supplementation increases the number of oxidative type I fibers in skeletal muscle of growing pigs. BMC Veterinary Research 9:177.

For shoulder and rump skin temperatures, time × day interactions (Figures 3 and 4; $P < 0.01$) were also observed. Shoulder skin temperatures were increased (linear, $P = 0.05$) at 6:00 a.m. on d 1 with increased dietary niacin, and gilts had higher ($P = 0.04$) shoulder skin temperatures than barrows. Shoulder and rump temperatures decreased (quadratic; $P < 0.04$) with increased dietary niacin at 9:00 a.m. on d 1, with pigs fed 172 mg/lb having the lowest skin temperatures. On d 2 at 6:00 a.m., a gender × dietary niacin interaction ($P = 0.03$) was observed for shoulder skin temperature because barrows fed 331 mg/lb niacin had higher temperatures than gilts fed the same diet, but barrows fed 14, 172, or 490 mg/lb niacin had lower temperatures than gilts fed the same diets. Also on d 2 at 9:00 a.m., decreased (linear; $P = 0.05$) shoulder skin and rump temperatures were observed for pigs fed increasing dietary niacin. On d 3 at 3:00 p.m., increasing ($P = 0.05$) skin temperatures were observed for pigs fed increasing dietary niacin, with pigs fed 331 mg/lb having the highest temperatures. Similar to rectal temperature data, dietary niacin supplementation appears not to have altered skin temperatures consistently over the collection period.

In the current study, seasonal heat stress within a commercial operation unfortunately was not as great as desired. Regardless, this study suggests that increasing dietary niacin to finishing pigs above their requirement does not consistently influence growth performance, carcass traits, meat quality, or pig body temperatures.

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

Item	Phase 1	Phase 2	Phase 3	Phase 4
Corn[2]	55.19	60.14	64.56	66.76
Soybean meal (46.5% CP)	22.47	17.68	13.40	11.36
Corn DDGS[3]	20.00	20.00	20.00	20.00
Limestone	1.10	1.20	1.15	1.05
Salt	0.35	0.35	0.35	0.35
Dicalcium phosphate	0.15	---	---	---
DL-methionine	0.01	---	---	---
L-threonine	0.05	0.02	---	---
Lysine sulfate	0.51	0.44	0.39	0.33
Phytase[4]	0.02	0.02	0.02	0.02
Vitamin premix[5]	0.08	0.08	0.08	0.08
Trace mineral premix[6]	0.07	0.07	0.05	0.05
Total	100.0	100.0	100.0	100.0

continued

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

Item	Phase 1	Phase 2	Phase 3	Phase 4
Calculated analysis				
Standardized ileal digestible (SID) amino acids, %				
Lysine	1.06	0.91	0.78	0.70
Isoleucine:lysine	68	70	73	76
Methionine:lysine	30	32	35	37
Met & cys:lysine	56	60	65	70
Threonine:lysine	62	62	63	66
Tryptophan:lysine	18.0	18.0	18.0	18.5
Valine:lysine	77	82	86	91
Total lysine, %	1.24	1.08	0.94	0.85
CP, %	21.2	19.2	17.5	16.6
ME, kcal/lb	1,505	1,507	1,510	1,512
SID lysine:ME, g/Mcal	3.20	2.74	2.34	2.10
Ca, %	0.53	0.52	0.49	0.44
P, %	0.45	0.40	0.38	0.37
Available P, %	0.30	0.27	0.26	0.26
Analyzed dietary concentrations[7]				
DM, %	90.80	90.14	90.30	89.75
CP, %	21.9	19.7	17.6	18.3
Fat, %	4.18	4.03	4.10	4.48
Ash, %	4.63	4.53	3.82	3.93
Ca, %	0.68	0.74	0.55	0.50
P, %	0.43	0.39	0.35	0.39

[1] Diets were fed in meal form during the experiment. Diets were fed in 4 phases from approximately 60 to 90, 90 to 150, 150 to 215, and 215 to 245 lb BW.
[2] The 4 dietary treatments were obtained by replacing corn in each diet with nicotinic acid (Lonza, Allendale, NJ) to achieve total niacin concentrations of 14, 172, 331,and 490 mg/lb of complete feed.
[3] Dried distillers grains with solubles.
[4] Optiphos 2000 (Enzyvia, Sheridan, IN) provided 363.2 phytase units (FTU)/lb, with a release of 0.12% available P.
[5] Provided per pound of premix: 3,200,000 IU vitamin A; 500,000 IU vitamin D_3; 16,000 IU vitamin E; 1,600 mg vitamin K; 2,800 mg riboflavin; 10,000 mg pantothenic acid; 18,000 IU niacin; 12 mg vitamin B_{12}.
[6] Provided per pound of premix: 50 g Zn from zinc sulfate; 50 mg Fe from iron sulfate; 15 g Mn from manganese oxide; 7.5 g Cu from copper sulfate; 150 mg I from calcium iodate; and 136 mg Se from sodium selenite.
[7] Analysis performed by Ward Laboratories Inc. (Kearney, NE); means represent the average of 4 samples within each dietary phase.

Table 2. Analyzed dietary niacin concentrations[1]

	Dietary niacin, mg/lb			
Formulated	14	172	331	490
Analyzed	18	117	256	564

[1] Analysis performed by AIB International (Manhattan, KS). Means represent the average of duplicate samples that were obtained by pooling samples across dietary phases within experimental treatments.

Table 3. Effects of increasing dietary niacin on finishing pig growth performance[1,2]

	Dietary niacin, mg/lb[3]					Probability, $P <$	
Item	14	172	331	490	SEM	Linear	Quadratic
d 0 to 98							
ADG, lb	1.81	1.81	1.82	1.81	0.01	0.40	0.50
ADFI, lb	4.47	4.59	4.63	4.56	0.04	0.07	0.71
F/G	2.48	2.54	2.54	2.51	0.02	0.17	0.89
BW, lb							
d 0	59.4	59.4	59.4	59.4	1.1	1.00	0.98
d 98	239.3	238.1	239.3	239.3	1.5	0.85	0.60

[1] A total of 1,232 pigs (PIC 337 × 1050; initially 59.4 lb) were used in a 98-d study to determine the influence of increasing dietary niacin concentrations on growth performance. There were 11 pens per treatment and 28 pigs per pen.
[2] The study was ended on d 98 prior due to a facility electronic malfunction.
[3] Nicotinic acid was used as the source of added niacin to achieve dietary treatment concentrations.

Table 4. Main effects of gender and dietary niacin concentration on carcass traits and meat quality measurements[1]

	Gender			Dietary niacin, mg/lb					Probability, *P*		
										Niacin	
Item	Barrow	Gilt	SEM	14	172	331	490	SEM	Gender	Linear	Quadratic
Carcass traits											
Live wt, lb	274.7	268.8	2.0	271.1	267.3	273.3	275.3	2.7	0.02	0.11	0.23
HCW, lb	201.1	194.1	1.4	196.5	195.5	199.5	198.9	2.0	0.01	0.19	0.26
Yield, %	73.3	72.4	0.4	72.7	73.1	73.1	72.3	0.5	0.03	0.48	0.81
Loin depth, in.[2]	2.60	2.73	0.03	2.63	2.69	2.67	2.68	0.05	0.01	0.59	0.56
Backfat, in.[2]	0.68	0.56	0.02	0.62	0.62	0.62	0.60	0.03	0.01	0.68	0.90
FFLI, %[2,3]	53.1	55.3	0.4	54.1	54.1	54.1	54.4	0.05	0.01	0.68	0.90
pH											
45 min	6.47	6.49	0.05	6.66	6.51	6.41	6.35	0.14	0.86	0.01	0.95
3 h	6.28	6.40	0.03	6.39	6.30	6.37	6.28	0.04	0.01	0.19	0.09
21 h	5.95	5.92	0.01	5.99	5.93	5.92	5.91	0.02	0.11	0.01	0.51
Ultimate	5.86	5.80	0.02	5.87	5.81	5.84	5.80	0.03	0.02	0.11	0.17
Meat quality											
Loin color[4]	3.47	3.33	0.08	3.43	3.34	3.44	3.39	0.11	0.15	0.92	0.47
Loin marbling[4]	1.50	1.34	0.07	1.43	1.27	1.42	1.55	0.10	0.08	0.22	0.43
Chop color[4]	3.04	2.83	0.07	3.05	2.83	2.93	2.92	0.11	0.04	0.54	0.38
Chop marbling[4]	1.70	1.55	0.05	1.63	1.61	1.57	1.69	0.08	0.04	0.65	0.56
Purge loss, %	1.39	1.60	0.14	1.45	1.40	1.51	1.62	0.21	0.27	0.47	0.85
24-h drip loss, %	2.88	3.04	0.26	2.97	2.83	3.42	2.62	0.38	0.63	0.76	0.18
L*	53.41	54.35	0.55	53.12	54.67	53.56	54.16	0.82	0.21	0.54	0.21
a*	18.61	18.61	0.26	18.20	18.30	18.89	19.05	0.39	0.99	0.05	0.58
b*	16.54	16.69	0.27	16.05	16.45	16.88	17.09	0.40	0.69	0.04	0.89
Loin niacin, mg/lb	52.23	52.39	2.53	53.45	49.54	50.20	56.04	3.57	0.96	0.56	0.97

[1] A total of 88 pigs (2 per pen; 1 barrow and 1 gilt) were used to determine the effects of gender and dietary niacin concentration on carcass traits and meat quality.

[2] Adjusted with HCW as a covariate.

[3] Fat-free lean index (FFLI) was calculated using NPPC (2000) guidelines for carcasses measured with an optical probe such that FFLI = (15.31 + (00.51 × HCW, lb) - (31.277 × last rib fat thickness, in.) + (3.813 × loin muscle depth, in.))/ HCW, lb.

[4] Subjective color scores were conducted using a scale of 1 to 5, and marbling scores were conducted using a numeric scale of 1 to 5 both are previously described by NPPC (2000).

Table 5. Interactive effects of gender and dietary niacin on carcass pH[1]

	Dietary niacin treatment									
	14		172		331		490			Probability, $P <$
Item	Barrow	Gilt	Barrow	Gilt	Barrow	Gilt	Barrow	Gilt	SEM	Interaction
pH										
45 min	6.48	6.83	6.59	6.42	6.51	6.32	6.31	6.39	0.12	0.08
3 h	6.28	6.50	6.32	6.28	6.21	6.54	6.30	6.27	0.06	0.01
21 h	5.98	6.00	5.96	5.89	5.91	5.93	5.96	5.87	0.03	0.09
Ultimate	5.90	5.84	5.84	5.77	5.91	5.77	5.80	5.79	0.05	0.60

[1] A total of 88 pigs (2 pigs per pen; 1 barrow and 1 gilt) were used to determine the effects of gender and dietary niacin on carcass pH.

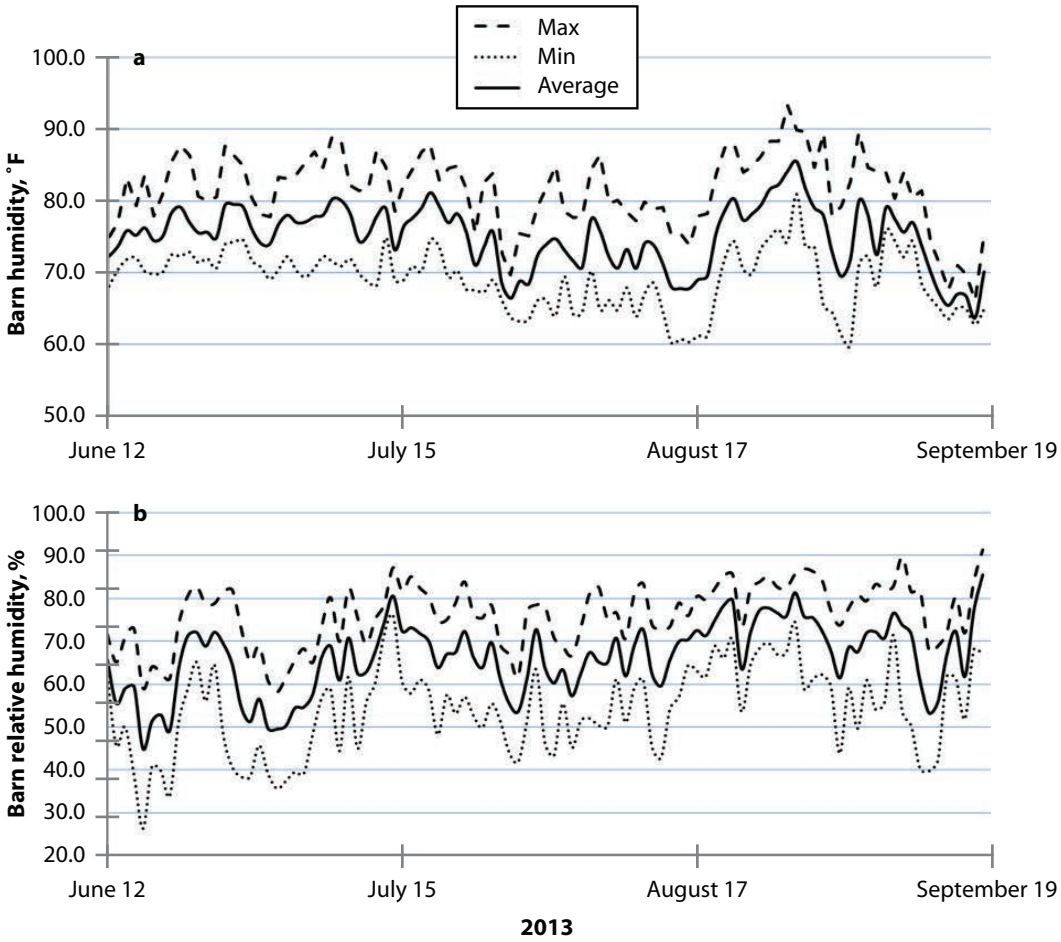

Figure 1. Temperature (°F) and relative humidity (%) of research barn from d 0 to 98 of study (June 12 through September 18, 2013).

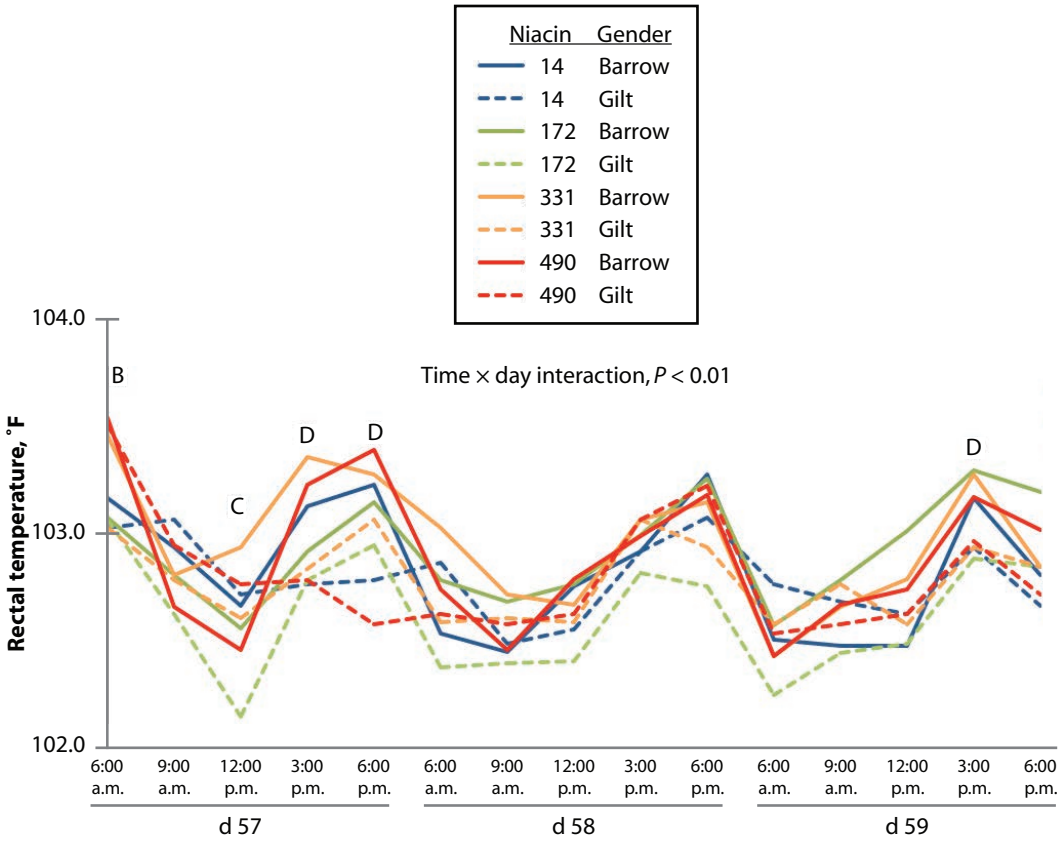

Figure 2. Rectal temperatures (°F) during d 57, 58, and 59 of the study. Temperatures were collected from 1 barrow and 1 gilt per pen. Letters denote differences ($P < 0.05$): B, linear dietary niacin effect; C, quadratic dietary niacin effect; D, gender effect.

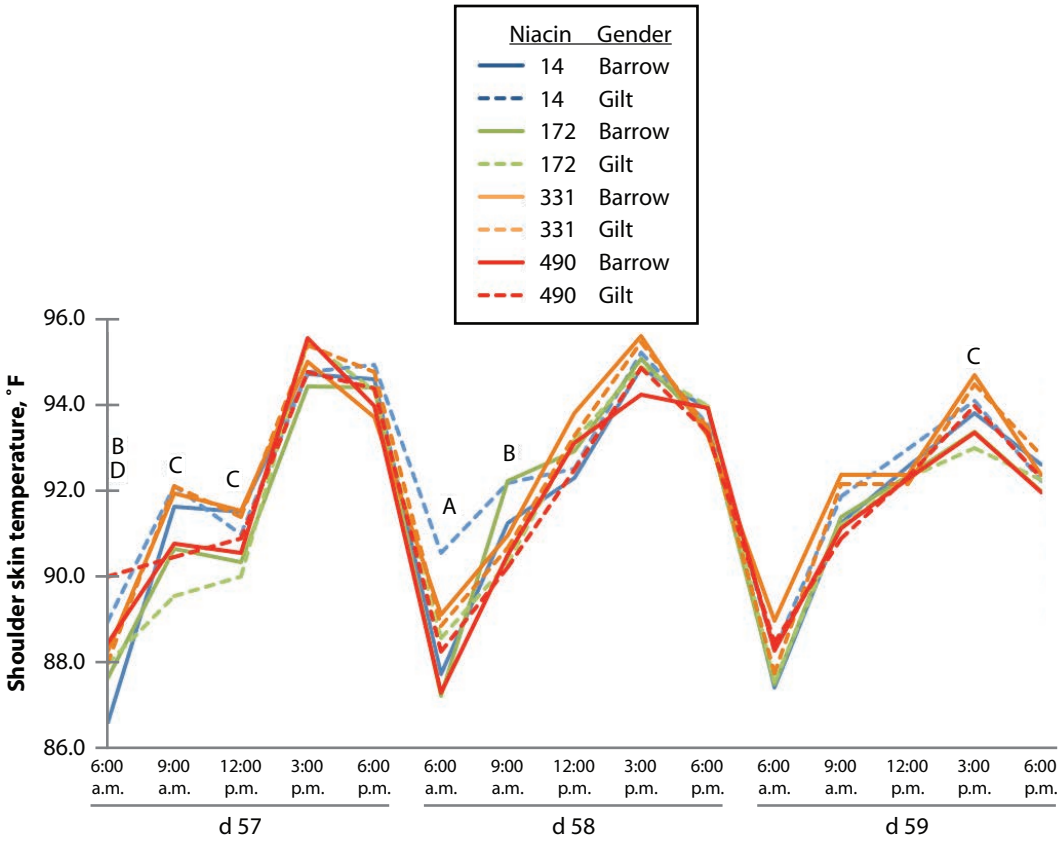

Figure 3. Shoulder skin temperatures (°F) during d 57, 58, and 59 of the study. Temperatures were collected from 1 barrow and 1 gilt per pen using an infrared dual laser thermometer. Letters denote differences ($P < 0.05$): A, dietary niacin × gender interaction; B, linear dietary niacin effect; C, quadratic dietary niacin effect; D, gender effect.

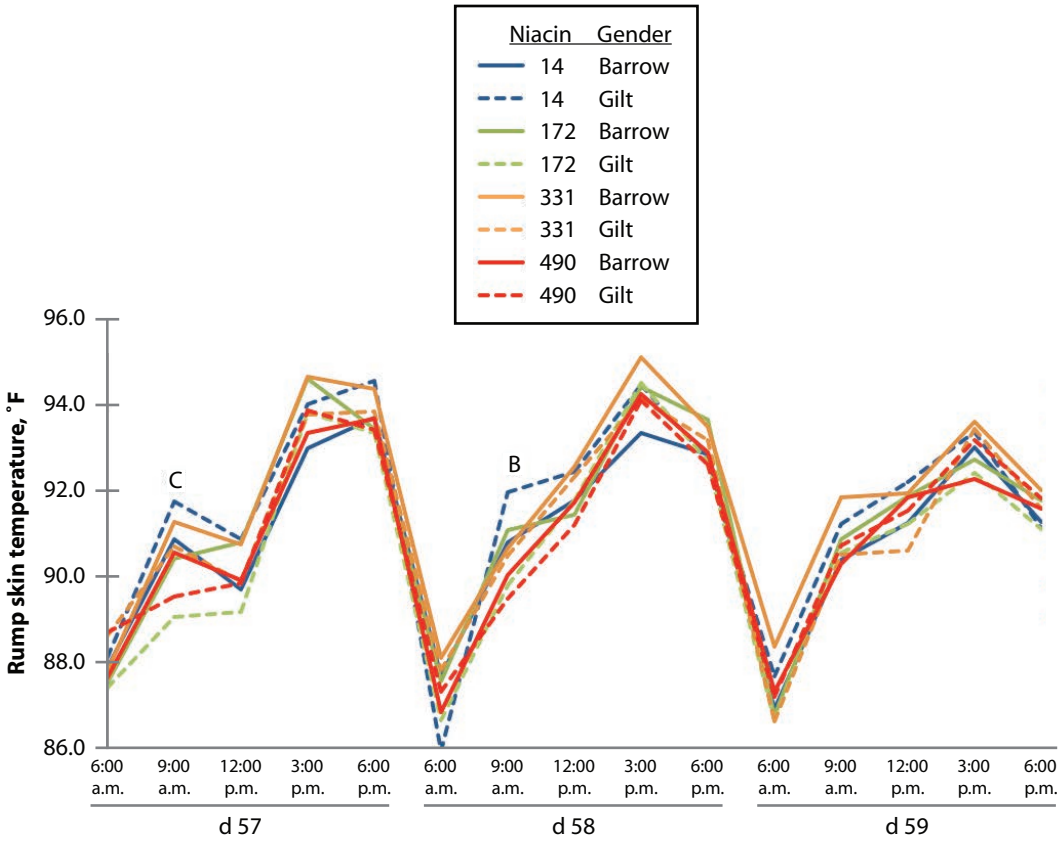

Figure 4. Rump skin temperatures (°F) during d 57, 58, and 59 of the study. Temperatures were collected from 1 barrow and 1 gilt per pen using an infrared dual laser thermometer. Letters denote differences ($P < 0.05$): B, linear dietary niacin effect; and C, quadratic dietary niacin effect.

Effects of 30% Dried Distillers Grains with Solubles and 5% Added Fat Prior to Slaughter on Growth Performance, Carcass Characteristics, and Economics of Finishing Pigs[1]

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Summary

Two groups of pigs (n = 1,258, initially 233.2 lb; group 1 PIC 337 × 1050; group 2 PIC 327 × 1050) were used in a 20-d experiment to determine the effects of 30% dried distillers grains with solubles (DDGS) and 5% added fat prior to slaughter on growth performance, carcass characteristics, and economics of finishing pigs. There were a total of 20 replications per treatment. All pigs were fed a common diet with 30% DDGS until 20 d prior to slaughter, at which point they were weighed and allotted to dietary treatments. The dietary treatments were arranged in a 2 × 2 factorial with 2 diet types, a corn-soybean meal–based diet with or without 30% DDGS and added fat of 0 or 5% (group 1 = tallow; group 2 = choice white grease). Diets were formulated on a standardized ileal digestible (SID) lysine basis and balanced on an SID lysine to NE ratio. There were no treatment × group interactions for any of the measured responses, so data for the two groups were combined for analysis. For the overall experiment, there was a tendency ($P < 0.10$) for a diet type × added fat interaction for ADG; this interaction was significant ($P < 0.05$) for F/G and caloric efficiency on an ME and NE basis. These were the result of pigs fed the diet with 30% DDGS having greater ADG and F/G improvements when fat was included compared with those fed the corn-soybean meal–based diet without DDGS. For the caloric efficiency interaction, pigs fed 30% DDGS had an improvement with added fat, whereas those fed the corn-soybean meal–based diet with added fat had worse caloric efficiency than pigs fed the corn-soy diet without added fat.

Although diet type did not affect final live weight, pigs fed the diet containing DDGS had reduced HCW ($P < 0.05$), which was the result of reduced carcass yield ($P < 0.05$). Adding 5% fat to the diet containing DDGS did not improve carcass yield. Jowl fat iodine value was increased by added fat ($P < 0.05$) and feeding DDGS ($P < 0.05$). For economics, there was a diet type × added fat interaction ($P < 0.05$) for cost per pound of gain, which was the result of a larger increase in cost for pigs fed added fat in the corn-soybean meal–based diet compared with the diet containing DDGS. Income over feed cost did not differ among dietary treatments. In conclusion, adding 5% fat to finishing pig diets containing 30% DDGS approximately 20 d prior to slaughter improved ADG and F/G but did not overcome the reduction in carcass yield from feeding DDGS.

Key words: finishing pig, fiber, fat, yield

[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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Introduction

Carcass yield is negatively influenced when diets containing high-fiber ingredients are fed during the late finishing period. The undigested fiber fraction remaining in the gastrointestinal tract causes an increase in gut fill, resulting in a lower carcass yield compared with pigs fed a lower fiber diet. Previous research has shown that when diets containing high-fiber ingredients, such as dried distillers grains with solubles (DDGS) and wheat middlings, are removed from finishing pig diets approximately 20 d prior to slaughter and replaced with a corn-soybean meal–based diet, carcass yield returns to normal levels (Asmus et al., 2012[3]; Coble et al., 2013[4]).

Asmus et al. (2012[3]) fed 3% choice white grease (CWG) in diets containing high-fiber ingredients during the last 19 days prior to marketing and improved ADG and F/G but did not alter carcass yield. The 3% added fat in high-fiber diets had no detectable impact on carcass yield, and research has not been completed at higher dietary fat levels that may have a more pronounced influence on carcass yield. Previous research has found that adding dietary fat to corn-soybean meal–based diets for the duration of the finishing period can improve carcass yield (Baudon et al., 2003[5]). Therefore, an experiment was conducted to determine the effects of 30% DDGS and 5% added fat prior to slaughter on growth performance, carcass characteristics, and economics of finishing pigs.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. One experiment was conducted involving two groups of pigs. Group 1 was housed in southwest Minnesota in a commercial research finisher, and group 2 was housed at the Kansas State University Swine Teaching and Research Center in Manhattan, KS. The barn that housed group 1 was naturally ventilated, double-curtain-sided, and equipped with a 4-hole stainless steel feeder that allowed ad libitum access to feed. The barn used for group 2 was mechanically ventilated and equipped with a 2-hole stainless steel feeder allowing for ad libitum access to feed. In both facilities, a robotic feeding system (FeedPro; Feedlogic Corp., Wilmar, MN) was used to deliver and record daily feed additions to each individual pen. Pens in each facility were completely slatted and contained a bowl waterer that allowed for ad libitum access to water.

A total of 1,258 pigs (initially 233.2 lb; group 1 PIC 337 × 1050; group 2 PIC 327 × 1050) were used in a 20-d study. Prior to d 0, pigs were fed a common diet containing 30% DDGS. The common diet was fed to the pigs in group 1 for 21 d and 53 d in group 2. On d 0, 20 d prior to slaughter, pigs were weighed and allotted to dietary treatments. Dietary treatments were arranged in a 2 × 2 factorial with 2 diet types; a corn-soybean meal–based diet (corn-soy) or a corn-soybean meal–based diet with 30% DDGS (DDGS) and added fat; 0 or 5% (group 1 = tallow; group 2 = choice white grease (CWG). Diets were formulated on a standardized ileal digestible (SID) lysine basis and balanced on a SID lysine to NE ratio (Tables 1 and 2). Samples of the DDGS were obtained at the time of manufacturing the diets. Samples of each treatment diet

[3] Asmus et al., Swine Day 2012, Report of Progress 1074, pp. 204–217.
[4] Coble et al., Swine Day 2013, Report of Progress 1092, pp. 186–204.
[5] Baudon et al., Swine Day 2003, Report of Progress 920, pp. 155–158.

were obtained by taking samples from the feeders 2 d after the start of the trial and 2 d prior to completing the trial. These samples were combined for a composite sample for each treatment. Proximate analysis and bulk density were completed on each diet and each source of DDGS.

Pens of pigs were ranked by BW and randomly allotted to 1 of the 4 dietary treatments within BW block. For group 1, pens contained 20 to 23 pigs (similar number of barrows and gilts) with 11 replications per treatment. For group 2, pens contained 7 to 8 pigs (similar number of barrows and gilts) with 9 replications per treatment, making a total of 20 replications per treatment. Pens of pigs were weighed and feed disappearance determined on d 0 and 20 to calculate ADG, ADFI, F/G, and ME and NE caloric efficiency.

After final weights were taken on d 20, pigs were transported to a commercial packing plant for processing and data collection. Group 1 was transported to JBS Swift and Company (Worthington, MN), and group 2 was transported to Triumph Foods, LLC (St. Joseph, MO). Carcass measurements taken at the plant included HCW, loin depth, backfat, and percentage lean. Also, carcass yield was calculated by dividing the average pen HCW by the corresponding average pen final live weight at the farm. Near-infrared spectroscopy (NIR) was used to measured jowl iodine value (IV) at the plant for group 2. To calculate HCW ADG, the initial carcass weight on d 0 was calculated with the assumed yield of 75% of the live weight and subtracted from final HCW to determine HCW gain over the 20-d period. Then, HCW gain was divided by 20 (total d of experiment). Hot carcass weight F/G was calculated by dividing overall intake (ADFI × 20 d) by HCW gain on a pen basis.

An economic analysis was completed to determine the financial impact of 30% DDGS and 5% added fat prior to slaughter. The total feed cost per pig was calculated by multiplying the ADFI by the feed cost per pound and 20 d. Cost per pound of gain was calculated by dividing the total feed cost per pig by the total pounds gained overall. Value of the weight gained during the experiment (gain value) was calculated by multiplying the carcass gain by an assumed carcass value of $93.76/cwt. To calculate IOFC, total feed cost was subtracted from the value of the carcass gain.

Experimental data were analyzed in a randomized complete block design using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen serving as the experimental unit and initial BW serving as the blocking factor. Data from groups 1 and 2 were initially analyzed as a combined dataset with the random effect of block within group and the fixed effects of treatment, group, and treatment × group. No group × treatment interactions were observed for any of the measured responses, so this was subsequently removed from the initial model. Contrasts between pigs fed with and without added DDGS and fat were tested, as well as their interaction. Hot carcass weight served as a covariate for the analysis of backfat, loin depth, and lean percentage. 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

Proximate analysis of diets and DDGS demonstrated that the nutrient values used in diet formulation were similar to analyzed values (Tables 3 and 4). Importantly, the diets containing the DDGS had analyzed NDF levels approximately 3 to 5 percentage units greater than the corn-soy diets, and the diets containing 5% added fat had analyzed EE levels 4 to 5 percentage units higher than those not containing the added fat as expected.

Overall, there was a tendency ($P < 0.10$) for a diet type × added fat interaction for ADG, whereas this interaction was significant ($P < 0.05$) for F/G and caloric efficiency on an ME and NE basis (Table 5). The interactions were the result of pigs fed the diet with 30% DDGS having greater ADG and F/G improvements when added fat was included compared with those fed the corn-soybean meal–based diet without DDGS. For the caloric efficiency interaction, pigs fed 30% DDGS had an improvement with added fat, whereas those fed the corn-soybean meal–based diet with added fat had worse caloric efficiency than pigs fed the corn-soy diet without added fat. Assuming the corn and soybean values are accurate, this may have been the result of overvaluing the NE and ME content used in formulation for the fat and DDGS sources used in the experiment. For ADFI, pigs fed the corn-soy diet did have an increase ($P < 0.05$) in ADFI compared with those fed the diet containing 30% DDGS.

For carcass characteristics, there were no diet type × added fat interactions for any of the measured responses (Table 6); however, pigs fed the diet containing 30% DDGS had decreased HCW ($P < 0.05$), which was driven by lower percentage yield ($P < 0.05$). Adding 5% fat to the diet containing 30% DDGS did not improve carcass yield, which is consistent with Asmus et al. (2012), who showed that adding 3% fat to high-fiber diets did not improve carcass yield. As expected, pigs fed the diet containing DDGS had an increase in jowl IV ($P < 0.05$) resulting from the increase in unsaturated dietary fat from the DDGS. Furthermore, adding 5% fat to either diet increased ($P < 0.05$) jowl IV and tended to increase backfat ($P < 0.10$). Carcass ADG was reduced ($P < 0.05$) by 7.5% when pigs were fed the diet containing DDGS but improved by 6% ($P < 0.05$) when 5% fat was added to the diet. Carcass F/G was worse ($P < 0.05$) for pigs fed the diet containing DDGS compared with the corn-soy diet; however, carcass F/G improved ($P < 0.05$) when added fat was included in the diet.

For experiment economics, there was a diet type × added fat interaction ($P < 0.05$) for cost per pound of gain, which was the result of a larger increase for pigs fed added fat in the corn-soybean meal–based diet compared with the diet containing DDGS. Total feed cost, cost per pound of gain, and the value of the weight gained during the experiment (gain value) were all reduced ($P < 0.05$) for those fed the diet containing 30% DDGS compared with pigs fed the corn-soybean meal diet; however, income over feed cost (IOFC) did not differ between diet types. Adding fat to the diet increased ($P < 0.05$) total feed cost, cost per pound of gain, and gain value but did not increase IOFC.

In conclusion, adding 5% fat to finishing pig diets for 20 d prior to slaughter improved ADG and F/G but did so to a greater extent in diets with 30% DDGS; however, adding fat did not improve carcass yield for pigs fed either diet type. Pigs fed the corn-soybean

meal–based diet had the highest carcass yield, further validating that feeding a higher-fiber diet until slaughter reduces carcass yield.

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

	Diet type:	DDGS[2]		Corn-soy	
Item	Added fat, %:	0	5	0	5
Ingredient, %					
Corn		66.41	58.87	84.76	76.88
Soybean meal , 46.5% CP		1.41	3.94	13.20	16.06
DDGS		30.00	30.00	---	---
Beef tallow		---	5.00	---	5.00
Dicalcium P, 18.5%		---	---	0.35	0.35
Limestone		1.18	1.18	0.92	0.92
Salt		0.35	0.35	0.35	0.35
L-lysine HCl		0.45	0.45	0.23	0.22
DL-methionine		---	---	0.02	0.04
L-threonine		0.06	0.07	0.06	0.06
L-tryptophan		0.03	0.03	---	---
Phytase[3]		0.03	0.03	0.03	0.03
Vitamin premix		0.05	0.05	0.05	0.05
Trace mineral premix		0.05	0.05	0.05	0.05
Total		100.0	100.0	100.0	100.0
Calculated analysis					
Standard ileal digestible (SID) amino acids, %					
Lysine		0.65	0.70	0.66	0.71
Isoleucine:lysine		58	58	62	62
Leucine:lysine		199	187	154	147
Methionine:lysine		36	34	31	33
Met & Cys:lysine		66	63	60	60
Threonine:lysine		65	65	65	65
Tryptophan:lysine		18	18	18	19
Valine:lysine		73	72	70	70
SID lysine: NE, g/Mcal		2.57	2.57	2.57	2.57
ME, kcal/lb		1,516	1,616	1,508	1,608
NE, kcal/lb		1,145	1,234	1,157	1,245
Total lysine, %		0.79	0.84	0.75	0.80
CP, %		14.4	15.0	12.7	13.4
Ca, %		0.46	0.47	0.47	0.47
P, %		0.36	0.36	0.38	0.38
Available P, %		0.30	0.30	0.25	0.25
Crude fiber, %		4.0	4.0	2.2	2.1
Diet cost,[4] $/ton		182.03	207.17	206.51	233.28

[1] Diets were fed from approximately 236.2 to 278.5 lb.
[2] Dried distillers grains with solubles.
[3] Optiphos 2000 (Huvepharma, Peach Tree, GA) provided 568 phytase units (FTU)/lb, with a release of 0.10% available P.
[4] Cost of corn = $4.18/bushel; soybean meal = $420/ton; DDGS = $164/ton; beef tallow = $520/ton.

Table 2. Group 2 diet composition (as-fed basis)[1]

Item	Diet type:	DDGS[2]		Corn-soy	
	Added fat, %:	0	5	0	5
Ingredient, %					
Corn		66.26	58.60	84.63	76.41
Soybean meal , 46.5% CP		1.32	4.00	13.05	16.30
DDGS		30.00	30.00	---	---
Choice white grease		---	5.00	---	5.00
Monocalcium P, 18.5%		---	---	0.33	0.33
Limestone		1.28	1.25	1.07	1.05
Salt		0.35	0.35	0.35	0.35
L-lysine HCl		0.45	0.45	0.23	0.21
DL-methionine		---	---	0.03	0.05
L-threonine		0.07	0.07	0.06	0.07
L-tryptophan		0.03	0.03	0.01	---
Phytase[3]		0.10	0.10	0.10	0.10
Vitamin premix		0.08	0.08	0.08	0.08
Trace mineral premix		0.08	0.08	0.08	0.08
Total		100.0	100.0	100.0	100.0
Calculated analysis					
Standard ileal digestible (SID) amino acids, %					
Lysine		0.65	0.70	0.66	0.71
Isoleucine:lysine		58	58	61	62
Leucine:lysine		199	187	153	146
Methionine:lysine		36	34	33	34
Met & Cys:lysine		67	63	61	61
Threonine:lysine		66	66	66	66
Tryptophan:lysine		19	19	19	19
Valine:lysine		73	72	70	70
SID lysine: NE, g/Mcal		2.57	2.57	2.57	2.57
ME, kcal/lb		1,513	1,619	1,505	1,611
NE, kcal/lb		1,143	1,238	1,154	1,247
Total lysine, %		0.79	0.84	0.75	0.81
CP, %		14.3	15.0	12.6	13.5
Ca, %		0.50	0.50	0.50	0.50
P, %		0.36	0.36	0.38	0.38
Available P, %		0.28	0.28	0.23	0.23
Crude fiber, %		4.0	4.0	2.2	2.1
Diet cost,[4] $/ton		199.89	236.50	207.70	245.58

[1] Phase 1 diets were fed from approximately 229.5 to 274.2 lb.
[2] Dried distillers grains with solubles.
[3] Natuphos 600 (BASF Corporation; Florham Park, NJ) provided 136 phytase units (FTU)/lb, with a release of 0.11% available P.
[4] Cost of corn = $4.18/bushel; soybean meal = $420/ton; DDGS = $164/ton; choice white grease = $740/ton.

Table 3. Group 1 diet proximate analysis (as-fed basis)[1]

	Diet type:	DDGS[2]		Corn-soy		
Item, %	Added fat,[3] %:	0	5	0	5	DDGS
Moisture		11.77	11.21	12.24	11.72	7.90
DM		88.23	88.79	87.76	88.28	92.10
CP		15.70	15.20	12.90	12.40	30.60
ADF		4.40	5.30	3.10	3.00	10.1
NDF		12.20	11.30	7.60	7.20	25.5
Crude fiber		2.90	2.90	1.80	1.80	8.00
Ca		0.64	0.71	0.51	0.56	0.07
P		0.36	0.39	0.31	0.35	0.74
Ether extract		4.40	8.50	2.80	7.50	9.20
Ash		3.69	3.90	3.19	3.17	4.08
Bulk density, lb/bushel		47.50	50.03	46.61	49.03	---

[1] Diets were sampled at the feeder 2 d after initiation and 2 d prior to termination of the experiment. Samples were combined in equal amounts to create composite samples for analysis.
[2] Dried distillers grains with solubles.
[3] Beef tallow served as the added fat source in diets for group 1.

Table 4. Group 2 diet proximate analysis (as-fed basis)[1]

	Diet type:	DDGS		Corn-soy		
Item, %	Added fat,[2] %:	0	5	0	5	DDGS
Moisture		10.30	9.97	11.09	10.49	10.05
DM		89.70	90.03	88.91	89.51	89.95
CP		16.60	17.10	14.50	15.70	29.70
ADF		4.40	5.70	2.50	4.20	11.80
NDF		10.20	10.90	5.50	8.10	24.10
Crude fiber		2.10	3.00	1.30	2.10	7.10
Ca		0.68	0.63	0.62	0.63	0.08
P		0.46	0.47	0.35	0.47	0.87
Ether extract		3.70	8.70	2.40	6.90	6.90
Ash		3.96	3.92	3.64	3.69	4.17
Bulk density, lb/bushel		---	57.04	51.06	52.08	44.88

[1] Diets were sampled at the feeder 2 d after initiation and 2 d prior to termination of the experiment. Samples were combined in equal amounts to create composite samples for analysis.
[2] Choice white grease served as the added fat source in diets for group 2.

Table 5. Interactive effects of diet type and added fat fed 20 d prior to slaughter on growth, carcass traits, and economics of finishing pigs[1]

Diet type:	DDGS[2]		Corn-soy			Probability, $P <$		
Added fat,[3] %:	0	5	0	5	SEM	Diet type × fat	Diet type	Added fat
Weight, lb								
d 0	232.9	232.8	233.0	232.8	1.65	0.982	0.989	0.880
d 20	274.2	277.4	276.6	277.3	1.66	0.338	0.400	0.135
d 0 to 20								
ADG, lb	2.06	2.23	2.17	2.23	0.031	0.054	0.056	0.001
ADFI, lb	6.92	6.80	7.07	7.03	0.067	0.472	0.002	0.182
F/G	3.38	3.06	3.26	3.18	0.041	0.006	0.947	0.001
Caloric efficiency[4]								
ME, kcal/lb gain	5,112	4,952	4,912	5,120	63.9	0.006	0.809	0.709
NE, kcal/lb gain	3,861	3,783	3,768	3,964	49.1	0.007	0.376	0.232
Carcass traits								
HCW, lb	199.9	201.9	202.6	203.5	1.22	0.556	0.026	0.122
Yield, %	72.75	72.67	73.05	73.24	0.132	0.294	0.001	0.633
Loin depth,[5] in.	2.36	2.38	2.35	2.34	0.019	0.342	0.168	0.738
Backfat,[5] in.	0.76	0.79	0.78	0.80	0.011	0.522	0.190	0.061
Lean,[5] %	53.58	53.22	53.26	53.03	0.182	0.735	0.165	0.101
Iodine value,[6] g/100 g	73.02	73.48	71.49	72.28	0.210	0.423	0.001	0.006
Carcass performance								
HCW ADG,[7] lb	1.26	1.37	1.39	1.45	0.028	0.354	0.001	0.006
HCW F/G[8]	5.53	5.00	5.14	4.90	0.103	0.171	0.022	0.001
Economics, $/pig								
Feed cost	13.20	15.03	14.69	16.84	0.153	0.280	0.001	0.001
Cost/lb gain	0.322	0.338	0.339	0.381	0.005	0.011	0.001	0.001
Gain value[9]	23.64	25.63	26.10	27.10	0.531	0.354	0.001	0.006
IOFC[10]	10.44	10.60	11.41	10.26	0.498	0.191	0.529	0.323

[1] 1,258 pigs (initial 233.2 lb; Group 1 PIC 337 × 1050; Group 2 PIC 327 × 1050) were used in a 20-d experiment. Pens contained 20 to 23 pigs per pen with 11 replications per treatment in group 1 and 7 to 8 pigs per pen with 9 replications per treatment in group 2, for a total of 20 replications per treatment.
[2] Dried distillers grains with solubles.
[3] Beef tallow served as the added fat source in diets for group 1 and choice white grease for group 2.
[4] Caloric efficiencies were calculate by the following equation (ADFI × kcal) ÷ (ADG).
[5] Hot carcass weight was used as a covariate.
[6] Iodine value was measured only in pigs from group 2.
[7] HCW ADG = (HCW – (d 0 wt. ×75% yield)) ÷ 20 d.
[8] HCW F/G = (ADFI × 20) ÷ (HCW- (d 0 wt. × 75% yield)).
[9] Gain value was calculated using the following equation: (HCW × $0.9376)-(d 0 wt × 0.75 ×$0.9376).
[10] Income over feed cost = gain value – feed cost.

Effects of Pelleting and Diet Type on Growth Performance, Carcass Yield, and Iodine Value of Finishing Pigs[1,2]

J.E. Nemechek, M.D. Tokach, S.S. Dritz[3], R.D. Goodband, J.M. DeRouchey, and J.C. Woodworth

Summary

A total of 288 pigs (PIC 327 × 1050, initially 107.0 lb BW) were used in an 87-d trial to determine the effects of diet form and corn oil on growth performance, carcass yield, and iodine value (IV) of growing-finishing pigs. Treatments were arranged in a 2 × 3 factorial with the main effects of diet form and oil source. The 2 diet forms were meal or pellet. The 3 dietary formulations were: (1) corn-soybean meal–based control, (2) control with 30% dried distillers grains with solubles (DDGS) and 19% wheat middlings, and (3) control with 3% corn oil.

No diet form × diet formulation interactions were observed for growth performance, HCW, or carcass yield. Overall (d 0 to 87), pigs fed pelleted diets had increased ($P < 0.05$) ADG, decreased ($P < 0.05$) ADFI, and improved ($P < 0.05$) F/G compared with pigs fed meal diets. Diet form did not influence HCW or carcass yield. Pigs fed diets containing DDGS and wheat middlings had decreased ($P < 0.05$) ADG compared with pigs fed the control or corn oil diets. Feeding the corn oil diet resulted in decreased ($P < 0.05$) ADFI compared with pigs fed the diet with DDGS and wheat middlings, with pigs fed the control diet intermediate. Feed efficiency followed dietary energy, with pigs fed the corn oil diet having the best ($P < 0.05$) F/G, pigs fed DDGS and wheat middlings diet having the worst, and pigs fed the control intermediate. Pigs fed the diet with DDGS and wheat middlings had decreased ($P < 0.05$) HCW and carcass yield compared with pigs fed the control or corn oil treatments.

No interaction was detected between diet form and oil source for belly fat IV. Pigs fed pelleted diets had increased ($P < 0.05$) belly fat IV compared with those fed meal diets, regardless of diet formulation. Belly fat IV was greatest ($P < 0.05$) for pigs fed DDGS and wheat middlings, lowest for pigs fed the control, and intermediate for pigs fed the corn oil diets. An interactive effect between diet form and oil source was detected ($P < 0.05$) for shoulder fat IV, caused by an increase in shoulder fat IV from feeding pelleted diets for the control or corn oil treatments. Thus, with the exception of the lack of increase in IV in pigs fed the pelleted DDGS and wheat middlings diet, feeding pelleted diets increased carcass fat IV. Furthermore, we found no evidence that the source of fat (endogenous vs. supplemental) in pelleted diets affected the IV response to pelleting.

Key words: corn oil, DDGS, diet form, pelleting, finishing pig

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[2] Appreciation is expressed to Farmland Foods, Milan, MO, for collecting carcass weights and fat samples and to Suzanne Ryan and Roger Johnson for technical assistance.
[3] Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University.

Introduction

Previous research has demonstrated that pelleting swine diets can improve ADG and feed efficiency in growing-finishing pigs. When carcass fat quality was evaluated, Nemechek et al. (2012[4]) reported that feeding pelleted diets increased carcass fat iodine value (IV) compared with feeding meal diets. This increase in carcass fat IV due to pelleting was greater when high-by-product (30% DDGS and 19% wheat middlings) diets were fed than when corn-soybean meal diets were fed. One hypothesis is that the pelleting process causes increased fat digestibility and results in an increase in the amount of dietary oil that is deposited as carcass fat. Kim et al. (2013[5]) reported that true ileal and total tract digestibility of acid-hydrolyzed ether extract was much greater for extracted corn oil than for the oil contained within DDGS (94.3 vs. 51.9%, respectively). We expected feeding pelleted diets to increase the digestibility at a greater rate from DDGS and wheat middlings than extracted corn oil. Thus, if the increases in IV caused by pelleting were a result of increased fat digestibility, we should observe a greater increase in IV when diets containing DDGS and wheat middlings are pelleted compared with a corn oil–supplemented diet with the same amount of fat. Therefore, the objective of this trial was to determine the effects of diet form and fat source on growth performance, carcass yield, and carcass fat IV 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 the K-State Swine Teaching and Research Center in Manhattan, KS. The facility was a totally enclosed, environmentally regulated, mechanically ventilated barn containing 36 pens (8 ft × 10 ft). The pens had adjustable gates facing the alleyway and allowed 10 ft^2/pig. Each pen was equipped with a cup waterer and a single-sided, dry self-feeder (Farmweld, Teutopolis, IL) with 2 eating spaces located in the fence line. Pens were located over a completely slatted concrete floor with a 4-ft pit underneath for manure storage. All pigs were provided ad libitum access to food and water.

A total of 288 pigs (PIC 327 × 1050, initially 107.0 lb BW) were used in an 87-d trial. Pens were randomly allotted to 1 of 6 experimental treatments with 6 pens per treatment and 8 pigs per pen (4 barrows and 4 gilts per pen). Treatments were arranged in a 2 × 3 factorial with the main effects of diet form and diet type (Tables 1 and 2). The 2 diet forms used were meal or pellet. The 3 dietary formulations were: (1) corn-soybean meal–based control, (2) control with 30% DDGS and 19% wheat middlings, and (3) control with 3% corn oil. The corn-soybean meal–based control provided a baseline, whereas the diet containing 30% DDGS and wheat middlings was a previously established diet that has been shown to cause predictable increases in IV. Based on research conducted by Benz et al. (2011[6]) with soybean oil, the third treatment diet was formulated to contain 3% corn oil in an effort to obtain similar carcass fat IV to pigs fed the diet containing DDGS and midds. Diets were fed in 4 phases from d 0 to 21, 21 to 45,

[4] Nemechek et al., Swine Day 2012, Report of Progress 1074, pp. 265–277.

[5] Kim, B.G., D.Y. Kil, and H.H. Stein. 2013. In growing pigs, the true ileal and total tract digestibility of acid hydrolyzed ether extract in extracted corn oil is greater than in intact sources of corn oil or soybean oil. J. Anim. Sci. 91:755-763.

[6] Benz, J.M., M.D. Tokach, S.S. Dritz, J.L. Nelssen, J.M DeRouchey, R.C. Sulabo, and R.D. Goodband. 2011. Effects of choice white grease and soybean oil on growth performance, carcass characteristics, and carcass fat quality of growing-finishing pigs. J. Anim. Sci. 89:404–413.

45 to 70, and 70 to 87. Diets within phase were formulated to contain equal amounts of standardized ileal digestible lysine (SID Lys) with 0.98, 0.86, 0.77, and 0.69 SID Lys for Phases 1, 2, 3, and 4, respectively. Pigs and feeders were weighed approximately every 2 wk to calculate ADG, ADFI, and F/G. Diets were prepared and pelleted at Hubbard Feeds in Beloit, KS. Pelleted feed was processed with a Sprout Waldron Pellet Mill, model Ace 501, equipped with an 11/64-in.-diameter die. Prior to pelleting, diets were conditioned with steam at a temperature of 71°C for approximately 20 sec. After manufacturing, diets were delivered in bulk and fed through bulk bins using a computerized feeding system (FeedPro; Feedlogic Corp., Willmar, MN) that delivered and recorded diets as specified. Feed samples were taken at the feeder during each phase. Feed was analyzed for moisture, CP, ADF, NDF, crude fiber, crude fat, Ca, and P (Tables 3 and 4) at Ward Laboratories, Inc. (Kearney, NE). Pellet durability index (PDI) was determined using the standard tumbling-box technique, and modified PDI was done by adding 5 hexagonal nuts prior to tumbling. Percentage fines were also determined for all pelleted diets, with fines characterized as material that would pass through a #6 sieve (3,360-μm openings).

On d 87, all pigs were weighed individually, then transported to Farmland Foods (Milan, MO). Pigs were individually tattooed in sequential order to allow for carcass data collection at the packing plant and data retrieval by pig. Hot carcass weights were measured immediately after evisceration and were used to calculate percentage yield by dividing HCW at the plant by live weight at the farm before transport. Belly fat samples were collected from the ventral side of the belly along the navel edge between the 10th and 12th rib of each pig. Shoulder fat samples were collected approximately 2 in. dorsal to the medial ridge of the scapula. All fat samples were analyzed for fatty acid profiles and calculation of IV. Iodine value was calculated using the formula (AOCS, 1998[7]): [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723.

Experimental data were analyzed using analysis of variance as a 2 × 3 factorial using the MIXED procedure of SAS (SAS Institute Inc., Cary, NC). Pen was the experimental unit for all data analysis. For HCW, carcass yield, and carcass fat IV, measurements were collected for each pig, then pen means were calculated and used in the model. All analysis included main effects of 2 diet forms and 3 diet types and their interactions as fixed effects. When a significant difference was found between diet types, differences were determined using the PDIFF statement in SAS. Significant differences were declared at $P \leq 0.05$ and trends at $P \leq 0.10$.

Results and Discussion

Pellet quality measurements

Standard PDI was greater than 88% during all phases for pelleted diets with modified PDI from 82.5 to 87.5% (Table 5). Percentage fines were low for all diets and phases, approximately 7 to 14.0% fines.

[7] AOAC. 1998. Official methods and recommended practices of AOCS. 5th ed. Am. Oil Chem. Soc., Champaign, IL.

Growth performance and carcass measurements

No diet form × diet formulation interactions were observed for growth performance, HCW, or carcass yield for the overall trial (Table 6).

Overall (d 0 to 87), pigs fed pelleted diets had increased ($P < 0.05$) ADG, decreased ($P < 0.05$) ADFI, and improved ($P < 0.05$) F/G compared with pigs fed meal diets (Table 7). The improvements in ADG and F/G were 3 and 6%, respectively. Pigs fed pelleted diets tended ($P < 0.10$) to have increased final BW, but diet form did not influence HCW or carcass yield. Pigs fed diets containing DDGS and wheat middlings had decreased ($P < 0.05$) ADG compared with pigs fed the control or corn oil diets. Feeding the corn oil diet resulted in decreased ($P < 0.05$) ADFI compared with feeding the DDGS and wheat middlings diet, with the control diet intermediate. Feed efficiency followed dietary energy, with pigs fed the corn oil diet having the best ($P < 0.05$) F/G, pigs fed the DDGS and wheat middlings diet having the worst ($P < 0.05$), and pigs fed the control intermediate. Pigs fed the diet with DDGS and wheat middlings had decreased ($P < 0.05$) HCW and carcass yield compared with pigs fed the control or corn oil treatments. These decreases in HCW and carcass yield when feeding high-fiber diets were expected and are consistent with previously reported data (Nemechek et al., 2012[8]; Coble et al., 2013[9]).

Belly fatty acid composition

Diet form × diet type interactions were detected ($P < 0.05$) for oleic acid (C18:1n9c), total C18:1, linoleic acid (C18:2n6c), total C18:2, total MUFA, and total PUFA (Table 8). These interactions were caused by the greater magnitude of decrease in C18:1 and increase in C18:2 fatty acids when pelleting the control diet than when pelleting the diet containing corn oil, with the diet containing DDGS and midds exhibiting an intermediate response to pelleting. There was also an interaction ($P < 0.05$) for myristic acid (C14:0) in which pelleting the control diet increased C14:0 concentration, but pelleting either of the other 2 treatment diets decreased C14:0 concentration, with the greatest decrease observed in pigs fed diets containing DDGS and midds.

Feeding pelleted diets also increased ($P < 0.05$) stearic (C18:0) and eicosenoic (C20:1) acids and decreased ($P < 0.05$) vaccenic acid (C18:1n7) compared with feeding meal diets (Table 9).

For diet types, pigs fed the control diet had increased ($P < 0.05$) palmitic (C16:0) and reduced ($P < 0.05$) eicosenoic (C20:1) acid concentrations compared with pigs fed the DDGS and midds or corn oil diets. Compared with pigs fed the control diet, pigs fed the diet containing DDGS and midds had decreased ($P < 0.05$) stearic acid (C18:0) and total SFA, with those fed the diet containing corn oil intermediate ($P < 0.05$). Pigs fed diets with DDGS and midds had increased ($P < 0.05$) margaric (C17:0) and α-linolenic (C18:3n3) acid concentrations compared with pigs fed either of the other 2 diet types. No interaction was observed between diet form and oil source for belly fat IV. Feeding pelleted diets increased ($P < 0.05$) belly fat IV, and there was no evidence that the increase was influenced by diet type. Similarly, in a previous experiment feeding pelleted diets increased belly fat IV (Nemechek et al., 2012[8]). However, the increase in belly fat

[8] Nemechek et al., Swine Day 2012, Report of Progress 1074, pp. 265–277.
[9] Coble et al., Swine Day 2013, Report of Progress 1092, pp. 205–214.

IV from pelleting was greater for pigs fed diets containing DDGS and wheat middlings than those fed a corn-soybean meal diet. Belly IV was greatest ($P < 0.05$) for pigs fed diets with DDGS and midds and lowest for pigs fed the control. Belly IV for pigs fed diets with corn oil were intermediate but were numerically closer to the belly IV for pigs fed the DDGS and midds.

Shoulder fatty acid composition

Similar to belly fat, there were diet form × diet type interactions ($P < 0.05$) for several fatty acids (C16:0, C18:1, C18:2, C20:1; Table 10). Pelleting the control diet resulted in a greater increase in unsaturated fatty acids and a reduction in saturated fatty acids compared with pelleting the diet containing corn oil, with the response to pelleting the diet containing wheat middlings and DDGS intermediate. These changes in individual fatty acids led to interactions ($P < 0.05$) between diet form and diet type for total MUFA, PUFA, PUFA:SFA, and IV, with tendencies for interactions ($P < 0.10$) for total SFA and UFA:SFA.

For main effects of diet type, pigs fed the control diet had increased ($P < 0.05$) myristic acid compared with pigs fed the diets containing corn oil or DDGS and midds (Table 11). Feeding the corn oil diet resulted in decreased ($P < 0.05$) vaccenic (C18:1n7) and α-linolenic (C18:3n3) acid concentrations compared with pigs fed the control diet, with pigs fed the diet containing DDGS and midds intermediate. Pigs fed corn oil had decreased ($P < 0.05$) stearic acid (C18:0) concentration compared with pigs fed the control diet, with further decrease ($P < 0.05$) when pigs were fed the diet containing DDGS and midds. For main effects of diet form, pigs fed meal diets had increased ($P < 0.05$) myristic acid (C14:0) concentrations compared with pigs fed pelleted diets.

A diet form × oil source interaction was detected ($P < 0.05$) for shoulder fat IV, a result of pigs fed the control or corn oil diets having higher shoulder fat IV when diets were fed as pellets rather than in meal form. However, pigs fed the DDGS and midds diet had a slight numeric decrease in shoulder fat IV when fed pelleted diets compared with meal.

Conclusions

Pigs fed diets with DDGS and wheat middlings had poorer growth performance, decreased HCW, and reduced carcass yield compared with pigs fed the control or corn oil diets, with pigs fed corn oil having the greatest improvements in F/G. Feeding pelleted diets increased ADG, decreased ADFI, and improved F/G. Diet form did not influence HCW or carcass yield. Belly fat IV was greater for pigs fed pelleted diets, regardless of diet formulation. Pigs fed the control or corn oil diets had increased shoulder IV when diets were fed in pelleted form compared with meal form. The lack of increase in shoulder IV from feeding pelleting diets containing DDGS and wheat middlings was unexpected. With this exception, feeding pelleted diets increased carcass fat IV, which is consistent with our previous experiment; furthermore, it does not appear that the source of fat (endogenous from the ingredient vs. supplemental) in pelleted diets impacted the carcass fat IV response to pelleting.

Table 1. Diet composition (as-fed basis)

	Phase 1[1]			Phase 2[2]		
Item	Control	DDGS[3] + midds	Corn oil	Control	DDGS + midds	Corn oil
Ingredient, %						
Corn	72.01	33.03	68.84	77.57	37.46	74.25
Soybean meal, 46.5% CP	25.56	15.70	25.64	20.17	11.36	20.40
DDGS	---	30.00	---	---	30.00	---
Wheat middlings	---	19.00	---	---	19.00	---
Corn oil	---	---	3.00	---	---	3.00
Monocalcium P, 21% P	0.45	---	0.52	0.37	---	0.44
Limestone	1.05	1.30	1.05	1.00	1.28	1.00
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.150	0.150	0.150	0.125	0.125	0.125
Trace mineral premix	0.150	0.150	0.150	0.125	0.125	0.125
L-lysine HCl	0.220	0.310	0.225	0.235	0.293	0.235
Methionine hydroxyl analog	0.020	---	0.028	0.013	---	0.015
L-threonine	0.030	---	0.040	0.035	---	0.040
Phytase[4]	0.012	0.012	0.012	0.015	0.015	0.015
Total	100.0	100.0	100.0	100.0	100.0	100.0
Standardized ileal digestible, %						
Lysine	0.98	0.98	0.98	0.86	0.86	0.86
Isoleucine:lysine	67	71	66	65	72	65
Methionine:lysine	28	33	29	29	35	29
Met & Cys:lysine	55	62	55	56	67	56
Threonine:lysine	60	62	61	61	63	61
Tryptophan:lysine	19	19	19	18	18	18
Valine:lysine	74	85	73	74	88	73
Total lysine, %	1.11	1.19	1.11	0.98	1.05	0.97
ME, kcal/lb	1,496	1,467	1,566	1,501	1,470	1,571
CP, %	18.4	21.7	18.1	16.3	20.0	16.1
Ca, %	0.55	0.57	0.56	0.50	0.55	0.52
P, %	0.47	0.56	0.47	0.42	0.54	0.43
Available P, %	0.29	0.37	0.30	0.26	0.37	0.28

[1] Phase 1 diets were fed from d 0 to 21.
[2] Phase 2 diets were fed from d 21 to 45.
[3] Dried distillers grains with solubles.
[4] Natuphos 2500 (BASF Corp., Mt. Olive, NJ) provided 136 phytase units (FTU)/lb, with a release of 0.10% available P.

Table 2. Diet composition (as-fed basis)

	Phase 3[1]			Phase 4[2]		
Item	Control	DDGS[3] + midds	Corn oil	Control	DDGS + midds	Corn oil
Ingredient, %						
Corn	81.04	40.70	77.72	83.98	43.80	80.62
Soybean meal, 46.5% CP	16.81	8.16	17.04	13.86	5.13	14.17
DDGS	---	30.00	---	---	30.00	---
Wheat middlings	---	19.00	---	---	19.00	---
Corn oil	---	---	3.00	---	---	3.00
Monocalcium P, 21% P	0.34	---	0.42	0.45	---	0.49
Limestone	0.98	1.29	0.98	0.93	1.28	0.93
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.100	0.100	0.100	0.075	0.075	0.075
Trace mineral premix	0.100	0.100	0.100	0.075	0.075	0.075
L-lysine HCl	0.225	0.278	0.225	0.215	0.270	0.213
Methionine hydroxyl analog	0.010	---	0.010	---	---	0.010
L-threonine	0.038	---	0.043	0.050	---	0.055
Phytase[4]	0.018	0.018	0.018	0.021	0.021	0.021
Total	100.0	100.0	100.0	100.0	100.0	100.0
Standardized ileal digestible, %						
Lysine	0.77	0.77	0.77	0.69	0.69	0.69
Isoleucine:lysine	66	74	65	66	75	66
Methionine:lysine	30	37	29	30	40	31
Met & Cys:lysine	59	71	58	60	75	61
Threonine:lysine	62	65	62	65	67	66
Tryptophan:lysine	18	18	18	18	18	18
Valine:lysine	75	92	74	77	96	76
Total lysine, %	0.88	0.96	0.88	0.79	0.87	0.79
ME, kcal/lb	1,504	1,472	1,574	1,505	1,474	1,575
CP, %	14.9	18.7	14.8	13.8	17.5	13.6
Ca, %	0.48	0.54	0.49	0.47	0.53	0.48
P, %	0.40	0.53	0.41	0.41	0.52	0.41
Available P, %	0.25	0.36	0.27	0.27	0.36	0.28

[1] Phase 3 diets were fed from d 45 to 70.
[2] Phase 4 diets were fed from d 70 to 87.
[3] Dried distillers grains with solubles.
[4] Natuphos 2500 (BASF Corp., Mt. Olive, NJ) provided 136 phytase units (FTU)/lb, with a release of 0.10% available P.

Table 3. Chemical analysis of diets[1]

	Phase 1[2]						Phase 2[3]					
Diet form:	Meal			Pellet			Meal			Pellet		
Item Diet type:	Control	DDGS[4] + midds	Corn oil	Control	DDGS + midds	Corn oil	Control	DDGS + midds	Corn oil	Control	DDGS + midds	Corn oil
DM, %	89.47	90.73	89.62	89.18	88.94	89.33	89.60	90.63	89.47	89.46	88.64	89.13
CP, %	17.7	18.4	18.0	18.8	23.0	18.1	18.1	18.6	17.4	16.9	21.6	17.0
ADF, %	2.7	7.1	2.6	3	7.3	3.1	3.2	7.3	3.3	2.9	6.4	3.2
NDF, %	7.6	17.7	6.6	6.7	16.6	6.6	5.9	18.0	6.7	5.1	14.0	5.3
Crude fiber, %	2.0	4.7	2.0	1.8	4.5	2.0	2.1	4.8	2.1	1.8	4.0	2.0
Crude fat, %	1.6	4.3	3.5	1.4	3.4	3.7	1.5	4.3	3.7	1.5	3.2	3.1
Ca, %	0.98	0.45	0.83	0.58	0.62	0.64	0.62	0.58	0.54	0.65	0.60	0.53
P, %	0.49	0.65	0.51	0.48	0.66	0.49	0.46	0.66	0.44	0.44	0.62	0.42

[1] A composite sample consisting of 6 subsamples was used for analysis.
[2] Phase 1 diets were fed from d 0 to 21.
[3] Phase 2 diets were fed from d 21 to 45.
[4] Dried distillers grains with solubles.

Table 4. Chemical analysis of diets[1]

	Phase 3[2]						Phase 4[3]					
Diet form:	Meal			Pellet			Meal			Pellet		
Item Diet type:	Control	DDGS[4] + midds	Corn oil	Control	DDGS + midds	Corn oil	Control	DDGS + midds	Corn oil	Control	DDGS + midds	Corn oil
DM, %	89.09	90.58	89.41	88.77	90.16	88.93	89.85	90.15	89.81	89.74	91.89	90.61
CP, %	17.1	21	15.3	16.3	20.8	15.9	14.2	22.3	14.0	14.5	18.4	14.3
ADF, %	2.8	7.6	3.0	3.4	5.9	2.8	3.4	8.2	2.8	3.3	6.5	2.6
NDF, %	6.4	16	6.4	5.9	14.4	6.6	6.7	16.8	6.3	5.1	16.5	5.1
Crude fiber, %	1.7	4.2	2.0	1.8	3.5	1.9	2.1	4.8	2.1	1.6	4.3	1.5
Crude fat, %	2.0	4.6	4.2	1.6	4.4	3.8	2.0	3.7	3.2	1.9	4.7	3.5
Ca, %	0.38	0.47	0.61	0.45	0.61	0.55	0.90	0.88	1.19	0.98	0.56	0.56
P, %	0.49	0.66	0.49	0.46	0.66	0.44	0.47	0.58	0.51	0.44	0.64	0.40

[1] A composite sample consisting of 6 subsamples was used for analysis.
[2] Phase 3 diets were fed from d 45 to 70.
[3] Phase 4 diets were fed from d 70 to 87.
[4] Dried distillers grains with solubles.

Table 5. Analysis of pellet quality[1]

Item	Diet type		
	Control[2]	DDGS + midds[3]	Corn oil[4]
Standard pellet durability index, %[5]			
Phase 1	93.6	92.0	91.5
Phase 2	94.2	90.4	88.9
Phase 3	94.1	89.9	90.5
Phase 4	90.0	94.3	92.7
Modified pellet durability index[6]			
Phase 1	85.5	84.2	84.8
Phase 2	86.4	84.1	82.5
Phase 3	86.0	84.9	84.0
Phase 4	83.0	87.5	83.0
Fines, %			
Phase 1	10.2	12.4	14.0
Phase 2	11.9	12.7	7.6
Phase 3	7.2	8.8	6.9
Phase 4	7.3	13.6	8.5

[1] A representative feed sample was taken at the feeder during each phase and analyzed in duplicate for each pellet quality measurement.
[2] Corn-soybean meal–based diet with 0% dried distillers grains with solubles (DDGS), 0% wheat middlings, and 0% corn oil.
[3] Control diet with 30% DDGS and 19% wheat middlings.
[4] Control diet with 3% corn oil.
[5] Pellet durability index was determined using the standard tumbling-box technique.
[6] Procedure was altered by adding 5 hexagonal nuts prior to tumbling.

Table 6. Interactive effects of diet form and diet type on growth, carcass yield, and iodine value of finishing pigs[1]

Diet form:	Meal			Pellet				Probability, $P <$		
Diet type:	Control[2]	DDGS + midds[3]	Corn oil[4]	Control	DDGS + midds	Corn oil	SEM	Diet form × type	Diet form	Diet type
Initial BW, lb	107.0	107.0	107.0	107.0	107.0	107.0	2.295	0.998	0.997	0.996
d 0 to 87										
ADG, lb	2.08	2.00	2.10	2.12	2.07	2.15	0.029	0.706	0.038	0.009
ADFI, lb	5.81	5.86	5.56	5.48	5.79	5.37	0.092	0.372	0.016	0.002
F/G	2.79	2.94	2.65	2.60	2.80	2.50	0.037	0.760	0.001	0.001
Final BW, lb	288.4	280.6	289.8	290.4	286.8	296.6	3.550	0.747	0.076	0.028
HCW, lb	217.3	207.1	217.4	216.5	211.5	224.0	2.708	0.366	0.132	0.001
Carcass yield, %	75.37	73.82	75.01	74.53	73.75	75.54	0.309	0.163	0.619	0.001

[1] A total of 288 pigs (PIC 327 × 1050, initially 107.0 lb BW) were used with 8 pigs per pen and 6 pens per treatment.
[2] Corn-soybean meal–based diet with 0% dried distillers grains with solubles (DDGS), 0% wheat middlings, and 0% corn oil.
[3] Control diet with 30% DDGS and 19% wheat middlings.
[4] Control diet with 3% corn oil.

Table 7. Main effects of diet form and diet type on growth, carcass yield, and iodine value of finishing pigs[1]

	Diet form			Diet type				Probability, $P <$	
	Meal	Pellet	SEM	Control[2]	DDGS + midds[3]	Corn oil[4]	SEM	Diet form	Diet type
Initial BW, lb									
d 0 to 87	2.06	2.11	0.017	2.10[b]	2.03[a]	2.13[b]	0.020	0.038	0.009
ADG, lb	5.74	5.55	0.053	5.65[ab]	5.83[b]	5.47[a]	0.065	0.016	0.002
ADFI, lb	2.79	2.63	0.021	2.70[b]	2.87[c]	2.57[a]	0.026	0.001	0.001
F/G	107.0	107.0	1.325	107.0	107.0	107.0	1.623	0.997	0.996
Final BW, lb	286.2	291.3	1.936	289.4[ab]	283.7[a]	293.2[b]	2.372	0.076	0.028
HCW, lb	213.9	217.3	1.551	216.9[b]	209.3[a]	220.1[b]	1.899	0.132	0.001
Carcass yield, %	74.73	74.60	0.178	74.95[b]	73.78[a]	75.27[b]	0.218	0.619	0.001

[a,b,c] Means for diet type with different superscripts within row significantly differ, $P < 0.05$.
[1] A total of 288 pigs (PIC 327 × 1050, initially 107.0 lb BW) were used with 8 pigs per pen and 18 pens per treatment for diet form and 12 pigs per pen for diet type.
[2] Corn-soybean meal-based diet with 0% dried distillers grains with solubles (DDGS), 0% wheat middlings, and 0% corn oil.
[3] Control diet with 30% DDGS and 19% wheat middlings.
[4] Control diet with 3% corn oil.

Table 8. Interactive effects of diet form and diet type on belly fatty acid profile[1]

	Diet form									
	Meal			Pellet				Probability, $P <$		
Item Diet type:	Control[2]	DDGS + midds[3]	Corn oil[4]	Control	DDGS + Midds	Corn oil	SEM	Diet form × type	Meal vs. pellet	Diet type
Myristic acid (C14:0), %	1.39	1.39	1.36	1.41	1.30	1.33	0.020	0.028	0.034	0.022
Palmitic acid (C16:0), %	23.62	22.16	22.48	23.20	22.27	22.27	0.152	0.239	0.177	0.001
Palmitoleic acid (C16:1), %	3.29	2.95	2.65	2.76	2.46	2.47	0.076	0.056	0.001	0.001
Margaric acid (C17:0), %	0.24	0.27	0.21	0.22	0.27	0.19	0.016	0.545	0.239	0.001
Stearic acid (C18:0), %	10.44	9.07	9.65	10.91	9.24	9.66	0.116	0.148	0.032	0.001
Oleic acid (C18:1n9c), %	46.66	42.56	42.55	44.99	41.66	42.31	0.239	0.019	0.001	0.001
Vaccenic acid (C18:1n7), %	0.93	0.84	0.63	0.73	0.64	0.61	0.048	0.130	0.001	0.001
Total C18:1 fatty acids[5], %	47.61	43.40	43.11	45.69	42.25	42.88	0.265	0.013	0.001	0.001
Linoleic acid (C18:2n6c), %	11.31	18.30	18.15	13.62	19.64	18.87	0.268	0.020	0.001	0.001
Total C18:2 fatty acids[6], %	11.94	19.13	18.93	14.31	20.53	19.68	0.274	0.021	0.001	0.001
α-Linolenic acid (C18:3n3), %	0.70	0.72	0.65	0.66	0.69	0.64	0.022	0.765	0.171	0.037
Eicosenoic acid (C20:1), %	0.43	0.71	0.69	0.53	0.77	0.73	0.016	0.181	0.001	0.001
Total SFA[7], %	35.69	32.89	33.70	35.74	33.07	33.45	0.202	0.545	0.958	0.001
Total MUFA[8], %	51.33	47.05	46.45	48.99	45.48	46.08	0.318	0.014	0.001	0.001
Total PUFA[9], %	12.60	19.77	19.49	14.92	21.16	20.23	0.263	0.019	0.001	0.001
UFA:SFA[10]	1.79	2.03	1.96	1.79	2.02	1.98	0.017	0.486	0.885	0.001
PUFA:SFA[11]	0.35	0.60	0.58	0.42	0.64	0.61	0.009	0.096	0.001	0.001
Iodine value, mg/g[12]	66.74	75.40	74.31	68.65	76.45	75.26	0.300	0.229	0.001	0.001

[1] All items calculated as a percentage of the total fatty acid content. Fat samples were collected and analyzed by individual pig and used to calculate means per pen.
[2] Corn-soybean meal-based control diet with 0% dried distillers grains with solubles (DDGS), 0% wheat middlings, and 0% corn oil.
[3] Control diet with 30% DDGS and 19% wheat middlings.
[4] Control diet with 3% corn oil.
[5] Total C18:1 fatty acids = [% C18:1n9c] + [% C18:1n7]
[6] Total C18:2 fatty acids = [% C18:2n6t] + [% C18:2n6c] + [% C18:2, 9c11t] + [% 18:2, 10t12c] + [% C18:2, 9c11c] + [C18:2, 9t11t].
[7] Total saturated fatty acids = [% C14:0] + [% C15:0] + [% C16:0] + [% C17:0] + [% C18:0] + [% C20:0] + [% C21:0] + [% C22:0] + [% C 24:0].
[8] Total monounsaturated fatty acids = [% C14:1] + [% C15:1] + [% C16:1] + [% C17:1] + [% C18:1n9t] + [% C18:1n9c] + [% C18:1n7] + [% C20:1] + [% C24:1].
[9] Total polyunsaturated fatty acids = [% C18:2n6t] + [% C18:2n6c] + [% C18:2 9c, 11t] + [% C18:2 10t, 12c] + [% C18:2 9c, 11c] + [% C18:2 9t, 11t] + [% C18:3n6] + [% C18:3n3].
[10] UFA:SFA = [total MUFA + total PUFA] / total SFA.
[11] PUFA:SFA = total PUFA / total SFA.
[12] Iodine value = [% C16:1] × 0.95 + [% C18:1] × 0.86 + [% C18:2] × 1.732 + [% C18:3] × 2.616 + [% C20:1] × 0.785.

Table 9. Main effects of diet form and diet type on belly fatty acid profile[1]

	Diet form			Diet type				Probability, $P <$	
Item	Meal	Pellet	SEM	Control[2]	DDGS + midds[3]	Corn oil[4]	SEM	Meal vs. pellet	Diet type
Myristic acid (C14:0), %	1.38	1.35	0.012	1.40[b]	1.35[a]	1.35[a]	0.014	0.034	0.022
Palmitic acid (C16:0), %	22.75	22.58	0.088	23.41[b]	22.21[a]	22.37[a]	0.107	0.177	0.001
Palmitoleic acid (C16:1), %	2.96	2.56	0.044	3.03[b]	2.70[a]	2.56[a]	0.054	0.001	0.001
Margaric acid (C17:0), %	0.24	0.23	0.009	0.23[a]	0.27[b]	0.20[a]	0.011	0.239	0.001
Stearic acid (C18:0), %	9.72	9.94	0.067	10.67[c]	9.16[a]	9.66[b]	0.082	0.032	0.001
Oleic acid (C18:1n9c), %	43.92	42.99	0.138	45.83[b]	42.11[a]	42.43[a]	0.169	0.001	0.001
Vaccenic acid (C18:1n7), %	0.80	0.66	0.028	0.83[b]	0.74[b]	0.62[a]	0.034	0.001	0.001
Total C18:1 fatty acids[5], %	44.71	43.61	0.153	46.65[b]	42.83[a]	42.99[a]	0.188	0.001	0.001
Linoleic acid (C18:2n6c), %	15.92	17.38	0.155	12.47[a]	18.97[b]	18.51[b]	0.190	0.001	0.001
Total C18:2 fatty acids[6], %	16.67	18.17	0.158	13.12[a]	19.83[b]	19.30[b]	0.194	0.001	0.001
α-Linolenic acid (C18:3n3), %	0.69	0.67	0.013	0.68[a]	0.71[b]	0.65[a]	0.016	0.171	0.037
Eicosenoic acid (C20:1), %	0.61	0.68	0.009	0.48[b]	0.74[a]	0.71[a]	0.011	0.001	0.001
Total SFA[7], %	34.10	34.09	0.116	35.71[c]	32.98[a]	33.58[b]	0.142	0.958	0.001
Total MUFA[8], %	48.28	46.85	0.184	50.16[b]	46.27[a]	46.27[a]	0.225	0.001	0.001
Total PUFA[9], %	17.29	18.77	0.152	13.76[a]	20.46[c]	19.86[b]	0.186	0.001	0.001
UFA:SFA[10]	1.93	1.93	0.010	1.79[a]	2.02[c]	1.97[b]	0.012	0.885	0.001
PUFA:SFA[11]	0.51	0.55	0.005	0.39[a]	0.62[c]	0.59[b]	0.006	0.001	0.001
Iodine value, mg/g[12]	72.15	73.45	0.173	67.70[a]	75.93[c]	74.79[b]	0.212	0.001	0.001

[1] All items calculated as a percentage of the total fatty acid content. Fat samples were collected and analyzed by individual pig and used to calculate means per pen.
[2] Corn-soybean meal–based control diet with 0% dried distillers grains with solubles (DDGS), 0% wheat middlings, and 0% corn oil.
[3] Control diet with 30% DDGS and 19% wheat middlings.
[4] Control diet with 3% corn oil.
[5] Total C18:1 fatty acids = [% C18:1n9c] + [% C18:1n7].
[6] Total C18:2 fatty acids = [% C18:2n6t] + [% C18:2n6c] + [% C18:2, 9c11t] + [% 18:2, 10t12c] + [% C18:2, 9c11c] + [C18:2, 9t11t].
[7] Total saturated fatty acids = [% C14:0] + [% C15:0] + [% C16:0] + [% C17:0] + [% C18:0] + [% C20:0] + [% C21:0] + [% C22:0] + [% C 24:0].
[8] Total monounsaturated fatty acids = [% C14:1] + [% C15:1] + [% C16:1] + [% C17:1] + [% C18:1n9t] + [% C18:1n9c] + [% C18:1n7] + [% C20:1] + [% C24:1].
[9] Total polyunsaturated fatty acids = [% C18:2n6t] + [% C18:2n6c] + [% C18:2 9c, 11t] + [% C18:2 10t, 12c] + [% C18:2 9c, 11c] + [% C18:2 9t, 11t] + [% C18:3n6] + [% C18:3n3].
[10] UFA:SFA = [total MUFA + total PUFA] / total SFA.
[11] PUFA:SFA = total PUFA / total SFA.
[12] Iodine value = [% C16:1] × 0.95 + [% C18:1] × 0.86 + [% C18:2] × 1.732 + [% C18:3] × 2.616 + [% C20:1] × 0.785.
[a,b,c] Within a row, means without a common superscript differ ($P < 0.05$)

Table 10. Interactive effects of diet form and diet type on shoulder fatty acid profile[1]

	Diet form									
	Meal			Pellet				Probability, $P <$		
Item Diet type:	Control[2]	DDGS + midds[3]	Corn oil[4]	Control	DDGS + midds	Corn oil	SEM	Diet form × type	Meal vs. pellet	Diet type
Myristic acid (C14:0), %	1.35	1.28	1.25	1.29	1.22	1.19	0.021	0.956	0.002	0.001
Palmitic acid (C16:0), %	23.82	22.46	22.54	22.96	23.23	22.64	0.244	0.008	0.974	0.008
Palmitoleic acid (C16:1), %	2.58	2.21	2.04	2.13	1.96	1.84	0.058	0.100	0.001	0.001
Margaric acid (C17:0), %	0.28	0.33	0.27	0.30	0.27	0.24	0.013	0.028	0.064	0.004
Stearic acid (C18:0), %	11.64	10.04	10.45	11.81	10.10	10.49	0.196	0.940	0.579	0.001
Oleic acid (C18:1n9c), %	44.45	40.69	40.74	42.36	39.96	40.20	0.307	0.035	0.001	0.001
Vaccenic acid (C18:1n7), %	0.55	0.51	0.42	0.65	0.47	0.37	0.070	0.469	0.891	0.020
Total C18:1 fatty acids[5], %	44.87	41.05	40.93	42.76	40.25	40.37	0.301	0.033	0.001	0.001
Linoleic acid (C18:2n6c), %	12.96	19.65	19.71	16.08	20.01	20.38	0.246	0.001	0.001	0.001
Total C18:2 fatty acids[6], %	13.68	20.55	20.55	16.89	20.96	21.32	0.245	0.001	0.001	0.001
α-Linolenic acid (C18:3n3), %	0.74	0.73	0.69	0.75	0.70	0.67	0.018	0.461	0.366	0.005
Eicosenoic acid (C20:1), %	0.51	0.81	0.81	0.68	0.86	0.85	0.018	0.002	0.001	0.001
Total SFA[7], %	37.09	34.10	34.51	36.37	34.82	34.56	0.282	0.052	0.946	0.001
Total MUFA[8], %	47.96	44.07	43.78	45.57	43.07	43.06	0.329	0.038	0.001	0.001
Total PUFA[9], %	14.55	21.46	21.40	17.73	21.72	22.12	0.244	0.001	0.001	0.001
UFA:SFA[10]	1.69	1.92	1.89	1.74	1.86	1.89	0.023	0.060	0.910	0.001
PUFA:SFA[11]	0.39	0.63	0.62	0.49	0.62	0.64	0.010	0.001	0.001	0.001
Iodine value, mg/g[12]	67.39	75.96	75.53	70.73	75.42	76.14	0.355	0.001	0.001	0.001

[1] All items calculated as a percentage of the total fatty acid content. Fat samples were collected and analyzed by individual pig and used to calculate means per pen.
[2] Corn-soybean meal–based control diet with 0% dried distillers grains with solubles (DDGS), 0% wheat middlings, and 0% corn oil.
[3] Control diet with 30% DDGS and 19% wheat middlings.
[4] Control diet with 3% corn oil.
[5] Total C18:1 fatty acids = [% C18:1n9c] + [% C18:1n7].
[6] Total C18:2 fatty acids = [% C18:2n6t] + [% C18:2n6c] + [% C18:2, 9c11t] + [% 18:2, 10t12c] + [% C18:2, 9c11c] + [C18:2, 9t11t].
[7] Total saturated fatty acids = [% C14:0] + [% C15:0] + [% C16:0] + [% C17:0] + [% C18:0] + [% C20:0] + [% C21:0] + [% C22:0] + [% C 24:0].
[8] Total monounsaturated fatty acids = [% C14:1] + [% C15:1] + [% C16:1] + [% C17:1] + [% C18:1n9t] + [% C18:1n9c] + [% C18:1n7] + [% C20:1] + [% C24:1].
[9] Total polyunsaturated fatty acids = [% C18:2n6t] + [% C18:2n6c] + [% C18:2 9c, 11t] + [% C18:2 10t, 12c] + [% C18:2 9c, 11c] + [% C18:2 9t, 11t] + [% C18:3n6] + [% C18:3n3].
[10] UFA:SFA = [total MUFA + total PUFA] / total SFA.
[11] PUFA:SFA = total PUFA / total SFA.
[12] Iodine value = [% C16:1] × 0.95 + [% C18:1] × 0.86 + [% C18:2] × 1.732 + [% C18:3] × 2.616 + [% C20:1] × 0.785.

Table 11. Main effects of diet form and diet type on shoulder fatty acid profile[1]

	Diet form			Diet type				Probability, $P <$	
Item	Meal	Pellet	SEM	Control[2]	DDGS + midds[3]	Corn oil[4]	SEM	Meal vs. pellet	Diet type
Myristic acid (C14:0), %	1.29	1.23	0.012	1.32[b]	1.25[a]	1.22[a]	0.015	0.002	0.001
Palmitic acid (C16:0), %	22.94	22.95	0.141	23.39[b]	22.85[a]	22.59[a]	0.172	0.974	0.008
Palmitoleic acid (C16:1), %	2.27	1.98	0.033	2.36[c]	2.08[b]	1.94[a]	0.041	0.001	0.001
Margaric acid (C17:0), %	0.29	0.27	0.008	0.29[b]	0.30[b]	0.25[a]	0.010	0.064	0.004
Stearic acid (C18:0), %	10.71	10.80	0.113	11.72[c]	10.07[a]	10.47[b]	0.138	0.579	0.001
Oleic acid (C18:1n9c), %	41.96	40.84	0.177	43.41[b]	40.32[a]	40.47[a]	0.217	0.001	0.001
Vaccenic acid (C18:1n7), %	0.49	0.50	0.040	0.60[b]	0.49[ab]	0.39[a]	0.049	0.891	0.020
Total C18:1 fatty acids[5], %	42.28	41.13	0.174	43.81[a]	40.65[b]	40.65[b]	0.213	0.001	0.001
Linoleic acid (C18:2n6c), %	17.44	18.82	0.142	14.52[a]	19.83[b]	20.04[b]	0.174	0.001	0.001
Total C18:2 fatty acids[6], %	18.26	19.72	0.142	15.28[a]	20.75[b]	20.93[b]	0.174	0.001	0.001
α-Linolenic acid (C18:3n3), %	0.72	0.71	0.010	0.75[b]	0.72[ab]	0.68[a]	0.013	0.366	0.005
Eicosenoic acid (C20:1), %	0.71	0.80	0.011	0.60[a]	0.83[b]	0.83[b]	0.013	0.001	0.001
Total SFA[7], %	35.23	35.25	0.163	36.73[b]	34.46[a]	34.53[a]	0.200	0.946	0.001
Total MUFA[8], %	45.27	43.90	0.190	46.77[b]	43.57[a]	43.42[a]	0.233	0.001	0.001
Total PUFA[9], %	19.13	20.52	0.141	16.14[a]	21.59[b]	21.76[b]	0.172	0.001	0.001
UFA:SFA[10]	1.83	1.83	0.013	1.71[a]	1.89[b]	1.89[b]	0.016	0.91	0.001
PUFA:SFA[11]	0.55	0.58	0.006	0.44[a]	0.63[b]	0.63[b]	0.007	0.001	0.001
Iodine value, mg/g[12]	72.96	74.10	0.205	69.06[a]	75.69[b]	75.83[b]	0.251	0.001	0.001

[1] All items calculated as a percentage of the total fatty acid content. Fat samples were collected and analyzed by individual pig and used to calculate means per pen.
[2] Corn-soybean meal-based control diet with 0% dried distillers grains with solubles (DDGS), 0% wheat middlings, and 0% corn oil.
[3] Control diet with 30% DDGS and 19% wheat middlings.
[4] Control diet with 3% corn oil.
[5] Total C18:1 fatty acids = [% C18:1n9c] + [% C18:1n7].
[6] Total C18:2 fatty acids = [% C18:2n6t] + [% C18:2n6c] + [% C18:2, 9c11t] + [% 18:2, 10t12c] + [% C18:2, 9c11c] + [C18:2, 9t11t].
[7] Total saturated fatty acids = [% C14:0] + [% C15:0] + [% C16:0] + [% C17:0] + [% C18:0] + [% C20:0] + [% C21:0] + [% C22:0] + [% C 24:0].
[8] Total monounsaturated fatty acids = [% C14:1] + [% C15:1] + [% C16:1] + [% C17:1] + [% C18:1n9t] + [% C18:1n9c] + [% C18:1n7] + [% C20:1] + [% C24:1].
[9] Total polyunsaturated fatty acids = [% C18:2n6t] + [% C18:2n6c] + [% C18:2 9c, 11t] + [% C18:2 10t, 12c] + [% C18:2 9c, 11c] + [% C18:2 9t, 11t] + [% C18:3n6] + [% C18:3n3].
[10] UFA:SFA = [total MUFA + total PUFA] / total SFA.
[11] PUFA:SFA = total PUFA / total SFA.
[12] Iodine value = [% C16:1] × 0.95 + [% C18:1] × 0.86 + [% C18:2] × 1.732 + [% C18:3] × 2.616 + [% C20:1] × 0.785.
[a,b,c] Within a row, means without a common superscript differ ($P < 0.05$).

Influence of Dietary Fat Source and Feeding Duration on Pig Growth Performance, Carcass Composition, and Fat Quality[1]

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Summary

A total of 160 finishing pigs (PIC 327 × 1050; initially 100.5 lb) were used in an 84-d experiment to evaluate the effects of dietary fat source and feeding duration on growth performance, carcass characteristics, and fat quality. Dietary treatments included a corn-soybean meal control diet with no added fat or a 3 × 3 factorial with main effects of fat source (4% tallow, 4% soybean oil, or a blend of 2% tallow and 2% soybean oil) and feeding duration (d 0 to 42, 42 to 84, or 0 to 84). One pig was identified in each pen on d 0, and biopsy samples of the back, belly, and jowl fat were collected on d 0, 41, and 81. At the conclusion of the study, all pigs were harvested, carcass characteristics were measured, and back, belly, and jowl fat samples were collected. Overall (d 0 to 84), there were no differences between fat sources for growth and carcass characteristics; however, pigs fed diets with added fat from d 0 to 84 had improved ($P < 0.036$) F/G compared with pigs fed a control diet without added fat. Pigs fed added fat throughout the entire study also had improved ($P < 0.042$) ADG and F/G and heavier d-84 BW ($P < 0.006$) compared with pigs fed additional fat for only period 1 or 2. Adding fat for the entire study increased ($P < 0.032$) backfat and tended to reduce ($P < 0.083$) fat-free lean index compared with pigs fed the control diet without added fat. Added fat also increased ($P < 0.05$) iodine value (IV) compared with pigs fed the control diet. Increasing the feeding duration of soybean oil or a blend of soybean oil and tallow decreased monounsaturated and increased polyunsaturated fatty acids relative to feeding tallow (duration × fat source interaction, $P < 0.05$), with the greatest changes in C18:1 and C18:2, respectively. In conclusion, feeding added fat improved ADG and F/G; however, feeding soybean oil for increasing duration, either alone or in a blend with tallow, negatively affected the fatty acid composition and IV of finishing pigs.

Key words: finishing pig, iodine value, fat, feeding duration

Introduction

Iodine value (IV) is commonly used by pork processors to evaluate pork fat quality. Measuring IV provides processors with an indication of the amount of unsaturated fatty acids present in fat. Processors that are measuring IV target a value of 73 to 75g/100 g (Benz et al., 2010[3]), and carcasses exceeding these values are generally discounted in price.

[1] Funding, wholly or in part, was provided by the National Pork Board.
[2] Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University.
[3] Benz, J.M., S.K. Linneen, M.D. Tokach, S.S. Dritz, J. L. Nelssen, J.M. DeRouchey, R.D. Goodband, R.C. Sulabo, and K.J. Prusa. 2010. Effects of dried distillers grains with solubles on carcass fat quality of finishing pigs. J. Anim. Sci. 88:3666-3682.

Feeding different dietary fat sources as well as ingredients high in unsaturated fat such as dried distillers grains with solubles (DDGS) has been shown to affect IV. When feeding a diet high in unsaturated fat sources, carcass fat quality as measured by IV will decrease (Asmus et al., 2011[4]). It has been shown that removing unsaturated fat sources in late finishing diets can partially alleviate some of the negative effects on pork fat quality. Adding a saturated fat source such as beef tallow in late finishing diets also has been shown to positively affect IV (Browne et al., 2013[5]).

Therefore, this study was conducted to determine the effects of feeding soybean oil, beef tallow, or a blend of the two as well as feeding duration of the dietary fat sources on finishing pig growth performance, carcass characteristics, and IV of belly, jowl, and backfat.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. Pigs were housed at the Kansas State University Swine Teaching and Research Center finishing barn. The building is an environmentally controlled facility with 5 × 5-ft pens with totally slatted flooring. Each pen is equipped with a dry self-feeder and a nipple waterer to provide ad libitum access to feed and water. Upon placement in the barn, pigs were fed a corn-soybean meal–based diet without added fat for 1 wk prior to the start of the experiment.

A total of 160 finishing pigs (PIC 327 × 1050; average initial BW of 100.5 lb) were used in an 84-d study. Pens of pigs were blocked by sex and BW and allotted to 1 of 10 dietary treatments, with 2 barrows or 2 gilts per pen with a total of 8 pens per treatment. Dietary treatments consisted of a corn-soybean meal control diet with no added fat or a 3 × 3 factorial arrangement with main effects of fat source (4% tallow, 4% soybean oil, or a blend of 2% tallow and 2% soybean oil) and feeding duration (d 0 to 42, 42 to 84, or 0 to 84; Table 1). Pigs were fed the control corn-soybean meal diet when not fed diets containing added fat. Soybean oil, tallow, or a blend of the two was added to provide diets with a range of unsaturated and saturated fatty acid concentrations. Samples of the complete diets were analyzed for chemical composition (Table 2), and soybean oil, tallow, and their blend were analyzed for fatty acid profiles (Table 3). Diets were formulated and fed in 3 phases (d 0 to 28, 28 to 56, and 56 to 84. A constant standardized ileal digestible lysine:NE ratio was maintained within each phase by increasing soybean meal in the basal diet when adding fat. Dietary treatments were prepared at the K-State O.H. Kruse Feed Technology Innovation Center.

Pigs and feeders were weighed approximately every 2 wk to calculate ADG, ADFI, and F/G. Pigs were individually tattooed prior to marketing so carcass measurements could be collected. On d 84, pigs were transported to Natural Foods Holdings (Sioux Center, IA) for harvest. Carcass measurements taken at the plant included HCW, loin depth, and backfat thickness.

[4] Asmus et al., Swine Day 2011. Report of Progress 1056, pp. 202-215.
[5] Browne, N.A., J.K. Apple, C.V. Maxwell, J.W. Yancey, T.M. Johnson, D.L. Galloway, and B.E. Bass, 2013. Alternating dietary fat sources for growing-finishing pigs fed dried distillers grains with solubles: II. Fresh belly and bacon quality characteristics. J. Anim. Sci. 91:1509–1521.

One pig from every pen was selected, and fat biopsy samples were collected and analyzed for fatty acid profile and IV on d 0, 41, and 81. For sample collection, pigs were restrained, the hair was clipped in each location (jowl, belly, and loin), and 1 mL of Lidocaine was administered to the sample location. After adequate time was given for the biopsy site to be desensitized, an 8-gauge needle was used to pierce the skin, and a 10-gauge needle biopsy needle was used to collect approximately 250 mg of fat tissue per biopsy site. Fat tissue samples were snap-frozen in liquid nitrogen, then stored in a -80°F freezer until analysis.

Fatty acid profiles were analyzed by mixing 0.025 g of fat with 2 mL of benzene containing methyl tridecanoate as an internal standard (2 mg/mL of benzene, Fluka 91558) and 3 mL methanolic-HCl, then flushed with nitrogen. Tubes were then capped, vortexed, and heated for 2 h at 70°C. Tubes were vortexed every 30 min during the 2-h period. Tubes were then cooled to room temperature, mixed with 5 mL 6% K_2CO_3 and 2 mL benzene, vortexed, then centrifuged at 500 × g for 5 min. The organic solvent layer was then analyzed by gas chromatography. An Agilent gas chromatograph (model 7890A, Santa Clara, CA) equipped with a HP-88 J&W Agilent GC capillary column (30 m × 0.25 mm × 0.20 μm film) was used for the analysis. The injection temperature was 250°C, the split ratio was 1:100, and the flame-ionization detector was set at 280°C and used hydrogen (35 mL/min), air (400 mL/min), makeup helium (25 mL/min), and helium carrier gas at constant flow (0.91 mL/min). The oven temperature program was set as follows: initial temperature of 80°C, hold 1 min, increase 14°C/min to 240°C, and hold 3 min. Supelco 37 Component FAME Mix (47885-U Supelco, Sigma-Aldrich) was used as a standard.

All data were analyzed as a randomized complete block design using the MIXED procedure in SAS (SAS Institute Inc., Cary, NC) with pen as the experimental unit. Pens were blocked by BW within sex. Block was included as a random effect, and fixed effects included sex, fat source, feeding duration, and all interactions. Hot carcass weight was used as a covariate for backfat, loin depth, and lean percentage. Statistical significance was determined at $P < 0.05$, and P-values falling within $P > 0.05$ and $P < 0.10$ were defined as a trend or tendency.

Results

Growth and carcass characteristics

From d 0 to 42 (period 1), pigs fed added fat had increased ($P = 0.005$) ADG and improved ($P = 0.001$) F/G compared with pigs fed the control diets without added fat (Table 4). Pigs fed diets with added tallow or soybean oil had improved ($P \leq 0.002$) F/G compared with pigs fed a diet containing a blend of soy oil and tallow.

From d 42 to 84 (period 2), pigs fed added dietary fat tended ($P = 0.052$) to have increased ADG and had improved F/G ($P < 0.001$) compared with those fed diets not containing added fat. No differences were observed among fat sources during period 2.

Overall (d 0 to 84), pigs fed added fat in both period 1 and 2 had increased ($P = 0.018$) ADG and improved ($P = 0.042$) F/G as well as greater final BW ($P = 0.006$) compared with pigs fed added fat only during a single period. In addition, pigs fed fat in both periods had improved ($P = 0.036$) F/G compared with pigs fed the control diet without

added fat. Pigs fed diets with soybean oil tended to have improved ($P = 0.092$) F/G vs. those fed the diet containing a blend of soybean oil and tallow.

For carcass characteristics, adding fat in both periods increased ($P = 0.032$) backfat depth and tended to reduce ($P = 0.083$) fat-free lean index (FFLI) compared with pigs fed diets with no added fat. No differences were detected in HCW, percentage yield, or longissimus muscle area among treatments.

Fatty acid composition

Backfat. A feeding duration × fat source interaction ($P < 0.030$) was observed for C18:1, C18:2, C18:3, SFA, MUFA, and PUFA for pigs fed tallow vs. soybean oil and for C18:2, C18:3, C20:1, MUFA, and PUFA for pigs fed soybean oil vs. the blend of soybean oil and tallow (Table 5). In both of these interactions, MUFA was decreased but PUFA was increased by the addition of soybean oil, whereas the opposite effect was observed for those fed beef tallow. A feeding duration × fat source (tallow vs. a blend of soybean oil and tallow) interaction ($P < 0.009$) was also observed for C18:2, C18:3, and PUFA because the unsaturated fatty acids were increased to a greater extent in the blend of soybean oil and tallow than in tallow alone. Feeding period × fat source interactions ($P < 0.010$) were observed for C18:2, C18:3, MUFA, and PUFA for PUFA for the blend vs. soybean oil and tallow vs. soybean oil. For tallow vs. soybean oil, the interaction ($P < 0.004$) also was observed for C18:1 and C20:1. These interactions were a result of pigs fed soybean oil from d 42 to 84 having a greater increase in PUFA and reduction in MUFA on d 84 than when fed soybean oil from d 0 to 42, whereas feeding tallow or a blend of soybean oil and tallow had a similar impact on MUFA and PUFA, regardless of period fed. Adding 4% fat increased ($P < 0.05$) C18:2, C18:3, C20:1, C22:5n3, and PUFA and decreased ($P < 0.05$) C16:1, C18:1, SFA and MUFA compared with pigs fed the control diet during both periods. Feeding a blend of soybean oil and tallow decreased ($P < 0.05$) C16:1, C18:1, SFA, and MUFA on both d 42 and 84 and C18:3 on d 84 compared with those fed tallow. Feeding the blend of soybean oil and tallow also increased ($P < 0.05$) concentrations of C18:2, C18:3, and PUFA on both d 42 and 84 compared with pigs fed tallow. Feeding soybean oil decreased ($P < 0.05$) C18:1, SFA, and MUFA on both d 42 and 84 but only decreased ($P < 0.05$) C16:1 and C20:1 when fed for 84 d compared with those fed the blend of soybean oil and tallow. Increases ($P < 0.05$) in C18:2, C18:3, and PUFA concentrations were observed on both d 42 and 84 for pigs fed soybean oil vs. the blend of soybean oil and tallow. In addition, pigs fed soybean oil had decreased ($P < 0.05$) concentrations of C16:1, C18:1, C20:1, SFA, and MUFA on both d 42 and 84 vs. those fed tallow. Similar to other comparisons, C18:2, C18:3, and PUFA increased ($P < 0.05$) on both d 42 and 84 for pigs fed soybean oil vs. tallow. C22:5n3 also increased ($P < 0.05$) on d 84 when pigs were fed soybean oil vs. tallow.

Belly fat. Feeding duration × fat source interactions ($P < 0.05$) occurred for tallow vs. the blend of soybean oil and tallow and the blend vs. soybean oil for C18:2, C18:3, and PUFA (Table 6). An interaction was also observed for tallow vs. soybean oil for C18:1, C18:2, C18:3, SFA, MUFA, and PUFA. These interactions were a result of elevated PUFA and decreased SFA and MUFA, with increasing feeding duration of soybean oil relative to other fat sources. A feeding period × fat source (tallow vs. soybean oil) interaction ($P < 0.05$) was observed for C18:1, C18:2, C18:3, C20:1, MUFA, and

PUFA. These were driven by decreased MUFA and increased PUFA levels in pigs fed soybean oil relative to pigs fed tallow. A feeding period × fat source (blend of soybean oil and tallow vs. soybean oil) interaction ($P < 0.05$) was observed for C18:2, C18:3, and PUFA, which again was due to increased concentrations in pigs fed soybean oil vs. the blend of soybean oil and tallow. Pigs fed the blend of soybean oil and tallow had a greater increase in C18:3 than those fed tallow (feeding period × fat source interaction, $P = 0.001$). Adding 4% fat increased ($P < 0.05$) C18:2, C18:3, MUFA, and PUFA and decreased ($P < 0.05$) C16:1, C18:1, and SFA for both periods compared with those fed the control diet without added fat. In addition, C20:1 decreased ($P < 0.05$) in pigs fed 4% fat compared with the control diet without fat. Feeding the blend of soybean oil and tallow increased ($P < 0.05$) C18:2, C18:3, and PUFA on both d 42 and 84 and C22:5n3 on d 42 compared with pigs fed tallow. Feeding the blend of soybean oil and tallow decreased ($P < 0.05$) C16:1, C18:1, and MUFA on both d 42 and 84 and decreased C20:1 on d 42 compared with those fed tallow. Feeding soybean oil decreased ($P < 0.05$) C18:1 and MUFA but increased ($P < 0.05$) C18:2, C18:3, and PUFA on both d 42 and 84 and increased C20:1 and SFA on d 84 compared with pigs fed the blend of soybean oil and tallow. Feeding soybean oil also decreased ($P < 0.05$) C16:1, C18:1, C20:1, and MUFA and increased ($P < 0.05$) C18:2, C18:3, C22:5n3, and PUFA on both d 42 and 84 and decreased SFA on d 84 compared with feeding tallow.

Jowl fat. A feeding duration × fat source interaction ($P < 0.05$) was observed among pigs fed tallow vs. soybean oil for C18:2, C18:3, C22:5n3, SFA, MUFA, and PUFA and for the blend of soybean oil and tallow vs. soybean oil for C18:2, C18:3, C20:1, and PUFA (Table 7). These interactions were driven by the elevated concentrations of PUFA and reduced levels of MUFA and SFA with increasing feeding duration for soybean oil relative to other fat sources. For C18:3, feeding duration × fat source interactions ($P = 0.001$) were observed for tallow vs. the blend of soybean oil and tallow. A feeding period × fat source interaction also was observed for the blend of soybean oil and tallow vs. soybean oil as well as tallow vs. soybean oil. This was the result of a greater increase in C18:3 concentration in pigs fed soybean oil relative to tallow or the blend of soybean oil and tallow. Pigs fed tallow had a greater increase in C20:1 than pigs fed soybean oil (feeding period × fat source interaction, $P = 0.017$). Adding 4% fat increased ($P < 0.05$) C16:1, C18:2, C18:3, C22:5n3, and PUFA and decreased ($P < 0.05$) SFA and MUFA on both d 42 and 84 and decreased ($P < 0.05$) total C18:1 on d 42 compared with pigs fed the control diet. Feeding the blend of soybean oil and tallow increased ($P < 0.05$) C18:2, C18:3, C22:5n3, and PUFA and decreased C18:1 and MUFA on both d 42 and 84 and decreased ($P < 0.05$) C20:1 on d 84 compared with tallow. Feeding soybean oil decreased ($P < 0.05$) C18:1 and MUFA for both d 42 and 84 but decreased C20:1 only for d 84 compared with pigs fed the blend of soybean oil and tallow. Conversely, feeding soybean oil increased ($P < 0.05$) C18:2, C18:3, C22:5n3, and PUFA concentrations compared with pigs fed the blend of soybean oil and tallow. Feeding soybean oil decreased ($P < 0.05$) C16:1, C18:1, C20:1, and MUFA on both d 42 and 84 and SFA on d 84 and increased ($P < 0.05$) C18:2, C18:3, C22:5n3 and PUFA on both d 42 and 84 compared with pigs fed tallow.

Iodine value

Backfat. Pigs fed diets containing 4% added fat had increased ($P < 0.05$) backfat IV compared with those fed the control diet, but the increase in backfat IV was dependent on dietary fat source, duration of feeding (84 d vs. 42 d), and the period that the fat was fed (d 0 to 42 vs. d 42 to 84; Table 5). Fat source × feeding duration interactions occurred for tallow vs. the blend of soybean oil and tallow ($P = 0.038$), tallow vs. soybean oil ($P = 0.001$), and soybean oil vs. the blend of soybean oil and tallow ($P = 0.003$). When feeding fat for 84 d compared with 42 d, pigs fed soybean oil had an IV increase of 8.5 g/100 g, whereas pigs fed the blend of soybean oil and tallow had a 4.0 g/100 g increase. The feeding duration of tallow did not affect IV. The more unsaturated the diet fed to pigs, the greater the increase in IV when increasing feeding duration from 42 to 84 d. The fat source × feeding period interactions ($P < 0.007$) occurred for tallow vs. soybean oil and soybean oil vs. the blend of soybean oil and tallow. Pigs fed tallow from d 0 to 42 had backfat IV similar to those fed tallow from d 42 to 84. Pigs fed the blend of soybean oil and tallow from d 0 to 42 had backfat IV similar to those fed the blend from d 42 to 84; however, pigs fed soybean oil from d 0 to 42 had 6 g/100 g lower backfat IV than those fed soybean oil from d 42 to 84. Therefore, the period in which the fat was fed (d 0 to 42 vs. 42 to 84) influenced IV only when feeding soybean oil. For pigs fed fat from d 0 to 84, the blend of soybean oil and tallow or soybean oil increased backfat IV by 7.2 and 15.4 g/100 g, respectively, compared with those fed tallow. For pigs fed fat from d 0 to 42 and then the control diet from d 42 to 84, soybean oil and the blend of soybean oil and tallow increased backfat IV by 4.1 and 3.0 g/100 g, respectively, compared with those fed tallow. For pigs fed the control diet from d 0 to 42 and then added fat from d 42 to 84, soybean oil and the blend of soybean oil and tallow increased backfat IV by 11.2 and 5.0 g/100 g, respectively, compared with those fed tallow.

Belly fat. Pigs fed diets containing 4% added fat had increased ($P < 0.05$) belly fat IV compared with those fed a control diet (Table 6). Similar to backfat, belly fat IV was dependent on dietary fat source, duration of feeding (84 d vs. 42 d), and the period that the fat was fed (d 0 to 42 vs. d 42 to 84). A fat source × feeding duration interaction was observed for the blend of soybean oil and tallow vs. soybean oil ($P = 0.004$) and tallow vs. soybean oil ($P = 0.001$). There was also a tendency ($P = 0.081$) for a tallow vs. blend of soybean oil and tallow × feeding duration interaction. When fed fat for 84 vs. 42 d, IV pigs fed soybean oil had a 6.2 g/100 g increase and 2.5 g/100 g in pigs fed the blend of soybean oil and tallow. Feeding duration did not affect IV in pigs fed tallow. A fat source × feeding period interaction ($P < 0.022$) occurred for both tallow vs. soybean oil and the blend vs. soybean oil. Pigs fed tallow or the blend from d 0 to 42 had belly fat IV similar to pigs fed a similar diet from d 42 to 84; however, pigs fed soybean oil from d 0 to 42 had a 3.6 g/100 g lower belly fat IV than pigs fed soybean oil from d 42 to 84. Therefore, similar to backfat, period influenced IV only when pigs were fed soybean oil. Feeding the blend of soybean oil and tallow or soybean oil from d 0 to 84 increased IV by 5.3 and 12.2 g/100 g, respectively, compared with pigs fed tallow. For pigs fed fat from d 0 to 42 and the control diet from d 42 to 84, soybean oil and the blend of soybean oil and tallow increased belly fat IV by 4.0 and 2.4 g/100 g, respectively, compared with those fed tallow. Conversely, for pigs fed the control diet from d 0 to 42 and then fed added fat from d 42 to 84, the blend of soybean oil and tallow and soybean oil increased belly fat IV by 3.9 and 8.9 g/100 g, respectively, compared with those fed tallow.

Jowl fat. Similar to both belly fat and backfat, pigs fed 4% added fat had increased ($P < 0.05$) jowl fat IV compared with pigs fed the control diet (Table 7). Fat source × feeding duration interactions were observed for the blend of soybean oil and tallow vs. soybean oil ($P = 0.005$) and for tallow vs. soybean oil ($P = 0.001$). There was also a trend ($P = 0.067$) for a fat source × feeding duration interaction for tallow vs. the blend of soybean oil and tallow. When pigs were fed added fat for 84 vs. 42 d, IV increased 5.5 g/100 g in pigs fed soybean oil and 2.3 g/100 g in pigs fed the blend, whereas duration of feeding did not affect IV in pigs fed tallow. No interaction was found for fat source × feeding period between any treatments for jowl fat IV. Feeding the blend of soybean oil and tallow or soybean oil from d 0 to 84 increased jowl fat IV by 4.7 and 10.8 g/100 g, respectively, compared with pigs fed tallow. For pigs fed fat from d 0 to 42 and the control diet from d 42 to 84, the blend of soybean oil and tallow or soybean oil increased jowl fat IV by 2.2 and 4.5, respectively, compared with those fed tallow. For pigs fed the control diet from d 0 to 42 then fed added fat from d 42 to 84, the blend of soybean oil and tallow or soybean oil increased jowl fat IV by 2.9 and 6.2 g/100 g, respectively, compared with those fed tallow.

Discussion

Adding fat from d 0 to 42 or 42 to 84 increased ADG and improved F/G compared with pigs fed no fat from d 0 to 84. Added fat from d 0 to 84 increased backfat depth, which tended to reduce the carcass FFLI. Similar improvements in ADG and F/G were observed among pigs when feeding either soybean oil, tallow, or their blend.

As previous data suggest, C18:2 increased as soybean oil was added to diets, which resulted in an increase in PUFA. As PUFA increased, IV increased within each fat depot. Conversely, as soybean oil was added to diets, C18:1 decreased, which lowered MUFA for all individual fat depots. Pigs fed diets containing the blend of soybean oil and tallow had similar responses, but not to the extent of the pigs fed only soybean oil. Pigs fed tallow had the least change in fatty acids and IV compared with pigs fed the other fat sources.

Jowl fat, unlike the other two depots, did not show a period effect for IV when adding dietary fat. The lack of a period effect for jowl fat is reflective of the slow turnover rate of this fat depot. Interestingly, tallow did not affect SFA levels in fat depots. Because neither MUFA nor PUFA were significantly affected by tallow compared with a control diet, IV values were not significantly altered by tallow. Therefore, feeding tallow can improve rate of gain and feed efficiency without affecting IV. Feeding soybean oil also can improve both ADG and feed efficiency, but it negatively affects fatty acid composition and IV. This negative impact can be improved by utilizing a withdrawal strategy, but IV levels remain above controls even after a long-term withdrawal of 42 d.

Table 1. Phase 1, 2 and 3 diet composition (as-fed basis)[1]

	Phase 1		Phase 2		Phase 3	
Item	Control	Added fat	Control	Added fat	Control	Added fat
Ingredient, %						
Corn	76.40	69.40	80.70	74.10	84.00	77.70
Soybean meal, 46.5% CP	20.95	23.90	17.00	19.60	14.00	16.25
Fat source[2]	---	4.00	---	4.00	---	4.00
Monocalcium P, 21% P	0.49	0.48	0.38	0.38	0.31	0.31
Limestone	1.05	1.05	1.00	1.00	0.90	0.90
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.15	0.15	1.00	1.00	0.08	0.08
Trace mineral premix	0.15	0.15	0.35	0.35	0.08	0.08
L-lysine HCl	0.28	0.28	0.23	0.23	0.20	0.20
DL-methionine	0.05	0.07	0.01	0.03	---	---
L-threonine	0.08	0.09	0.05	0.65	---	---
Phytase[3]	0.08	0.08	0.08	0.08	0.08	0.08
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis						
Standard ileal digestible (SID) amino acids, %						
Lysine	0.91	0.98	0.78	0.83	0.68	0.73
Isoleucine:lysine	63	63	66	65	67	67
Leucine:lysine	143	138	157	150	168	160
Methionine:lysine	32	32	29	30	31	31
Met & Cys:lysine	58	58	58	58	61	60
Threonine:lysine	63	63	64	64	65	65
Tryptophan:lysine	18	18	18	18	18	18
Valine:lysine	71	70	75	74	78	76
SID lysine:NE, g/Mcal	3.65	3.65	3.08	3.08	2.68	2.68
ME, kcal/lb	1,497	1,590	1,502	1,595	1,507	1,600
NE, kcal/lb	1,130	1,211	1,143	1,225	1,154	1,236
Total lysine, %	1.03	1.10	0.88	0.94	0.78	0.83
CP, %	16.6	17.5	15.0	15.7	13.8	14.4
Ca, %	0.54	0.55	0.50	0.50	0.44	0.45
P, %	0.45	0.45	0.41	0.41	0.38	0.38
Available P, %	0.26	0.26	0.24	0.24	0.22	0.22
Crude fiber, %	2.3	2.3	2.3	2.2	2.2	2.2

[1] Phase 1, 2, and 3 diets were fed from d 0 to 28, d 28 to 56, and d 56 to 84, respectively.
[2] Fat sources were either tallow, soybean oil, or a blend of 2% tallow and 2% soybean oil.
[3] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 204.3 phytase units (FTU)/lb, with a release of 0.11% available P.

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

	Phase 1[2]				Phase 2[2]				Phase 3[2]			
Item, %[3]	Control	Tallow	Blend	Soy	Control	Tallow	Blend	Soy	Control	Tallow	Blend	Soy
Moisture	10.07	9.33	9.97	10.01	10.32	10.01	10.01	10.29	10.48	9.77	10.47	10.25
DM	89.93	90.67	90.03	89.99	89.68	89.99	89.99	89.71	89.52	90.23	89.53	89.75
CP	17.9	18.7	17.5	18.3	16.1	16	16.3	16.7	15	15.2	15.3	14.9
ADF	2.6	3.6	3.3	3.4	3.3	3.2	3.0	3.4	1.9	2.4	2.8	2.3
NDF	6.5	8.0	8.0	6.6	5.9	5.2	6.0	5.4	7.1	8.4	8.4	6.8
Crude fiber	1.9	2.7	2.9	2.4	1.5	2.4	2.4	2.1	2	2.5	2.9	2.5
NFE	63.1	58.2	59.4	58.2	65	61.5	60.9	61.4	66.3	62.1	62.3	63
Fat	3.0	6.7	6.2	6.5	2.3	6.3	6.7	5.5	3.1	7.1	5.9	6.4
Ash	3.85	4.2	4.27	4.29	3.65	3.64	3.71	3.37	3.64	3.87	3.78	3.59
Starch	47.1	37.8	40.9	42.1	51.5	47.5	45.6	48.2	49.8	43.1	43.5	45.1

[1] Phase 1, 2, and 3 diets were fed from d 0 to 28, d 28 to 56, and d 56 to 84, respectively.
[2] Control = no added fat; tallow = 4% beef tallow; soy = 4% soybean oil; blend = 2% soybean oil and 2% tallow.
[3] Values represent the mean of one composite sample of each diet.

Table 3. Fatty acid analysis of ingredients and treatment diets

			Diets[1]											
	Ingredients		Phase 1				Phase 2				Phase 3			
Item	Tallow	Soy oil	Control	Tallow	Blend	Soy	Control	Tallow	Blend	Soy	Control	Tallow	Blend	Soy
Myristic acid (C14:0), %	2.94	0.08	0.06	1.51	0.81	0.09	0.09	1.56	0.94	0.09	0.05	1.52	1.09	0.08
Palmitic acid (C16:0), %	24.09	9.61	16.83	20.78	16.92	12.85	16.78	21.06	17.42	13.59	16.17	20.80	18.38	13.36
Palmitoleic acid (C16:1), %	3.77	0.11	0.15	1.91	1.14	0.14	0.20	1.99	1.28	0.13	0.14	1.98	1.38	0.12
Stearic acid (C18:0), %	16.91	4.34	2.48	10.49	7.00	3.68	2.56	10.50	7.87	3.89	2.01	10.40	8.85	3.86
Oleic acid (C18:1 *cis*-9), %	38.38	24.52	20.99	28.51	25.88	23.06	21.61	29.70	25.63	21.47	22.45	28.71	26.15	21.79
Linoleic acid (C18:2n-6), %	5.07	51.80	51.11	27.36	39.08	50.77	50.31	26.32	36.98	50.42	52.14	27.12	35.17	50.60
α-linoleic acid (C18:3n-3), %	0.32	6.81	2.31	1.45	3.01	4.71	2.47	1.41	3.80	6.07	2.07	1.61	2.94	5.99
Arachidic acid (C20:0), %	0.16	0.33	0.43	0.27	0.33	0.38	0.39	0.25	0.29	0.36	0.37	0.26	0.29	0.37
Gadoleic acid (C20:1), %	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other fatty acids, %	8.10	2.40	5.63	7.70	5.83	4.33	5.60	7.21	5.79	3.98	4.61	7.59	5.75	3.82
Total SFA, %[2]	45.72	15.10	24.24	36.48	28.13	19.79	24.19	36.20	29.27	20.50	22.24	36.03	31.20	20.14
Total MUFA, %[3]	47.57	26.04	22.15	34.10	29.34	24.48	22.86	35.45	29.53	22.82	23.43	34.61	30.26	23.09
Total PUFA, %[4]	6.71	58.86	53.61	29.43	42.52	55.73	52.96	28.35	41.20	56.68	54.33	29.36	38.54	56.77
UFA:SFA ratio[5]	1.19	5.62	3.13	1.74	2.55	4.05	3.13	1.76	2.42	3.88	3.50	1.78	2.21	3.97
PUFA:SFA ratio[6]	0.15	3.90	2.21	0.81	1.51	2.82	2.19	0.78	1.41	2.76	2.44	0.81	1.24	2.82
Iodine value, g/100 g[7]	49.94	129.89	113.41	80.22	100.67	121.15	112.96	79.47	99.27	122.72	115.69	80.52	94.37	123.05
Analyzed IVP[8]	499.44	1298.85	34.02	53.75	62.41	78.75	25.98	50.07	66.51	67.49	35.86	57.17	55.68	78.75

[1] Control = no added fat; tallow = 4% beef tallow; soy = 4% soybean oil; blend = 2% tallow and 2% soybean oil.
[2] Total SFA = ([C6:0] + [C8:0] + [C10:0] + [C11:0] + [C12:0] + [C14:0] + [C15:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C21:0] + [C22:0] + [C23:0] + [C24:0]); brackets indicate concentration.
[3] Total MUFA = ([C14:1] + [C15:1] + [C16:1] + [C18:1*n99*] + [C18:1n9t] + [C18:1n11t] + [C18:1n11c] + [C20:1] + [C22:1n9] + [C24:1]); brackets indicate concentration.
[4] Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [CLA 9c11t] + [CLA10t, 12c] + [CLA9c,11c] + [CLA9t, 11t] + [C20:3n6] + [C20:3n3] + [C22:2] +[C20:5n3] +[C22:5n3] + [C22:6n3]; brackets indicate concentration.
[5] UFA:SFA = (total MUFA+PUFA)/ total SFA.
[6] PUFA:SFA = total PUFA/ total SFA.
[7] Calculated as IV value (IV) = [C16:1] × 0.950 + [C18:1] × 0.860 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C20:4] × 3.201 + [C22:1] × 0.723 + [C22:5] × 3.697 + [C22:6] × 4.463; brackets indicate concentration.
[8] Iodine value of dietary lipids calculated from analyzed fatty acid composition × % analyzed dietary lipids × 0.10.

Table 4. Effects of added fat source and feeding duration on finishing pig growth performance and carcass characteristics[1]

Treatment[2]:	A	B	C	D	E	F	G	H	I	J							
d 0 to 42:	Control	Tallow	Tallow	Control	Blend	Blend	Control	Soy	Soy	Control		Contrasts[3,4,5,6], $P <$					
d 42 to 84:	Control	Tallow	Control	Tallow	Blend	Control	Blend	Soy	Control	Soy	SEM	1	2	3	4	5	6
BW, lb																	
d 0	100.6	100.7	100.5	100.5	101.1	100.0	100.9	100.5	100.3	100.2	2.42	0.844	0.492	0.659	0.902	0.606	0.695
d 42	186.2	191.6	193.0	187.8	188.8	186.8	185.2	191.4	188.3	182.6	4.11	0.179	0.089	0.067	0.078	0.832	0.121
d 84	286.3	292.0	291.4	287.2	295.7	283.6	283.9	295.7	287.2	286.1	5.59	0.089	0.006	0.606	0.444	0.553	0.864
d 0 to 42																	
ADG, lb	2.03	2.17	2.20	2.08	2.10	2.06	2.02	2.17	2.09	1.97	0.06	0.005	-	-	0.067	0.345	0.372
ADFI, lb	5.06	5.11	5.18	5.38	5.24	5.09	5.06	5.16	4.97	4.89	0.14	0.752	-	-	0.910	0.447	0.519
F/G	2.50	2.36	2.35	2.59	2.51	2.49	2.51	2.38	2.37	2.49	0.05	0.001	-	-	0.002	0.008	0.607
d 42 to 84																	
ADG, lb	2.39	2.39	2.34	2.37	2.48	2.31	2.35	2.48	2.31	2.46	0.07	0.052	-	-	0.586	0.362	0.145
ADFI, lb	7.09	6.82	7.11	6.92	7.15	6.82	6.61	7.01	7.07	6.68	0.19	0.177	-	-	0.967	0.863	0.895
F/G	2.95	2.84	3.04	2.92	2.90	2.97	2.81	2.82	3.05	2.73	0.06	0.001	-	-	0.713	0.218	0.112
d 0 to 84																	
ADG, lb	2.21	2.28	2.27	2.22	2.27	2.18	2.19	2.33	2.19	2.21	0.05	0.134	0.018	0.842	0.219	0.384	0.718
ADFI, lb	6.08	5.97	6.15	6.15	6.13	5.95	5.84	6.09	5.97	5.78	0.15	0.924	0.372	0.401	0.301	0.803	0.202
F/G	2.75	2.61	2.70	2.77	2.70	2.75	2.66	2.61	2.72	2.62	0.04	0.036	0.042	0.294	0.732	0.092	0.176
Carcass characteristics																	
HCW, lb	214.4	218.6	217.2	212.8	213.0	212.9	216.1	216.4	215.5	213.1	5.5	0.801	0.717	0.787	0.631	0.822	0.798
Yield, %	74.6	74.1	74.5	73.8	74.1	74.5	74.5	74.2	74.3	74.5	0.5	0.455	0.548	0.671	0.510	0.950	0.552
LEA,[7] in.[2]	9.27	9.28	9.70	9.30	9.50	9.32	9.43	9.21	9.61	9.39	0.37	0.859	0.550	0.493	0.971	0.957	0.928
BF,[7] in.	0.67	0.76	0.77	0.73	0.88	0.82	0.77	0.86	0.71	0.76	0.06	0.032	0.125	0.763	0.166	0.336	0.665
FFLI,[8] %	56.74	55.85	56.24	56.18	54.77	55.11	55.79	54.74	56.72	55.97	0.83	0.083	0.121	0.946	0.189	0.373	0.667

[1] A total of 160 finishing pigs (PIC 337 × 1050, initial BW of 100.5 lb) were used in an 84-d finishing trial with 2 pigs per pen and 8 pens per treatment.

[2] Control = no added fat; tallow = 4% beef tallow; soy = 4% soybean oil; blend = 2% tallow and 2% soybean oil

[3] There were no fat × fat source interactions $P > 0.05$.

[4] The period 1 (d 0 to 42) contrast statements are as follows: 1 = no added fat vs. added fat (treatments A, D, G, J vs. B, C, E, F, H, I); 4 = tallow vs. blend (treatments B and C vs. E and F); 5 = blend vs. soy oil (treatments E and F vs. H and I); 6 = tallow vs. soy oil (treatments B and C vs. H and I).

[5] The period 2 (d 42 to 84) contrast statements are as follows 1 = no added fat vs. added fat (treatments A, C, F, I vs. B, D, E, G, H, J); 4 = tallow vs. blend (treatments B and D vs. E and G); 5 = blend vs. soy oil (treatments E and G vs. H and J); 6 = tallow vs. soy oil (treatments B and D vs. H and J).

[6] The overall (d 0 to 84) and carcass characteristics contrast statements are as follows: 1 = no added fat vs. added fat both periods (treatment A vs. B, E, H); 2 = added fat both periods vs. added fat only during a single period (treatments B, E, H vs. C, D, F, G, I, J); 3 = added fat only during period 1 vs. added fat only during period 2 (treatments C, F, I vs. D, G, J); 4 = tallow vs. blend (treatments B, C, D vs. E, F, G); 5 = blend vs. soy oil (treatments E, F, G vs. H, I, J); 6 = tallow vs. soy oil (treatments B, C, D, vs. H, I, J).

[7] Adjusted using HCW as a covariate.

[8] Fat-free lean index was calculated using the NPPC (2001) equation.

Table 5. Effects of fat source and feeding duration on backfat fatty acid profiles[1,2]

Treatment[3]:	A	B	C	D	E	F	G	H	I	J								
d 0 to 42:	Control	Tallow	Tallow	Control	Blend	Blend	Control	Soy	Soy	Control		Contrasts[4,5], *P* <						
d 42 to 84:	Control	Tallow	Control	Tallow	Blend	Control	Blend	Soy	Control	Soy	SEM	1	2	3	4	5	6	
Palmitoleic acid (C16:1), %																		
d 0[a]	3.51	3.81	3.40	3.89	3.27	3.43	3.99	3.35	3.50	3.46	0.13							
d 42[a,b,d]	2.72	2.58	2.83	3.04	2.16	2.22	3.01	2.07	1.86	2.83	0.13							
d 84[e,f,g,,h]	2.51	2.55	2.61	2.51	2.14	2.37	2.38	1.81	2.21	1.94	0.10	0.180	0.881	0.130	0.567	0.146	0.353	
Total C18:1, %[6]																		
d 0	40.36	41.00	41.75	40.49	40.33	42.25	42.81	41.12	39.21	40.34	0.76							
d 42[a,b,c,d]	42.15	43.97	44.60	43.24	40.78	40.87	44.20	39.34	37.73	43.64	0.76							
d 84[e,f,g,h]	42.14	44.32	43.19	44.11	41.11	41.76	41.70	36.91	40.41	38.11	0.61	0.173	0.069	0.001	0.386	0.053	0.004	
Total C18:2, %[7]																		
d 0	13.07	12.24	12.24	12.84	12.78	12.13	11.94	12.79	14.07	14.08	0.65							
d 42[a,b,c,d]	10.61	10.05	10.88	9.32	15.13	15.58	9.25	17.83	21.15	10.52	0.65							
d 84[e,f,g,h]	12.28	11.72	12.15	11.10	16.48	14.16	14.38	22.29	15.35	18.91	0.53	0.009	0.001	0.001	0.186	0.001	0.001	
Total C18:3, %[8]																		
d 0	0.62	0.65	0.63	0.65	0.67	0.63	0.61	0.66	0.81	0.70	0.07							
d 42[a,b,c,d]	0.65	0.44	0.51	0.43	0.99	1.08	0.45	1.34	1.56	0.49	0.07							
d 84[e,f,g,h]	0.69	0.61	0.58	0.60	1.35	0.92	1.14	2.14	1.01	1.82	0.06	0.001	0.001	0.001	0.073	0.001	0.001	
Gadoleic acid (C20:1), %																		
d 0	0.60	0.63	0.55	0.63	0.63	0.63	0.63	0.64	0.55	0.59	0.03							
d 42[a,d]	0.72	0.71	0.66	0.69	0.64	0.64	0.66	0.61	0.59	0.67	0.03							
d 84[e,f,g,h]	0.68	0.68	0.66	0.71	0.65	0.65	0.61	0.53	0.64	0.55	0.03	0.547	0.029	0.104	0.063	0.343	0.004	
Docosapentaenoic acid (C22:5n3), %																		
d 0	0.21	0.16	0.12	0.12	0.19	0.12	0.12	0.12	0.11	0.12	0.03							
d 42	0.11	0.06	0.07	0.11	0.13	0.09	0.11	0.09	0.10	0.07	0.03							
d 84[h]	0.07	0.07	0.07	0.08	0.12	0.09	0.10	0.14	0.09	0.13	0.02	0.397	0.938	0.347	0.848	0.765	0.615	

continued

Table 5. Effects of fat source and feeding duration on backfat fatty acid profiles[1,2]

Treatment[3]:	A	B	C	D	E	F	G	H	I	J								
d 0 to 42:	Control	Tallow	Tallow	Control	Blend	Blend	Control	Soy	Soy	Control		Contrasts[4,5], $P <$						
d 42 to 84:	Control	Tallow	Control	Tallow	Blend	Control	Blend	Soy	Control	Soy	SEM	1	2	3	4	5	6	
Total SFA, %[9]																		
d 0	38.11	38.45	38.71	38.04	38.78	38.02	37.44	38.36	38.20	38.02	0.75							
d 42[a,b,c,d]	40.41	40.50	38.61	41.04	38.16	37.80	40.48	37.03	35.15	40.26	0.75							
d 84[e,f,g,h]	40.01	38.27	39.06	39.04	36.17	38.24	37.85	34.33	38.52	36.67	0.63	0.219	0.121	0.005	0.722	0.180	0.081	
Total MUFA, %[10]																		
d 0	46.57	47.24	47.25	46.98	46.30	47.96	48.83	46.76	45.41	46.01	0.67							
d 42[a,b,c,d]	47.16	48.01	48.93	48.26	44.44	44.32	48.87	42.65	40.84	47.95	0.67							
d 84[e,f,g,h]	45.99	48.22	47.14	48.07	44.61	45.47	45.42	39.79	43.94	41.21	0.54	0.090	0.024	0.001	0.334	0.011	0.001	
Total PUFA, %[11]																		
d 0[d]	15.28	14.31	14.00	15.01	14.89	14.00	13.72	14.89	16.36	16.05	0.75							
d 42[a,b,c,d]	12.40	11.48	12.41	10.73	17.37	17.85	10.64	20.33	23.97	11.87	0.75							
d 84[e,f,g,h]	13.58	13.04	13.32	12.45	18.58	15.74	16.18	25.10	16.97	21.54	0.61	0.007	0.001	0.001	0.234	0.001	0.001	
Iodine value, g/100 g[12]																		
d 0	67.36	65.91	64.97	66.64	66.80	65.79	65.93	66.01	68.71	67.52	1.28							
d 42[a,b,c,d]	63.03	60.48	62.85	60.63	68.29	68.86	60.58	71.98	76.75	61.60	1.28							
d 84[e,f,g,h]	63.29	64.03	63.82	62.72	71.25	66.85	67.74	79.43	67.88	73.90	1.05	0.038	0.003	0.001	0.276	0.007	0.001	

[1] A total of 160 finishing pigs (PIC 337 × 1050, initial BW of 100.5 lb) were used in an 84-d finishing trial with 2 pigs per pen and 8 pens per treatment.

[2] C22:6n3 not included, all values were equal to or less than 0.003.

[3] Control = corn soybean meal diet with no fat; tallow = 4% beef tallow; blend = 2% tallow and 2% soybean oil; soy = 4% soybean oil.

[4] There was a fat source × feeding duration interaction ($P < 0.001$) for all variables except C 22:5n3 ($P = 0.3066$).

[5] The d-84 contrast statements for interactions are as follows: 1 = feeding duration (84 d vs. 42 d) × fat source (tallow vs. blend); 2 = feeding duration (84 d vs. 42 d) × fat source (blend vs. soy oil); 3 = feeding duration (84 d vs. 42 d) × fat source (tallow vs. soy oil); 4 = feeding period (d 0 to 42 vs. d 42 to 84) × fat source (tallow vs. blend); 5 = feeding period (d 0 to 42 vs. d 42 to 84) × fat source (blend vs. soy oil); 6 = feeding period (d 0 to 42 vs. d 42 to 84) × fat source (tallow vs. soy oil).

[6] Total C18:1= ([C18:1n9t] + [C18:1n11t] + [C18:1n9c] + [C18:1n11c]); brackets indicate concentration.

[7] Total C18:2= ([C18:2n6t] + C18:2n6c]); brackets indicate concentration.

[8] Total C18:3= ([C18:3n6] + [C18:3n3]); brackets indicate concentration.

[9] Total SFA= ([C6:0] + [C8:0] + [C10:0] + [C11:0] + [C12:0] + [C14:0] + [C15:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C21:0] + [C22:0] + [C23:0] + [C24:0]); brackets indicate concentration.

[10] Total MUFA= ([C14:1] + [C16:1] + [C17:1] + [C18:1n9t] + [C18:1n11t] + [C18:1n9c] + [C18:1n11c] + [C20:1] + [C22:1n9] + [C24:1]); brackets indicate concentration.

[11] Total PUFA=([C18:2n6t] + [C18:2n6c] + [C18:3n6] + [C18:3n3] + [CLA 9c11t] + [CLA 10t12c] + [CLA 9c11c] + [CLA 9t11t] + [C20:2] +[C20:3n6] + [C20:3n3] + [C22:2] + [C20:5n3] + [C22:5n3] + [C22:6n3]); brackets indicate concentration.

[12] Calculated as IV value= [C16:1] × 0.9502 + [C18:1] × 0.8598 + [C18:2] × 1.7315] + [C18:3] × 2.6125 + [C20:1] × 0.7852 + [C22:1n9] × 3.2008 + [C22:5n3] × 3.6974 + [C22:6n3] × 4.4632; brackets indicate concentrations.

[a,b,c,d] Within a row, superscripts represent significant ($P < 0.05$) main effects where a = control vs. fat (treatments A, D, G, J vs. B, C, E, F, H, I); b = tallow vs. blend (treatments B and C vs. E and F); c = blend vs. soy oil (treatments E and F vs. H and I); d = tallow vs. soy oil (treatments B and C vs. H and I).

[e,f,g,h] Within a row, superscripts represent significant ($P < 0.05$) main effects where e = control vs. fat (treatments A, C, F, I vs. B, D, E, G, H, J); f = tallow vs. blend (treatments B and D vs. E and G); g = blend vs. soy oil (treatments E and G vs. H and J); h = tallow vs. soy oil (treatments B and D vs. H and J).

Table 6. Effects of fat source and feeding duration on belly fat fatty acid profiles[1,2]

Treatment[3]:	A	B	C	D	E	F	G	H	I	J		Contrasts[4,5], *P* <					
d 0 to 42:	Control	Tallow	Tallow	Control	Blend	Blend	Control	Soy	Soy	Control							
d 42 to 84:	Control	Tallow	Control	Tallow	Blend	Control	Blend	Soy	Control	Soy	SEM	1	2	3	4	5	6
Palmitoleic acid (C16:1), %																	
d 0	4.58	4.86	4.78	4.81	4.38	4.71	5.14	4.64	5.01	5.03	0.16						
d 42 [a,b,d]	3.96	3.75	3.67	4.24	3.20	3.29	4.13	2.91	3.25	3.93	0.16						
d 84 [e,f,h]	3.21	3.12	3.29	3.31	2.64	2.91	2.93	2.43	2.86	2.65	0.13	0.635	0.832	0.482	0.997	0.373	0.353
Total C18:1, %[6]																	
d 0	42.51	43.63	42.70	42.86	42.31	43.28	43.45	42.65	43.34	41.21	0.81						
d 42 [a,b,c,d]	45.27	46.97	45.56	46.29	43.22	43.43	46.21	40.74	41.00	44.88	0.81						
d 84 [e,f,g,h]	45.60	46.50	46.13	47.09	43.77	45.01	44.46	40.77	44.06	41.88	0.65	0.407	0.227	0.038	0.213	0.189	0.008
Total C18:2, %[7]																	
d 0	11.43	10.51	11.10	10.94	10.85	10.42	10.35	11.31	10.52	11.50	0.62						
d 42 [a,b,c,d]	9.52	9.42	10.89	8.06	12.48	13.37	8.62	16.16	16.10	9.30	0.62						
d 84 [e,f,g,h]	9.87	9.85	10.13	8.93	13.77	11.83	11.96	18.20	13.05	15.65	0.51	0.044	0.012	0.001	0.148	0.008	0.001
Total C18:3, %[8]																	
d 0	0.54	0.49	0.55	0.51	0.64	0.52	0.49	0.53	0.50	0.54	0.05						
d 42 [a,b,c,d]	0.42	0.42	0.56	0.35	0.78	0.87	0.38	1.18	1.18	0.41	0.05						
d 84 [e,f,g,h]	0.45	0.45	0.44	0.41	1.04	0.66	0.85	1.67	0.80	1.39	0.04	0.001	0.001	0.001	0.001	0.001	0.001
Gadoleic acid (C20:1), %																	
d 0	0.60	0.63	0.61	0.60	0.63	0.61	0.61	0.62	0.62	0.61	0.03						
d 42 [b,d]	0.66	0.74	0.69	0.67	0.66	0.64	0.68	0.60	0.62	0.65	0.03						
d 84 [e,g,h]	0.67	0.66	0.64	0.68	0.64	0.65	0.61	0.54	0.63	0.57	0.03	0.579	0.057	0.169	0.134	0.516	0.026
Docosapentaenoic acid C22:5n3, %																	
d 0	0.10	0.09	0.16	0.20	0.20	0.16	0.16	0.18	0.15	0.21	0.03						
d 42 [b,d]	0.12	0.05	0.11	0.08	0.18	0.14	0.11	0.19	0.17	0.17	0.03						
d 84 [h]	0.05	0.06	0.05	0.06	0.09	0.07	0.08	0.11	0.08	0.10	0.03	0.698	0.864	0.567	0.866	0.931	0.790

continued

Table 6. Effects of fat source and feeding duration on belly fat fatty acid profiles[1,2]

Treatment[3]:	A	B	C	D	E	F	G	H	I	J								
d 0 to 42:	Control	Tallow	Tallow	Control	Blend	Blend	Control	Soy	Soy	Control		Contrasts[4,5], $P <$						
d 42 to 84:	Control	Tallow	Control	Tallow	Blend	Control	Blend	Soy	Control	Soy	SEM	1	2	3	4	5	6	
Total SFA, %[9]																		
d 0	38.01	37.65	37.37	37.22	37.66	37.74	37.15	37.18	37.36	37.75	0.64							
d 42 [a]	37.94	36.78	36.30	38.50	36.87	36.01	37.97	35.56	35.34	38.11	0.64							
d 84 [e,g,h]	38.81	37.75	37.83	38.01	36.41	37.35	37.62	34.68	37.09	36.22	0.53	0.258	0.263	0.022	0.926	0.234	0.252	
Total MUFA, %[10]																		
d 0	48.94	50.32	49.73	50.07	49.32	50.17	50.77	49.66	50.48	48.87	0.78							
d 42 [a,b,c,d]	51.04	52.29	51.03	52.17	48.44	48.46	52.07	45.62	46.00	51.01	0.78							
d 84 [e,f,g,h]	50.06	50.93	50.71	51.75	47.66	49.22	48.61	44.26	48.16	45.68	0.62	0.336	0.164	0.017	0.166	0.121	0.002	
Total PUFA, %[11]																		
d 0	12.60	11.58	12.46	12.27	12.51	11.69	11.66	12.67	11.76	12.93	0.70							
d 42 [a,b,c,d]	10.56	10.49	12.20	8.98	14.12	15.02	9.57	18.15	18.06	10.49	0.70							
d 84 [e,f,g,h]	11.11	11.32	11.46	10.24	15.92	13.43	13.76	21.05	14.79	18.09	0.57	0.032	0.009	0.001	0.13	0.004	0.001	
Iodine value, g/100 g[12]																		
d 0	69.59	68.73	70.42	70.92	70.77	69.62	70.04	70.95	69.71	71.08	1.03							
d 42 [a,b,c,d]	67.89	67.63	70.23	65.65	72.17	73.40	66.98	77.36	77.21	68.10	1.03							
d 84 [e,f,g,h]	66.53	67.25	67.51	66.22	72.53	69.90	70.08	79.45	71.49	75.11	0.86	0.081	0.004	0.001	0.316	0.022	0.001	

[1] A total of 160 finishing pigs (PIC 337 × 1050, initial BW of 100.5 lb) were used in an 84-d finishing trial with 2 pigs per pen and 8 pens per treatment.

[2] C22:6n3 not included, all values were equal to or less than 0.003.

[3] Control = corn soybean meal diet with no fat; tallow = 4% beef tallow; blend = 2% tallow and 2% soybean oil; soy = 4% soybean oil.

[4] There was a fat source × feeding duration interaction ($P < 0.005$) for all variables except C 22:5n3 ($P = 0.7639$).

[5] The d-84 contrast statements for interactions are as follows: 1 = feeding duration (84 d vs. 42 d) × fat source (tallow vs. blend); 2 = feeding duration (84 d vs. 42 d) × fat source (blend vs. soy oil); 3 = feeding duration (84 d vs. 42 d) × fat source (tallow vs. soy oil); 4 = feeding period (d 0 to 42 vs. d 42 to 84) × fat source (tallow vs. blend); 5 = feeding period (d 0 to 42 vs. d 42 to 84) × fat source (blend vs. soy oil); 6 = feeding period (d 0 to 42 vs. d 42 to 84) × fat source (tallow vs. soy oil).

[6] Total C18:1= ([C18:1n9t] + [C18:1n11t] + [C18:1n9c] + [C18:1n11c]); brackets indicate concentration.

[7] Total C18:2= ([C18:2n6t] + C18:2n6c]); brackets indicate concentration.

[8] Total C18:3= ([C18:3n6] + [C18:3n3]); brackets indicate concentration.

[9] Total SFA= ([C6:0] + [C8:0] + [C10:0] + [C11:0] + [C12:0] + [C14:0] + [C15:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C21:0] + [C22:0] + [C23:0] + [C24:0]); brackets indicate concentration.

[10] Total MUFA= ([C14:1] + [C16:1] + [C17:1] + [C18:1n9t] + [C18:1n11t] + [C18:1n9c] + [C18:1n11c] + [C20:1] + [C22:1n9] + [C24:1]); brackets indicate concentration.

[11] Total PUFA=([C18:2n6t] + [C18:2n6c] + [C18:3n6] + [C18:3n3] + [CLA 9c11t] + [CLA 10t12c] + [CLA 9c11c] + [CLA 9t11t] + [C20:2] +[C20:3n6] + [C20:3n3] + [C22:2] + [C20:5n3] + [C22:5n3] + [C22:6n3]); brackets indicate concentration.

[12] Calculated as IV value= [C16:1] × 0.9502 + [C18:1] × 0.8598 + [C18:2] × 1.7315] + [C18:3] × 2.6125 + [C20:1] × 0.7852 + [C22:1n9] × 3.2008 + [C22:5n3] × 3.6974 + [C22:6n3] × 4.4632; brackets indicate concentrations.

[a,b,c,d] Within a row, superscripts represent significant ($P < 0.05$) main effects where a = control vs. fat (treatments A, D, G, J vs. B, C, E, F, H, I); b = tallow vs. blend (treatments B and C vs. E and F); c = blend vs. soy oil (treatments E and F vs. H and I); d = tallow vs. soy oil (treatments B and C vs. H and I).

[e,f,g,h] Within a row, superscripts represent significant ($P < 0.05$) main effects where e = control vs. fat (treatments A, C, F, I vs. B, D, E, G, H, J); f = tallow vs. blend (treatments B and D vs. E and G); g = blend vs. soy oil (treatments E and G vs. H and J); h = tallow vs. soy oil (treatments B and D vs. H and J).

Table 7. Effects of fat source and feeding duration on jowl fat fatty acid profiles[1,2]

Treatment[3]:	A	B	C	D	E	F	G	H	I	J								
d 0 to 42:	Control	Tallow	Tallow	Control	Blend	Blend	Control	Soy	Soy	Control		Contrasts[4,5], *P* <						
d 42 to 84:	Control	Tallow	Control	Tallow	Blend	Control	Blend	Soy	Control	Soy	SEM	1	2	3	4	5	6	
Palmitoleic acid (C16:1), %																		
d 0[a]	4.30	4.49	4.31	4.38	4.02	4.10	4.58	4.04	4.46	4.64	0.18							
d 42[a,d]	3.42	3.19	3.36	3.51	3.07	3.30	3.31	2.72	2.98	3.37	0.18							
d 84[c,h]	3.35	3.12	3.41	3.27	2.78	2.98	3.09	2.59	2.86	2.79	0.14	0.885	0.934	0.951	0.337	0.503	0.774	
Total C18:1, %[6]																		
d 0	43.38	43.64	44.68	44.30	44.81	44.23	44.88	44.01	44.48	43.44	0.76							
d 42[a,b,c,d]	47.27	49.98	48.84	49.34	47.80	47.16	50.80	43.36	42.74	48.00	0.76							
d 84[f,g,h]	47.82	48.54	48.36	48.82	46.52	47.02	47.11	42.97	44.90	44.52	0.62	0.590	0.196	0.063	0.739	0.667	0.424	
Total C18:2, %[7]																		
d 0	13.19	12.55	11.81	12.43	12.30	12.48	12.19	12.80	12.15	13.06	0.61							
d 42[a,b,c,d]	11.49	10.22	10.65	9.54	12.59	13.20	9.83	17.22	17.01	10.08	0.61							
d 84[c,f,g,h]	10.32	10.20	10.30	9.72	13.31	12.11	11.89	17.83	14.23	14.60	0.53	0.095	0.002	0.001	0.66	0.466	0.222	
Total C18:3, %[8]																		
d 0	0.66	0.63	0.59	0.61	0.62	0.62	0.61	0.63	0.58	0.67	0.07							
d 42[a,b,c,d]	0.53	0.46	0.49	0.43	0.79	0.84	0.44	1.28	1.24	0.46	0.07							
d 84[c,f,g,h]	0.46	0.46	0.44	0.44	0.94	0.67	0.76	1.51	0.88	1.17	0.06	0.001	0.001	0.001	0.082	0.001	0.001	
Gadoleic acid (C20:1), %																		
d 0	0.62	0.70	0.69	0.72	0.71	0.66	0.66	0.66	0.69	0.64	0.03							
d 42[d]	0.72	0.74	0.75	0.73	0.76	0.74	0.69	0.68	0.70	0.67	0.03							
d 84[f,g,h]	0.81	0.86	0.81	0.88	0.82	0.79	0.78	0.70	0.78	0.73	0.03	0.555	0.031	0.109	0.171	0.358	0.017	
Docosapentaenoic acid C22:5n3, %																		
d 0[a,c]	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.09	0.01							
d 42[a,b,c,d]	0.05	0.05	0.05	0.05	0.07	0.07	0.05	0.09	0.08	0.06	0.01							
d 84[e,f,g,h]	0.05	0.05	0.04	0.05	0.07	0.06	0.06	0.09	0.06	0.07	0.00	0.110	0.315	0.009	0.717	0.787	0.508	

continued

Table 7. Effects of fat source and feeding duration on jowl fat fatty acid profiles[1,2]

Treatment[3]:	A	B	C	D	E	F	G	H	I	J							
d 0 to 42:	Control	Tallow	Tallow	Control	Blend	Blend	Control	Soy	Soy	Control		Contrasts[4,5], $P <$					
d 42 to 84:	Control	Tallow	Control	Tallow	Blend	Control	Blend	Soy	Control	Soy	SEM	1	2	3	4	5	6
Total SFA, %[9]																	
d 0	35.76	35.97	35.98	35.57	35.65	36.00	35.20	35.72	35.45	35.05	0.71						
d 42 [a]	34.93	33.57	34.01	34.85	33.13	32.80	33.43	32.70	33.27	35.73	0.71						
d 84 [e,h]	35.75	34.98	35.01	35.20	33.79	34.78	34.69	32.57	34.70	34.51	0.57	0.364	0.233	0.033	0.797	0.927	0.717
Total MUFA, %[10]																	
d 0	49.46	49.90	50.71	50.37	50.54	49.96	51.10	49.80	50.77	49.99	0.80						
d 42 [a,b,c,d]	52.18	54.74	53.78	54.25	52.35	51.95	55.46	47.41	47.11	52.76	0.80						
d 84 [e,f,g,h]	52.57	53.23	53.25	53.63	50.72	51.42	51.62	46.79	49.15	48.61	0.66	0.540	0.185	0.049	0.879	0.533	0.414
Total PUFA, %[11]																	
d 0	14.89	14.20	13.34	14.01	13.87	14.04	13.73	14.42	13.70	14.86	0.67						
d 42 [a,b,c,d]	13.01	11.76	12.24	10.83	14.57	15.25	11.13	19.82	19.52	11.40	0.67						
d 84 [e,f,g,h]	11.68	11.79	11.73	11.17	15.46	13.85	13.70	20.64	16.19	16.87	0.58	0.069	0.001	0.001	0.63	0.361	0.144
Iodine value, g/100 g[12]																	
d 0	68.43	67.15	66.57	67.36	67.19	67.09	67.56	67.82	67.37	68.83	0.99						
d 42 [a,b,c,d]	66.96	66.50	66.59	64.97	69.55	70.48	66.51	74.93	74.08	64.80	0.99						
d 84 [e,f,g,h]	65.03	65.18	65.40	64.72	69.88	67.61	67.66	75.94	69.93	70.88	0.84	0.067	0.005	0.001	0.598	0.518	0.220

[1] A total of 160 finishing pigs (PIC 337 × 1050, initial BW of 100.5 lb) were used in an 84-d finishing trial with 2 pigs per pen and 8 pens per treatment.

[2] C22:6n3 not included, all values were equal to or less than 0.01.

[3] Control = no added fat; tallow = 4% beef tallow; soy = 4% soybean oil; blend = 2% tallow and 2% soybean oil.

[4] There was a fat source × feeding duration interaction ($P < 0.001$) for all variables except C 16:1 ($P = 0.1233$), C 20:1 ($P = 0.0326$), and saturated ($P = 0.074$).

[5] The d-84 contrast statements for interactions are as follows: 1= feeding duration (84 d vs. 42 d) × fat source (tallow vs. blend); 2 = feeding duration (84 d vs. 42 d) × fat source (blend vs. soy oil); 3 = feeding duration (84 d vs. 42 d) × fat source (tallow vs. soy oil); 4 = feeding period (d 0 to 42 vs. d 42 to 84) × fat source (tallow vs. blend); 5 = feeding period (d 0 to 42 vs. d 42 to 84) × fat source (blend vs. soy oil); 6 = feeding period (d 0 to 42 vs. d 42 to 84) × fat source (tallow vs. soy oil).

[6] Total C18:1= ([C18:1n9t] + [C18:1n11t] + [C18:1n9c] + [C18:1n11c]); brackets indicate concentration.

[7] Total C18:2= ([C18:2n6t] + C18:2n6c]); brackets indicate concentration.

[8] Total C18:3= ([C18:3n6] + [C18:3n3]); brackets indicate concentration.

[9] Total SFA= ([C6:0] + [C8:0] + [C10:0] + [C11:0] + [C12:0] + [C14:0] + [C15:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C21:0] + [C22:0] + [C23:0] + [C24:0]); brackets indicate concentration.

[10] Total MUFA= ([C14: 1] + [C16:1] + [C17:1] + [C18:1n9t] + [C18:1n11t] + [C18:1n9c] + [C18:1n11c] + [C20:1] + [C22:1n9] + [C24:1]); brackets indicate concentration.

[11] Total PUFA=([C18:2n6t] + [C18:2n6c] + [C18:3n6] + [C18:3n3] + [CLA 9c11t] + [CLA 10t12c] + [CLA 9c11c] + [CLA 9t11t] + [C20:2] +[C20:3n6] + [C20:3n3] + [C22:2] + [C20:5n3] + [C22:5n3] + [C22:6n3]); brackets indicate concentration.

[12] Calculated as IV value= [C16:1] × 0.9502 + [C18:1] × 0.8598 + [C18:2] × 1.7315] + [C18:3] × 2.6125 + [C20:1] × 0.7852 + [C22:1n9] × 3.2008 + [C22:5n3] × 3.6974 + [C22:6n3] × 4.4632; brackets indicate concentrations.

[a,b,c,d] Within a row, superscripts represent significant ($P < 0.05$) main effects where a = control vs. fat (treatments A, D, G, J vs. B, C, E, F, H, I); b = tallow vs. blend (treatments B and C vs. E and F); c = blend vs. soy oil (treatments E and F vs. H and I); d = tallow vs. soy oil (treatments B and C vs. H and I).

[e,f,g,h] Within a row, superscripts represent significant ($P < 0.05$) main effects where e = control vs. fat (treatments A, C, F, I vs. B, D, E, G, H, J); f = tallow vs. blend (treatments B and D vs. E and G); g = blend vs. soy oil (treatments E and G vs. H and J); h = tallow vs. soy oil (treatments B and D vs. H and J).

Generating Equations Using Meta-Analyses to Predict Iodine Value of Pork Carcass Back, Belly, and Jowl Fat[1]

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Summary

Meta-analyses used data from existing literature to generate equations to predict finishing pig back, belly, and jowl fat iodine value (IV) followed by a prospective study to validate these equations. The final database included 24, 21, and 29 papers for back, belly, and jowl fat IV, respectively. For experiments that changed dietary fatty acid composition, initial diets (INT) were defined as those fed before the change in diet composition and final diets (FIN) were those fed after. The predictor variables tested were divided into 5 groups: (1) diet fat composition (dietary % C16:1, C18:1, C18:2, C18:3, essential fatty acid [EFA], UFA, and iodine value product) for both INT and FIN diets; (2) duration of feeding the INT and FIN diets; (3) ME or NE of the INT and FIN diet; (4) performance criteria (initial BW, final BW, ADG, ADFI, and G:F); and (5) carcass criteria (HCW and backfat thickness). PROC MIXED in SAS (SAS Institute, Inc., Cary, NC) was used to develop regression equations. Evaluation of models with significant terms was then conducted based on the Bayesian Information Criterion (BIC). The optimum equations to predict back, belly, and jowl fat IV were:

backfat IV =84.83 + (6.87*INT EFA) - (3.90*FIN EFA) - (0.12*INT d) - (1.30*FIN d) - (0.11*INT EFA*FIN d) + (0.048*FIN EFA*INT d) + (0.12*FIN EFA*FIN d) - (0.0132*FIN NE) + (0.0011*FIN NE*FIN d) - (6.604*BF);

belly fat IV = 106.16 + (6.21*INT EFA) - (1.50*FIN d) - (0.11*INT EFA*FIN d) - (0.0265*INT NE) + (0.00152*INT NE*FIN d) - (0.0816*HCW) - (6.35*BF); and

jowl fat IV = 85.50 + (1.08*INT EFA) + (0.87*FIN EFA) - (0.014*INT d) - (0.050*FIN d) + (0.038*INT EFA*INT d) + (0.054*FIN EFA*FIN d) - (0.0146*INT NE) + (0.0322*INT BW) - (0.993*ADFI) - (7.366*BF),

where INT EFA = initial period dietary essential fatty acids, %; FIN EFA = final period dietary essential fatty acids, %; INT d = initial period days; FIN d=final period days; INT NE = initial period dietary net energy, kcal/lb; FIN NE = final period dietary net energy, kcal/lb; BF = backfat depth, in.; ADFI = average daily feed intake, lb; INT BW = BW at the beginning of the experiment, lb.

[1] Appreciation is expressed to the National Pork Board for providing partial financial support for this experiment.

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Dietary treatments from the validation experiment (see "Influence of Dietary Fat Source and Feeding Duration on Pig Growth Performance, Carcass Composition, and Fat Quality," p. 210) consisted of a corn-soybean meal control diet with no added fat or a 3 × 3 factorial arrangement with main effects of fat source (4% tallow, 4% soybean oil, or a blend of 2% tallow and 2% soybean oil) and feeding duration (d 0 to 42, 42 to 84, or 0 to 84). The back, belly, and jowl fat IV equations tended to overestimate IV when actual IV values were less than approximately 65 g/100 g and underestimate belly fat IV when actual IV values were greater than approximately 74 g/100 g or when the blend or soybean oil diets were fed from d 42 to 84. Overall, with the exceptions noted, the regression equations were an accurate tool for predicting carcass fat quality based on dietary and pig performance factors.

Key words: iodine value, meta-analysis, pork quality

Introduction

In the last decade, the pork industry has placed considerable importance on pork fat quality. Iodine value (IV), a measure of fatty acid unsaturation, is one method used by pork processors to assess pork fat quality. Increases in fatty acid unsaturation or IV are associated with negative effects on pork fat quality. This can lead to problems with belly slicing efficiency, fat smearing, and reduced shelf life because of oxidative rancidity (NRC, 2012[3]).

Several swine packers impose penalties on carcasses that possess carcass fat IV above certain thresholds. Carcass fat composition of monogastric animals, particularly pigs, is directly related to the fatty acid composition of the diet (Madsen et al., 1992[4]). Thus, feeding ingredients with high amounts of dietary unsaturated fatty acids will increase carcass fat IV. Examples of these ingredients include dried distillers grains with solubles (DDGS), bakery meal, or added fats such as animal-vegetable blends, choice white grease, or soybean oil. Increased use of these ingredients in swine diets has led to concerns by pork processors related to the associated negative impacts on carcass fat quality correlated with high carcass fat IV values.

Carcass fat IV varies among the three important fat depots (back, belly, and jowl), and the IV of these depots show differential responses to the fatty acid composition of dietary feedstuffs (Benz et al., 2010[5]). Although many studies have been conducted to measure carcass fat IV based on different levels of dietary fatty acid composition, accurately predicting final carcass fat IV of the various fat depots is challenging for producers and processors. Therefore, the objective of this study was to conduct a meta-analysis of existing literature to generate predictive equations for back, belly, and jowl fat IV of finishing pigs. A prospective study was also conducted to validate the developed equations.

[3] NRC. 2012. Nutrient Requirements of Swine. 11th ed. Natl. Acad. Press, Washington, DC.
[4] Madsen, A., K. Jacobsen, and H.P. Mortensen. 1992. Influence of dietary fat on carcass fat quality in pigs. A review. Acta. Agric. Scand. 42:220–225.
[5] Benz, J.M., S.K. Linneen, M.D. Tokach, S.S. Dritz, J.L. Nelssen, J.M. DeRouchey, R.D. Goodband, R.C. Sulabo, and K.J. Prusa. 2010. Effects of dried distillers grains with solubles on carcass fat quality of finishing pigs. J. Anim. Sci. 88:3666–3682.

Procedures

The term *meta-analysis* is defined as the quantitative summarization of past research. A literature review was conducted to compile studies that examined the effects of dietary fatty acids and dietary energy on variables associated with growth and carcass characteristics and back, belly, and jowl fat IV. The literature search was conducted via the Kansas State University Libraries, using the CABI search engine and the keywords "iodine value and pig" or "iodine value and swine." Data were derived from both refereed and non-refereed publications, including theses, technical memos, and university publications. The final database resulted in publication dates from 2002 to 2013.

To be included in the final database, experiments had to meet the following criteria: (1) pigs used in experiments had ad libitum access to feed and water; (2) gender of the pigs was classified as either barrows, gilts, mixed gender, or immunocastrate barrows; (3) the percentage of dietary ingredients fed throughout the experiment was adequately defined; (4) the pigs were fed diets without added conjugated linoleic acid; (5) the experiments provided information including duration of the feeding period, initial BW, final BW, ADG, ADFI, G:F, HCW, and backfat depth. The initial screen yielded 46 publications. Papers were eliminated from the analysis because pigs were not allowed ad libitum access to food and water (1 paper), dietary conjugated linoleic acid was fed (2 papers and 3 treatments from 1 paper), carcass criteria were not included (4 papers), and growth criteria were not reported (5 papers). The final database resulted in 24 papers with 169 observations for backfat IV, 21 papers with 124 observations for belly fat IV, and 29 papers with 197 observations for jowl fat IV. In all papers, back, belly, or jowl fat IV was determined by either fatty acid analysis (NRC, 2012) or near-infrared analysis (Zamora-Rojas et al., 2013[6]).

The dietary composition of experimental diets was used to calculate percentage dietary C16:1, C18:1, C18:2, and C18:3 fatty acids, essential fatty acid (EFA; sum of C18:2 and C18:3), total UFA), dietary iodine value product (IVP), and dietary ME (kcal/lb) and NE (kcal/lb) concentrations. Reported individual fatty acid percentages from analyzed ingredients or complete diets were calculated as a percentage of total fatty acids. When analyzed values were not reported, fatty acids, as a percentage of total fatty acids, were obtained from Sauvant et al. (2004[7]) or from the U.S. Department of Agriculture (2010[8]). The fatty acid profile of corn oil from Sauvant et al. (2004) was used for DDGS. Dietary fatty acid concentrations were calculated by multiplying the percentage of each fatty acid by the reported analyzed ether extract of the ingredient or diet. If ether extract was not reported, it was derived from the NRC (2012). Iodine value was calculated using the following equation (NRC, 2012): Total IV = % C16:1 (0.9502) + % C18:1 (0.8598) + % C18:2 (1.7315) + % C18:3 (2.6152) + % C20:4 (3.2008) + % C20:5 (4.0265) + % C22:1 (0.7225) + % C22:5 (3.6974) + % C22:6 (4.4632). In the equation, % is the percentage that each fatty acid methyl ester represents of the

[6] Zamora-Rojas, E., A. Garrido-Varo, E. De Pedro-Sanz, J.E. Guerrero-Ginel, D. Perez-Marin. 2013. Prediction of fatty acids content in pig adipose tissue by near infrared spectroscopy: At-line versus in-situ analysis. Meat Sci. 95:503–511.

[7] Sauvant, D., J.M. Perez, and G. Tran. 2004. Tables of composition and nutritional value of feed materials: pigs, poultry, sheep, goats, rabbits, horses, fish. The Netherlands: Wageningen Academic.

[8] USDA Agricultural Research Service. 2010. USDA National Nutrient Database for Standard Reference, Release 26. Nutrient Data Laboratory Home Page. Available online at http://www.ars.usda.gov/Services/docs.htm?docid=8964. Accessed November 11, 2013.

sum total of all fatty acid methyl esters in the gas chromatographic analysis. The dietary IVP was calculated for all dietary treatments using the following equation (NRC, 2012): IVP = (IV of ingredient fat) × (% fat in the ingredient) × (0.1). The ME and NE content of every diet was determined by using the ingredient ME and NE values provided in the NRC (2012). The ME and NE values for glycerol was obtained from Lammers et al. (2008[9]) and Hinson (2009[10]), respectively.

Some observations (back [n = 36], belly [n = 37], and jowl [n = 45]) changed diet composition during the experiment, which resulted in changes in dietary fatty acid composition. Therefore, dietary variables were determined for initial (INT) and final (FIN) diets. Initial diets are defined as diets fed prior to the change in ingredient composition, and final diets are defined as diets fed after the change in diet composition. Feeding duration of both the INT and FIN diets were used in the meta-analyses. In the database, observations that did not change dietary fatty acid composition had equal INT and FIN dietary variables, the initial duration was defined as the total duration of the experiment, and final duration equaled 0 days. For INT or FIN diets applied during more than one dietary phase, a weighted average of each variable, based on feeding duration within the INT or FIN period, was calculated to describe the treatment applied within that period.

Statistical analysis

Descriptive statistics of candidate variables were evaluated using PROC UNIVARIATE in SAS (SAS institute, Inc., Cary, NC). All candidate variables were then evaluated for correlation using PROC CORR in SAS to determine relationships between variables and prevent multicolinearity. Based on descriptive statistics and correlations, the predictor variables tested were divided into the following groups: (1) diet fat composition (C16:1, C18:1, C18:2, C18:3, EFA, UFA, and IVP); (2) duration of feeding for initial and final diets; (3) energy content of the diet (ME or NE); (4) performance criteria (initial BW, final BW, ADG, ADFI, and G:F); (5) carcass criteria (HCW and backfat thickness). PROC MIXED in SAS was then used to develop regression equations to separately predict back, belly, and jowl fat IV. The method of maximum likelihood (ML) was used in the model selection. The treatment applied within each experiment was the experimental unit for modeling of the equations, and experiment within paper was included as a random effect. The statistical significance for inclusion of terms in the models was determined at $P < 0.10$. Further evaluation of models with significant terms was then conducted based on the Bayesian Information Criterion (BIC). A model comparison with a reduction in BIC of more than 2 was considered improved (Kass and Raftery, 1995[11]). Throughout the selection process, studentized residual plots were observed to determine if quadratic terms or interaction terms needed to be tested in the model. The model was determined using a manual forward selection procedure while progressing through the groups of the predictor variables. First, the best single predictor for back, belly, or jowl fat IV was determined. Variables from the dietary fat composition group had the lowest BIC value. Next, the

[9] Lammers, P.J., B.J. Kerr, T.E. Weber, W.A. Dozier III, M.T. Kidds, K. Bregendahl, and M.S. Honeyman. 2008. Digestible and metabolizable energy of crude glycerol for growing pigs. J. Anim. Sci. 86:602–608.

[10] Hinson, R.B. 2009. Net energy content of soybean meal and glycerol for growing and finishing pigs. PhD Diss. Univ. of Missouri, Columbia.

[11] Kass, R.E., and A.E. Raftery. 1995. Bayes Factors. J. Am. Statist. 90:773–795.

chosen initial and final dietary fat composition variables and the initial and final duration and their interactions were added to the model. Once the best dietary fat composition × duration model was determined, dietary energy content (ME or NE) was added to the model to determine if either were significant and improved the precision of the model. The model was then evaluated for improvement by adding the significant growth performance and carcass criteria parameters.

The method of residual maximum likelihood (REML) was then used to obtain the estimate of the parameters for the candidate models. The adequacies of candidate models were also examined by evaluating a histogram of residuals for evidence of normality and plotting residuals against predicted values of Y (back, belly, or jowl IV; Kuehl, 2000[12]; St-Pierre, 2003[13]). Actual IV was plotted against predicted IV and was evaluated using the line of equality to determine if there was bias in estimation (Altman and Bland, 1983[14]). Residual plots were also used to investigate outliers. Any residual greater or less than 3 standard deviations from the mean were deemed outliers under review. Outliers were reviewed to determine if they were biologically significant. As a result, one observation for back and belly fat IV was removed.

Validation experiment

A prospective study was conducted to validate the regression equations used to estimate back, belly, and jowl fat IV. Data from this experiment were not included in the meta-analysis dataset. The procedures of the validation experiment are in Influence of Dietary Fat Source and Feeding Duration on Pig Growth Performance, Carcass Composition, and Fat Quality" (p. 210). Dietary treatments consisted of: a corn-soybean meal control diet with no added fat fed from d 0 to 84 (C); 4% tallow from d 0 to 84 (T); 4% tallow from d 0 to 42 and the control from d 42 to 84 (T-C); control from d 0 to 42 and 4% tallow from d 42 to 84 (C-T); blend of 2% tallow and 2% soybean oil from d 0 to 84 (B); blend of 2% tallow and 2% soybean oil from d 0 to 42 and the control from d 42 to 84 (B-C); control from d 0 to 42 and blend of 2% tallow and 2% soybean oil from d 42 to 84 (C-B); 4% soybean oil from d 0 to 84 (SBO); 4% soybean oil from d 0 to 42 and the control from d 42 to 84 (SBO-C); and control from d 0 to 42 and 4% soybean oil from d 42 to 84 (C-SBO). Soy oil, tallow, and a blend of the two were added to create treatments of high levels of dietary unsaturated fatty acids, high levels of saturated fatty acids, and a blend of the two, respectively. Back, belly, and jowl fat IV means and the 95% confidence interval determined in the experiment were used to validate the estimated means derived from the equations.

Results

The backfat IV database included INT diets that were fed from 21 to 125 d and were analyzed to contain an IVP range of 21.3 to 107.2 g/100 g, an EFA range of 0.80 to 4.88%, and an NE range of 1,026 to 1,264 kcal/lb (Table 1). The FIN diets were fed up to 66 d prior to market and were analyzed to consist of an IVP range of 21.3 to 107.2 g/100 g, an EFA range of 0.80 to 4.90%, and NE range of 1,026 to 1,264 kcal/lb. Before

[12] Kuehl, R.O. 2000. Design of experiments: Statistical principles of research design and analysis. 2nd ed. Duxbury Press. New York. NY.

[13] St-Pierre, N.R. 2003. Reassessment of biases in predicted nitrogen flows to the duodenum by NRC 2001. J. Dairy Sci. 86:344–350.

[14] Altman, D.G., and J.M. Bland. 1983. Measurement in Medicine: the Analysis of Method Comparison Studies. The Statistician 32: 307–317.

beginning the INT period diet, pigs had an average BW range of 48.3 to 207.9 lb. These pigs' ADFI intake ranged from 3.44 to 8.02 lb/d, and they produced carcasses with HCW from 61.9 to 221.6 lb and backfat thicknesses from 0.41 to 1.16 in. Backfat IV values were from 58.3 to 86.1 g/100 g.

The belly fat IV database included INT diets that were fed from 21 to 125 d and were analyzed to contain an IVP range of 33.8 to 96.2 g/100 g, an EFA range of 1.51 to 4.09%, and an NE range of 1,026 to 1,264 kcal/lb. The FIN diets were fed up to 66 d prior to market and were analyzed to consist of an IVP range of 33.8 to 88.1 g/100 g, an EFA range of 1.50 to 3.60%, and an NE range of 1,026 to 1,264 kcal/lb. These pigs' ADFI ranged from 4.50 to 7.30 lb/d, and they produced carcasses with HCW from 175.3 to 221.6 lb and backfat thickness from 0.55 to 1.15 in. Belly fat IV values were from 58.9 to 87.3 g/100 g.

The jowl fat IV database included INT diets fed from 21 to 125 d and were analyzed to contain an IVP range of 22.1 to 101.1 g/100 g, an EFA range of 1.08 to 4.63%, and an NE range of 1,026 to 1,264 kcal/lb. The FIN diets were fed up to 66 d prior to market and were analyzed to contain an IVP range of 22.1 to 101.1 g/100 g, an EFA range of 1.10 to 4.60%, and an NE range of 1,026 to 1,264 kcal/lb. These pigs' ADFI ranged from 4.48 to 7.39 lb/d, and they produced carcasses with HCW from 162.0 to 221.6 lb and backfat thickness from 0.41 to 1.02 in. The jowl fat IV ranged from 61.4 to 86.2 g/100 g.

Correlations between predictor variables were determined, and as expected, some of the variables within each category were highly correlated. For variables determining dietary fat composition in all 3 datasets, IVP was positively correlated ($R^2 > 0.83$; $P < 0.001$) with C18:2, EFA, and UFA for both INT and FIN diets (Table 2). It was also determined that C18:2 was positively correlated ($R^2 = 1.00$; $P < 0.001$) with EFA for INT and FIN diet in all 3 datasets. The ME content of the diet was positively correlated ($R^2 > 0.86$; $P < 0.001$) with the NE content. For growth and carcass characteristics in all 3 datasets, FIN BW was positively correlated ($R^2 > 0.64$; $P < 0.001$) with HCW (Table 3).

Significant single-variable models used to predict back, belly, and jowl fat IV for the dietary fat composition category included the INT and FIN diet IVP, C18:1, C18:2, C18:3, EFA, and UFA ($P < 0.01$; Table 4). Also, INT C16:1 ($P < 0.07$) was a significant predictor of backfat IV. For the dietary energy content category, the INT and FIN ME were significant predictors for backfat IV ($P < 0.001$). For belly and jowl fat IV, the INT and FIN dietary NE were significant predictors ($P < 0.01$). Common significant single-variable models used to predict back, belly, and jowl fat IV for the growth and carcass characteristic category included ADG, ADFI, HCW, and BF ($P < 0.05$; Table 5). In addition, FIN BW and G:F were significant predictors of backfat IV($P < 0.07$), FIN BW for belly fat IV($P < 0.04$), and INT BW for jowl fat IV($P < 0.06$). Predictors C18:2 and EFA had the lowest BIC values within INT (back BIC = 870.6 and 871.6, belly BIC = 624.5 and 622.6, jowl BIC = 853.7 and 962.1, respectively) and FIN (back BIC = 886.6 and 888.1, belly = 629.1 and 627.3, jowl BIC = 961.4 and 962.1, respectively) diets.

For backfat IV, using variables from the dietary fat composition and duration of feeding categories, INT EFA, FIN EFA, INT d, FIN d, INT EFA*FIN d, FIN EFA*INT d, and FIN EFA*FIN d had the lowest BIC (755.2) for all models tested (Table 6). Next, variables from the dietary energy category were tested and the prediction equation developed was improved (BIC = 744.9) by adding FIN NE and FIN NE*FIN d to the model. Lastly, pig growth and carcass characteristics were investigated for inclusion in the model. Adding backfat depth resulted in the best final model (BIC = 734.5).

Utilizing variables from the dietary fat composition and duration of feeding categories for belly fat IV, INT EFA, FIN d, and INT EFA*FIN d resulted in the lowest BIC (586.0) compared with all models tested. Next, dietary energy was tested with the addition of INT NE and INT NE*FIN d improving the model (BIC = 566.9). Lastly, pig growth and carcass characteristics were tested, and the model was further improved by adding HCW and backfat thickness (BIC = 557.9).

For jowl fat IV, dietary fat composition and duration of feeding variables including INT EFA, FIN EFA, INT d, FIN d, INT EFA*INT d, and FIN EFA*FIN d were determined to be components of the best model (BIC = 814.6). Next, the inclusion of diet energy content was tested, with the model further improved by adding INT NE (BIC = 792.6). The final step determined the growth and carcass characteristics that should be included. Adding INT BW, ADFI, and backfat thickness improved (BIC = 756.2) the final model.

For back, belly, and jowl fat IV, the residual plots showed no evidence of prediction bias (Figure 1). The residual plots portray improved precision for the estimation of back and jowl fat IV compared with precision when predicting belly fat IV. When evaluating bias for all 3 fat depots, the final equations tended to overestimate carcass fat IV when the actual fat IVs were at the lower end of the range (Figure 2). The final equation for belly fat IV tended to underestimate IV when the actual IV values were at the upper end of the range.

Validation experiment

Regression equation input variables derived from the validation experiment are presented in Table 7. Back, belly, and jowl fat IV means determined in the experiment and estimated IV are presented in Table 8. For backfat IV, the means estimated using the regression equations fell within 3.77 g/100 g of the actual IV for all dietary treatments except C-T, which was 7.47 g/100 g greater than the actual value. For belly fat IV, the means estimated using the regression equations fell within 9.22 g/100 g of the actual IV for all dietary treatments. However, estimated IV for the C, T, T-C, C-T, B-C, and SBO-C treatments were within 3.77 g/100 g of the actual IV. For jowl fat IV, the means estimated using the regression equations fell within 3.43 g/100 g of the actual IV for all dietary treatments.

Discussion

Prediction equations are tools that can become an integral part of a pork enterprise; however, it is essential that they are used correctly to prevent the generation of faulty information. It is important to realize that the equations are valid only as long as the input variables consist of values within the ranges used to generate the predictive equa-

tion. For example, backfat IV is estimated to be reduced from 73.4 to 68.7 g/100 g by lowering the INT EFA from 4 to 2.7% when the INT diet is fed for 90 d followed by a final diet containing 2.7% EFA fed for 30 d (FIN NE of 2,580, backfat depth of 0.79 in.). However, if FIN d is increased to a value outside of the range used in generating the equations (d 0 to 66), the equation does not behave appropriately and will generate inaccurate predictions; for example, when INT d equals 30 and FIN d equals 90, with all other variables remaining constant, the estimated backfat IV increases from 60.0 to 64.0 g/100 g. Previous research has documented that reducing the INT EFA will result in decreased carcass backfat IV (Xu et al., 2010[15]; Benz et al., 2011[16]). Therefore, in the example, the increase in backfat IV results from using values outside of the range of the predictor variables.

Many factors, both dietary and biological, affect the fatty acid composition of adipose tissue in pigs. Iodine value is a measure of fatty acid unsaturation and is commonly used to assess pork fat quality. Equations incorporating the appropriate factors to estimate carcass fat IV will allow producers to feed their pigs appropriately to avoid monetary discounts associated with IV that are higher than acceptable at harvest. Although a number of different factors were evaluated, we found that dietary EFA, NE content, and backfat thickness exhibited the greatest influence on predicting IV of 3 distinct fat depots. Regression equations from this paper can be used to predict back, belly, and jowl fat IV.

[15] Xu, G., S.K. Baidoo, L.J. Johnston, D. Bibus, J.E. Cannon, and G.C. Shurson. 2010. Effects of feeding diets containing increasing content of corn distillers dried grains with solubles to grower-finisher pigs on growth performance, carcass composition, and pork fat quality. J. Anim. Sci. 88:1394–1410.

[16] Benz, J.M., M.D. Tokach, S.S. Dritz, J.L. Nelssen, J.M. DeRouchey, R.C. Sulabo, and R.D. Goodband. 2011a. Effects of choice white grease and soybean oil on growth performance, carcass characteristics, and carcass fat quality of growing-finishing pigs. J. Anim. Sci. 89:404–413.

Table 1. Descriptive statistics for data included in the evaluation

	Initial period[1]				Final period[2]										
Item	IVP,[3] g/100 g	EFA,[4]%	NE, kcal/lb	Days	IVP,[3] g/100 g	EFA,%	NE, kcal/lb	Days	INT-BW,[5] lb	FIN-BW,[6] lb	ADG, lb	ADFI, lb	HCW, lb	Backfat depth, in.	Fat IV, g/100 g
Backfat IV[7]															
Mean	60.9	2.48	1,170	69	55.3	2.23	1,171	8	106.3	261.7	2.07	5.80	194.0	0.79	70.5
SD	21.0	0.99	58	27	18.7	0.82	52	17	44.5	37.0	0.18	0.84	29.3	0.15	6.0
Minimum	21.3	0.80	1,026	21	21.3	0.80	1,026	0	48.3	100.3	1.61	3.44	61.9	0.41	58.3
Maximum	107.2	4.88	1,264	125	107.2	4.90	1,264	66	207.9	305.6	2.43	8.02	221.6	1.16	86.1
Belly fat IV[8]															
Mean	57.3	2.33	1,145	76	51.9	2.10	1,156	9	101.6	273.1	2.09	5.75	203.0	0.81	69.3
SD	13.7	0.56	50	27	13.5	0.49	44	17	52.9	13.7	0.15	0.62	9.3	0.15	5.4
Minimum	33.8	1.51	1,026	21	33.8	1.50	1026	0	48.3	233.7	1.83	4.50	175.3	0.55	58.9
Maximum	96.2	4.09	1,257	125	88.1	3.60	1,257	66	221.8	305.6	2.71	7.30	221.6	1.15	87.3
Jowl fat IV[9]															
Mean	59.1	2.49	1,134	75	54.0	2.25	1,143	7	109.6	274.7	2.07	5.95	201.5	0.74	72.1
SD	16.8	0.75	49	21	16.0	0.65	42	14	41.2	14.6	0.18	0.66	9.9	0.10	4.3
Minimum	22.1	1.08	1,026	21	22.1	1.10	1,026	0	52.9	214.7	1.70	4.48	162.0	0.41	61.4
Maximum	101.1	4.63	1264	125	101.1	4.60	1,264	66	221.8	305.6	2.71	7.39	221.6	1.02	86.2

[1] Characteristics of initial diets fed during the experiment.
[2] Characteristics of final diets fed during the experiment.
[3] Iodine value product (IVP = [iodine value of the dietary lipids] × [percentage dietary lipid] × 0.10); and IV = iodine value (IV = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C20:4] × 3.2008 + [C20:5] × 4.0265 + [C22:1] × 0.7225 + [C22:5] × 3.6974 + [C22:6] × 4.4632; NRC, 2012).
[4] Essential fatty acids, %.
[5] Refers to BW of pigs at the beginning of the experiment.
[6] Refers to BW of pigs at the end of the experiment.
[7] The final database resulted in 24 papers with 169 observations for backfat IV.
[8] The final database resulted in 21 papers with 124 observations for belly fat IV.
[9] The final database resulted in 29 papers with 197 observations for jowl fat IV.

Table 2. Pearson's correlation coefficients between dependent dietary variables used to predict back, belly, and jowl fat iodine value (IV)[1]

	Initial period[2]								Final period[3]							
	Fatty acids, %						Energy, kcal/lb		Fatty acids, %						Energy, kcal/lb	
Item	C16:1	C18:1	C18:2	C18:3	EFA[4]	UFA	ME	NE	C16:1	C18:1	C18:2	C18:3	EFA	UFA	ME	NE
IVP, [5] g/100 g	0.13	0.57	0.93	0.82	0.94	0.97	0.68	0.58	0.33	0.68	0.91	0.71	0.92	0.97	0.65	0.55
	0.48	0.73	0.83	0.47	0.83	0.97	0.47	0.17	0.59	0.81	0.82	0.28	0.83	0.97	0.54	0.34
	0.30	0.71	0.90	0.59	0.91	0.98	0.40	0.12	0.43	0.79	0.89	0.43	0.90	0.98	0.46	0.14
C16:1, %	1.00	0.71	-0.17	-0.12	-0.17	0.33	0.43	0.36	1.00	0.71	0.01	-0.08	0.01	0.49	0.43	0.38
	1.00	0.83	-0.02	0.33	-0.01	0.64	0.70	0.57	1.00	0.79	0.12	0.09	0.14	0.69	0.57	0.49
	1.00	0.86	-0.12	0.11	-0.11	0.50	0.73	0.70	1.00	0.84	0.01	0.13	0.02	0.58	0.65	0.67
C18:1, %		1.00	0.25	0.17	0.24	0.76	0.79	0.70		1.00	0.34	0.16	0.34	0.84	0.71	0.65
		1.00	0.24	0.26	0.24	0.88	0.84	0.66		1.00	0.34	0.14	0.36	0.92	0.78	0.67
		1.00	0.35	0.31	0.35	0.85	0.75	0.59		1.00	0.44	0.28	0.46	0.90	0.72	0.56
C18:2, %			1.00	0.84	1.00	0.82	0.45	0.36			1.00	0.78	1.00	0.80	0.42	0.32
			1.00	0.38	1.00	0.67	-0.01	-0.29			1.00	0.24	1.00	0.68	0.11	-0.11
			1.00	0.53	1.00	0.79	0.06	-0.23			1.00	0.40	1.00	0.79	0.14	-0.22
C18:3, %				1.00	0.88	0.69	0.53	0.51				1.00	0.81	0.57	0.46	0.44
				1.00	0.41	0.42	0.29	0.10				1.00	0.28	0.22	0.23	0.10
				1.00	0.58	0.53	0.41	0.32				1.00	0.42	0.39	0.27	0.18
EFA, %					1.00	0.82	0.46	0.38					1.00	0.80	0.44	0.35
					1.00	0.67	-0.01	-0.28					1.00	0.69	0.14	-0.09
					1.00	0.80	0.09	-0.20					1.00	0.80	0.16	-0.19
UFA, %						1.00	0.78	0.67						1.00	0.71	0.61
						1.00	0.63	0.36						1.00	0.65	0.47
						1.00	0.53	0.26						1.00	0.56	0.28
ME, kcal/lb							1.00	0.94							1.00	0.94
							1.00	0.91							1.00	0.93
							1.00	0.89							1.00	0.86

[1] The 1st, 2nd, and 3rd row within each variable represents Pearson's correlation coefficients for back, belly, and jowl fat IV datasets, respectively.
[2] Correlations between characteristics of initial diets fed during the experiment.
[3] Correlations between characteristics of final diets fed during the experiment.
[4] Essential fatty acids.
[5] Iodine value product (IVP = [iodine value of the dietary lipids] × [percentage dietary lipid] × 0.10); and IV = iodine value (IV = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C20:4] × 3.2008 + [C20:5] × 4.0265 + [C22:1] × 0.7225 + [C22:5] × 3.6974 + [C22:6] × 4.4632; NRC, 2012).

Table 3. Pearson's correlation coefficients between dependent growth performance and carcass characteristic variables used to predict back, belly, and jowl fat iodine value (IV)[1]

	FIN-BW, [7] lb	ADG, lb	ADFI, lb	GF	HCW, lb	Backfat depth, in.
INT BW,[2] lb	0.25	0.27	0.57	-0.62	0.21	0.05
	0.14	0.49	0.62	-0.43	0.01	-0.05
	0.03	0.03	0.47	-0.57	-0.03	-0.02
FIN BW,[3] lb	1.00	0.70	0.63	-0.44	0.96	0.41
	1.00	0.53	0.32	0.08	0.64	0.24
	1.00	0.47	0.45	-0.13	0.89	0.36
ADG, lb		1.00	0.72	-0.24	0.64	0.25
		1.00	0.66	0.02	0.45	0.15
		1.00	0.54	0.29	0.50	0.39
ADFI, lb			1.00	-0.79	0.59	0.35
			1.00	-0.70	0.19	0.31
			1.00	-0.59	0.30	0.19
G:F				1.00	-0.46	-0.38
				1.00	0.20	-0.26
				1.00	0.04	0.04
HCW, lb					1.00	0.47
					1.00	0.47
					1.00	0.40

[1]The 1st, 2nd, and 3rd row within each variable represents Pearson's correlation coefficients for back, belly, and jowl fat IV datasets, respectively.
[2]Refers to BW of pigs at the beginning of the experiment.
[3]Refers to BW of pigs at the end of the experiment.

Table 4. Dietary characteristic single-variable models used to predict back, belly, and jowl fat iodine value (IV)

Item	IVP,[1] g/100 g	C16:1, %	C18:1, %	C18:2, %	C18:3, %	EFA,[2] %	UFA, %	ME, kcal/lb	NE, kcal/lb
Initial period[3]									
Backfat IV									
Probability, *P* <	0.001	0.07	0.01	0.001	0.001	0.001	0.001	0.001	0.16
BIC[4]	897.9	1,040.9	1,034.6	870.6	959.6	871.7	942.1	1,032.7	1,042.3
Belly fat IV									
Probability, *P* <	0.001	0.29	0.001	0.001	0.001	0.001	0.001	0.34	0.01
BIC[4]	632.5	716.1	695.5	624.5	695.9	622.6	648.4	716.3	705.2
Jowl fat IV									
Probability, *P* <	0.001	0.92	0.001	0.001	0.001	0.001	0.001	0.83	0.001
BIC[4]	896.8	1,104.5	1,065.4	853.7	1,066.7	858.9	940.7	1,104.4	1,078.8
Final period[5]									
Backfat IV									
Probability, *P* <	0.001	0.17	0.001	0.001	0.001	0.001	0.001	0.001	0.12
BIC[4]	918.2	1,042.3	1031	886.6	986.7	888.1	951.1	1,031.3	1,041.8
Belly fat IV									
Probability, *P* <	0.001	0.67	0.001	0.001	0.46	0.001	0.001	0.42	0.001
BIC[4]	644.2	717	702	629.1	716.7	627.3	659.4	716.6	707
Jowl fat IV									
Probability, *P* <	0.001	0.77	0.001	0.001	0.2	0.001	0.001	0.56	0.01
BIC[4]	992	1,104.4	1,075.1	961.4	1,102.8	962.1	1,013.1	1,104.2	1,090.5

[1] IVP = iodine value product (IVP = [iodine value of the dietary lipids] × [percentage dietary lipid] × 0.10); and IV = iodine value (IV = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C20:4] × 3.2008 + [C20:5] × 4.0265 + [C22:1] × 0.7225 + [C22:5] × 3.6974 + [C22:6] × 4.4632; NRC, 2012).

[2] Dietary essential fatty acids.

[3] Characteristics of initial diets fed during the experiment.

[4] Bayesian Information Criterion (BIC) values were used to compare the precision of the model. Models that minimized BIC variables within fat depot were used to select variables for initial model building.

[5] Characteristics of final diets fed during the experiment.

Table 5. Pig growth and carcass characteristic single-variable models used to predict back, belly, and jowl fat iodine value (IV)

Item	INT BW,[1] lb	FIN BW,[2] lb	ADG, lb	ADFI, lb	G:F	HCW, lb	Backfat depth, in.
Backfat IV							
Probability, *P* <	0.19	0.02	0.05	0.03	0.07	0.02	0.01
BIC[3]	1,042.5	1,038.3	1,040.4	1,039.5	1,041.1	1,038.3	1,036.5
Belly fat IV							
Probability, *P* <	0.97	0.04	0.01	0.01	0.77	0.001	0.001
BIC[3]	717.2	713.2	710.1	709.8	717.1	704.8	705.5
Jowl fat IV							
Probability, *P* <	0.06	0.15	0.01	0.05	0.76	0.01	0.001
BIC[3]	1,101.1	1,102.4	1,097.8	1,100.5	1,104.4	1,094.7	1,082.0

[1] Refers to BW of pigs at the beginning of the experiment.
[2] Refers to BW of pigs at the end of the experiment.
[3] Bayesian Information Criterion (BIC) values were used to compare the precision of the model. BIC variables within fat depot were used to select variables for initial model building.

Table 6. Regression equations generated from meta-analyses of existing data for prediction of back, belly, and jowl fat iodine value (IV)[1]

Dependent Variable	Models	BIC[2]
Backfat IV	= 60.30 + (3.70*INT EFA) + (2.37*FIN EFA) - (0.051*INT d) - (0.086*FIN d)	817.0
	= 69.40 + (0.55*INT EFA) + (2.06*FIN EFA) - (0.18*INT d) - (0.088*FIN d) + (0.053*INT EFA*INT d)	782.4
	= 70.66 + (1.22*INT EFA) + (0.86*FIN EFA) - (0.20*INT d) - (0.20*FIN d) + (0.058*INT EFA*INT d) + (0.047*FIN EFA*FIN d)	775.8
	= 69.00 + (6.66*INT EFA) - (4.31*FIN EFA) - (0.18*INT d) - (0.13*FIN d) - (0.095*INT EFA*FIN d) + (0.055*FIN EFA*INT d) + (0.13*FIN EFA*FIN d)	755.2
	= 86.93 + (6.67*INT EFA) - (3.91*FIN EFA) - (0.17*INT d) - (0.14*FIN d) - (0.90*INT EFA*FIN d) + (0.051*FIN EFA*INT d) + (0.13*FIN EFA*FIN d) - (0.0161*INT NE)	746.9
	=87.76 + (7.03*INT EFA) - (3.96*FIN EFA) - (0.17*INT d) - (1.34*FIN d) - (0.11*INT EFA*FIN d) + (0.047*FIN EFA*INT d) + (0.12*FIN EFA*FIN d) - (0.0174*FIN NE) + (0.0011*FIN NE*FIN d)	744.9
	=84.83 + (6.87*INT EFA) - (3.90*FIN EFA) - (0.12*INT d) - (1.30*FIN d) - (0.11*INT EFA*FIN d) + (0.048*FIN EFA*INT d) + (0.12*FIN EFA*FIN d) - (0.0132*FIN NE) + (0.0011*FIN NE*FIN d) - (6.604*BF)	734.5
Belly fat IV	= 54.59 + (6.73*INT EFA) + (0.31*FIN d) - (0.14*INT EFA*FIN d)	586.0
	= 82.77 + (6.37*INT EFA) + (0.28*FIN d) - (0.13*INT EFA*FIN d) - (0.022*INT NE)	580.1
	= 93.05 + (6.45*INT EFA) - (1.43*FIN d) - (0.12*INT EFA*FIN d) - (0.033*INT NE) + (0.00148*INT NE*FIN d)	566.9
	= 111.08 + (6.20*INT EFA) - (1.42*FIN d) - (0.11*INT EFA*FIN d) - (0.032*INT NE) + (0.00146*INT NE*FIN d) - (0.0953*HCW)	561.3
	=90.53 + (6.41*INT EFA) - (1.53*FIN d) - (0.12*INT EFA*FIN d) - (0.0265*INT NE) + (0.00157*INT NE*FIN d) - (6.35*BF)	560.7
	= 106.16 + (6.21*INT EFA) - (1.50*FIN d) - (0.11*INT EFA*FIN d) - (0.0265*INT NE) + (0.00152*INT NE*FIN d) - (0.0816*HCW) - (6.35*BF)	557.9
Jowl fat IV	= 58.11 + (3.86*INT EFA) + (1.54*FIN EFA) + (0.013*INT d)	831.1
	= 65.14 + (0.87*INT EFA) + (0.85*FIN EFA) - (0.073*INT d) - (0.078*FIN d) + (0.045*INT EFA*INT d) + (0.051*FIN EFA*FIN d)	814.6
	= 85.28 + (1.18*INT EFA) + (0.95*FIN EFA) - (0.058*INT d) - (0.087*FIN d) + (0.038*INT EFA*INT d) + (0.051*FIN EFA*FIN d) - (0.0183*INT NE)	792.6
	= 86.17 + (0.64*INT EFA) + (0.91*FIN EFA) - (0.065*INT d) - (0.080*FIN d) + (0.043*INT EFA*INT d) + (0.053*FIN EFA*FIN d) - (0.0126*INT NE) - (8.89*BF)	767.7
	= 77.88 + (1.04*INT EFA) + (1.01*FIN EFA) - (0.0063*INT d) - (0.041*FIN d) + (0.038*INT EFA*INT d) + (0.053*FIN EFA*FIN d) - (0.0123*INT NE) + (0.0299*INT BW) - (9.144*BF)	759.3
	= 85.50 + (1.08*INT EFA) + (0.87*FIN EFA) - (0.014*INT d) - (0.050*FIN d) + (0.038*INT EFA*INT d) + (0.054*FIN EFA*FIN d) - (0.0146*INT NE) + (0.0322*INT BW) - (0.993*ADFI) - (7.366*BF)	756.2

[1] INT EFA = initial period dietary essential fatty acids, %; FIN EFA = final period dietary essential fatty acids, %; INT d = initial period days; FIN d = final period days; INT NE = initial period dietary net energy, kcal/lb; FIN NE = final period dietary net energy, kcal/lb; BF = backfat depth, in.; INT BW = BW at the beginning of the experiment, lb.

[2] Bayesian Information Criterion (BIC) values were used to compare the precision of the model. Models that minimized BIC were preferred candidate models, with a reduction of more than 2 considered improved (Kass and Raftery, 1995).

Table 7. Inputs from validation experiment used in the regression equations to predict back, belly, and jowl fat iodine value (IV)[1]

Treatment[2]:	A	B	C	D	E	F	G	H	I	J
d 0 to 42:	Control	Tallow	Tallow	Control	Blend	Blend	Control	Soy	Soy	Control
d 42 to 84:	Control	Tallow	Control	Tallow	Blend	Control	Blend	Soy	Control	Soy
Initial diet essential fatty acid, %	1.47	1.87	1.87	1.47	2.65	2.65	1.47	3.44	3.44	1.47
Initial diet NE, kcal/lb	1,134	1,204	1,204	1,134	1,210	1,210	1,134	1,216	1,216	1,134
Initial diet days	42	42	42	42	42	42	42	42	42	42
Final diet essential fatty acids, %	1.52	1.94	1.52	1.94	2.41	1.52	2.41	3.45	1.52	3.45
Final diet NE, kcal/lb	1,150	1,221	1,150	1,221	1,227	1,150	1,227	1,232	1,150	1,232
Final diet days	42	42	42	42	42	42	42	42	42	42
Backfat, in.	0.67	0.76	0.77	0.73	0.88	0.82	0.77	0.86	0.71	0.76
HCW, lb	214.40	218.60	217.20	212.80	213.00	212.90	216.10	216.40	215.50	213.10
ADFI, lb	6.08	5.97	6.15	6.15	6.13	5.95	5.84	6.09	5.97	5.78
Initial BW, lb	100.60	100.70	100.50	100.50	101.10	100.00	100.90	100.50	100.30	100.20

[1]Inputs were obtained from the experiment conducted for validation of regression equations (see "Influence of Dietary Fat Source and Feeding Duration on Pig Growth Performance, Carcass Composition, and Fat Quality," p. 210).

[2]Control = no added fat; Tallow = 4% beef tallow; Soy = 4% soybean oil; Blend = 2% tallow and 2% soybean oil

Table 8. Validation of regression equations used to predict back, belly, and jowl fat iodine value (IV)

Treatment[1]:	A	B	C	D	E	F	G	H	I	J	
d 0 to 42:	Control	Tallow	Tallow	Control	Blend	Blend	Control	Soy	Soy	Control	
d 42 to 84:	Control	Tallow	Control	Tallow	Blend	Control	Blend	Soy	Control	Soy	SEM
Backfat IV											
Actual[2]	63.29	64.03	63.83	62.72	71.17	66.92	67.83	79.43	67.87	73.86	1.16
Predicted[3]	65.61	66.92	67.16	70.19	70.42	68.59	71.60	76.93	71.09	75.13	
Belly fat IV											
Actual	66.23	67.25	67.50	66.15	72.42	69.91	70.39	79.45	72.44	74.96	0.94
Predicted[4]	63.70	63.48	68.57	65.95	66.89	70.07	65.43	72.29	72.03	65.74	
Jowl fat IV											
Actual	64.68	65.10	65.43	64.66	69.96	67.56	67.84	75.94	71.07	70.90	0.96
Predicted[5]	67.79	68.32	66.54	68.09	70.42	68.36	69.59	75.23	71.18	72.96	

[1] Control = no added fat; Tallow = 4% beef tallow; Soy = 4% soybean oil; Blend = 2% tallow and 2% soybean oil.

[2] Means were obtained from the experiment conducted for validation of regression equations (see Stephenson et al., "Influence of Dietary Fat Source and Feeding Duration on Pig Growth Performance, Carcass Composition, and Fat Quality," p. 210).

[3] Backfat IV = 84.83 + (6.87*INT EFA) - (3.90*FIN EFA) - (0.12*INT d) - (1.30*FIN d) - (0.11*INT EFA*FIN d) + (0.048*FIN EFA*INT d) + (0.12*FIN EFA*FIN d) - (0.0060*FIN NE) + (0.0005*FIN NE*FIN d) - (0.26*BF) where INT EFA = initial period dietary essential fatty acids, %; FIN EFA = final period dietary essential fatty acids, %; INT d = initial period days; FIN d = final period days; FIN NE = final period dietary net energy, kcal/kg; BF= backfat depth, in.

[4] Belly fat IV = 106.16 + (6.21*INT EFA) - (1.50*FIN d) - (0.11*INT EFA*FIN d) - (0.012*INT NE) + (0.00069*INT NE*FIN d) - (0.18*HCW) - (0.25*BF) where INT NE = initial period dietary NE, kcal/kg.

[5] Jowl fat IV = 85.50 + (1.08*INT EFA) + (0.87*FIN EFA) - (0.014*INT d) - (0.050*FIN d) + (0.038*INT EFA*INT d) + (0.054*FIN EFA*FIN d) - (0.0066*INT NE) + (0.071*INT BW) - (2.19*ADFI) - (0.29*BF) where INT BW = BW at the beginning of the experiment, kg.

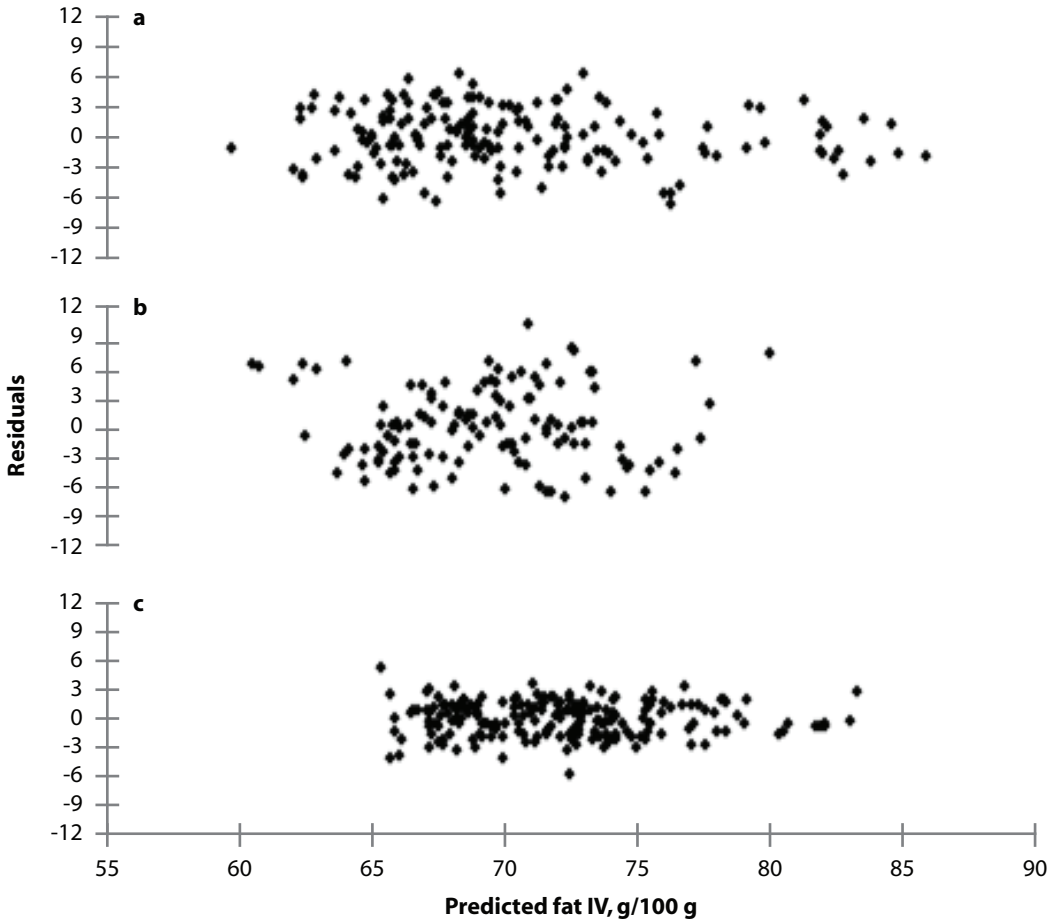

Figure 1. Plot of residuals against predicted (A) back, (B) belly, and (C) jowl fat iodine value (IV) from each mixed model analysis. The following equations were used:

(A) backfat IV = 84.83 + (6.87*INT EFA) - (3.90*FIN EFA) - (0.12*INT d) - (1.30*FIN d) - (0.11*INT EFA*FIN d) + (0.048*FIN EFA*INT d) + (0.12*FIN EFA*FIN d) - (0.0132*FIN NE) + (0.0011*FIN NE*FIN d) - (6.604*BF);

(B) belly fat IV = 106.16 + (6.21*INT EFA) - (1.50*FIN d) - (0.11*INT EFA*FIN d) - (0.0265*INT NE) + (0.00152*INT NE*FIN d) - (0.0816*HCW) - (6.35*BF);

(C) jowl fat IV = 85.50 + (1.08*INT EFA) + (0.87*FIN EFA) - (0.014*INT d) - (0.050*FIN d) + (0.038*INT EFA*INT d) + (0.054*FIN EFA*FIN d) - (0.0146*INT NE) + (0.0322*INT BW) - (0.993*ADFI) - (7.366*BF),

where INT EFA = initial period dietary essential fatty acids, %; FIN EFA = final period dietary essential fatty acid, %; INT d = initial period days; FIN d = final period days; INT NE= initial period dietary net energy, kcal/lb; FIN NE = final period dietary net energy, kcal/lb; BF = back-fat depth, in.; ADFI = average daily feed intake, lb; and INT BW = BW at the beginning of the experiment, lb.

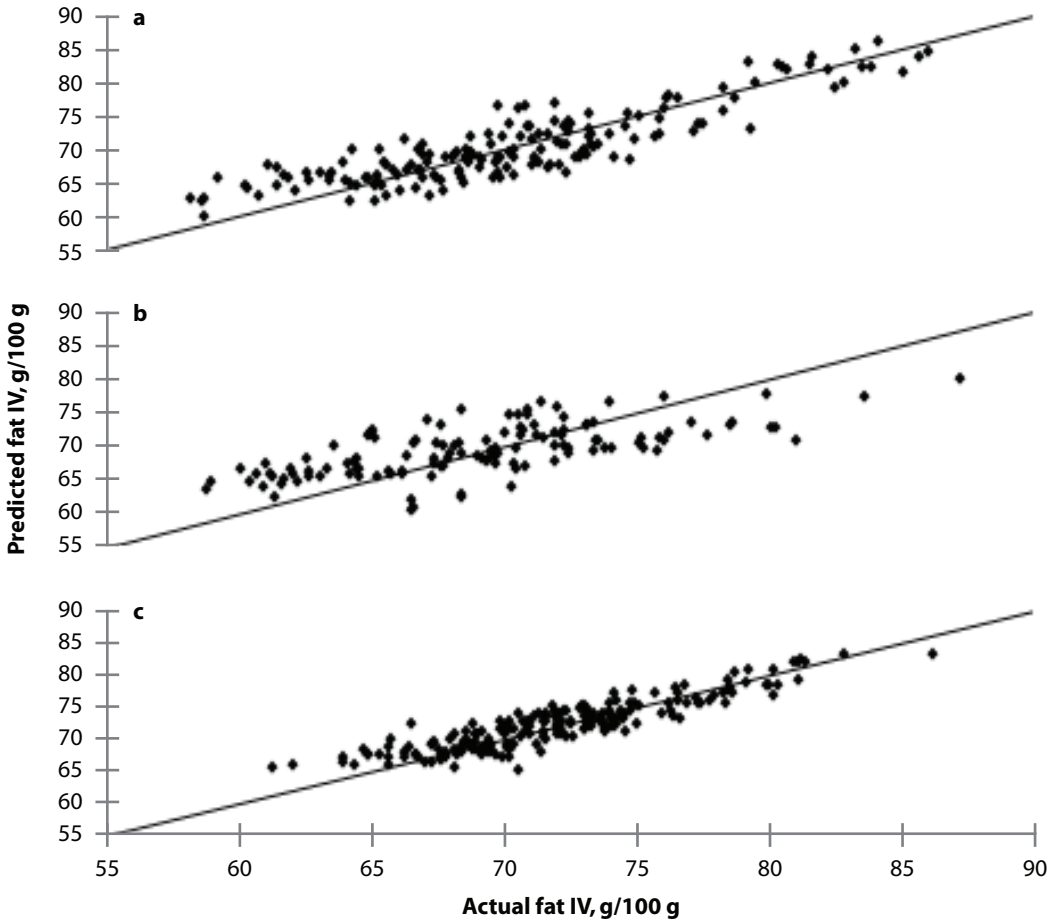

Figure 2. Plot of actual iodine value (IV) vs. predicted IV relative to the line of equality for (A) back, (B) belly, and (C) jowl fat IV from each mixed model analysis. The following equations were used:

(A) backfat IV =84.83 + (6.87*INT EFA) - (3.90*FIN EFA) - (0.12*INT d) - (1.30*FIN d) - (0.11*INT EFA*FIN d) + (0.048*FIN EFA*INT d) + (0.12*FIN EFA*FIN d) - (0.0132*FIN NE) + (0.0011*FIN NE*FIN d) - (6.604*BF);

(B) belly fat IV = 106.16 + (6.21*INT EFA) - (1.50*FIN d) - (0.11*INT EFA*FIN d) - (0.0265*INT NE) + (0.00152*INT NE*FIN d) - (0.0816*HCW) - (6.35*BF); and

(C) jowl fat IV = 85.50 + (1.08*INT EFA) + (0.87*FIN EFA) - (0.014*INT d) - (0.050*FIN d) + (0.038*INT EFA*INT d) + (0.054*FIN EFA*FIN d) - (0.0146*INT NE) + (0.0322*INT BW) - (0.993*ADFI) - (7.366*BF),

where INT EFA = initial period dietary essential fatty acids, %; FIN EFA = final period dietary essential fatty acids, %; INT d = initial period days; FIN d = final period days; INT NE = initial period dietary net energy, kcal/lb; FIN NE = final period dietary net energy, kcal/lb; BF = back-fat depth, in.; ADFI = average daily feed intake, lb; and INT BW = BW at the beginning of the experiment, lb.

Effects of Feeding Different Dietary Net Energy Levels to Growing-Finishing Pigs When Dietary Lysine is Adequate

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Summary

A total of 543 pigs (PIC 1050 × 327: PIC Hendersonville, TN) were used in 2 consecutive experiments with initial BW of 105 and 125 lb in Experiments 1 and 2, respectively. The objective was to validate the regression equations predicting growth rate and feed efficiency of growing-finishing pigs based on dietary NE content by comparing actual and predicted performance. Thus, the 5 treatments included diets with: (1) 30% dried distillers grains with solubles (DDGS), 20% wheat middlings, and 4 to 5% soybean hulls (low-energy); (2) 20% wheat middlings and 4 to 5% soybean hulls (low-energy); (3) a corn-soybean meal diet (medium-energy); (4) diet 2 supplemented with 3.7% choice white grease (CWG) to equalize NE level to diet 3 (medium-energy); and (5) a corn-soybean meal diet with 3.7% CWG (high-energy). In Experiments 1 and 2, increasing dietary NE increased (linear, $P < 0.01$) final weight, ADG, and improved feed efficiency but decreased ($P < 0.11$) ADFI. Only small differences were observed between the predicted and observed values of ADG and feed efficiency, except for the low-energy diet containing the highest fiber content (30% DDGS, wheat middlings and soy hulls; diet 1). Carcass weight and carcass yield increased (linear, $P = 0.01$) with increasing dietary NE. Also, backfat depth increased (linear, $P = 0.01$), loin depth decreased (quadratic, $P = 0.05$), and lean percentage decreased (linear, $P = 0.01$) with increasing dietary NE (linear, $P = 0.01$). Jowl iodine value (IV) also decreased with increasing dietary NE. No differences ($P > 0.26$) in net energy caloric efficiency (NEE) on a live weight basis were observed with increasing dietary NE. Nevertheless, feeding 30% DDGS (diet 1) resulted in a poorer ($P = 0.05$) NEE on a carcass basis compared with feeding the other diets. In conclusion, the prediction equations provided a good estimate of growth rate and feed efficiency of growing-finishing pigs fed different levels of dietary NE except for the pigs fed low-energy diet containing highest fiber content (diet 1). These predictions of growth performance can be used to model the economic value of different dietary energy strategies.

Key words: growth, growing-finishing pig, net energy, regression

Introduction

A meta-analysis was recently conducted to predict growth rate and feed efficiency of growing-finishing pigs based on dietary NE content, and results revealed that improvements in growth rate and feed efficiency could be obtained by increasing dietary NE (Nitikanchana et al., 2013[2]). However, the magnitude of improvement in growth performance when increasing dietary NE will be minimized if dietary lysine is limit-

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[2] Nitikanchana et al., Swine Day 2013, Report of Progress 1092, pp. 236–245.

ing. Therefore, this study was conducted to validate these newly developed prediction equations by comparing actual and predicted performance of growing-finishing pigs fed different dietary NE where dietary lysine was provided above the requirement.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in these experiments. The experiments were conducted at the K-State Swine Teaching and Research Center in Manhattan, KS. The facility was a totally enclosed, environmentally regulated, mechanically ventilated barn containing 38 pens (7.9 × 10.2 ft). The pens had adjustable gates facing the alleyway that allowed for 8 ft^2/pig. Each pen was equipped with a cup waterer and a single-sided, dry self-feeder (Farmweld, Teutopolis, IL) with 2 eating spaces located in the fence line. The facility was also equipped with a computerized feeding system (FeedPro; Feedlogic Corp., Willmar, MN) that delivered and recorded diets as specified. Pigs had ad libitum access to feed and water.

A total of 543 pigs (PIC 1050 × 327: PIC Hendersonville, TN) were used in 2 consecutive experiments with initial BW of 105 and 125 lb in Experiments 1 and 2, respectively. There were 4 barrows and 4 gilts per pen and 13 to 14 pens per treatment. Pens of pigs were assigned to 1 of 5 dietary treatments in a completely randomized design while balancing for initial BW within study. The dietary treatments included 3 different levels of dietary NE by adding low-energy ingredients (wheat middlings or soybean hulls), 30% dried distillers grains with solubles (DDGS), or choice white grease (CWG) to a corn-soybean meal–based diet. Thus, the 5 treatments included diets with: (1) 30% DDGS, 20% wheat middlings, and 4 to 5% soybean hulls (low-energy); (2) 20% wheat middlings and 4 to 5% soybean hulls (low-energy); (3) a corn-soybean meal diet (medium-energy); (4) diet 2 supplemented with 3.7% CWG to equalize NE level to diet 3 (medium-energy); and (5) a corn-soybean meal diet with 3.7% CWG (high-energy). The difference in dietary NE content between high vs. medium and medium vs. low energy was 75 kcal/lb (166 kcal/kg) across all phases of feeding. The NRC ingredient library (chapter 17, NRC, 2012[3]) was used as a reference for nutrient values in diet formulation except for DDGS. Samples of DDGS were analyzed for oil content (Ward Laboratories, Inc., Kearney NE; Table 1) prior to feed manufacturing and used to determine the NE content from the equation: NE (kcal/kg) = 115.011×oil (%) + 1501.01 (Nitikanchana et al., 2013[4]). The equation adapted from Main et al. (2008[5]) [Gilts SID Lys:NE ratio : – 0.000000153 × ((Initial BW (kg) + Final BW (kg)) × 1.1)^3 + 0.000104928 × ((Initial BW (kg) + Final BW (kg)) × 1.1)^2 ‾ 0.030414451 × ((Initial BW (kg) + Final BW (kg)) × 1.1) + 6.043540689; Barrow SID Lys:NE ratio : 0.0000454 × ((Initial BW (kg) + Final BW (kg)) × 1.1)^2 – 0.0249885 × ((Initial BW (kg) + Final BW (kg)) × 1.1) + 5.8980083] was used to calculate the standardized ileal digestible lysine (SID Lys) requirement at different dietary energy levels and BW. SID Lys was formulated at 105% requirement of the lightest BW pig fed the highest energy level in each feeding phase to ensure that the SID Lys intake was above the estimated

[3] NRC. 2012. Nutrient Requirements of Swine. 11th ed. Natl. Acad. Press, Washington, DC.
[4] Nitikanchana, S., A.B. Graham, R.D. Goodband, M.D. Tokach, S.S. Dritz, and J.M. DeRouchey. 2013. Predicting digestible energy (DE) and net energy (NE) of dried distillers grains with solubles from its oil content. J. Anim. Sci. 91(E-Suppl. 2):701 (Abstr.).
[5] Main, R.G., S.S. Dritz, M.D. Tokach, R.D. Goodband, and J.L. Nelssen. 2008. Determining an optimum lysine:calorie ratio for barrows and gilts in a commercial finishing facility. J. Anim. Sci. 86:2190–2207.

requirement. All diets were fed in meal form and fed in 3 phases from 105 to 125, 125 to 167, and 167 to 216 lb in Experiment 1, and 125 to 169, 169 to 216, and 216 to 273 lb in Experiment 2 (Tables 2 through 7). Thus, Experiment 1 was terminated prior to harvest at a lighter BW than in Experiment 2. Diet samples were collected from feeders during every phase and stored at -20°C, then the proximate analysis was conducted on composite samples (Ward Laboratories, Inc., Kearney NE).

Pens of pigs were weighed and feed disappearance was recorded at d 9, 29, and 53 in Experiment 1 and at d 21, 44, and 74 in Experiment 2 to determine ADG, ADFI, and G:F. At the end of Experiment 2, pigs were individually weighed and transported to a commercial packing plant (Triumph Foods LLC, St. Joseph, MO) for processing and carcass data collection. Before slaughter, pigs were tattooed to allow for carcass data collection. Hot carcass weights were measured immediately after evisceration, and carcass criteria of backfat depth and loin depth were collected using an optical probe. Carcass percentage yield was calculated by dividing carcass weight at the plant by live weight at the farm. A processor proprietary equation that depended on backfat and loin depth was used to calculate percentage lean. Net energy caloric efficiencies (NEE) were calculated on a pen basis by multiplying total feed intake by the dietary NE concentration and dividing by total live or carcass weight gain. The carcass weight gain was obtained from subtracting HCW from the initial carcass weight by assuming 75% carcass yield across all pigs.

The experimental data were analyzed using the MIXED procedure of SAS (SAS institute, Inc., Cary, NC) where treatment was a fixed effect. Pen was the experimental unit for all data analysis. Significance and tendencies were set at $P \leq 0.05$ and $P \leq 0.10$, respectively. Analysis of backfat depth, loin depth, and percentage lean were adjusted to a common HCW. Contrast coefficients were used to evaluate linear and quadratic responses to dietary NE level.

Calculations of predicted performance

Prediction equations used in the analysis were used to calculate predicted ADG and G:F by feeding phase [ADG (g/day) = 0.1135 × NE (kcal/kg) + 8.8142 × Average BW (kg) – 0.05068 × Average BW (kg) × Average BW (kg) + 275.99; G:F = 0.000096 × NE (kcal/kg) – 0.0025 × Average BW (kg) + 0.003071 × fat (%) + 0.3257]. The actual BW at the beginning and end of each phase was averaged and used to represent the average BW in the equation. The total gain in each phase was then calculated by multiplying the predicted ADG and days on feed for each phase. Next, the total gain for each phase was divided with the predicted G:F in that phase to calculate the total feed intake for each phase. Lastly, the overall G:F was obtained by dividing the summation of total gain with the summation of total feed intake, and the overall ADG was calculated by dividing the summation of total gain with the overall days on feed. To accommodate the variation between baseline predicted and actual performance, the difference between predicted and actual growth performance of pigs fed the corn-soybean meal diet was used to adjust the intercept of the prediction equations, thus adjusting the growth performance of the other pens fed the other diets.

Results

The proximate analysis of diet samples was in agreement with the calculated values in the diet formulation for both Experiment 1 and 2 (Tables 8 and 9).

Experiment 1

For the overall period (d 0 to 53), increasing dietary NE resulted in increased final BW, ADG, and G:F but decreased ADFI (linear, $P < 0.04$; Table 10). Pigs fed the diet with wheat middlings and soybean hulls had greater ($P < 0.01$) ADG and G:F than those fed the diet containing 30% DDGS, wheat middlings, and soybean hulls; however, there was no difference ($P = 0.83$) in ADFI. Pigs fed the corn-soybean meal diet had similar ADG and ADFI ($P > 0.34$) but poorer feed efficiency ($P = 0.05$) compared with pigs fed diets with wheat middlings, soybean hulls, and CWG.

Only small differences between predicted and actual ADG and G:F were observed when feeding the diets, with the exception of pigs fed the lowest-energy, highest-fiber diet. The prediction equations overestimated ADG and G:F of pigs fed the diet containing 30% DDGS, wheat middlings, and soybean hulls by 4.5 and 6.1%, respectively.

There was no difference in NEE on a live weight basis due to increasing dietary NE ($P > 0.26$). Nevertheless, feeding the diet containing wheat middlings and soybean hulls resulted in similar ($P = 0.22$) NEE for pigs fed diets with CWG but resulted in improved ($P < 0.01$) NEE compared with other diets. Pigs fed the wheat middlings and soybean hulls diet with CWG had NEE similar ($P > 0.06$) to those fed the corn-soybean meal diet with or without CWG but had improved ($P = 0.03$) NEE compared with those fed the diet containing 30% DDGS, wheat middlings, and soybean hulls. No differences in NEE were observed between pigs fed 30% DDGS diet, corn-soybean meal diet, and corn-soybean meal diet with addition of CWG.

Experiment 2

For the overall period (d 0 to 74), increasing dietary NE increased (linear, $P < 0.01$; Table 11) final weight, ADG, and G:F but tended ($P = 0.11$) to decrease ADFI. Pigs fed the diet containing wheat middlings and soybean hulls tended ($P = 0.08$) to have better feed efficiency than those fed the diet containing 30% DDGS, wheat middlings, and soybean hulls; however, there were no differences ($P > 0.41$) in ADG and ADFI. Pigs fed the diet with wheat middlings, soybean hulls, and CWG had similar ($P > 0.14$) ADG, ADFI, and feed efficiency to those fed the corn-soybean meal diet.

The prediction equations overestimated ADG and G:F of pigs fed the diet containing 30% DDGS, wheat middlings, and soybean hulls by 3.2 and 6.1%, respectively; however, the predicted ADG and G:F of pigs fed with other diets were within the 95% confidence interval of the actual performance.

For carcass characteristics, carcass weight and carcass yield linearly increased ($P = 0.01$) with increasing dietary NE. In addition, backfat depth increased (linear, $P = 0.01$) and loin depth decreased (quadratic, $P = 0.05$) with increasing dietary NE, resulting in a reduction of percentage lean (linear, $P = 0.01$). Decreased (linear, $P = 0.01$) jowl IV was also observed with increasing dietary NE. Pigs fed the diet containing 30% DDGS, wheat middlings, and soybean hulls tended to have lower carcass weight ($P = 0.11$), carcass yield ($P = 0.01$), and backfat depth ($P = 0.06$) but had greater lean percentage

($P = 0.01$) and jowl IV ($P = 0.01$) than pigs fed the diet containing wheat middlings and soybean hulls; however, there was no difference ($P = 0.19$) in loin depth. Pigs fed the wheat middling, soybean hulls, and CWG diet had lower ($P = 0.02$) carcass yield and greater ($P = 0.01$) jowl IV than those fed the corn-soybean meal diet, but there were no differences in carcass weight, backfat depth, loin depth, and percentage lean.

No differences ($P = 0.35$) in NEE on a live weight basis were observed with increasing dietary NE and across diets. Nevertheless, feeding the diet containing 30% DDGS, wheat middlings, and soybean hulls resulted in poorer ($P = 0.05$) NEE on a carcass basis compared with feeding other diets.

Discussion

An improvement in ADG and feed efficiency with increasing dietary NE in Experiments 1 and 2 generally agree with the prediction equations derived from the meta-analysis (Nitikanchana et al., 2013[6]). These equations indicate a linear improvement in ADG and feed efficiency when dietary NE increases. Low feed intake was also observed with increasing dietary NE, indicating an adjustment of feed intake according to energy density to achieve a suitable amount of energy intake on a daily basis.

From the prediction equations, feeding diets with the same NE should result in similar ADG as long as the dietary SID Lys is adequate. This is based on the equations in which as long as pigs were fed adequate Lys, dietary NE was the only significant dietary predictor for growth rate. As predicted in both experiments, pigs fed the corn-soybean meal diet with added CWG had the best growth rate. Adding CWG to a diet with wheat middlings and soybean hulls to restore the dietary NE to those fed the corn-soybean meal diet resulted in a similar growth rate to feeding corn-soybean meal diet as predicted. This result was similar in both Experiments 1 and 2. However, pigs fed the diet containing 30% DDGS, wheat middlings, and soybean hulls had lower ADG than those fed the diet with wheat middlings and soybean hulls that had the same dietary NE in both experiments. Average daily gain was 4.5 and 3.2% lower than predicted in Experiment 1 and Experiment 2, respectively, whereas ADG of pigs fed the diet with wheat middlings and soybean hulls was similar to the predicted value in both experiments.

Dried distillers grains with solubles, wheat middlings, and soybean hulls are fibrous ingredients that when combined together resulted in higher fiber than other diets in the experiments. The bulkiness property of dietary fiber would increase mastication time and stimulate the mechanoreceptors in the gastrointestinal tract, which will promote meal termination, thus limiting the meal size (Leeuw et al., 2008[7]). Thus, when the fiber content of the diet is high enough, the pig may not be able to compensate for the increased eating time needed to consume the same amount of calories as with a high–energy density diet, leading to a lower growth rate. Nevertheless, the feed intake of pigs fed the diet containing 30% DDGS, wheat middlings, and soybean hulls was not negatively affected compared with feeding the diet with only wheat middlings and soybean hulls even though the dietary fiber content was greater when DDGS was also

[6] Nitikanchana et al., Swine Day 2013, Report of Progress 1092, pp. 236–245.
[7] Leeuw, J.A.D., J.E. Bolhuis, G. Bosch, and W.J.J. Gerrits. 2008. Effects of dietary fibre on behaviour and satiety in pigs. Proc. Nutr. Soc. 67:334–342.

included. Another effect of fiber to be considered is the increase in size and weight of gastro-intestinal tract. The proliferation of intestinal cells will result in a higher demand for energy to support the increase in protein turnover in the epithelial lining of the gut. Thus, energy requirements for maintenance are increased and a lower amount of energy from the diet is used for growth. This would explain the poorer ADG in pigs fed the diet containing 30% DDGS, wheat middlings, and soybean hulls compared with those fed the diet with only wheat middlings and soybean hulls and may also explain the overestimation of the prediction equation. Another consideration would be that the NE of DDGS was overestimated. In this study, NE of DDGS was estimated to be 91 to 95% of NE of corn in diet formulation.

Little difference (0.25 to 2.2%) between observed and predicted feed efficiency was noted for all treatments except for pigs fed the diet containing 30% DDGS, wheat middlings, and soybean hulls. For the pigs fed the diet containing 30% DDGS, wheat middlings, and soybean hulls, feed efficiency was 6.1% lower than predicted in Experiments 1 and 2. The good agreement between determined and predicted feed efficiency from the prediction equation that accounts for fat content suggests that the value of adding fat to the diet is underestimated by NE calculations.

In the prediction equation for feed efficiency, both dietary NE and fat content were significant dietary predictors. Therefore, the equation predicted better feed efficiency for the wheat middlings and soybean hulls diet with CWG compared with the corn-soybean meal diet even though they had the same dietary NE content. Similarly, for pigs fed the 2 low-energy treatments, a better feed efficiency was predicted for pigs fed the diet containing 30% DDGS, wheat middlings, and soybean hulls due to the high dietary fat content.

The increased carcass yield, greater backfat depth, and decreased lean shown in this study are common observations when diets are increased in energy density (Stahly and Cromwell, 1979[8]). In the present study, the reduced dietary NE was associated with incorporating wheat middlings, soybean hulls, and DDGS in the diets. Addition of these high-fiber ingredients increases gut fill, thus reducing carcass yield, which has been observed in several studies (Asmus, 2012[9]), including the current results. The diet combination of DDGS, wheat middlings, and soybean hulls resulted in the lowest carcass yield compared with other diets, which also was the diet with the highest fiber content. Increasing dietary NE by adding CWG to the wheat middlings and soybean hulls diet or to the corn-soybean meal diet in this study did not improve carcass yield. Therefore, the increase in carcass yield with increasing dietary NE observed in the present study was driven mainly by the correlation with lower fiber content as dietary NE increased.

[8] Stahly, T.S., and G.L. Cromwell. 1979. Effect of environmental temperature and dietary fat supplementation on the performance and carcass characteristics of growing and finishing swine. J. Anim. Sci. 49:1478–1488.

[9] Asmus, M.D. 2012. Effects of dietary fiber on the growth performance, carcass characteristics, and carcass fat quality in growing-finishing pigs. M.S. Thesis. Kansas State Univ., Manhattan, KS.

The interaction between energy intake and protein deposition has been described as a linear-plateau (Campbell and Taverner, 1988[10]). The increase in energy intake results in greater protein deposition in a linear fashion until the maximum is reached, at which no further increase in protein deposition occurs. The addition of energy after the maximum point is then incorporated into body fat content. This relationship potentially describes the increase in backfat depth with increasing dietary NE, whereas no further improvements in loin depth were observed in our study.

In the current study, pigs fed the diet with wheat middlings and soybean hulls had jowl IV similar to those fed the corn-soybean meal diet. This finding disagreed with the results from Asmus (2012[7]) and Salyer et al. (2012[11]), who found an increase in jowl IV when 19 to 20% wheat middlings was added to the corn-soybean meal diet. Nevertheless, 4 to 5% soybean hulls were included in the diets with wheat middlings in our study, which may partly contribute to the difference in the responses. Adding CWG to the corn-soybean meal diet also resulted in a jowl IV similar to feeding a corn-soybean meal diet with or without wheat middlings and soybean hulls. However, when including CWG in the wheat middling and soybean hulls diet, jowl IV was significantly increased. A similar finding was also reported by Asmus (2012[9]), who found an increase in jowl IV when feeding wheat middlings and DDGS, where a greater response was observed when CWG was added in this diet. In addition, the increased jowl IV when including DDGS in diets in this study was consistent with other studies that documented higher unsaturated carcass fatty acids determined by IV value with increasing DDGS (Asmus, 2012[9]; Salyer et al., 2012[10]).

If the NE system truly valued the ingredient energy content correctly, the NEE should be constant among diets. In our study, NEE calculated on a live weight basis was not affected by dietary NE in either Experiment 1 or 2. The NEE on a live weight basis of the corn-soybean meal diet with wheat middlings and soybean hulls with and without CWG was slightly lower than the rest of diets in Experiment 1, but was similar in Experiment 2. This discrepancy might be due to the variation in the source of wheat middlings or soybean hulls between experiments that affected the energy content of these by-product ingredients. The NEE on a carcass basis was also similar across diets except for the diet containing 30% DDGS, wheat middlings, and soybean hulls that demonstrated a greater (poorer) value due to a lower carcass weight gain from a negative impact on carcass yield with feeding this diet. Thus, this result may suggest that NE value of DDGS used in this study was overestimated.

The similar NEE across experimental diets suggested that the assigned NE values of ingredients used in this study which were based on NRC (2012) values (except for DDGS) can be used to determine NE level in the diet. Nevertheless, a discrepancy remained when calculating NEE on carcass basis due to a negative impact of carcass yield in a high-fiber diet containing DDGS.

[10] Campbell, R.G., and M.R. Taverner. 1986. The effects of dietary fiber, source of fat and dietary energy concentration on the voluntary food intake and performance of growing pigs. Anim. Prod. 43:327–333.
[11] Salyer, J.A., J.M. DeRouchey, M.D. Tokach, S.S. Dritz, R.D. Goodband, J.L. Nelssen, and D.B. Petry. 2012. Effects of dietary wheat middlings, distillers dried grains with solubles, and choice white grease on growth performance, carcass characteristics, and carcass fat quality of finishing pigs. J. Anim. Sci. 90:2620–2630.

In conclusion, the prediction equations provided a good estimation of growth rate and feed efficiency of growing-finishing pigs fed different levels of dietary NE except for the pigs fed the highest-fiber diet with DDGS, wheat middlings, and soy hulls. These predictions of growth performance can then be used to model economic value of different dietary energy strategies.

Table 1. Analyzed nutrient composition of dried distillers grains with solubles (as-fed basis)[1]

	Exp. 1		Exp. 2
Items	Phases 1 and 2	Phase 3	All phases
DM, %	90.3	90.0	90.1
CP, %	30.0	30.2	29.2
Crude fat, %	8.6	8.2	9.0
Calculated NE, kcal/kg[2]	2,490 (1,129)	2,444 (1,109)	2,536 (1,150)
Crude fiber, %	7.2	8.3	8.1
ADF, %	9.8	10.7	13.0
NDF, %	25.3	24.8	28.6
Ash, %	4.4	4.4	4.3

[1] Samples of dried distillers grains with solubles (DDGS) were analyzed for fat content prior to each feed manufacturing to determine the net energy content (NE) from the equation: NE (kcal/kg) = 115.011 × oil (%) + 1501.01 (Nitikanchana et al., 2013[3]).
[2] Values in parentheses are NE in kcal/lb.

Table 2. Composition of diets (Experiment 1, Phase 1; as-fed basis)[1]

NE level:	Low		Medium		High
Ingredient combinations:	DDGS,[2] wheat middlings, soybean hull	Wheat middlings, soybean hull	Corn-soybean meal	Wheat middlings, soybean hull, choice white grease (CWG)	Corn-soybean meal, CWG
Ingredient, %					
Corn	23.5	47.3	68.0	43.3	64.0
Soybean meal, (46.5% CP)	19.7	24.8	28.8	25.0	29.1
DDGS	30.0	---	---	---	---
Soybean hulls	4.3	5.0	---	5.0	---
Wheat middlings	20.0	20.0	---	20.0	---
CWG	---	---	---	3.7	3.7
Monocalcium P, (21% P)	---	0.55	0.88	0.55	0.88
Limestone	1.5	1.2	1.2	1.2	1.2
Salt	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.15	0.15	0.15	0.15	0.15
Trace mineral premix	0.15	0.15	0.15	0.15	0.15
L-lysine HCl	0.38	0.36	0.33	0.36	0.33
DL-methionine	---	0.10	0.10	0.11	0.10
L-threonine	0.04	0.12	0.10	0.12	0.10
Total	100	100	100	100	100

continued

Table 2. Composition of diets (Experiment 1, Phase 1; as-fed basis)[1]

NE level:	Low		Medium		High
Ingredient combinations:	DDGS,[2] wheat middlings, soybean hull	Wheat middlings, soybean hull	Corn-soybean meal	Wheat middlings, soybean hull, choice white grease (CWG)	Corn-soybean meal, CWG
Calculated analysis					
Standardized ileal digestible (SID) amino acids, %					
Lysine	1.14	1.14	1.14	1.14	1.14
Isoleucine:lysine	67	59	62	59	61
Leucine:lysine	160	121	130	118	128
Methionine:lysine	30	32	32	32	32
Methionine & Cys:lysine	56	56	56	56	56
Threonine:lysine	61	61	61	61	61
Trptophan:lysine	18	18	18	18	18
Valine:lysine	79	67	68	66	67
Total lysine, %	1.37	1.29	1.28	1.29	1.28
NE, kcal/kg[3]	2,262	2,269	2,434	2,434	2,599
NE, kcal/lb	1,026	1,029	1,104	1,104	1,179
CP, %	24.3	19.9	19.8	19.7	19.6
Crude fiber,%	5.9	4.7	2.5	4.6	2.4
ADF, %	7.6	5.9	3.5	5.8	3.4
NDF, %	20.9	16.3	8.6	16.0	8.2
Crude fat, %	4.4	2.7	2.8	6.2	6.3
Ca, %	0.68	0.66	0.67	0.66	0.67
P, %	0.58	0.62	0.57	0.61	0.56
Available P, %	0.26	0.26	0.26	0.26	0.26

[1] Phase 1 experimental diets were fed from d 0 to 9 (106- to 126-lb BW).
[2] Dried distillers grains with solubles.
[3] All energy levels used to calculate dietary net energy (NE) were based on NRC (2012) values except DDGS, where the energy value was calculated from its oil content: NE (kcal/kg) = 115.011 × oil (%) + 1501.01 (Nitikanchana et al., 2013[3]).

Table 3. Composition of diets (Experiment 1, phase 2; as-fed basis)[1]

NE level:	Low		Medium		High
Ingredient combinations:	DDGS,[2] wheat middlings, soybean hull	Wheat middlings, soybean hull	Corn-soybean meal	Wheat middlings, soybean hull, choice white grease (CWG)	Corn-soybean meal, CWG
Ingredient, %					
Corn	29.7	53.5	74.3	49.3	70.3
Soybean meal, (46.5% CP)	13.8	18.8	22.8	19.3	23.1
DDGS	30.0	---	---	---	---
Soybean hulls	4.3	5.0	---	5.0	---
Wheat middlings	20.0	20.0	---	20.0	---
CWG	---	---	---	3.8	3.8
Monocalcium P (21%P)	---	0.48	0.78	0.48	0.78
Limestone	1.4	1.1	1.1	1.1	1.1
Salt	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.13	0.13	0.13	0.13	0.13
Trace mineral premix	0.13	0.13	0.13	0.13	0.13
L-lysine HCl	0.33	0.31	0.28	0.31	0.28
DL-methionine	---	0.06	0.05	0.07	0.06
L-threonine	0.02	0.09	0.07	0.09	0.08
Total	100	100	100	100	100

continued

Table 3. Composition of diets (Experiment 1, phase 2; as-fed basis)[1]

NE level:	Low		Medium		High
Ingredient combinations:	DDGS,[2] wheat middlings, soybean hull	Wheat middlings, soybean hull	Corn-soybean meal	Wheat middlings, soybean hull, choice white grease (CWG)	Corn-soybean meal, CWG
Calculated analysis					
Standardized ileal digestible (SID) amino acids, %					
Lysine	0.96	0.96	0.96	0.96	0.96
Isoleucine:lysine	69	60	63	60	63
Leucine:lysine	176	129	140	127	138
Methionine:lysine	32	31	31	31	31
Methionine & Cys:lysine	62	57	57	57	57
Threonine:lysine	62	62	62	61	62
Trptophan:lysine	18	18	18	18	18
Valine:lysine	84	69	70	69	70
Total lysine, %	1.17	1.10	1.08	1.10	1.08
NE, kcal/kg[3]	2,301	2,309	2,474	2,475	2,641
NE, kcal/lb	1,044	1,047	1,122	1,123	1,198
CP, %	21.9	17.5	17.4	17.3	17.2
Crude fiber,%	5.8	4.6	2.4	4.5	2.3
ADF, %	7.5	5.8	3.3	5.7	3.2
NDF, %	20.9	16.4	8.6	16.0	8.3
Crude fat, %	4.5	2.8	2.9	6.4	6.5
Ca, %	0.61	0.60	0.60	0.60	0.60
P, %	0.56	0.58	0.52	0.57	0.51
Available P, %	0.25	0.23	0.23	0.23	0.23

[1] Phase 2 experimental diets were fed from d 9 to 29 (126- to 168-lb BW).

[2] Dried distillers grains with solubles.

[3]All energy levels used to calculate dietary net energy (NE) were based on NRC (2012) values except DDGS, where the energy value was calculated from its oil content: NE (kcal/kg) = 115.011 × oil (%) + 1501.01 (Nitikanchana et al., 2013[3]).

Table 4. Composition of diets (Experiment 1, phase 3; as-fed basis)[1]

NE level:	Low		Medium		High
Ingredient combinations:	DDGS,[2] wheat middlings, soybean hull	Wheat middlings, soybean hull	Corn-soybean meal	Wheat middlings, soybean hull, choice white grease (CWG)	Corn-soybean meal, CWG
Ingredient, %					
Corn	33.1	57.0	77.8	52.8	73.8
Soybean meal, (46.5% CP)	10.6	15.7	19.7	16.1	20.0
DDGS	30.0	---	---	---	---
Soybean hulls	4.3	5.0	---	5.0	---
Wheat middlings	20.0	20.0	---	20.0	---
CWG	---	---	---	3.8	3.7
Monocalcium P, (21% P)	---	0.45	0.75	0.45	0.75
Limestone	1.2	1.0	0.9	1.0	0.9
Salt	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.10	0.10	0.10	0.10	0.10
Trace mineral premix	0.10	0.10	0.10	0.10	0.10
L-lysine HCl	0.28	0.26	0.23	0.25	0.23
DL-methionine	---	0.03	0.02	0.04	0.03
L-threonine	---	0.08	0.06	0.08	0.07
Total	100	100	100	100	100

continued

Table 4. Composition of diets (Experiment 1, phase 3; as-fed basis)[1]

NE level:	Low		Medium		High
Ingredient combinations:	DDGS,[2] wheat middlings, soybean hull	Wheat middlings, soybean hull	Corn-soybean meal	Wheat middlings, soybean hull, choice white grease (CWG)	Corn-soybean meal, CWG
Calculated analysis					
Standardized ileal digestible (SID) amino acids, %					
Lysine	0.84	0.84	0.84	0.84	0.84
Isoleucine:lysine	73	62	66	62	65
Leucine:lysine	193	139	152	136	149
Methionine:lysine	35	30	30	31	31
Methionine & Cys:lysine	67	59	58	59	58
Threonine:lysine	64	64	64	64	64
Trptophan:lysine	18.5	18.5	18.5	18.5	18.5
Valine:lysine	89	73	74	73	73
Total lysine, %	1.04	0.97	0.95	0.97	0.95
NE, kcal/kg[3]	2,312	2,333	2,498	2,498	2,664
NE, kcal/lb	1,049	1,058	1,133	1,133	1,208
CP, %	20.7	16.2	16.1	16.0	15.9
Crude fiber,%	6.1	4.6	2.3	4.5	2.2
ADF,%	7.7	5.7	3.3	5.6	3.2
NDF,%	20.8	16.4	8.7	16.1	8.4
Crude fat, %	4.5	2.9	3.0	6.4	6.5
Ca, %	0.53	0.53	0.53	0.53	0.53
P, %	0.54	0.56	0.50	0.55	0.49
Available P, %	0.25	0.22	0.22	0.22	0.22

[1] Phase 3 experimental diets were fed from d 29 to 53 (76- to 125-lb BW).

[2] Dried distillers grains with solubles.

[3] All energy levels used to calculate dietary net energy (NE) were based on NRC (2012) values except DDGS, where the energy value was calculated from its oil content: NE (kcal/kg) = 115.011 × oil (%) + 1501.01 (Nitikanchana et al., 2013[3]).

Table 5. Composition of diets (Experiment 2, phase 1; as-fed basis)[1]

NE level:	Low		Medium		High
Ingredient combinations:	DDGS,[2] wheat middlings, soybean hull	Wheat middlings, soybean hull	Corn-soybean meal	Wheat middlings, soybean hull, choice white grease (CWG)	Corn-soybean meal, CWG
Ingredient, %					
Corn	27.1	51.3	72.2	47.2	68.0
Soybean meal, (46.5% CP)	16.0	21.1	25.0	21.4	25.4
DDGS	30.0	---	---	---	---
Soybean hulls	4.7	5.0	---	5.0	---
Wheat middlings	20.0	20.0	---	20.0	---
CWG	---	---	---	3.7	3.8
Monocalcium	---	0.45	0.85	0.45	0.85
Limestone	1.4	1.2	1.1	1.2	1.1
Salt	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.13	0.13	0.13	0.13	0.13
Trace mineral premix	0.13	0.13	0.13	0.13	0.13
L-lysine HCl	0.31	0.29	0.27	0.29	0.26
DL-methionine	---	0.06	0.05	0.07	0.06
L-threonine	---	0.08	0.07	0.08	0.07
Total	100	100	100	100	100

continued

Table 5. Composition of diets (Experiment 2, phase 1; as-fed basis)[1]

NE level:	Low		Medium		High
Ingredient combinations:	DDGS,[2] wheat middlings, soybean hull	Wheat middlings, soybean hull	Corn-soybean meal	Wheat middlings, soybean hull, choice white grease (CWG)	Corn-soybean meal, CWG
Calculated analysis					
Standardized ileal digestible (SID) amino acids, %					
Lysine	1.00	1.00	1.00	1.00	1.00
Isoleucine:lysine	70	61	64	61	64
Leucine:lysine	174	129	140	127	138
Methionine:lysine	32	30	31	31	31
Methionine & Cys:lysine	61	56	56	56	56
Threonine:lysine	61	61	61	61	61
Trptophan:lysine	18.5	18.5	18.5	18.5	18.5
Valine:lysine	84	70	71	69	70
Total lysine, %	1.22	1.14	1.13	1.14	1.13
NE, kcal/kg[3]	2,295	2,295	2,460	2,460	2,625
NE, kcal/lb	1,041	1,041	1,116	1,116	1,191
CP, %	22.6	18.3	18.2	18.1	18.1
Crude fiber,%	6.3	4.7	2.4	4.6	2.3
ADF,%	8.7	5.9	3.4	5.8	3.3
NDF,%	22.1	16.4	8.6	16.0	8.3
Crude fat, %	4.6	2.8	2.9	6.3	6.4
Ca, %	0.62	0.62	0.62	0.62	0.62
P, %	0.57	0.58	0.55	0.57	0.54
Available P, %	0.26	0.23	0.25	0.23	0.25

[1] Phase 1 experimental diets were fed from d 0 to 21 (125- to 170-lb BW).

[2] Dried distillers grains with solubles.

[3] All energy levels used to calculate dietary net energy (NE) were based on NRC (2012) values except DDGS, where the energy value was calculated from its oil content: NE (kcal/kg) = 115.011 × oil (%) + 1501.01 (Nitikanchana et al., 2013[3]).

Table 6. Composition of diets (Experiment 2, phase 2; as-fed basis)[1]

NE level:	Low		Medium		High
Ingredient combinations:	DDGS,[2] wheat middlings, soybean hull	Wheat middlings, soybean hull	Corn-soybean meal	Wheat middlings, soybean hull, choice white grease (CWG)	Corn-soybean meal, CWG
Ingredient, %					
Corn	32.7	57.0	77.7	52.8	73.7
Soybean meal, (46.5% CP)	10.6	15.7	19.7	16.1	20.0
DDGS	30.0	---	---	---	---
Soybean hulls	4.7	5.0	---	5.0	---
Wheat middlings	20.0	20.0	---	20.0	---
CWG	---	---	---	3.7	3.7
Monocalcium P, (21% P)	---	0.40	0.80	0.40	0.80
Limestone	1.2	1.0	0.9	1.0	0.9
Salt	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.10	0.10	0.10	0.10	0.10
Trace mineral premix	0.10	0.10	0.10	0.10	0.10
L-lysine HCl	0.28	0.26	0.23	0.25	0.23
DL-methionine	---	0.03	0.02	0.04	0.03
L-threonine	---	0.08	0.06	0.08	0.07
Total	100	100	100	100	100

continued

Table 6. Composition of diets (Experiment 2, phase 2; as-fed basis)[1]

NE level:	Low		Medium		High
Ingredient combinations:	DDGS,[2] wheat middlings, soybean hull	Wheat middlings, soybean hull	Corn-soybean meal	Wheat middlings, soybean hull, choice white grease (CWG)	Corn-soybean meal, CWG
Calculated analysis					
Standardized ileal digestible (SID) amino acids, %					
Lysine	0.84	0.84	0.84	0.84	0.84
Isoleucine:lysine	73	62	66	62	65
Leucine:lysine	193	139	152	136	149
Methionine:lysine	35	30	30	30	31
Methionine & Cystine:lysine	67	58	58	58	58
Threonine:lysine	64	64	64	64	64
Trptophan:lysine	18.5	18.5	18.5	18.5	18.5
Valine:lysine	89	73	74	73	73
Total Lysine, %	1.04	0.97	0.95	0.97	0.95
NE, kcal/kg[3]	2,332	2,332	2,496	2,496	2,661
NE, kcal/lb	1,058	1,058	1,132	1,132	1,207
CP, %	20.4	16.2	16.1	16.0	15.9
Crude fiber, %	6.2	4.6	2.3	4.5	2.2
ADF, %	8.5	5.7	3.3	5.6	3.2
NDF, %	22.2	16.4	8.7	16.1	8.4
Crude fat, %	4.7	2.9	3.0	6.4	6.5
Ca, %	0.55	0.55	0.55	0.55	0.55
P, %	0.54	0.55	0.51	0.54	0.51
Available P, %	0.25	0.21	0.23	0.21	0.23

[1] Phase 2 experimental diets were fed from d 21 to 44 (170- to 216-lb BW).

[2] Dried distillers grains with solubles.

[3] All energy levels used to calculate dietary net energy (NE) were based on NRC (2012) values except DDGS, where the energy value was calculated from its oil content: NE (kcal/kg) = 115.011 × oil (%) + 1501.01 (Nitikanchana et al., 2013[3]).

Table 7. Composition of diets (Experiment 2, phase 3; as-fed basis)[1]

NE level:	Low		Medium		High
Ingredient combinations:	DDGS,[2] wheat middlings, soybean hull	Wheat middlings, soybean hull	Corn-soybean meal	Wheat middlings, soybean hull, choice white grease (CWG)	Corn-soybean meal, CWG
Ingredient, %					
Corn	36.2	60.5	81.3	56.5	77.3
Soybean meal, (46.5% CP)	7.3	12.4	16.2	12.7	16.5
DDGS	30.0	---	---	---	---
Soybean hulls	4.7	5.0	---	5.0	---
Wheat middlings	20.0	20.0	---	20.0	---
CWG	---	---	---	3.7	3.7
Monocalcium P, (21% P)	---	0.43	0.85	0.43	0.85
Limestone	1.1	0.9	0.8	0.9	0.8
Salt	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.08	0.08	0.08	0.08	0.08
Trace mineral premix	0.08	0.08	0.08	0.08	0.08
L-lysine HCl	0.25	0.23	0.21	0.23	0.21
DL-methionine	---	0.02	0.02	0.02	0.02
L-threonine	---	0.09	0.07	0.09	0.07
Total	100	100	100	100	100

continued

Table 7. Composition of diets (Experiment 2, phase 3; as-fed basis)[1]

NE level:	Low		Medium		High
Ingredient combinations:	DDGS,[2] wheat middlings, soybean hull	Wheat middlings, soybean hull	Corn-soybean meal	Wheat middlings, soybean hull, choice white grease (CWG)	Corn-soybean meal, CWG
Calculated analysis					
Standardized ileal digestible (SID) amino acids, %					
Lysine	0.74	0.74	0.74	0.74	0.74
Isoleucine:lysine	75	63	67	63	67
Leucine:lysine	208	147	162	144	158
Methionine:lysine	38	31	31	30	31
Methionine & Cys:lysine	73	61	61	60	60
Threonine:lysine	67	68	67	67	67
Tryptophan:lysine	18.5	18.5	18.5	18.5	18.4
Valine:lysine	94	76	77	75	76
Total lysine, %	0.93	0.86	0.85	0.86	0.84
NE, kcal/kg[3]	2,355	2,355	2,519	2,519	2,684
NE, kcal/lb	1,068	1,068	1,143	1,143	1,217
CP, %	19.1	14.9	14.7	14.7	14.5
Crude fiber, %	6.1	4.5	2.2	4.4	2.2
ADF, %	8.5	5.7	3.2	5.6	3.1
NDF, %	22.2	16.5	8.7	16.1	8.4
Crude fat, %	4.8	3.0	3.1	6.4	6.6
Ca, %	0.50	0.50	0.50	0.50	0.50
P, %	0.53	0.54	0.51	0.53	0.50
Available P, %	0.24	0.21	0.24	0.21	0.24

[1] Phase 3 experimental diets were fed from d 44 to 74 (216- to 273-lb BW).
[2] Dried distillers grains with solubles.
[3] All energy levels used to calculate dietary net energy (NE) were based on NRC (2012) values except DDGS, where the energy value was calculated from its oil content: NE (kcal/kg) = 115.011 × oil (%) + 1501.01 (Nitikanchana et al., 2013[3]).

Table 8. Analyzed nutrient composition of experimental 1 diets (as-fed basis)[1]

NE level:	Low		Medium		High
Ingredient combinations:	DDGS,[2] wheat middlings, soybean hull	Wheat middlings, soybean hull	Corn-soybean meal	Wheat middlings, soybean hull, choice white grease (CWG)	Corn-soybean meal, CWG
Phase 1					
DM	89.8	89.8	89.7	90.1	89.9
CP	23.7	23.0	19.9	20.2	19.1
Crude fat	4.4	3.8	2.9	5.6	5.8
Crude fiber	5.6	3.8	1.5	4.4	1.9
ADF	9.1	6.2	4.5	6.4	4.1
NDF	20.5	13.1	9.2	14.0	7.3
Ash	6.0	5.4	5.2	5.3	5.0
Phase 2					
DM	90.4	89.6	89.2	90.0	89.7
CP	23.5	18.1	17.4	18.1	17.0
Crude fat	4.7	2.8	3.0	5.0	5.4
Crude fiber	5.3	3.9	1.6	4.3	1.9
ADF	10.1	6.1	1.8	7.4	2.1
NDF	19.2	13.1	6.7	13.5	6.5
Ash	5.7	5.3	4.9	5.2	4.6
Phase 3					
DM	90.5	89.7	89.7	90.1	90.0
CP	21.1	16.5	17.3	17.4	17.4
Crude fat	4.9	3.0	2.7	5.2	4.5
Crude fiber	5.7	4.4	2.3	4.5	2.2
ADF	7.4	5.3	3.0	5.3	2.5
NDF	19.5	14.9	8.6	14.1	8.3
Ash	5.3	5.0	4.4	5.2	4.5

[1] Diet samples were collected from feeders during phase and stored at -20°C, then the proximate analysis was conducted on composite samples (Ward Laboratories, Inc., Kearney NE). Diets were fed in 3 phases from 106 to 126, 126 to 168, and 168 to 216 lb.
[2] Dried distillers grains with solubles.

Table 9. Analyzed nutrient composition of experimental 2 diets (as-fed basis)[1]

NE level:	Low		Medium		High
Ingredient combinations:	DDGS,[2] wheat middlings, soybean hull	Wheat middlings, soybean hull	Corn-soybean meal	Wheat middlings, soybean hull, choice white grease (CWG)	Corn-soybean meal, CWG
Phase 1					
DM	89.6	88.6	88.7	89.5	89.1
CP	22.8	18.4	17.6	18.6	18.4
Crude fat	3.6	2.2	2.3	5.5	5.4
Crude fiber	5.2	4.2	1.7	4.6	2.1
ADF	7.0	5.3	2.1	5.2	2.4
NDF	17.3	13.4	6.3	13.3	5.5
Ash	5.9	5.1	4.7	5.2	4.8
Phase 2					
DM	89.8	89.2	88.9	89.5	88.9
CP	20.5	16.8	16.5	16.3	16.1
Crude fat	4.3	2.8	2.6	5.8	5.7
Crude fiber	5.7	3.9	2.0	4.7	2.3
ADF	7.1	5.0	2.3	5.5	2.2
NDF	17.6	12.8	6.7	14.4	6.5
Ash	5.3	4.9	4.1	4.4	4.1
Phase 3					
DM	90.2	89.5	89.3	89.9	87.7
CP	19.7	15.4	15.7	15.6	16.4
Crude fat	4.4	3.4	2.7	6.2	5.5
Crude fiber	5.9	4.4	2.1	5.5	2.4
ADF	7.7	5.2	1.9	6.5	2.7
NDF	17.7	15.4	7.0	16.1	7.0
Ash	5.1	4.6	2.7	4.4	3.7

[1] Diet samples were collected from feeders during phase and stored at -20°C, then the proximate analysis was conducted on composite samples (Ward Laboratories, Inc., Kearney NE). Diets were fed in 3 phases from 125 to 170, 170 to 216, and 216 to 273 lb.
[2] Dried distillers grains with solubles.

Table 10. Effects of feeding different dietary net energy (NE) levels to growing-finishing pigs when dietary lysine is adequate (Experiment 1)[1]

NE level:	Low		Medium		High		Probability, $P <$		
								NE level	
Ingredient combinations[2]:	DDGS,[2] wheat middlings, soybean hull	Wheat middlings, soybean hull	Corn-soybean meal	Wheat middlings, soybean hull, choice white grease (CWG)	Corn-soybean meal, CWG	SEM	TRT	Linear	Quad
Initial BW, lb	106.0	106.0	106.0	105.8	106.0	1.81	1.00	0.99	0.99
Final BW, lb	210.5^{a}	216.3^{ab}	217.4^{b}	218.9^{b}	220.7^{b}	2.67	0.11	0.04	0.65
Overall period									
ADG, lb	1.97^{a}	2.08^{b}	2.10^{cb}	2.13^{cb}	2.16^{c}	0.025	0.01	0.01	0.34
95% CI[4] of ADG	1.92–2.02	2.03–2.13	2.05–2.16	2.08–2.18	2.11–2.22	---	---	---	---
ADFI, lb	5.51^{b}	5.49^{b}	5.44^{b}	5.34^{ab}	5.20^{a}	0.067	0.02	0.01	0.53
F/G (G:F)[5]	2.79 (0.358^{a})	2.63 (0.380^{bf})	2.58 (0.387^{df})	2.51 (0.399^{c})	2.40 (0.416^{e})	0.004	0.01	0.01	0.91
95% CI of F/G	2.73–2.86	2.58–2.70	2.53–2.65	2.46–2.56	2.36–2.45	---	---	---	---
Predicted performance[6]									
ADG, lb	2.06	2.06	2.10	2.10	2.15	---	---	---	---
F/G	2.63	2.69	2.58	2.51	2.43	---	---	---	---
Live wt NEE[7], Mcal/lb	2.92^{a}	2.77^{b}	2.91^{ac}	2.82^{bc}	2.84^{ac}	0.03	0.01	0.26	0.97

[1] A total of 273 pigs (PIC 1050 × 327; initially 106.0 lb BW) were used in a 53-d growing-finishing trial with 8 pigs per pen and 6 to 7 pens per treatment.

[2] The dietary treatments included 3 different levels of dietary NE by adding low-energy ingredients (wheat middlings or soybean hulls), 30% dried distillers grains with solubles, or choice white grease to a corn-soybean meal–based diet. The difference of dietary NE content between high vs. medium and medium vs. low energy was 75 kcal/lb (166 kcal/kg) across all phases of feeding.

[3] Dried distillers grains with solubles.

[4] 95% confidence interval.

[5] Values in parentheses are gain:feed. Statistics were done on a gain:feed basis.

[6] The prediction equations used were [ADG (g/day) = 0.1135 × NE (kcal/kg) + 8.8142 × Average BW (kg) – 0.05068 × Average BW (kg) × Average BW (kg) + 275.99; G:F = 0.000096 × NE (kcal/kg) – 0.0025 × Average BW (kg) + 0.003071 × fat (%) + 0.3257] were used to calculate predicted ADG and G:F. The difference between predicted and actual growth performance of pigs fed corn-soybean meal diet was used to adjust the intercept of the prediction equations thus adjusting the growth performance of the other pens fed the other diets.

[7] Net energy caloric efficiencies (NEE) were calculated on a pen basis by multiplying total feed intake by the dietary NE concentration and dividing by total live or carcass weight gain. The carcass weight gain was obtained from subtracting HCW with the initial carcass weight by assuming 75% carcass yield across diet.

[abcdef] Within a row, means without a common superscript differ ($P \leq 0.05$).

Table 11. Effects of feeding different dietary net energy (NE) levels to growing-finishing pigs when dietary lysine is adequate (Experiment 2)[1]

NE level:	Low		Medium		High		Probability, $P <$		
								NE level	
Ingredient combinations[2]:	DDGS,[3] wheat middlings, soybean hull	Wheat middlings, soybean hull	Corn-soybean meal	Wheat middlings, soybean hull, choice white grease (CWG)	Corn-soybean meal, CWG	SEM	TRT	Linear	Quad
Initial BW, lb	125.2	125.2	125.2	125.2	125.2	2.16	1.00	0.99	1.00
Final BW, lb	268.5^{a}	271.6^{a}	275.8^{ab}	273.1^{a}	282.9^{b}	2.82	0.02	0.01	0.46
Overall period									
ADG, lb	1.94^{a}	1.96^{ab}	2.03^{b}	2.00^{ab}	2.12^{c}	0.027	0.01	0.01	0.43
95% CI[4] of ADG	1.88–1.99	1.90–2.02	1.97–2.09	1.94–2.05	2.0 –2.18	---	---	---	---
ADFI, lb	5.88^{a}	5.78^{ab}	5.74^{ab}	5.54^{b}	5.65^{ab}	0.090	0.11	0.11	0.25
F/G (G:F)[5]	3.03 (0.330^{a})	2.95 (0.339^{a})	2.82 (0.355^{b})	2.78 (0.360^{b})	2.66 (0.376^{c})	0.004	0.01	0.01	0.58
95% CI of F/G	2.96–3.12	2.87–3.02	2.75–2.90	2.7 –2.84	2.60–2.72	---	---	---	---
Predicted performance[6]									
ADG, lb	2.00	1.99	2.03	2.04	2.07	---	---	---	---
F/G	2.86	2.94	2.82	2.72	2.66	---	---	---	---
Carcass wt, lb	192.9^{a}	197.8^{ab}	202.2^{bc}	198.9^{b}	207.7^{c}	2.05	0.01	0.01	0.62
Yield, %	72.4^{a}	73.4^{bd}	74.0^{dc}	73.2^{b}	74.3^{c}	0.22	0.01	0.01	0.90
Backfat[7], in.	0.60^{a}	0.65^{b}	0.70^{c}	0.67^{bc}	0.76^{d}	0.017	0.01	0.01	0.73
Loin depth, in.	2.45^{ab}	2.41^{ab}	2.46^{a}	2.43^{ab}	2.39^{b}	0.02	0.13	0.18	0.05
Lean, %	55.0^{a}	54.2^{b}	54.0^{b}	54.1^{b}	53.1^{c}	0.18	0.01	0.01	0.20
Jowl IV	74.3^{c}	70.1^{a}	69.6^{a}	71.6^{b}	70.4^{a}	0.42	0.01	0.01	0.08
Live wt NEE[8], Mcal/lb	3.22	3.12	3.19	3.15	3.21	0.04	0.35	0.36	0.60
Carcass NEE, Mcal/lb	4.66^{a}	4.36^{b}	4.44^{b}	4.43^{b}	4.44^{b}	0.07	0.05	0.43	0.52

^{abcd}Within a row, means without a common superscript differ ($P \leq 0.05$).

[1] A total of 271 pigs (PIC 1050 × 327; initially 125.2 lb BW) were used in a 74-d growing-finishing trial with 7 to 8 pigs per pen and 6 to 7 pens per treatment.

[2] The dietary treatments included 3 different levels of dietary NE by adding low-energy ingredients (wheat middlings or soybean hulls), 30% dried distillers grains with solubles, or choice white grease to a corn-soybean meal base diet. The difference of dietary NE content between high vs. medium and medium vs. low energy was 75 kcal/lb (166 kcal/kg) across all phases of feeding.

[3] Dried distillers grains with solubles.

[4] 95% confidence interval.

[5] Values in parentheses are gain:feed. Statistics were done on a gain:feed basis.

[6] The prediction equations from the meta-analysis [ADG (g/day) = 0.1135 × NE (kcal/kg) + 8.8142 × Average BW (kg) – 0.05068 × Average BW (kg) × Average BW (kg) + 275.99; G:F = 0.000096 × NE (kcal/kg) – 0.0025 × Average BW (kg) + 0.003071 × fat (%) + 0.3257] were used to calculate predicted ADG and G:F. The difference between predicted and actual growth performance of pigs fed corn-soybean meal diet was used to adjust the intercept of the prediction equations thus adjusting the growth performance of the other pens fed the other diets.

[7] Backfat, loin depth, and lean percentage were adjusted to a common HCW.

[8] Net energy caloric efficiencies (NEE) were calculated on a pen basis by multiplying total feed intake by the dietary NE concentration and dividing by total live or carcass weight gain. The carcass weight gain was obtained from subtracting HCW with the initial carcass weight by assuming 75% carcass yield across diet.

Effects of Hard Red Winter Wheat Particle Size in Meal Diets on Finishing Pig Growth Performance, Diet Digestibility, and Caloric Efficiency[1]

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Summary

A total of 288 pigs (PIC 327 × 1050; initially 96.4 lb) were used in an 83-d study to determine the effects of hard red winter wheat particle size on finishing pig growth performance, diet digestibility, and caloric efficiency. Pens of pigs were balanced by initial BW and randomly allotted to 1 of 3 treatments with 8 pigs per pen and 12 pens per treatment. The same wheat-soybean meal–based diets were used for all treatments. Diets were fed in three phases in meal form. The 3 dietary treatments were hard red winter wheat ground with a hammer mill to 730, 580, or 330 µ.

From d 0 to 40, decreasing wheat particle size decreased (linear; $P < 0.05$) ADFI but improved (quadratic; $P < 0.05$) F/G and caloric efficiency (CE), with no change in ADG. From d 40 to 83, decreasing wheat particle size increased (quadratic; $P < 0.05$) ADG and improved (linear; $P < 0.05$) F/G and CE, with no change in ADFI. Overall from d 0 to 83, decreasing wheat particle size improved (linear; $P < 0.05$) F/G and CE on both an ME and NE basis, with no difference in ADG or ADFI. Finally, reducing wheat particle size improved (linear; $P < 0.05$) DM and GE digestibility.

In summary, fine-grinding hard red winter wheat was detrimental to feed intake in early finishing, but improved ADG in late finishing and improved F/G in both periods and overall. Dry matter and GE digestibility as well as CE were all improved for the overall period with fine-grinding wheat. Grinding wheat from 730 to 330 improved the caloric content on an NE basis by 100 kcal/lb.

Key words: finishing pig, performance, particle size, wheat

Introduction

Particle size of cereal grains is an important aspect of swine nutrition when considering feed efficiency and performance in finishing pigs. In corn-soybean meal–based diets, reducing corn particle size below 400 µ can improve F/G in finishing pigs (De Jong

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et al., 2013[4]) fed mash diets. In wheat-based diets, Kim et al. (2005[5]) observed that decreasing wheat particle size from 929 to 580μ improved starch digestibility. In addition, Mavromichalis et al. (2000[6]) observed improved feed efficiency when wheat was ground from 600 to 400 μ. Although much data exists with corn ground below 400 μ, little is available that illustrates the impacts of feeding diets containing finely ground wheat. Therefore, the objective of this study was to determine the effects of hard red winter wheat particle size on finishing pig growth performance, diet digestibility, and caloric efficiency.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted at the Kansas State University Swine Teaching and Research Center in Manhattan, KS. The barn had completely slatted flooring and deep pits. Each pen was equipped with a 2-hole stainless steel feeder and bowl waterer for ad libitum access to feed and water. Feed was delivered to each individual pen by a robotic feeding system (FeedPro; Feedlogic Corp., Wilmar, MN).

A total of 288 pigs (PIC 327 × 1050; initially 96.4 lb) were used in an 83-d study. Pens of pigs were balanced by initial BW and randomly allotted to 1 of 3 treatments with 8 pigs per pen and 12 pens per treatment. The same wheat-soybean meal–based diets were used for all treatments. Diets were fed in three phases from d 0 to 27, 27 to 60, and 60 to 83 (Table 1). The 3 dietary treatments included hard red winter wheat ground with a hammer mill to approximately 730, 580, or 330 μ. Pigs and feeders were weighed approximately every 2 wk to determine ADG, ADFI, and F/G. Caloric efficiency was determined on both an ME and NE basis. Caloric efficiency was calculated by multiplying total feed intake × energy in the diet (kcal/lb) and dividing by total gain. Feed ingredients were assigned ME values from the NRC (2012[7]). For NE, values were for the growing pig by INRA (2004[8]).

Feed was manufactured at the K-State O.H. Kruse Feed Technology Innovation Center. Wheat was ground to three particle sizes (728, 579, and 326 μ) by a hammer mill equipped with either a # 4, 8, or 12 screen (0.06, 0.13, 0.19 in., respectively).

Composite samples of the wheat used in the diets were collected prior to feed manufacturing and analyzed for DM, CP, fat, NDF, ADF, ash, and amino acids (Table 2). Analyzed values were then used in diet formulation. Feed samples were taken from each feeder during each phase and then combined within treatment and phase for analysis

[4] De Jong. J.A., J.M. DeRouchey, M.D. Tokach, R.D. Goodband, S.S. Dritz, and J.L. Nelssen. 2013. Effects of corn particle size, complete diet grinding, and diet form on pig growth performance, caloric efficiency, and carcass characteristics. J. Anim. Sci. 91:70.

[5] Kim, J.C., P.H. Simmins, B.P. Mullan, and J.R. Pluske. 2005. The digestible energy value of wheat for pigs, with special reference to the post-weaned animal. Anim. Feed Sci. Technol. 122:257–287.

[6] Mavromichalis, I., J.D. Hancock, B.W. Senne, T.L. Gugle, G.A. Kennedy, R.H. Hines, and C.L. Wyatt. 2000. Enzyme supplementation and particle size of wheat in diets for nursery and finishing swine. J. Anim. Sci. 78:3086–3095.

[7] NRC. 2012. Nutrient Requirements of Swine. 11th ed. Natl. Acad. Press, Washington DC.

[8] INRA (Institut National de la Recherche Agronomique). 2004. Tables of composition and nutritional value of feed materials, Sauvant, D., J-M. Perez, and G. Tran, Eds. Wageningen Academic Publishers, The Netherlands and INRA, Paris, France.

(Table 3). Bulk density, particle size, and angle of repose of major ingredients and all diets were measured (Table 4). Particle sizes were determined using Tyler sieves, with numbers 6, 8, 10, 14, 20, 28, 35, 48, 65, 100, 150, 200, and 270 and a pan. A Ro-Tap shaker (W.S. Tyler, Mentor, OH) was used to sift the 100-g samples for 10 min. Particle size was conducted with and without a flow agent (Amorphous silica powder, Gilson Company Inc., Middleton, WI), which was added at 0.001 oz to 3.52 oz of feed. Angle of repose was measured by allowing feed to flow freely over a flat circular platform of a known diameter. The diameter of the platform and height of the resulting pile were used to calculate the angle of repose.

Fecal samples were collected on d 7 of phase 3 (d 67 of the study) from 2 pigs per pen. Phase 3 diets contained 0.5% titanium dioxide as an indigestible marker. After collection, fecal samples were dried in a 50°C forced-air drying oven, then ground for analysis of GE and titanium concentration. The digestibility values were calculated using the indirect method.

Data were analyzed as a completely randomized design using PROC MIXED in SAS with pen as the experimental unit. Linear and quadratic contrasts were completed to determine the effects of decreasing wheat particle size. Results were considered significant at $P \leq 0.05$ and tendencies between $P > 0.05$ and $P \leq 0.10$.

Results and Discussion

Bulk density decreased (Table 4) as wheat particle size decreased. As expected, angle of repose increased as particle size decreased, which indicates poorer flowability.

From d 0 to 40, decreasing wheat particle size decreased (linear; $P < 0.05$) ADFI but improved (quadratic; $P < 0.05$) F/G and CE, with no change ($P > 0.10$) in ADG (Table 5). From d 40 to 83, decreasing wheat particle size increased (quadratic; $P < 0.05$) ADG and improved (linear; $P < 0.05$) F/G and CE, with no change ($P > 0.10$) in ADFI. Overall from d 0 to 83, reducing wheat particle size had no effect on ADG or ADFI but improved (linear; $P < 0.05$) F/G and CE on both an ME and NE basis. Finally, reducing wheat particle size improved (linear; $P < 0.05$) DM and GE digestibility.

In summary, fine-grinding wheat was detrimental to feed intake in early finishing, but this was not observed in late finishing. Fine-grinding wheat improved ADG in late finishing and F/G for both periods and for the overall study period. In addition, DM and GE digestibility were improved as wheat was more finely ground, as was caloric efficiency for the overall period. The improvement in caloric efficiency can be attributed to the finer particle size of the wheat resulting in improved digestibility. Grinding the wheat from 728 to 326 µ improved the caloric content of the wheat by 100 kcal/lb of NE, or approximately 25 kcal NE per 100 µ. It is recommended that wheat be ground to a particle size under 400 µ when feeding hard red winter wheat in meal diets for maximum nutrient digestibility.

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

	Phase[1]		
Item	1	2	3
Ingredient, %			
Hard red winter wheat	81.29	87.46	92.69
Soybean meal, 46.5% CP	15.84	10.14	4.94
Monocalcium P, 21%	0.28	0.03	---
Limestone	1.43	1.28	1.30
Salt	0.35	0.35	0.35
L-lysine HCl	0.33	0.33	0.35
DL-methionine	0.04	0.02	0.02
L-threonine	0.09	0.09	0.11
Trace mineral premix	0.15	0.13	0.10
Vitamin premix	0.15	0.13	0.10
Phytase[2]	0.08	0.08	0.05
Titanium dioxide	---	---	0.50
Total	100.00	100.00	100.00
Calculated analysis			
Standardized ileal digestible (SID) amino acids, %			
Lysine	0.94	0.81	0.71
Isoleucine:lysine	64	63	61
Leucine:lysine	118	121	120
Methionine:lysine	30	30	30
Met & Cys:lysine	61	63	66
Threonine:lysine	62	63	66
Tryptophan:lysine	23.1	23.7	23.7
Valine:lysine	68	69	67
SID lysine:ME, g/Mcal	2.98	2.56	2.24
ME, kcal/lb	1,431	1,435	1,435
Total lysine, %	1.05	0.91	0.79
CP, %	19.7	17.9	16.2
Ca, %	0.67	0.56	0.55
P, %	0.50	0.44	0.42
Available P, %	0.30	0.25	0.24
Crude fiber, %	2.70	2.60	2.60

[1] Phase 1 diets were fed from approximately 85 to 140 lb; Phase 2 from 140 to 182 lb; and Phase 3 from 182 to 265 lb.

[2] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 204.3 phytase units (FTU)/lb, with a release of 0.11% available P.

[3] Titanium was included in the Phase 3 diet as an indigestible marker and was fed for the first 7 d of the phase at a level of 0.5% at the expense of corn.

Table 2. Chemical analysis of ingredients (as-fed basis)[1]

Item	Hard red winter wheat	Soybean meal
DM, %	90.86	90.14
CP, %	11.8	45.8
ADF, %	3.2	6.2
NDF, %	8.1	6.8
NFE, %	72.9	33.6
Ca, %	0.07	0.40
P, %	0.38	0.70
Fat, %	1.8	1.2
Ash, %	1.81	6.11
Starch	55.4	1.5
Particle size (no flow agent), μ	728; 579; 326[2]	942
Particle size (flow agent), μ	714; 554; 284[3]	
Bulk density, lb/bu	60.7; 60.7; 59.3[4]	60.8

[1] A composite sample consisting of 3 subsamples was used for analysis.
[2] Particle sizes were determined using Tyler sieves, with numbers 6, 8, 10, 14, 20, 28, 35, 48, 65, 100, 150, 200, and 270 and a pan. A Ro-Tap shaker (W.S. Tyler, Mentor, OH) was used to sift the 3.52-oz samples for 10 min.
[3] Particle sizes were run with and without flow agent, which was used at an inclusion level of 0.001 oz.
[4] Wheat for treatments 1, 2, and 3 respectively.

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

Item[2]	Phase 1	Phase 2	Phase 3
DM, %	90.28	89.91	89.16
CP, %	19.7	18.4	16.1
ADF, %	2.9	2.8	2.5
NDF, %	9.3	8.2	7.8
Crude fiber, %	2.6	2.2	2.3
NFE, %	62.4	62.9	65.7
Ca, %	0.74	0.89	0.74
P, %	0.51	0.48	0.41
Fat, %	1.4	1.5	1.6
Ash, %	4.41	4.79	3.70
Starch, %	44.1	45.0	51.3

[1] A composite sample consisting of 6 subsamples was used for analysis.
[2] All treatments were analyzed and values were averaged as all treatments were formulated identically.

Table 4. Analysis of diets[1]

	Wheat particle size, µ		
Item	728	579	326
Bulk density, lb/bu			
Phase 1	59.6	59.4	57.6
Phase 2	59.9	59.7	57.8
Phase 3	59.1	59.1	56.1
Particle size, µ[2]			
Phase 1	634	527	432
Phase 2	665	493	354
Phase 3	650	492	336
Angle of repose, °			
Phase 1	44.4	45.6	51.4
Phase 2	44.0	44.1	49.0
Phase 3	45.8	50.3	51.8

[1] A composite sample of four subsamples was used for analysis.
[2] Analysis were run without flow agent.

Table 5. Effects of wheat particle size on finishing pig performance[1]

	Wheat particle size, μ				Probability, *P* <	
Item	728	579	326	SEM	Linear	Quadratic
d 0 to 40						
ADG, lb	2.02	2.04	1.98	0.03	0.349	0.247
ADFI, lb	5.04	4.94	4.84	0.06	0.033	0.966
F/G	2.50	2.42	2.44	0.02	0.015	0.014
d 40 to 83						
ADG, lb	2.02	1.99	2.10	0.02	0.015	0.014
ADFI, lb	6.33	6.18	6.25	0.08	0.484	0.228
F/G	3.14	3.11	2.98	0.03	0.001	0.180
d 0 to 83						
ADG, lb	2.02	2.01	2.04	0.02	0.470	0.470
ADFI, lb	5.71	5.58	5.57	0.06	0.130	0.434
F/G	2.83	2.77	2.73	0.02	0.001	0.824
Caloric efficiency[2]						
ME	4,056	3,973	3,913	28.7	0.001	0.755
NE	3,024	2,963	2,919	21.5	0.001	0.746
Digestibility[3]						
DM, %	88.95	91.15	91.46	0.64	0.013	0.246
GE, %	65.47	70.33	73.46	1.71	0.004	0.685
BW, lb						
d 0	96.5	96.5	96.5	1.1	0.996	0.998
d 40	177.2	177.9	176.2	1.8	0.716	0.586
d 83	264.0	263.4	266.9	2.5	0.414	0.511

[1] A total of 288 pigs (PIC 327 ×1050) were used, with 12 pens per treatment and 8 pigs per pen.
[2] Caloric efficiency is expressed as kcal/lb of gain and represents the d 0 to 83 data.
[3] Fecal samples were taken on d 67 of the study via rectal massage from two pigs per pen.

Effects of Wheat Source and Particle Size in Pelleted Diets on Finishing Pig Growth Performance, Caloric Efficiency, and Carcass Characteristics[1]

J.A. De Jong, J.M. DeRouchey, M.D. Tokach, R.D. Goodband, C.B. Paulk, J.C. Woodworth, C.K. Jones[2], C.R. Stark[2] and S.S. Dritz[3]

Summary

A total of 576 pigs (PIC 327 × 1050; initially 96 lb BW) from 2 consecutive finishing groups were used to determine the effects of wheat source and particle size of pelleted diets on finishing pig growth performance, caloric efficiency, and carcass characteristics. Pigs were allotted randomly to pens upon entry into the finisher. Pens of pigs were balanced by initial BW and randomly allotted to 1 of 6 dietary treatments with 12 replications per treatment and 8 pigs per pen in two groups of finisher pigs. The experimental diets all had the same wheat-soybean meal formulation, with the 6 treatments formed by including the wheat from 1 of 2 sources (hard red winter vs. soft white winter) that were processed to 1 of 3 mean particle sizes (200, 400, or 600 μ). All diets were fed in pelleted form.

Overall, feeding hard red winter wheat improved ($P < 0.05$) ADG, ADFI, and caloric efficiency on both an ME and NE basis compared with soft white winter wheat. There was a tendency ($P < 0.07$) for a quadratic particle size × wheat source interaction for ADG, ADFI, and both DM and GE digestibility because the lowest ADG, ADFI, and both DM and GE digestibility values were for 400-μ hard red winter wheat, and the highest were for 400-μ soft white winter wheat. No significant ($P > 0.10$) main effects were detected of particle size, or of particle size within wheat source. Finally, dietary treatments did not affect carcass characteristics.

In conclusion, decreasing wheat particle size from 600 to 200 μ in pelleted diets had no effect on growth performance. Feeding hard red winter wheat improved ADG and ADFI compared with feeding soft white winter wheat.

Key words: finishing pig, grinding, pelleting, wheat

Introduction

Reducing the particle size of cereal grains has been shown to improve the efficiency of gain in swine. Opinions vary regarding the optimum particle size of cereal grains for animal production and feed manufacturing economics. Most experiments exploring optimum particle size of grain have been conducted in meal diets. Previous research in

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finishing pigs completed at Kansas State University in meal feed has shown improvements in ADG and F/G when hard red winter wheat was ground from 800 to 400 μ.

In addition to fine-grinding cereal grains, pelleting has been shown to consistently improve performance in finishing pigs through reduced intake and improved feed efficiency. Reducing particle size of cereal grains can improve pellet quality by increasing the surface area of the grains during the pelleting process and improving adhesion of the pellet. Murphy et al. (2009[4]) reported no differences in growth performance in growing pigs as wheat particle size of pelleted diets was reduced from 639 to 552 μ, but no research has focused on grinding wheat to finer particle sizes. Thus, the objective of our study was to determine the effects of wheat source and particle size in pelleted diets on finishing pig growth performance, caloric efficiency, and carcass characteristics.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted at the Kansas State University Swine Teaching and Research Center in Manhattan, KS. The barns were tunnel-ventilated with completely slatted flooring and deep pits. Each pen was equipped with a 2-hole stainless steel feeder and bowl waterer for ad libitum access to feed and water. Feed was delivered to each individual pen by a robotic feeding system (FeedPro; Feedlogic Corp., Wilmar, MN).

A total of 576 pigs (PIC 327 × 1050; initially 96 lb BW) from 2 consecutive finishing groups were used to determine the effects of wheat source and particle size of pelleted diets on finishing pig growth performance, caloric efficiency, and carcass characteristics. Pigs were allotted randomly to pens upon entry into the finisher and remained in the experiment for 75 and 89 d, respectively, for each group. Pens of pigs were balanced by initial BW and randomly allotted to 1 of 6 dietary treatments with 12 replications per treatment and 8 pigs per pen. The 6 basal diets consisted of the same wheat-soybean meal formulation. The experimental treatments were arranged as a 2 × 3 factorial with 2 wheat sources (hard red winter wheat or soft white winter wheat) and 3 particle sizes (200, 400, or 600 μ). All diets were fed in pelleted form.

Pigs and feeders were weighed approximately every 2 wk to determine ADG, ADFI, and F/G. Caloric efficiencies of pens were determined on both an ME and NE basis. Efficiencies were calculated by multiplying total feed intake × energy in the diet (kcal/lb) and dividing by total gain. Feed ingredients were assigned an ME and NE value taken from the NRC (2012[5]).

Composite samples of the wheat used in the diets were collected prior to feed manufacturing and analyzed for DM, CP, fat, NDF, ADF, ash, and amino acids (Table 1). Nutrient analyses were then used in diet formulation (Table 2). Feed samples were taken from each feeder during each phase, then combined within treatment and phase for analysis (Tables 3, 4, and 5). Bulk density, pellet durability index (PDI), and

[4] Murphy, A., C. Collins, A. Philpotts, A. Bunyan, and D. Henman. 2009. Influence of hammer mill screen size and grain source (wheat or sorghum) on the growth performance of male grower pigs. Co-op. Res. Cen. for an Inter. Comp. Pork Ind. Rep. QAF Meat Industries Pty Ltd., Corowa, NSW, Australia.
[5] NRC. 2012. Nutrient Requirements of Swine. 11th ed. Natl. Acad. Press, Washington DC.

percentage fines were determined for all diets (Table 6). Particle size, angle of repose, and bulk density was determined for each wheat source at the three different particle sizes. Particle sizes were determined using Tyler sieves, with numbers 6, 8, 10, 14, 20, 28, 35, 48, 65, 100, 150, 200, and 270 and a pan. A Ro-Tap shaker (W.S. Tyler, Mentor, OH) was used to sift the 100-g samples for 10 min. Particle size testing was conducted with and without a flow agent (amorphous silica powder, Gilson Company Inc., Middleton, WI) added at 0.5 g to 100 g of feed. Angle of repose was measured by allowing feed to flow freely over a flat circular platform of a known diameter. The diameter of the platform and height of the resulting pile were used to calculate the angle of repose.

Feed was manufactured at the K-State O.H. Kruse Feed Technology Innovation Center. Wheat was ground to three particle sizes (200, 400, and 600 μ targets) for each of the 2 wheat sources (hard red and soft white wheat). The 3 particle sizes of the hard red wheat were created using a hammer mill equipped with either a # 2, 10, or 16 screen (0.03, 0.16, 0.25 in., respectively). The hard red wheat ground to 245 μ was first ground through a roller mill to ensure a fine enough grind was achieved through the hammer mill. Soft white wheat was ground through a #4, 12, and 16 hammer-mill screen (0.06, 0.19, 0.25 in., respectively). During feed manufacturing, electrical consumption and throughput were measured (Table 7).

Fecal samples were collected on d 7 of Phase 3 (d 61 and 59, respectively, for group 1 and 2) from 2 pigs per pen. The Phase 3 diets contained 0.5% titanium dioxide as an inert digestibility marker. After collection, fecal samples were then dried in a 50°C forced-air drying oven, then ground for measurement of energy by bomb calorimetry and titanium concentration. The digestibility values were calculated using the indirect method.

Prior to marketing, all pigs were individually weighed and tattooed for carcass data collection and transported to Triumph Foods LLC (St. Joseph, MO). Standard carcass characteristics were measured, and jowl fat samples were collected and analyzed at the plant by near-infrared analysis for iodine value.

Data were analyzed as a completely randomized design using PROC MIXED in SAS (SAS Institute, Inc., Cary, NC) with pen serving as the experimental unit. Linear and quadratic contrasts were completed to determine the main effects of decreasing wheat particle size as well as the interaction with wheat source. The main effects of wheat source were also determined. Lastly, linear and quadratic contrasts within wheat source for particle size were also tested. Results were considered significant at $P \leq 0.05$ and tendencies between $P > 0.05$ and $P \leq 0.10$.

Results and Discussion

Analysis of dietary treatments showed that all values were similar to those used in formulation. Bulk density and percentage fines were similar among treatments, but PDI was lower for the soft white wheat diets than for the hard red wheat. Decreasing the particle size of the wheat improved PDI as expected. Wheat particle sizes decreased for hard red winter wheat and soft white winter wheat as expected. Reductions in particle size led to increases in angle of repose for both wheat sources, which would suggest

decreased flowability; however, no issues with diet flowability in feed lines or feeders were observed during the trial. In addition, decreased wheat particle size decreased bulk density.

Grinding hard red winter wheat required more kilowatt hours (kWh) than grinding soft white winter wheat (Table 7). For both sources, fine-grinding increased kWh as expected. Pelleting soft white winter wheat diets increased electrical consumption compared with hard red winter wheat. Finely ground wheat increased electrical consumption for hard red wheat during pelleting but decreased electrical consumption for soft white wheat. Throughput during pelleting was improved by increasing wheat particle size as well as by pelleting soft white wheat compared with hard red wheat.

Overall, feeding hard red winter wheat improved ($P < 0.05$) ADG, ADFI, and caloric efficiency on both an ME and NE basis when compared with soft white winter wheat (Table 8). The improvement in caloric efficiency reflected source differences in the ME and NE values obtained from the NRC because there were no differences in F/G, which suggests the energy value for the wheat sources was similar. There was a tendency ($P < 0.07$) for a quadratic particle size × wheat source interaction for ADG, ADFI, and both DM and GE digestibility because the lowest ADG, ADFI, and both DM and GE digestibility values were for 400-µ hard red winter wheat, and the highest were for 400-µ soft white winter wheat. There were no main effects ($P > 0.10$) of particle size or particle size within wheat source (Table 9). Finally, dietary treatments did not affect ($P > 0.10$) carcass characteristics.

Results from this study suggest that reducing the particle size of either hard red or soft white winter wheat from 600 to 200 µ does not improve growth performance when diets are pelleted. This is in contrast to previous work done with meal diets but agrees with Nemechek et al. (2013[6]), who showed that corn-based diets had larger improvements to fine-grinding when diets were fed in meal form compared with similar diets fed in pelleted form. Less electrical consumption is needed to grind wheat to a particle size of 600 µ compared with 200 µ, and thus should result in diets that cost less to manufacture. Feeding hard red compared with soft white winter wheat improved growth rate and feed intake of pigs fed pelleted diets.

[6] Nemechek, J.E., M.D. Tokach, K.F. Coble, C.W. Hastad, J.M. DeRouchey, S.S. Dritz, and R.D. Goodband. Effects of corn particle size and diet form on finishing pig growth performance and carcass characteristics. J. Anim. Sci. 92:54 Supp 2.

Table 1. Chemical analysis of wheat sources (as-fed basis)[1]

Item	Hard red winter wheat	Soft white winter wheat
DM, %	90.86	91.80
CP, %	11.8	11.2
ADF, %	3.2	2.8
NDF, %	8.1	8.6
NFE, %	72.9	74.8
Ca, %	0.07	0.13
P, %	0.38	0.40
Fat, %	1.8	1.6
Ash, %	1.81	1.89
Starch, %	55.4	56.9

[1] A composite sample consisting of 6 subsamples was used for analysis.

Table 2. Diet composition (as-fed basis)[1]

Item	Source:	Hard red winter wheat			Soft white winter wheat		
	Phase:	1	2	3	1	2	3
Ingredient, %							
Wheat		78.45	85.02	89.95	78.45	85.02	89.95
Soybean meal (46.5% CP)		17.31	11.19	6.33	17.31	11.19	6.33
Choice white grease		1.50	1.50	1.50	1.50	1.50	1.50
Monocalcium phosphate (21% P)		0.25	---	---	0.25	---	---
Limestone		1.38	1.28	1.25	1.38	1.28	1.25
Salt		0.35	0.35	0.35	0.35	0.35	0.35
L-lysine HCl		0.29	0.30	0.32	0.29	0.30	0.32
DL-methionine		0.05	0.05	0.01	0.05	0.05	0.01
L-threonine		0.09	0.08	0.10	0.09	0.08	0.10
Trace mineral premix		0.13	0.10	0.08	0.13	0.10	0.08
Vitamin premix		0.13	0.10	0.08	0.13	0.10	0.08
Phytase[2]		0.08	0.08	0.05	0.08	0.08	0.05
Titanium[3]		---	---	0.50	---	---	0.50
Total		100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis							
Standard ileal digestible (SID) amino acids, %							
Lysine		0.94	0.81	0.71	0.94	0.81	0.71
Isoleucine:lysine		66	65	63	68	67	67
Leucine:lysine		121	122	123	120	121	121
Methionine:lysine		31	30	30	30	30	30
Met & Cys:lysine		62	63	66	62	64	66
Threonine:lysine		63	63	66	62	63	66
Tryptophan:lysine		23.5	24.0	24.3	22.1	22.1	22.1
Valine:lysine		70	70	70	74	75	75
Total lysine, %		1.05	0.91	0.80	1.05	0.91	0.80
ME, kcal/lb[4]		1,467	1,470	1,470	1,491	1,497	1,498
NE kcal/lb[4]		1,099	1,114	1,123	1,143	1,161	1,174
SID lysine:ME, g/Mcal		2.91	2.50	2.19	2.86	2.45	2.15
CP, %		17.8	15.6	13.9	17.4	15.2	13.5
Crude fiber, %		2.7	2.6	2.6	0.7	0.4	0.2
Ca, %		0.65	0.55	0.53	0.65	0.55	0.53
P, %		0.48	0.41	0.40	0.48	0.41	0.40
Available P, %		0.28	0.23	0.22	0.28	0.23	0.22

[1] Treatment diets fed for 79 and 85 d for groups 1 and 2, respectively.
[2] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 340.5 phytase units (FTU)/lb, with a release of 0.12% available P.
[3] Titanium was included in diets fed from day 7 to 14 in group 1 at a level of 0.5%, at the expense of corn.
[4] NRC. 2012. Nutrient Requirements of Swine, 11th ed. Natl. Acad. Press, Washington DC.

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

Source:	Hard red winter wheat			Soft white winter wheat		
Particle size:	200	400	600	200	400	600
Item						
DM, %	89.68	89.69	90.19	91.16	91.73	91.48
CP, %	20.1	20.2	20.5	19.1	20.3	19.5
ADF, %	2.7	2.7	2.2	2.3	3.5	3.1
NDF, %	7.6	8.1	7.5	6.9	9.9	8.9
NFE, %	60.8	60.8	61.5	63.5	61.8	62.6
Ca, %	0.72	0.69	0.76	0.87	0.76	0.80
P, %	0.49	0.52	0.50	0.46	0.51	0.52
Fat, %	2.8	2.7	2.6	2.6	2.6	2.6
Ash, %	3.78	3.85	3.88	4.10	4.20	4.21
Starch, %	39.8	39.9	39.9	42.7	41.0	41.8

[1] A composite sample consisting of 3 subsamples was used for analysis.
[2] All values are averages of the 2 finishing groups' feed.

Table 4. Chemical analysis of diets, Phase 2 (as-fed basis)[1,2]

Source:	Hard red winter wheat			Soft white winter wheat		
Particle size:	200	400	600	200	400	600
Item						
DM, %	90.63	90.26	90.66	91.6	91.54	91.54
CP, %	18.5	18.0	18.4	18.2	17.0	17.4
ADF, %	2.2	2.9	1.9	3.0	2.9	2.9
NDF, %	7.4	8.3	6.2	8.1	7.4	9.7
NFE, %	64.4	63.9	64.8	64.5	66.1	65.5
Ca, %	0.66	0.72	0.67	0.69	0.64	0.67
P, %	0.45	0.44	0.41	0.39	0.44	0.42
Fat, %	2.5	2.7	2.6	2.7	2.6	2.7
Ash, %	3.47	3.44	3.32	3.76	3.50	3.62
Starch, %	45.1	44.4	46.6	45.3	45.0	43.9

[1] A composite sample consisting of 3 subsamples was used for analysis.
[2] All values are averages of the 2 finishing groups' feed.

Table 5. Chemical analysis of diets, Phase 3 (as-fed basis)[1,2]

Source:	Hard red winter wheat			Soft white winter wheat		
Particle size, µ:	200	400	600	200	400	600
Item						
DM, %	90.24	89.83	89.92	89.98	90.82	90.64
CP, %	15.7	15.8	16.5	16.8	14.2	15.1
ADF, %	2.0	1.7	1.9	2.3	1.4	2.9
NDF, %	7.3	6.9	6.6	7.7	6.5	8.7
NFE, %	67.3	68.3	66.1	65.6	69.5	67.2
Ca, %	0.63	0.63	0.61	0.62	0.65	0.62
P, %	0.43	0.46	0.45	0.46	0.35	0.42
Fat, %	2.4	2.4	2.4	2.2	2.5	2.5
Ash, %	4.16	3.61	3.45	3.54	3.63	3.57
Starch, %	48.4	47.9	46.1	46.6	53.7	47.6

[1] A composite sample consisting of 3 subsamples was used for analysis.
[2] All values are averages of the 2 finishing groups' feed.

Table 6. Physical analysis of diets and wheat[1,2]

	Source:	Hard red winter wheat			Soft white winter wheat		
Item	Particle size, µ:	200	400	600	200	400	600
Diet[3]							
Bulk density, lb/bu		68.0	66.8	67.5	68.6	68.0	66.3
Pellet durability index, %		88.5	81.2	74.2	54.5	50.9	48.7
Percentage fines, %		24.0	22.9	26.9	22.2	27.2	24.1
Wheat							
Particle size (no flow agent)[4], µ		245	465	693	258	402	710
Particle size (flow agent), µ		201	415	631	210	341	638
Angle of repose, °		50.8	49.5	45.8	58.1	58.2	43.6
Bulk density, lb/bu		56.6	55.0	54.3	59.4	56.5	56.1

[1] A composite sample consisting of 3 subsamples was used for analysis.
[2] All values are averages of samples taken from the 2 groups.
[3] Diet samples from phases were averaged; no differences existed between phases.
[4] Particle sizes were determined using Tyler sieves, with numbers 6, 8, 10, 14, 20, 28, 35, 48, 65, 100, 150, 200, and 270 and a pan. A Ro-Tap shaker (W.S. Tyler, Mentor, OH) was used to sift the 100-g samples for 10 min. Particle sizes were run with and without flow agent at an inclusion level of 0.5 g.

Table 7. Electrical consumption and throughput during feed manufacturing[1]

Source:	Hard red winter wheat			Soft white winter wheat		
Particle size, μ:	200	400	600	200	400	600
Item						
Wheat grinding						
Kilowatts, kW[2]	11.04	9.33	8.37	8.58	8.47	7.59
Kilowatt hours, kWh[3]	7.88	7.00	6.98	5.00	4.94	4.43
Cost/ton, $[4]	0.32	0.28	0.28	0.20	0.20	0.18
Pelleting						
Kilowatts, kW	20.64	20.57	20.99	22.56	22.80	22.68
Kilowatt hours, kWh	14.07	12.66	12.25	13.63	13.83	14.88
Cost/ton, $	2.25	2.03	1.96	2.18	2.21	2.38
Throughput, lb/hr	5,033	5,443	5,804	5,862	5,961	5,909

[1] Voltage was recorded during each manufacturing run, then averaged across the phases and between the groups.
[2] kW was calculated by the formula kW = amperage × voltage / 1000.
[3] kWh was calculated by the formula kWh = kW × hours used.
[4] Cost per kWh was $0.12.

Table 8. Interactive effects of wheat source and particle size of pelleted diets on finishing pig growth performance, caloric efficiency, and carcass characteristics[1]

	Wheat source and particle size, μ								
	Hard red winter			Soft white winter				Quadratic particle size	Source
Item	200	400	600	200	400	600	SEM	× source[2]	main effect
ADG, lb	2.26	2.21	2.26	2.14	2.20	2.18	0.03	0.075	0.004
ADFI, lb	5.85	5.70	5.88	5.58	5.67	5.63	0.08	0.068	0.003
F/G	2.58	2.58	2.61	2.61	2.58	2.58	0.02	0.994	0.948
Initial wt, lb	95.6	95.6	95.6	95.6	95.5	95.6	8.3	0.983	0.978
Final wt, lb	281.9	276.8	280.5	271.5	277.1	276.1	7.03	0.289	0.129
Caloric efficiency[3]									
ME	3,796	3,783	3,829	3,903	3,851	3,859	28	0.985	0.041
NE	2,098	2,087	2,121	2,189	2,164	2,140	114	0.447	0.001
Digestibility									
DM, %	87.7	87.0	88.0	85.8	87.7	85.1	0.80	0.030	0.048
GE, %	68.3	64.5	66.3	62.3	67.5	64.9	1.94	0.053	0.360
Carcass traits									
Feed/carcass gain[4]	3.53	3.57	3.69	3.58	3.77	3.76	0.09	0.454	0.065
HCW, lb	201.4	199.1	202.3	197.1	200.8	199.3	3.2	0.331	0.479
Yield, %	73.0	72.8	72.9	73.0	73.1	73.1	73.1	0.241	0.167
BF, in.	0.77	0.76	0.75	0.75	0.77	0.78	0.02	0.945	0.466
Loin depth, in.	2.28	2.28	2.31	2.21	2.29	2.27	0.05	0.474	0.447
Fat-free lean, %	0.52	0.53	0.53	0.52	0.53	0.52	0.02	0.792	0.397
Jowl iodine value, mg/100 g	69.1	69.0	68.6	68.4	68.6	68.3	0.4	0.928	0.210

[1]A total of 576 pigs (PIC 327 × 1050; initially 96 lb BW) in 2 groups were used in a 75- and 89-d study with 8 pigs per pen and 12 replications per treatment.
[2]No source × particle size interactions, main effects of particle size, or linear or quadratic effects of particle size within wheat source.
[3]Caloric efficiency is expressed as kcal/lb of gain.
[4]Feed/carcass gain is expressed as total intake / lb carcass gain with an assumed initial yield of 75%.

Table 9. Main effects of wheat source and particle size of pelleted diets on finishing pig growth performance, caloric efficiency, and carcass characteristics[1]

	Wheat source		Particle size				Probability, $P <$	
Item	Hard red winter	Soft white winter	200	400	600	SEM	Source main effect	Particle size main effect
ADG, lb	2.24	2.18	2.20	2.21	2.22	0.02	0.004	0.510
ADFI, lb	5.81	5.63	5.71	5.69	5.76	0.06	0.003	0.566
F/G	2.59	2.59	2.60	2.58	2.59	0.01	0.948	0.845
Initial wt, lb	95.6	95.6	95.6	95.6	95.6	8.2	0.978	0.979
Final wt, lb	279.7	274.9	276.7	276.9	278.3	6.6	0.129	0.627
Caloric efficiency[2]								
ME	3,696	3,861	3,843	3,732	3,762	86	0.041	0.407
NE	2,102	2,165	2,143	2,126	2,131	114	0.001	0.463
Digestibility								
DM, %	87.84	86.22	86.73	87.37	86.55	0.57	0.048	0.818
GE, %	66.37	64.91	65.32	66.00	65.60	1.38	0.360	0.884
Carcass traits								
Feed/carcass gain[3]	3.63	3.73	3.66	3.68	3.71	0.04	0.065	0.431
HCW, lb	201.0	199.1	199.2	199.9	200.8	2.23	0.479	0.618
Yield, %	72.9	73.1	73.1	73.0	73.0	0.01	0.167	0.787
Backfat, in.	0.76	0.77	0.76	0.76	0.76	0.01	0.466	0.884
Loin depth, in.	2.29	2.26	2.25	2.28	2.29	0.03	0.447	0.469
Fat-free lean, %	52.6	52.4	52.5	52.6	52.6	0.01	0.397	0.609
Jowl iodine value, mg/100 g	68.9	68.4	68.7	68.8	68.4	0.31	0.210	0.475

[1] A total of 576 pigs (PIC 327 × 1050, initially 96 lb BW) in 2 groups were used in a 75- and 89-d study with 8 pigs per pen and 12 replications per treatment.
[2] Caloric efficiency is expressed as kcal/lb of gain.
[3] Feed/carcass gain is expressed as total intake/lb carcass gain with an assumed initial yield of 75%.

Effects of Different Feed Mills and Conditioning Temperature of Pelleted Diets on Nursery Pig Performance and Feed Preference from 14 to 50 lb

J.A. De Jong, J.M. DeRouchey, M.D. Tokach, R.D. Goodband, and S.S. Dritz[1]

Summary

A total of 644 pigs (PIC 1050 or 327 × 1050, initial BW~14 lb) were used in 3 experiments to determine possible explanations for poorer pig performance in previous studies with pigs fed pelleted diets compared with those fed meal diets. Therefore, we examined feed pelleted from different mills as well as conditioning temperature as factors influencing our previous results.

In Experiment 1, pens of pigs were randomly allotted to 1 of 3 dietary treatments with 10 pens per treatment and 7 pigs per pen. The 3 dietary treatments used the identical corn-soybean meal–based formulation and were mixed from the same batch of ingredients. Experimental diets were: (1) feed mixed at mill B but pelleted in mill A; (2) feed mixed and pelleted at mill B; and (3) feed mixed at mill B and fed in meal form. Experiment 2 was a feed preference study where pens of pigs were randomly allotted to the same diets as Experiment 1 with 4 pens per treatment and 7 pigs per pen. Pens contained 2 feeders, each containing 1 of 3 treatment diets. Feeders were rotated once daily within each pen for the entire 33-d study with three diet comparisons tested: 1 vs. 2, 1 vs. 3, and 2 vs. 3.

In Experiment 3, pens of pigs were randomly allotted to 1 of 5 dietary treatments and fed for 16 d with 14 pens per treatment and 5 pigs per pen. Similar to Experiment 1, all diets used the identical corn-soybean meal–based formulation and were mixed from the same batch of ingredients. The experimental diets were: (1) feed mixed at mill A and fed in meal form; (2) feed mixed at mill A, but pelleted at mill B; (3), (4), and (5) feed mixed and pelleted at mill A at a conditioning temperature of 140, 160, or 180°F, respectively.

In Experiment 1, pigs fed the mill-B pelleted diet had the greatest ($P < 0.05$) ADG, whereas pigs fed the mill-A pelleted diet had the lowest ($P < 0.05$) ADG, with the meal diet from mill B intermediate (Table 6). There were no differences in ADFI among the three experimental diets. The mill-A pelleted diet significantly worsened ($P < 0.05$) F/G and final BW compared with the mill-B pelleted diet, whereas the mill-B mash diet only tended ($P < 0.06$) to worsen F/G compared with the mill-B pelleted diet.

In Experiment 2 for comparison 1, pigs consumed more ($P < 0.05$) of the mill-B pelleted diet than the mill-A pelleted diet, which translated into pigs eating 70% of

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their daily intake from the mill B pellet (Table 7). For comparison 2 and 3, pigs fed either the mill-A or mill-B pellet consumed more feed ($P < 0.05$) than the mill B diet fed in mash form, with the pellets equated to 90% of their daily intake.

For Experiment 3, there were no differences among the three diets pelleted under increasing conditioning temperatures at mill A, so they were combined for analysis (Table 8). Pigs fed the meal diet had improved ($P < 0.05$) ADG compared with pigs fed the mill-A pellet with the mill-B pellet fed pigs intermediate. For ADFI, both mill-B and mill-A pellet-fed pigs had reduced ($P < 0.05$) intake compared with the meal diet but improved ($P < 0.05$) F/G. Final BW was reduced when pigs were fed the mill-A pelleted diet compared with the mash diet, with the pigs fed the mill-B pellet intermediate.

In our study, conditioning temperature did not seem to explain the differences between mill-related growth performance differences observed in Experiments 1 and 2. More research is needed to fully elucidate the reason why pig performance may differ when the same feed is processed in different mills.

Key words: feed preference, conditioning temperature, nursery pig, pelleting

Introduction

Pelleting swine diets typically improves pig growth performance and feed efficiency by approximately 4 to 6%. In recent Kansas State University studies, however, pigs fed pelleted diets had decreased ADG and poorer F/G than those fed meal-based diets. These differences in the response to pelleting were unexpected. The pellets used in these studies had no visible characteristics that might be responsible for the differences in performance. We questioned if something inherent in the pelleting process at one mill might be responsible for the differences; therefore, our objective was to compare pig performance and preference for the same diet pelleted at different feed mills, then to determine if conditioning temperatures might be the reason for the change in pig performance.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocols used in these experiments. The studies were conducted at the K-State Swine Teaching and Research Center and Segregated Early Weaning Facility in Manhattan, KS.

A total of 644 pigs (PIC 1050 or 327 × 1050, initially ~14 lb) were used in three experiments. In all experiments, pigs were randomly allotted to pens based on initial pig weight.

In Experiment 1, pens of pigs were randomly allotted to 1 of 3 dietary treatments with 10 pens per treatment and 7 pigs per pen. Experimental diets were fed for 42 d. The 3 dietary treatments used identical corn-soybean meal–based formulations and were batched from similar lots of ingredients (Table 1). Experimental treatments were: (1) feed mixed at mill B but pelleted in mill A; (2) feed mixed and pelleted at mill B; and (3) feed mixed at mill B and fed in meal form.

Experiment 2 was a feed preference study in which pens of pigs were randomly allotted to the same treatments as Experiment 1, with 4 pens per treatment and 7 pigs per pen. Pens contained two feeders, each feeder containing 1 of 3 treatment diets. Feeders were rotated once daily within each pen for the entire 33-d study, with three diet comparisons tested: 1 vs. 2, 1 vs. 3, and 2 vs. 3.

In Experiment 3, pens of pigs were randomly allotted to 1 of 5 dietary treatments and fed for 16 d with 14 pens per treatment and 5 pigs per pen. The 5 dietary treatments used the identical corn-soybean meal–based formulation. Batches of feed were made for the Phase 1 and 2 diets, respectively, then sacked, and bags were pulled randomly from each batch to create the base feed for each treatment. The experimental treatments were: (1) feed mixed at mill A and fed in meal form; (2) feed mixed at mill A, but pelleted at mill B (conditioning temperature of 143°F); and (3), (4), and (5) feed mixed and pelleted at mill A at a conditioning temperatures of 140, 160, or 180°F.

In Experiment 1, each pen contained a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water. Pens had wire-mesh floors and allowed approximately 3 ft^2/pig. Pig weight and feed disappearance were measured on d 0, 7, 14, 21, 26, 33, and 42 of the trial to determine ADG, ADFI, and F/G. In Experiment 2, each pen contained two, 2-hole, dry self-feeders and a nipple waterer to provide ad libitum access to feed and water. Pens were similar to Experiment 1, and pigs were weighed and feed disappearance was measured on d 0, 7, 14, 21, 26, and 33. In Experiment 3, pigs were provided unlimited access to feed and water by way of a 4-hole dry self-feeder and a cup waterer in each pen (5 ft × 5 ft). Pig weight and feed disappearance were measured on d 0, 6, 13, and 16 of the trial to determine ADG, ADFI, and F/G.

Complete diet samples were collected and submitted to Ward Laboratories, Inc. (Kearney, NE) for analysis of DM, CP, ADF, NDF, ADF, NDF, Ca, P, crude fat, and ash. In addition, diet samples from Experiment 1 were analyzed for total and available lysine. Percentage fines and pellet durability index (PDI) were also determined for pelleted diets in all three experiments. Bulk density was determined for all diets and angle of repose for all mash diets.

Data were analyzed using PROC MIXED in SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. The LSMEANS procedure was used to determine the mean differences of treatments. Statistics were considered significant at $P < 0.05$ and tendencies at $P \leq 0.10$.

Results and Discussion

As expected, chemical analysis of complete diets from all three trials revealed no notable differences between treatments within experiment (Tables 2 and 3). Diets analyzed from Experiment 1 showed no differences in total and available lysine. Pellet durability and percentage fines were also similar among pelleted diets within experiment (Tables 4 and 5).

Overall in Experiment 1, pigs fed the mill-B pelleted diet had the greatest ($P < 0.05$) ADG, whereas pigs fed the mill-A pelleted diet had the lowest ($P < 0.05$) ADG, with the meal diet from mill B intermediate (Table 6). There were no differences in ADFI

among the three experimental diets. The mill-A pelleted diet significantly worsened ($P < 0.05$) F/G and final BW compared with the mill-B pelleted diet, whereas the mill-B mash diet only tended ($P < 0.06$) to worsen F/G compared with the mill-B pelleted diet.

In Experiment 2 for comparison 1, pigs consumed more ($P < 0.05$) of the mill-B pelleted diet than the mill-A pelleted diet, which translated into pigs eating 70% of their daily intake from the mill B pellet (Table 7). For comparison 2 and 3, pigs fed either the mill-A or mill-B pellet consumed more feed ($P < 0.05$) than the mill B diet fed in mash form, with the pellets equated to 90% of their daily intake.

For Experiment 3, there were no differences among the three diets pelleted under increasing conditioning temperatures at mill A, so they were combined for analysis (Table 8). Pigs fed the meal diet had improved ($P < 0.05$) ADG compared with pigs fed the mill-A pellet, with the mill-B pellet fed pigs intermediate. For ADFI, both mill-B and mill-A pellet-fed pigs had reduced ($P < 0.05$) intake compared with the meal diet but improved ($P < 0.05$) F/G. Final BW was reduced when pigs were fed the mill-A pelleted diet compared with the mash diet, with the pigs fed the mill-B pellet intermediate.

In conclusion, the same diet when produced at different feed mills may affect pig performance. In our study, Experiment 3 demonstrated that the conditioning temperature range of pelleted diets did not affect nursery pig growth performance; thus, differences in pelleting temperatures do not seem to explain the inter-mill growth performance and preference differences exhibited in the first two experiments. We speculate other factors that may explain the difference include mill operator experience level, post-pelleting handling techniques, pellet cooling systems, or humidity and room temperatures during the pelleting process. Additional research is needed to better understand how mill-to-mill variation affects growth performance of pigs.

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

	Phase:		
Item	1	2	3
Ingredient, %			
Corn	36.05	52.76	61.31
Soybean meal (46.5% CP)	19.97	29.67	33.79
Spray-dried blood meal	1.25	1.25	---
Spray-dried blood plasma	4.00	---	---
DDGS[2]	5.00	---	---
Select menhaden fish meal	1.25	1.25	---
Spray-dried whey	25.00	10.00	---
Choice white grease	3.00	1.50	1.50
Monocalcium phosphate (21% P)	0.90	0.93	1.15
Limestone	1.00	1.05	0.95
Salt	0.30	0.30	0.35
L-lysine HCl	0.23	0.30	0.30
DL-methionine	0.15	0.18	0.12
L-threonine	0.09	0.15	0.12
Vitamin premix	0.25	0.25	0.15
Trace mineral premix	0.15	0.15	0.25
Choline chloride	0.04	---	---
Phytase[3]	---	0.02	0.02
Zinc oxide	0.39	0.25	---
Medication[4]	1.00	---	---
Total	100	100	100

continued

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

	Phase:		
Item	1	2	3
Calculated analysis			
Standard ileal digestible (SID) amino acids, %			
Lysine	1.40	1.35	1.24
Isoleucine:lysine	56	58	63
Leucine:lysine	127	124	128
Methionine:lysine	32	35	33
Met & Cys:lysine	57	57	57
Threonine:lysine	63	64	63
Tryptophan:lysine	19	18.1	18.7
Valine:lysine	71	68	68
Total lysine, %	1.56	1.50	1.39
ME, kcal/lb[5]	1,552	1,520	1,515
NE, kcal/lb[6]	1,102	1,115	1,100
SID lysine:ME, g/Mcal	4.09	4.03	3.71
CP, %	22.10	22.10	21.60
Crude fiber, %	2.00	2.20	2.50
Ca, %	0.85	0.80	0.70
P, %	0.72	0.66	0.65
Available P, %	0.51	0.47	0.42

[1] Treatment diets were fed for 42, 33, and 16 d for Experiments 1, 2, and 3, respectively.
[2] Dried distillers grains with solubles.
[3] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 340.5 phytase units (FTU)/lb, with a release of 0.12% available P.
[4] Mecadox 2.5 was used during the first phase.
[5] NRC. 2012. Nutrient Requirements of Swine, 11th ed. Natl. Acad. Press, Washington DC.
[6] INRA (Institut National de la Recherche Agronomique). 2004. Tables of composition and nutritional value of feed materials, Sauvant, D., J-M. Perez and G. Tran, Eds. Wageningen Academic Publishers, The Netherlands and INRA, Paris, France

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

Phase:	1			2			3		
Mill:	A	B	B	A	B	B	A	B	B
Item Diet form:	Pellet	Pellet	Meal	Pellet	Pellet	Meal	Pellet	Pellet	Meal
DM, %	92.29	91.31	93.08	91.23	92.01	91.68	89	88.69	88.25
CP, %	20.6	21.4	19.3	22.2	22	20.2	22.5	22.9	22.5
ADF, %	3.2	3.3	3.4	2.8	3.3	4.3	2.8	2.6	3.3
NDF, %	6.8	5.9	7.2	6.6	6.3	6.6	6.9	7.1	7.1
NFE, %	55.6	54.4	58.3	53.1	54.5	54.2	54.4	54.4	53.2
Ca, %	0.91	1.03	0.84	1.03	1.10	1.04	1.01	1.04	0.91
P, %	0.71	0.82	0.68	0.66	0.81	0.59	0.64	0.64	0.59
Fat, %	5.8	5.7	5.5	5.4	5.3	5.2	4.1	3.6	4.3
Ash, %	7.78	7.12	7.34	8.28	7.51	8.78	5.78	5.82	5.58
Starch, %	25.3	26.5	26.2	28.8	25.8	31.3	34.7	34.7	34.4
Total lysine, %	1.21	1.29	1.13	1.16	1.31	1.07	1.40	1.35	1.35
Available lysine[2], %	1.18	1.26	1.10	1.13	1.28	1.05	1.37	1.33	1.33

[1] A composite sample consisting of 3 subsamples was used for analysis. Samples from Experiments 1 and 2 were combined for analysis because they were batched and pelleted together at the mill.
[2] Available lysine has not been bound and is still available to the pig.

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

Phase:	1			2		
Mill:	A	A	B	A	A	B
Item Diet form:	Meal	Pellet	Pellet	Meal	Pellet	Pellet
DM, %	91.83	91.61	92.05	90.40	89.57	90.50
CP, %	22.2	23.0	22.2	23.5	22.7	23.3
ADF, %	2.7	2.9	2.8	2.9	2.7	2.8
NDF, %	6.0	6.3	6.4	6.3	5.9	6.3
NFE, %	55.7	54.40	55.2	55.0	55.70	55.6
Ca, %	1.13	1.07	1.07	0.97	0.82	0.94
P, %	0.74	0.74	0.71	0.70	0.61	0.66
Fat, %	4.9	5.0	4.8	3.7	3.6	3.5
Ash, %	6.89	6.85	7.52	5.94	5.37	5.88
Starch, %	22.8	22.37	23.4	29.9	32.77	30.9

[1] A composite sample consisting of 3 subsamples was used for analysis.
[2] Results from treatments 3, 4, and 5 were averaged.

Table 4. Physical analysis of diets, Experiments 1 and 2 (as-fed basis)[1,2]

Phase:	1			2			3		
Mill:	A	B	B	A	B	B	A	B	B
Item Diet form:	Pellet	Pellet	Meal	Pellet	Pellet	Meal	Pellet	Pellet	Meal
Percentage fines, %	8.4	1.0	---	1.8	1.4	---	16.2	1.6	---
PDI[3], %	78.4	67.9	---	86.6	64.2	---	30.8	33.2	---
Bulk density, lb/bu	61.4	60.5	57.9	63.4	60.7	57.1	61.54	59.3	54.8
Angle of repose, ˚	---	---	53.9	---	---	53.6	---	---	52.6

[1] A composite sample consisting of 3 subsamples was used for analysis.
[2] Samples from Experiments 1 and 2 were combined for analysis as they were batched and pelleted together at the mill.
[3] Pellet durability index.

Table 5. Physical analysis of diets, Experiments 3 (as-fed basis)[1]

Phase:	1			2		
Mill:	B	A	A	B	A	A
Item Diet form:	Pellet	Pellet[2]	Meal	Pellet	Pellet	Meal
Percentage fines, %	0.4	0.3	---	0.1	0.8	---
PDI, %	87.6	94.8	---	80.1	93.7	---
Bulk density, lb/bu	62.3	59.7	58.5	61.9	58.9	58.2
Angle of repose, ˚	---	---	50.2	---	---	42.3

[1] A composite sample consisting of 3 subsamples was used for analysis.
[2] Results from treatments 4, 5, and 6 were averaged.

Table 6. Effects of mill on nursery pig growth performance, Experiments 1[1]

Mill:	A	B			
Item Diet form:	Pellet	Pellet	Meal	SEM	Probability, $P <$
d 0 to 42					
ADG, lb	0.84[b]	0.95[a,x]	0.91[a,y]	0.02	0.001
ADFI, lb	1.43	1.51	1.51	0.03	0.208
F/G	1.71[b]	1.59[a,x]	1.67[a,y]	0.03	0.028
Wt, lb					
d 0	14.0	14.1	14.0	0.05	0.834
d 21	35.8[b]	40.3[a,x]	37.7[a,y]	0.63	0.001

[1] A total of 210 pigs (PIC 327 × 1050, initial BW 14 lb) were used in a 42-d growth trial with 7 pigs per pen and 10 pens per treatment.
[a,b] Superscripts within a row are different ($P < 0.05$).
[x,y] Superscripts within a row tend to be different ($P < 0.10$).

Table 7. Effects of mill on feed intake preference of pelleted and meal diets in nursery pigs, Experiments 2[1]

Item	ADFI, lb	ADFI, %[2]
Comparison 1		
Mill A pellet	0.34	30.22
Mill B pellet	0.80	69.78
SEM	0.04	2.54
Probability, *P* <	0.001	0.001
Comparison 2		
Mill B pellet	1.02	89.56
Mill B mash	0.12	10.44
SEM	2.41	0.03
Probability, *P* <	0.001	0.001
Comparison 3		
Mill A pellet	0.93	89.52
Mill B mash	0.11	10.48
SEM	0.04	13.98
Probability, *P* <	0.001	0.001

[1] A total of 84 pigs (PIC 327 × 1050, initial BW 14 lb) were used in a 33-d growth trial with 7 pigs per pen and 4 pens per treatment. Feeders were rotated once daily within each pen to eliminate any location effects of feeder.
[2] ADFI, % is a percentage of total feed intake for each treatment within a comparison.

Table 8. Effects of mill on nursery pig growth performance, Experiments 3[1,2]

Mill:	A				B		Probability, $P <$			
Diet form:	Meal	Pellet	Pellet	Pellet	Pellet					
Item Cond. temp., °F:	---	140	160	180	143	SEM	Treatment[3]	Mill A meal vs. mill B pellets	Mill A meal vs. mill A pellets	Mill A pellets vs. mill B pellets
d 0 to 42										
ADG, lb	0.64	0.59	0.57	0.59	0.59	0.02	0.055	0.075	0.018	0.840
ADFI, lb	0.86	0.69	0.68	0.70	0.69	0.01	0.001	0.001	0.001	0.738
F/G	1.35	1.20	1.20	1.19	1.19	0.03	0.001	0.001	0.001	0.993
Wt, lb										
d 0	13.5	13.5	13.5	13.5	13.5	0.07	0.999	0.975	0.945	0.975
d 21	23.9	23.0	22.6	23.2	23.1	0.35	0.071	0.125	0.023	0.666

[1] A total of 350 pigs (PIC 1050 barrows, initially 14 lb BW) were used in a 16-d growth trial with 5 pigs per pen and 14 pens per treatment.
[2] Pellets with different conditioning temperatures from mill A were not significantly different and were combined for statistical analysis.
[3] Shows the overall treatment effect.

Formation of Fines During the Pelleted Feed Manufacturing Process and the Resulting Differences in Nutrient Composition of Fines and Pellets[1,2]

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Summary

A 3-wk study was conducted at a commercial feed mill in northwest Iowa to determine where the formation of fines occurs during pelleted feed manufacturing and if differences are present in nutrient composition between fines and pellets. During the study, 1,781pelleted feed samples were collected from 4 swine and 2 turkey diets. Samples were collected from 4 different locations throughout the mill to determine progression of fines formation during the manufacturing process. These locations included the pellet mill, pellet cooler, fat coater, and at load-out. Samples were taken on 7 to 10 different runs for each diet throughout the 3-wk period. Pellet durability index (PDI) and percentage fines were determined for all samples, and nutrient analysis was determined on a pooled sample from each run within diet. Nutrient analysis was determined via near-infrared spectroscopy (NIR) at the processing site and via wet chemistry at a commercial lab.

Overall, PDI was different ($P < 0.05$) between locations in the mill. Pellet durability index increased from the pellet mill to the fat coater but then decreased between the fat coater and load-out. The largest increase in PDI was seen between the cooler and fat coater. Percentage fines decreased ($P < 0.05$) from the pellet mill to the cooler, but then increased as pellets went to the fat coater and then to load-out. The largest increase in fines was found between the cooler and fat coater and between the fat coater and load-out (5.6 and 6.5%). Dry matter and crude fiber were greater ($P < 0.05$) and fat tended to be greater ($P < 0.08$) in fines than in pellets as determined by NIR, whereas CP was significantly lower ($P < 0.05$) in the fines than in pellets. These differences were verified by wet chemistry results. Wet chemistry also found that fines tended to be higher ($P < 0.05$) in ADF, but fines were similar in Ca and P compared with pellets.

In conclusion, fines increased as pellets were moved from the pellet mill to the load-out area. Pellet durability index improved from the pellet mill to the fat coater due to the removal of moisture in the pellet but then worsened at load-out, most likely due to the addition of fat, which may have started to soften the pellets. Both NIR and wet chemistry found that fines were higher in fiber and fat but lower in CP than pellets. These differences in nutrient content of the pellets compared with fines and the possibility of

[1] A special thanks to DFS Inc. for technical assistance and facility use during the project.
[2] This project was supported by National Research Initiative Competitive Grant no. 2011-68004-30336 from the USDA National Institute of Food and Agriculture.
[3] Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University.
[4] DFS Inc. (Newell, IA).

fines refusal at the feeder may lead to poorer pig performance. More research is needed to determine if fines formation can be reduced in the mill and if differences in nutrient composition of fines compared with pellets could lead to performance differences in pigs.

Key words: feed mill, fines, pelleting, pellet durability index

Introduction

Pellet quality and its subsequent effects on pig performance have been extensively studied in recent years. Nemechek et al. (2012[5,6]) found that the percentage of fines should be minimized to achieve the maximum benefit from pelleting both nursery and finishing pig diets. Reducing the percentage of fines in pellets can be accomplished in a number of ways, including but not limited to manipulating diet formulation, conditioning time and temperature, or post-pelleting handling techniques.

When pellets exit a pellet mill, they are not immediately loaded onto a truck for delivery, but instead take a much longer path through the feed mill. Pellets exiting a pellet mill must remain intact through a cooling process, fat application process, and then through load-out. Within each of these steps are various elevators and conveyors that move the pellets throughout the mill. The path that the pellets must travel through the mill is suspected to damage pellets and increase the percentage of fines; however, few studies have evaluated the pathways within a mill that can cause more or less damage to a pellet. If the formation of fines can be better understood, feed mills might be able to implement strategies to reduce pellet damage.

Researchers also have suggested that the nutrient composition of fines and pellets may differ. This is of importance to swine producers, because pigs normally prefer to consume whole pellets rather than fines.

Thus, the objective of our study was to determine where the formation of fines occurs during feed manufacturing and if nutrient composition of fines and pellets differ.

Procedures

A 3-wk study was conducted at a commercial feed mill in northwest Iowa. During the study, samples were collected from 4 swine and 2 turkey diets pelleted at the mill. Samples were collected when exiting 4 different locations throughout the mill to determine progression of fines formation during the manufacturing process. Samples were taken on 7 to 10 different runs for each diet throughout the 3-wk period. These locations included the pellet mill, cooler, fat coater, and at load-out. Pellet durability index (PDI), percentage fines, and bulk density were determined for all samples, and nutrient analysis was determined on a pooled sample from each run within diet.

Diets were selected at the start of the trial based on the greatest total tonnage made in an average week. Once diets were selected, sampling occurred every time a diet was manufactured. The first sampling port was located directly underneath the die on the pellet mill. Samples were taken and immediately placed in a bench-top pellet cooler

[5] Nemechek, J.E., Swine Day 2012, Report of Progress 1074, pp. 278–289.
[6] Nemechek, J.E., Swine Day 2012, Report of Progress 1074, pp. 290–304.

to reduce the temperature of the pellets to room temperature. The second sampling port was located under the drag immediately after the pellets exit the cooler. The third sampling port was underneath the fat coater where post-pelleting liquid fat was added to 5 of the 6 diets. The sixth diet was directed through the fat coater for the duration of the experiment to replicate the fat coating process. The last sampling occurred during load-out as feed was exiting the spout and going into feed trucks.

One 2-lb sample of pelleted feed was taken from each sampling port during 7 to 10 feed manufacturing runs for each diet approximately every 15 to 20 min throughout the duration of the run. The feed manufacturing runs varied from 60 to 148 tons of feed.

Once samples were collected, they were split to conduct a PDI test using a Holmen NHP200 (Tekpro Limited, Norfolk, United Kingdom: Tables 1 and 2). Percentage fines were also determined on each individual sample. Fines were characterized as material that would pass through a #6 Tyler Sieve (3,360-μ opening) during 15 sec of manual shaking. While determining the percentage fines, a small subsample of both fines and pellets was taken from each sample. These subsamples were then combined separately (fines or pellets) within a diet and manufacturing run for near-infrared spectroscopy (NIR) analysis (FOSS NIRS 5000, Feed and Forage Analyzer, Hillerod, Denmark). Combined samples of both fines and pellets from 4 diets were retained and sent for chemical analysis to Ward Laboratories, Inc. (Kearney, NE) for analysis of DM, CP, ADF, crude fiber, Ca, P, and crude fat (Table 3).

Data were analyzed using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with location or feed form (pellet vs. fines) as the experimental unit for the physical and chemical analysis, respectively. Location, run, and location within run were considered a random effect for physical analysis. Pairwise comparisons were used to determine differences. Results were considered significant at $P \leq 0.05$ and a trend at $P \leq 0.10$.

Results and Discussion

Overall, PDI was different ($P < 0.05$) between pellets collected at different locations in the mill. Pellet durability index increased from the pellet mill to the fat coater but then decreased at load-out (Table 1). We found no evidence that fines increased in the pellet cooler. Fines did increase ($P < 0.05$) as pellets went to the fat coater and to load-out. The change in PDI was greatest ($P < 0.05$) when moving from the cooler to fat coater and fat coater to load-out than from the pellet mill to the cooler (Table 2). The largest increase in fines was seen between the cooler and fat coater as well as between the fat coater and load-out (5.6 and 6.5% percentage point change).

Dry matter and CF were greater ($P < 0.05$) and fat tended to be greater ($P < 0.08$) in the fines than in the pellets as determined by NIR, whereas CP was lower ($P < 0.05$) in the fines than in pellets. Wet chemistry confirmed these results. Additional wet chemistry analysis found that fines tended to be higher ($P < 0.08$) in ADF but were similar in Ca and P compared with pellets.

Fines increased as pellets moved from the pellet mill to load-out. Pellet durability index improved from the pellet mill to the fat coater but then worsened at load-out. This

was most likely due to the addition of liquid fat, which may have begun to soften the pellets. In this feed mill, most of the fines were created between the cooler and load-out. Characterizing the location where higher amounts of fines are produced will allow millers to focus resources on these areas to obtain the largest benefit and eventually reduce fines presented to the pig at the feeder. Another potential area to evaluate that was not addressed in this study is fines formation during the transport and unloading process from the feed mill to the farm. Once fines formation from the mill to the feeder is characterized, steps can be taken to improve the manufacturing and transport process and present the best possible pellet to the pig.

Table 1. Mill effects on pellet durability and percentage fines[1]

Item	Pellet mill	Cooler	Fat coater	Load-out	SEM	Probability, $P <$
PDI[2], %	77.0[d]	78.3[c]	84.6[a]	81.9[b]	0.82	0.001
Percentage fines, %	9.44[c]	8.54[c]	14.20[b]	20.46[a]	0.77	0.001

[1] Eight to 10 samples were taken from each location in the mill within a run for 8 runs over 3 weeks.
[2] Pellet durability index.
[a,b,c,d] Superscripts within a row are different ($P < 0.05$).

Table 2. Mill effect on the incremental changes in pellet durability and percentage fines[1,2]

Item	Pellet mill to cooler	Cooler to fat coater	Fat coater to load-out	SEM	Probability, $P <$
PDI[3], %	1.46[b]	6.10[a]	-1.77[c]	0.41	0.001
Percentage fines, %	-0.83[b]	5.56[a]	6.45[a]	0.64	0.001

[1] 1,781 samples were taken over 3 weeks, with 5 to 10 samples per location across 8 runs of 7 diets.
[2] Values represent changes in PDI or percentage fines from the previous sample location.
[3] Pellet durability index.
[a,b,c] Superscripts within a row are different ($P < 0.05$).

Table 3. Nutrient composition of fines and pellets[1]

						Probability, $P <$	
Analytic procedure:	Commercial lab[2]		NIR[3]			Commercial lab	NIR
Item	Fines	Pellets	Fines	Pellets	SEM	Fines vs. pellets	Fines vs. pellets
DM, %	88.83	88.32	87.08	86.61	0.16	0.031	0.001
CP, %	13.58	15.24	14.36	16.16	0.48	0.021	0.001
ADF, %	4.09	3.59	---	---	0.20	0.087	---
Crude fiber, %	---	---	2.43	2.17	0.05	---	0.001
Ca, %	0.74	0.74	---	---	0.07	0.975	---
P, %	0.50	0.53	---	---	0.02	0.354	---
Fat, %	9.00	7.71	9.03	8.10	0.42	0.039	0.083

[1] Samples from the fat coater and load out were combined within run and form (pellets or fines) for analysis.
[2] One turkey and 3 swine diets were sent to a commercial lab with 5 replications within diet for a total of 20 samples of both fines and pellets.
[3] Near-infrared spectroscopy. All 7 diets were utilized for analysis. One composite sample of fines or pellets within each diet and run was tested for a total of 111 samples.

Determining the Optimal Sampling Method to Estimate the Mean and Standard Deviation of Pig Body Weights Within a Population[1,2]

C.B. Paulk, M.D. Tokach, S.S. Dritz[3], J.L. Nelssen, J.M. DeRouchey, and R.D. Goodband

Summary

The accuracy and precision of pig subsampling methods can determine the swine producer's ability to sell pigs at optimal market BW and reduce economic discounts. The first objective of this experiment was to determine the time required to weigh pigs for different sampling methods used to estimate the mean and SD of a population. The second objective was to define the optimal sampling method considering the time required to weigh pigs as well as the precision and accuracy of each sampling method. A total of 68 pens of pigs (359 × 1050, PIC, Hendersonville, TN; 169.8 lb BW) in 2 commercial finishing facilities with 20 to 35 pigs per pen were used. Pens of pigs were blocked by location within barn and randomly allotted to 1 of 4 treatments with 17 pens per treatment. The 4 treatments included (1) selecting and weighing the heaviest and lightest pig per pen; and (2), (3), and (4) weighing the first 5, 10, and 15 pigs out of the pen, respectively. The time required for 2 people to complete each treatment was recorded. To determine the total barn time required to conduct a specific sample, the time required to weigh the specific number of pigs per pen was multiplied by n pens. The accuracy and precision for estimating the mean BW and SD for each sampling method was determined by using datasets A and C reported in Paulk (2014[4]). The precision was determined by calculating a 95% confidence interval (CI) for the sample means and SD. The time taken to select and weigh the heaviest and lightest pigs in a pen (Treatment 1) did not differ from weighing 5 pigs per pen (Treatment 2). Increasing the number of pigs weighed per pen (Treatments 3 and 4) increased ($P < 0.05$) the amount of time to weigh a single pen. Based on these results, the number of pens for each treatment that can be weighed without influencing weighing time was determined to be 15 pens (30 pigs), 15 pens (75 pigs), 9 pens (90 pigs), and 6 pens (90 pigs) from Treatments 1, 2, 3, and 4, respectively. For dataset A, these 4 sampling methods had a similar CI range for estimating the mean BW and SD. For dataset C, Treatments 1 (30 pigs) and 2 (75 pigs) had a reduced CI range for estimating the mean BW compared with Treatments 3 (90 pigs) and 4 (90 pigs); however, Treatments 2 (75 pigs) and 3 (90 pigs) had a reduced CI range for estimating the SD compared with Treatments 1 (30 pigs) and 4 (90 pigs). Therefore, we conclude that swine producers should weigh 5 pigs from 15 pens to estimate the mean BW and SD within a barn.

[1] Appreciation is expressed to Elanco Animal Health (Greenfield, IN) for providing partial financial support for this experiment.

[2] Appreciation is expressed to Dr. Jason Kelly and Jeff Wickman of Suidae Health and Production (Algona, IA) for providing assistance during this experiment.

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

[4] Paulk, C.B. 2014. Predicting market pig weights and fat iodine value and effect of zinc on growth performance and immune function of finishing pigs. Ph.D. Thesis. Kansas State University, Manhattan, KS.

Key words: finishing pig, mean estimation, standard deviation estimation, sample size

Introduction

Because individual pig BW in a barn typically follows a normal distribution, subsampling methods to predict the mean and SD can be used to model distributions of BW. The accuracy and precision of these subsampling methods can determine the swine producer's ability to sell pigs at optimal market BW and reduce economic discounts. Paulk (2014[4]) determined the accuracy and precision of varying sampling methods used to estimate the mean and SD of pig BW within a population. Increasing the sample size of a random sample, regardless of pen arrangement, improved the precision for estimating the mean and SD of pig BW; however, a majority of the improvement occurred when the sample size was increased from 10 to 30 pigs. Increasing the sample size of a random sample requires additional labor and cost.

Because the greatest improvement in estimating the mean and SD was at 30 pigs, Paulk (2014) also evaluated methods to improve the estimates without increasing the sample size of 30 pigs. When the total sample size was held constant, increasing the number of pens sampled improved the precision. However, the precision of estimating the mean and SD could be further improved by selecting the heaviest and lightest pigs from 15 pens. In determining the optimum sampling method, swine producers should use both the time required to weigh the pigs and the precision and accuracy of each sampling method. Therefore, the first objective of this experiment was to determine the time required to weigh pigs for different sampling methods used to estimate the mean and SD of pig BW of a population. The second objective was to determine the optimal sampling method using the time required to weigh pigs and the precision and accuracy of each sampling method.

Procedures

Time required to weigh pigs for different sampling methods

A total of 68 pens of pigs (359 × 1050, PIC, Hendersonville, TN) in 2 commercial finishing facilities (Barns 1 and 2) in northern Iowa were used in the experiment. Pigs in Barn 1 and 2 were approximately 163.8 and 175.9 lb BW, respectively. Pigs were housed in curtain-sided finishing barns with 20 to 35 pigs per pen. Pens of pigs were blocked by location within barn and randomly allotted to 1 of 4 treatments with 9 replicate pens in Barn 1 and 8 replicate pens in Barn 2 for a total 17 pens per treatment.

The 4 treatments included: (1) selecting and weighing the heaviest and lightest pig per pen; and (2), (3), and (4) weighing the first 5, 10, and 15 pigs out of the pen, respectively. The time required to complete each treatment was recorded. All treatments were completed by 2 people using an individual pig scale with a digital weight indicator (SW600, Digi-Star, Ft. Atkinson, WI). The scale was made out of aluminum and had 2 wheels attached to the front, so it could be moved easily by 1 person. The scale contained 2 swinging gates at the front and back end. The back gate was opened and closed using a latch on top of the gate. The front gate was attached to an aluminum arm with a handle. The arm extended the length of the scale so the handle was located in close proximity to the back gate. The handle was lifted up and pushed forward to open the gate and lifted up and pulled back to close the gate, so 1 person was able to open and close both gates while standing in the same spot. The same 2 people completed

the treatments on all 68 pens in the experiment. Treatments were conducted in Barn 1 on d 1 and Barn 2 on d 2. Person 1's first responsibility was to place the scale a pen's length away from the pen to be weighed. Once the scale was set in place, Person 1 and 2 met at the gate of the pen to be weighed. When both persons were ready, Person 1 recorded the time and retrieved the scale, placed it in position next to the current pen to be weighed, and zeroed the scale. For Treatment 1, Person 2 began searching for the heaviest and lightest pig in the pen while Person 1 set up the scale. After Person 1 zeroed the scale, he helped Person 2 decide which pigs were the heaviest and lightest by visual evaluation. Then, Person 2 marked those pigs with marking paint. Person 1 then opened the gate while Person 2 started sorting the heaviest and lightest pig toward the scale. For Treatments 2, 3, and 4, while Person 1 set up the scale, Person 2 opened the gate and was positioned in the pen ready to start assisting pigs onto the scale. For all treatments, while weighing pigs, Person 1's responsibilities were to open and close the scale gates and record pig BW, and Person 2's responsibility was to use a 30- × 36-in. sorting board to assist pigs onto the scale. For Treatment 1, after the first pig was weighed, Person 1 backed that pig off the scale back into the pen while Person 2 sorted the second pig to the scale. After the second pig was weighed, Person 1 backed that pig off the scale back into the pen, and Person 2 closed the pen gate when the pig was in the pen. After the pen gate was closed, Person 1 recorded the time. For Treatments 2, 3, and 4, after Person 1 recorded the BW of each pig, the gate at the front of the scale was opened and the pig was run into the aisle. After all pigs were weighed, Person 2 moved the scale to the other side of the open gate to allow Person 1 to move the pigs back into the pen. After all pigs were returned to the pen, the gate was shut and the time was recorded. The same person assumed the same responsibilities for completing treatments on all 68 pens. Treatments were conducted on assigned pens in order of location block; therefore, each of the 4 treatments was conducted on the designated pen within block before starting on the next block. When Person 1 and 2 took a break, it was taken between blocks.

Treatments were initially analyzed using 2 response criteria: (1) time to complete each treatment per pen; and (2) time to conduct each treatment on a total of 30 pigs. To obtain the time required to conduct a sample size of 30 pigs, the time required to conduct each treatment (select and weigh the heaviest and lightest pig per pen or weigh the first 5, 10, and 15 pigs out of the pen) was multiplied by a factor of 15, 6, 3, and 2, respectively. After preliminary analysis, it was determined that to achieve a total sample size of 30 pigs, selecting and weighing the heaviest and lightest pigs (Treatment 1) from 15 pens required more time than weighing the first 5, 10, or 15 pigs from 6, 3, or 2 pens, respectively. Therefore, the time required to weigh a total of 30 pigs by selecting and weighing the heaviest and lightest pigs (Treatment 1) from 15 pens was compared with the time required to weigh a total of 60, 75, and 90 pigs by weighing the first 5, 10, or 15 pigs (Treatments 2, 3, and 4) from the required number of pens. This was completed to determine the number of total pigs that could be weighed in an amount of time similar to that required to select the heaviest and lightest pigs (Treatment 1) in 15 pens (30 pigs). This led to 3 additional response criteria: (3) time to conduct Treatments, 2, 3, and 4 so that the total pigs weighed equaled 60; (4) time to conduct Treatments 2 and 4 so that the total pigs weighed equaled 75; and (5) time to conduct Treatments 2, 3, and 4 so that the total pigs weighed equaled 90. Regression analysis was also completed to predict the time required to weigh 5 to 15 pigs per pen. The slope of the line from the

regression analysis represents the additional time required to weigh each additional pig per pen.

The time analysis did not account for the time required to change clothes for biosecurity measures and set up the barn. This was not included because it was considered to be consistent across all treatments. Changing clothes and setting up the scale and preparing the barn took approximately 27 min in both barns.

Data were analyzed as a randomized complete block design using the MIXED procedure of SAS (SAS Institute Inc., Cary, NC) with pen as the experimental unit. Treatment was included as the fixed effect and location block as a random effect. Differences between treatments were determined using the PDIFF option of SAS. Sampling methods were analyzed using 4 response criteria: (1) time to complete each method per a pen; (2) time to conduct each sample method so that the total pigs weighed equaled 30; (3) time to conduct Treatment 1 so that the total pigs weighed equaled 30 and time to conduct Treatments 2, 3, and 4 so that the total pigs weighed equaled 60; (4) time to conduct Treatment 1 so that the total pigs weighed equaled 30 and time to conduct Treatments 2 and 4 so that the total pigs weighed equaled 75; and (5) time to conduct Treatment 1 so that the total pigs weighed equaled 30 and time to conduct Treatments 2, 3, and 4 so that the total pigs weighed equaled 90. Significant differences were declared at $P < 0.05$ and trend at $P < 0.10$. In addition, the REG procedure of SAS was used to develop a regression equation to predict the time required to weigh 5 to 15 pigs per pen.

Precision for estimating the mean and SD

For a sample size of 30 pigs, the heaviest and lightest pigs in 15 pens can be selected and weighed to achieve a confidence interval (CI) range of 14.8 to 15.2 lb when estimating the mean and 11.9 to 16.8 lb when estimating the SD (Paulk, 2014). However, preliminary analysis determined that when weighing the first 5, 10, or 15 pigs per pen, a larger sample size can be conducted in the same amount of time as selecting and weighing the heaviest and lightest pigs in 15 pens. Therefore, datasets A and C from Paulk (2014) were used herein to determine CI range for a total sample size of 60, 75, and 90 pigs. These sample sizes were achieved by taking random samples of 5 pigs within 12, 15, or 18 pens; 10 pigs within 6 or 9 pens; and 15 pigs within 4, 5, or 6 pens. Datasets A and C were used because they had similar pen arrangements to the 2 barns used in the experiment conducted herein (i.e., approximately 20 to 35 pigs per pen). These sampling methods were evaluated using a simulation model developed using R (Paulk, 2014; R Foundation for Statistical Computing, Vienna, Austria). Each sample size was conducted 10,000 times, generating 10,000 estimated means and SD. These were used to determine the accuracy and precision for each sample method. The accuracy was determined by comparing the mean of the 10,000 sample means and associated SD to the actual population mean and SD pig BW, respectively. The precision was determined by calculating a 95% CI for the 10,000 sample means and SD. The distances between the upper and lower confidence limits represent the estimated means and SD CI range. When the heaviest and lightest pigs were selected from 15 pens, the mean was estimated using the following equation: Estimated mean, lb = 0.77 × sample mean, lb + 0.25 × sample median, lb, and the SD was estimated by subtracting the sample's lightest pig BW from the heaviest pig BW and dividing the difference by 6 (Paulk 2014).

Results

Time required to weigh pigs for different sampling methods

The time taken to select and weigh the heaviest and lightest pigs in a pen (Treatment 1) did not differ from weighing 5 pigs per pen (Treatment 2; Table 1). Increasing the number of pigs weighed per pen (Treatments 2, 3, and 4) increased ($P < 0.05$) the amount of time required to weigh a single pen. For conducting a sample size of 30 pigs, selecting and weighing the heaviest and lightest pigs in 15 pens (Treatment 1) increased ($P < 0.05$) the time required compared with weighing the first 5, 10, or 15 pigs (Treatments 2, 3, and 4), from 6, 3, or 2 pens, respectively. Weighing 5 pigs (Treatment 2) from 6 pens tended to increase ($P < 0.10$) time required compared with weighing 15 pigs (Treatment 4) from 2 pens, with the time needed to weigh 10 pigs (Treatment 3) from 3 pens being intermediate. For conducting a sample size of 60 pigs, selecting and weighing the heaviest and lightest pigs in 15 pens (Treatment 1) increased ($P < 0.05$) the time required compared with weighing the first 5 pigs (Treatment 2) from 12 pens. Both of these treatments increased ($P < 0.05$) the time required compared with weighing 10 or 15 pigs (Treatments 3 and 4) from 6 or 4 pens, respectively. For conducting a random sample of 75 pigs, the time required for selecting and weighing the heaviest and lightest pigs in 15 pens (Treatment 1) did not differ from weighing the first 5 pigs (Treatment 2) from 15 pens; however, both of these treatments required more ($P < 0.05$) time than to weigh the first 15 pigs (Treatment 4) from 5 pens. For conducting a random sample of 90 pigs, the time taken to select and weigh the heaviest and lightest pigs in 15 pens (Treatment 1), weigh the first 10 pigs (Treatment 3) from 9 pens, and weigh the first 15 pigs (Treatment 4) in 6 pens did not differ, but all took less ($P < 0.05$) time than weighing the first 5 pigs (Treatment 2) from 18 pens.

The following regression equation ($R^2 = 0.74$; SE = 2.53) was developed to predict the time needed to weigh 5 to 15 pigs per pen:

$$y = 30.23x + 64.18$$

where y = time (s) required to weigh x number of pigs and x = the number of pigs per pen to be weighed. The predicted time needed to weigh 5 to 15 pigs per pen can then be multiplied by the number of pens to determine the time needed to conduct the total sample.

Precision for estimating the mean and SD

For dataset A, selecting and weighing the heaviest and lightest pigs (Treatment 1) in 15 pens and weighing 5 or 10 pigs per pen (Treatments 2 and 3, respectively) to equal a total of 75 or 90 pigs had a similar (within 1.3 lb) CI range for estimating the mean and SD of BW (Table 2). For dataset C, selecting and weighing the heaviest and lightest pigs (Treatment 1) in 15 pens and weighing 5 pigs per pen (Treatment 2) to equal a total of 75 or 90 pigs had a similar (within 2.4 lb) CI range for estimating the mean BW. Selecting and weighing the heaviest and lightest pigs (Treatment 1) in 15 pens and weighing 5, 10, or 15 pigs per pen (Treatments 2, 3, and 4, respectively) to equal a total of 75 or 90 pigs had a CI range within 5.5 lb of each method for estimating the SD, with Treatment 1 having the highest CI range and Treatment 2 having the lowest.

Discussion

In a finishing pig barn, pigs are typically housed with 25 to 60 pigs per pen and 19 to 48 pens per barn depending on the design of the barn. For weighing a set number of pigs, the precision for estimating the mean and SD BW is improved by increasing the number of pens sampled (Paulk, 2014). However, weighing pigs from multiple pens requires more resources and time, including opening gates and entering pens and moving the scale throughout the barn. The intercept and slope of the developed regression equation represent the estimated time required to set up the scale for each pen and the time to weigh each pig, respectively. Therefore, it took approximately 64 sec to move the scale 1 pen's length, zero the scale, and open the gate before weighing any pigs and 30 sec for each pig weighed per pen.

For a sample size of 30 pigs, the precision for estimating the mean and SD of pig BW can be further improved by selecting the heaviest and lightest pigs from 15 pens vs. weighing n random pigs from n random pens to equal a total sample size of 30 pigs (Paulk, 2014). Although this improved the precision without increasing the number of pigs weighed, selecting and weighing pigs from 15 pens includes additional time to select and sort pigs and weigh multiple pens as previously discussed. Personnel weighing pigs altered the workload and time required by backing each pig off of the scale; however, selecting pigs and sorting them to the scale took additional time. It took the same amount of time to select and weigh the heaviest and lightest pig per pen as it did to weigh the first 5 pigs per pen. In addition, for a total sample size of 30 pigs, selecting and weighing the heaviest and lightest pigs in 15 pens took 2.5, 3.0, and 3.1x longer to complete compared with weighing 5 pigs from 6 pens, 10 pigs from 3 pens, and 15 pigs from 2 pens, respectively. Therefore, the comparison of sampling methods needed to be reevaluated based upon the time required to conduct the sample instead of the number of pigs weighed.

A similar amount of time was necessary, approximately 52 to 54 min, to conduct the following sampling methods: selecting and weighing the heaviest and lightest pig in 15 pens (30 pigs), weighing 5 pigs from 15 pens (75 pigs), 10 pigs from 9 pens (90 pigs), and 15 pigs from 6 pens (90 pigs). Based on the CI range, an optimal sampling method was not clearly defined for estimating both the mean and SD. However, for datasets A and C, weighing 5 pigs from 15 pens had a CI range similar to or reduced compared with the other 3 methods when estimating the mean and SD of BW. Also, weighing 10 pigs from 9 pens (90 pigs), and 15 pigs from 6 pens (90 pigs) increased the CI range when estimating the mean for dataset C. Weighing 5 pigs from 15 pens increased the CI range by 1.1 to 2.4 lb for estimating the mean but reduced the CI range by 0.2 and 5.5 lb for estimating the SD compared with selecting and weighing the heaviest and lightest pig in 15 random pens.

In addition to improvements in the CI range, weighing 5 vs. 10 or 15 pigs per pen may have caused less stress when moving pigs back to the pen after being weighed. Although stress levels were not measured in this experiment, Lewis and McGlone (2006[5]) observed elevated heart rates of pigs moved in groups larger than 5 or 6 pigs. Also, when the heaviest and lightest pigs were selected and weighed, each pig was backed off the

[5] Lewis, C.R.G., and J.J. McGlone. 2007. Moving finishing pigs in different group sizes: Cardiovascular responses, time, and ease of handling. Livest. Sci. 107:86–90.

scale into the pen instead of let into the aisle. Therefore, moving pigs back to their pens was not a concern, but stress-related measurements of backing each pig off the scale were not determined.

Determining whether to select and weigh the heaviest and lightest pigs in 15 random pens or weigh the first 5 pigs in 15 random pens may also depend on personnel skill. The time required to select the heaviest and lightest pigs can depend on the person's ability to assess the BW of pigs within a pen and make the decision. The accuracy and precision for estimating the mean and SD can also depend on their ability to accurately select the heaviest and lightest pigs. Personnel not experienced at selecting pigs may prefer to weigh 5 pigs per pen because it can be done by randomly selecting pens and weighing the first 5 pigs in each of those pens.

In conclusion, based on time required to conduct the sample and the precision and accuracy of the sampling method, weighing the first 5 pigs in 15 pens is the recommended sampling method. In addition, weighing the first 5 pigs per pen does not include the assumption that personnel can select the correct pigs and reduces the possibility of bias occurring. It is expected to take 2 employees approximately 55 min to weigh the first 5 pigs from 15 pens, not including time to prepare and clean up.

Table 1. Time required to select and weigh pigs for designated sampling methods[1]

	Treatment[2]					
Total sample	HL	5 pigs	10 pigs	15 pigs	SEM	$P <$
Time per pen,[3] min	3.6[a]	3.6[a]	6.0[b]	8.7[c]	0.3	0.001
Time required for weighing,[4] min						
30 pigs	53.4[a]	21.6[b]	17.9[b]	17.4[b]	2.4	0.001
60 pigs[5]	53.4[a]	43.2[b]	35.9 [c]	34.8[c]	2.1	0.001
75 pigs[5]	53.4[a]	54.0[a]	---	43.5[b]	3.5	0.009
90 pigs[5]	53.4[a]	64.8[b]	53.9[a]	52.3[a]	3.5	0.003

[1] A total of 68 pens in 2 barns with 25 to 30 pigs per pen were used to conduct sampling methods.
[2] Treatments included: (HL) selecting weighing the heaviest and lightest pig per pen and weighing the first 5, 10, and 15 pigs out of the pen.
[3] Time required to conduct sampling method on a single pen.
[4] The time observed for selecting and weighing the heaviest and lightest pig per pen and weighing the first 5, 10, and 15 pigs out of the pen was multiplied a factor of n to equal the total sample size.
[5] The time observed for selecting and weighing the heaviest and lightest pig per pen was kept constant at a total sample size of 30 pigs.
[a,b,c] Within a row, means without a common superscript differ ($P < 0.05$).

Table 2. The confidence interval (CI) range (lb) when a varying number of pigs and pens are sampled to estimate the mean and SD BW of the population[1]

	Treatment[2]			
Total sample	HL[3]	5 pigs	10 pigs	15 pigs
Dataset A[4]				
Mean				
30 pigs,[5]	14.8	26.0	28.9	32.0
60 pigs,[6]	---	17.6	20.5	22.0
75 pigs,[7]	---	15.9	---	19.6
90 pigs,[8]	---	13.9	16.1	18.1
SD				
30 pigs,[5]	11.9	19.0	19.6	19.8
60 pigs,[6]	---	13.9	13.4	13.9
75 pigs,[7]	---	12.3	---	11.7
90 pigs,[8]	---	11.7	11.2	11.0
Dataset C[9]				
Mean				
30 pigs,[5]	15.2	30.0	40.3	47.8
60 pigs,[6]	---	21.8	27.3	33.3
75 pigs,[7]	---	17.6	---	28.7
90 pigs,[8]	---	15.9	21.4	26.5
SD				
30 pigs,[5]	16.8	20.9	23.6	25.1
60 pigs,[6]	---	15.0	16.3	18.5
75 pigs,[7]	---	12.3	---	16.8
90 pigs,[8]	---	11.2	13.4	15.0

[1] Samples were simulated using datasets from Paulk et al., 2014 (see footnote 4 in main text). Samples were completed 10,000 times for each sampling method. The CI range was calculated for the 10,000 sample means and SD of each sampling method.

[2] Treatments included: (HL) selecting weighing the heaviest and lightest pig per pen and weighing the first 5, 10, and 15 pigs out of the pen.

[3] The mean was estimated using following equation: Estimated mean, lb = 0.77 × sample mean, lb + 0.25 × sample median, lb, and the SD was estimated by subtracting the sample's lightest pig BW from the heaviest pig BW and dividing the difference by 6.

[4] A total of 1,260 pigs (mean = 253.1 lb, median = 254.0 lb, SD = 32.8 lb, and CV = 13.0%) with 23 to 28 pigs per pen and a total of 48 pens.

[5] Samples included selecting the heaviest and lightest pig from 15 pens, 5 random pigs from 6 pens, 10 random pigs from 3 pens, and 15 random pigs from 2 pens for Treatments 1, 2, 3, and 4, respectively.

[6] Samples included selecting the heaviest and lightest pig from 15 pens, 5 random pigs from 12 pens, 10 random pigs from 6 pens, and 15 random pigs from 4 pens for Treatments 1, 2, 3, and 4, respectively.

[7] Samples included 5 random pigs from 15 pens and 15 random pigs from 5 pens for Treatments 2 and 4, respectively.

[8] Samples included 5 random pigs from 18 pens, 10 random pigs from 9 pens, and 15 random pigs from 6 pens for Treatments 2, 3, and 4, respectively.

[9] A total of 1,069 pigs were weighed (population mean = 222.4 lb, median = 224.0 lb, SD = 32.0 lb, and CV = 14.4%) with 40 pens and 20 to 35 pigs per pen.

Effects of Electrostatic Particle Ionization on Air Quality, Emissions, and Growth Performance of Pigs Housed in a Thermo-Regulated Facility

J.A. De Jong, K.N. Card, J.M. DeRouchey, M. Baumgartner[1], and P.J. Tomlinson[2]

Summary

Two identical 200-head nurseries at the Kansas State University Segregated Early Weaning Facility were used for 5 consecutive all-in, all-out groups to determine the effect of electrostatic particle ionization (EPI) on air quality, emissions, and growth performance of pigs housed in a thermo-regulated facility. During five 6-wk periods (13 to 51 lb BW), the EPI system was used in one barn for a complete group and then used in the other barn for the next group. At the beginning of each 6-wk trial period, pigs were randomly allotted to pens based on average pig weight. Air measurements and pig growth were measured every week throughout the studies.

Overall, when active, the EPI system reduced ($P < 0.05$) 0.3, 0.5, 1.0, 2.5, 5.0, and 10.0 μ dust particles in the barn and dust particles/ft^3 at the exhaust fan. There were no differences ($P > 0.10$) for in-barn air ammonia and hydrogen sulfide concentrations and no significant differences ($P > 0.10$) in ammonia concentrations in the dust between the control and EPI barn. The EPI system tended to improve ($P = 0.09$) ADG, which led to a tendency for improved ($P = 0.06$) final BW. No differences were detected ($P > 0.10$) for ADFI or F/G.

The EPI system improved barn and exhaust air by removing particulate matter from suspension, which tended to improve growth rate in 13- to 51-lb pigs.

Key words: dust, electrostatic particle ionization, emissions, growth, nursery pig

Introduction

Dust particles in hog barns have been problematic for swine producers since the inception of raising pigs in confinement. Ventilation for thermo-controlled barns has been uniquely created to ensure barn temperatures remain within a set range according to the pig's thermo-neutral zone. Feces, dried skin, feed, and other particles make up the majority of the airborne particles in swine facilities in thermo-regulated barns. These irritants have been shown to cause health problems in both humans and swine (Collins et al., 1986[3]; Iverson et al., 2000[4]). Particulate matter in confined spaces also can trap odorous compounds such as ammonia (NH_3) and hydrogen sulfide (H_2S), which creates an incentive for many producers to reduce emissions from hog barns. Technolo-

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[2] Department of Agronomy, College of Agriculture, Kansas State University.
[3] Collins, M., and B. Algers. 1986. Effects of stable dust on farm animals: A review. Vet. Res. Comm. 10(6):415–428.
[4] Iverson, M., S. Kirychuk, I.L. Drost, and L. Jacobson. 2000. Human health effects of dust exposure in animal confinement buildings. Journal of Agric. Safety and Health 6(4):283–286.

gies have been implemented to control barn particulate matter, including filtration systems, fat addition to diets, and spraying barns with oil. Each has had limited success in providing sustainable and cost-effective results.

Electrostatic particle ionization (EPI) is an emerging technology that emits up to a thousand trillion negative ions into the air per second, which creates polarized air particles. When these polarized particles in the air collide with other floating particles, they cause the floating particles to become polarized, having both a positive and negative side. Due to the charge from the system, polarized particles stick to one another and any surfaces that they collide with. These polarized air particles attach to conductive or grounded surfaces in the barn, such as the ground, walls, and pens, clearing them from the pig's breathing zone (Figure 1). Extensive research has been conducted in poultry facilities and confirmed that this technology reduces barn air particulate matter. A large commercial swine operation conducted a similar trial that showed H_2S and NH_3 concentrations, along with particulate matter, could be reduced by more than 50% and result in improved growth performance (http://epiair.com/why-epi/epi-data-certifications/).

Thus, the objective of our experiment was to determine the effects of electrostatic particle ionization (EPI) on air quality, emissions, and growth performance of nursery pigs housed in a confinement facility.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol for this experiment.

Two identical 200-head totally enclosed, environmentally controlled nurseries at the Kansas State University Segregated Early Weaning Facility were used in a 12-month study. During five 6-wk periods (13 to 51 lb BW), the EPI system was used in one barn for a complete group and then used in the other barn for the next group.

Dust particles were collected weekly inside the barn and in fan exhaust air for determination of particle size and average quantity of dust for each group. These particles were collected using a handheld particle counter (Model 3016-IAQ, Lighthouse Worldwide Solutions, Fremont, CA). Particles were collected at four different spots in each barn and inside the exhaust fans. During exhaust measurements, all external fans were temporarily turned off except for the exhaust fan sampled. Air velocity was measured at 8 different cross-sections along the diameter of the fan shell using a digital air velocity meter (Model 575C1, Test Products International Beaverton, OR).

Hydrogen sulfide concentrations were measured weekly at 10 locations in the barn using a H_2S analyzer (Jerome 631-X, Arizona Instruments, Chandler, AZ). These measurements were then averaged for each barn within week. A pump (Dräger Accuro pump, Lübeck, Germany) was used to measure NH_4 concentrations at two locations in each barn on the first, third, and fifth weeks of the group, which were then averaged within treatment group for analysis. Dust samples were taken from four 12-in. plastic circles mounted above the pens in each quadrant of the barn, then analyzed for NH_4 on the first day of the first, third, and fifth weeks of the group. Air samples were also taken

during the first, third, and fifth weeks of the group using 10-mL vials and analyzed for NH_3 and H_2S.

At the beginning of each 6-wk trial period, pigs were randomly allotted to pens based on average pig weight. Pigs were provided unlimited access to feed and water by way of a 4-hole dry self-feeder and a cup waterer in each pen (5 ft × 5 ft). Pig weight and feed disappearance were measured approximately every week to determine ADG, ADFI, and F/G. In tandem with the current study, other nutritional trials were also conducted during each group. Nutritional treatments were balanced across each barn to eliminate the confounding effects of dietary treatment.

Data from all groups were combined and analyzed as a randomized complete block design using PROC MIXED in SAS (SAS Institute, Inc., Cary, NC) with barn as the experimental unit. Air filtering (EPI or control without filtering) treatment was considered a fixed effect, and group was considered a random block effect in the statistical model. Pairwise comparisons were used to determine differences between the EPI and control barns. Results were considered significant at $P \leq 0.05$ and a trend at $P \leq 0.10$.

Results and Discussion

Overall, the EPI system reduced ($P < 0.05$) 0.3, 0.5, 1.0, 2.5, 5.0, and 10.0 μ dust particles in the barns and dust particles/ft^3 of emissions at the exhaust fan (Table 1). There were no differences ($P > 0.10$) for in-barn air NH_3 or H_2S concentrations and no significant differences ($P > 0.10$) in NH_3 concentrations in the dust between the control and EPI barns. The EPI system tended to improve ($P = 0.09$) ADG, which led to a tendency for improved ($P = 0.06$) final BW. No differences were detected ($P > 0.10$) for ADFI or F/G.

Results from this study show that the EPI system significantly reduced levels of airborne particulate matter in the barn by up to 50%. This reduction inside the barn led to significantly reduced airborne particulate matter emitted outside of the barn. Even though dust particles were removed from suspension inside the barn, there was no effect of EPI on barn H_2S and NH_3 concentrations, which disagrees with previous work. This may be a result of overall improved air quality baseline in our research facility compared with commercial barns or our sampling method. By removing airborne particulate matter from inside the barn, the EPI system tended to improve both ADG and final BW with no effect on ADFI and F/G. In conclusion, the use of the EPI improved air quality and emissions by reducing airborne particulate matter that tended to improve pig growth rate.

Table 1. The effects of electrostatic particle ionization (EPI) on hog barn air quality, emissions, and pig growth performance[1]

Item Treatment:	Control	EPI	SEM	Probability, $P <$
Inside dust[3], particles/min				
0.3 µ	687,345	417,797	98,698	0.02
0.5 µ	94,019	46,602	11,098	0.009
1.0 µ	94,470	41,361	18,088	0.02
2.5 µ	173,363	77,759	27,236	0.01
5.0 µ	28,956	13,512	3,708	0.002
10.0 µ	166,980	72,998	30,189	0.01
Exhaust dust[4], particles/ft^3				
0.3 µ	306.2	160.5	49.4	0.03
0.5 µ	37.9	18.6	6.6	0.02
1.0 µ	32.1	14.4	8.2	0.03
2.5 µ	54.3	22.1	12.8	0.02
5.0 µ	7.6	2.9	1.7	0.03
10.0 µ	20.6	7.4	4.6	0.04
Air quality[5]				
NH_3, ppm	4.02	4.21	1.39	0.86
H_2S, ppm	0.81	0.82	0.31	0.89
Dust quality[6]				
NH_4, ppm	939.48	961.35	99.11	0.75
Growth performance[2]				
ADG, lb	0.91	0.98	0.23	0.09
ADFI, lb	1.57	1.62	0.19	0.45
F/G	1.61	1.61	0.59	0.99
Final BW, lb	49.7	51.2	4.96	0.06

[1] Two identical 200-head nurseries at the Kansas State University Segregated Early Weaning Facility were used in a 12-month study to determine the effect of EPI on air quality, emissions, and growth performance of pigs housed in a thermo-regulated facility.
[2] Within replication, pigs were weighed every week. Data collection ranged from 3 to 6 wk in duration across groups.
[3] Dust samples were taken weekly at 4 locations within each barn.
[4] Dust samples were taken at a single exhaust fan from each barn weekly.
[5] Air quality measurements were taken approximately every 3 weeks in the 4 quadrants of the barn.
[6] Dust samples were taken from plastic mounts above the pens from the 4 quadrants of the barn.

Figure 1. Dust accumulation on pen railing in experimental barns.

Effects of Diet Bulk Density on Mixing Uniformity

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Summary

The objective of this study was to determine how the time required to create a uniformly mixed batch of feed is influenced by diets that differ in bulk density. Three 60-lb batches of a corn-soybean meal–based diet (high bulk density) or a high-fiber diet (low bulk density) containing 30% dried distiller's grains with solubles (DDGS), and 19% wheat midds were prepared. The ingredients for each batch were placed in a 60-lb capacity experimental double-ribbon mixer with all batches containing 0.35% table salt. Ten samples were obtained from different parts of the mixer for each batch of feed after 60, 120, and 240 sec of mixing time. Ten additional samples were taken as the feed was discharged from the bottom of the mixer after 240 sec. The three batches of each diet type were mixed and sampled using the same procedures and were considered separate observations, making 3 replications for each mixing time within diet type. The CV among 10 samples collected at each mix time was used to determine mixer efficiency by measuring Cl concentration (Quantabs, Environmental Test Systems, Elkhart, IN). After 60 sec of mixing, the corn-soybean meal–based diet achieved a CV of less than 10%; however, the high-fiber diet required 240 sec to achieve a CV of less than 10%. In conclusion, using this experimental ribbon mixer, diet bulk density affected the time required to mix a batch of feed thoroughly, which suggests that feed manufacturers should reevaluate mixing times when using low-bulk-density ingredients such as DDGS and wheat midds. Further research is needed to verify these results in large-scale commercial mixers.

Key words: bulk density, diet type, mixing efficiency

Introduction

In general, a CV of less than 10% among 10 samples from a batch of feed is considered ideal when determining the time needed for adequate diet mixing. Mixing times for different types of mixers usually have been established for corn-soybean-meal diets; however, less information is available on the effects of low bulk density ingredients on mixing uniformity.

Generally, mixers are rated for an amount of material based on weight (i.e., a 1-ton mixer), but this rating does not consider the density of the material to be mixed. Based on its volume, a low-density, high-fiber diet may require more mix time than a corn-soybean meal diet, but data is not available to support this assumption. Therefore, the objective of this study was to determine the difference in mixing times needed to minimize CV of diets with different bulk density.

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Procedures

An experimental 60-lb capacity, 1.5-ft^3, double-ribbon mixer was used in this experiment. Two diets were formulated that differed in bulk density: (1) a typical corn-soybean meal–based diet (high bulk density), and (2) a corn-soybean meal diet containing 30% dried distillers grains with solubles (DDGS) and 19% wheat midds (low bulk density; Table 1). A total of 3 batches of each diet were prepared. Each batch was 60 lb and ingredients were weighed individually, separating the minor ingredients from the major ingredients. The major ingredients (corn, DDGS, wheat midds, soybean meal) were weighed into the bag in the reverse order they would normally be batched into a mixer. When the bags were dumped into the mixer, the ingredients were arranged in the order of major ingredients on the bottom, followed by the addition of minor ingredients.

After loading the mixer, the diet was blended for 60 sec, stopped and sampled, then blended for an additional 60 sec, stopped and sampled, and finally blended for an additional 120 sec before the final samples were obtained. Consequently, samples were obtained after 60, 120, and 240 sec of total mixing time for each batch. A total of 10 samples also were collected as the feed was discharged from the mixer after the final mix was completed. During the first 10 sec of mixing for each batch, the discharge slide was opened and a small amount of feed was collected into a bucket then returned to the mixer to eliminate any dead spots within the mixer. A stainless steel scoop was used to collect samples obtaining 1.0 ounce of the high-fiber feed and 1.3 ounces of the corn-soybean meal feed. At each sample time, samples were taken from 10 locations within the mixer. The mixer was thoroughly cleaned between each batch. A 2-lb sample was also collected at discharge to determine bulk density of the final mixed diet.

Mixing uniformity was determined using Quantab Cl titrators (Environmental Test Systems, Elkhart, IN). For each sample, 10 g were weighed and placed into a plastic cup. Ninety milliliters of hot (170°F) distilled water was added to the cup and stirred for 30 sec, let stand for 60 sec, then stirred for an additional 30 sec. Folded circular filter paper was then placed into the solution followed by the placement of the Quantab chloride titrator. The solution was allowed time to completely saturate the wick of the titrator until the indicator strip at the top turned from yellow in color to black. The titrator was then removed from the solution, read, and recorded. The strip values were converted to a percentage based on the dilution factor table provided by the titrators. These values were then used to calculate CV.

Results and Discussion

The bulk density of the corn-soybean meal diet was 36.2 lb/ft^3, whereas the high-fiber diet containing 30% DDGS and 15% wheat midds had a bulk density of 28.8 lb/ft^3. As mixing time increased, CV decreased and the corn-soybean meal–based diet achieved a CV of 8% at 60 sec (Figure 1). The diet containing low-bulk-density ingredients required a mixing time of 240 sec to achieve a CV less than 10% (Table 2).

The difference in CV between the corn-soybean meal–based diet and the high-fiber diet are meaningful at the lower mixing times. Based on the amount of volume required by the low-density diet in the mixer compared with the high-density diet, optimum mixing time is affected (Figures 2 and 3). Our data demonstrate that differences in bulk density

affect the mixing time needed to acquire a uniform mixture. Feed manufacturers may need to consider different mixing times when using low-bulk-density ingredients such as DDGS and wheat midds. Additional research should be conducted using large-scale commercial mixers to determine the optimum mixing times of diets differing in bulk density.

Table 1. Diet composition

Item	Corn-soybean diet	High-fiber diet
Ingredient, %		
Corn	74.57	41.78
Soybean meal	22.92	6.34
DDGS[1]	-	30.00
Wheat middlings	-	19.00
Monocalcium P, (21% P)	0.4	-
Limestone	1.25	1.65
Sodium chloride[2]	0.35	0.35
L-lysine HCl	0.15	0.45
DL-methionine	0.03	-
L-threonine	0.015	0.065
L-tryptophan	-	0.045
Trace mineral premix	0.15	0.15
Vitamin premix	0.15	0.15
Phytase	0.015	0.015
Total	100	100
Calculated analysis, %		
Total lysine, %	0.98	1.04
CP,%	17.2	18.2
Ca, %	0.61	0.67
P, %	0.44	0.52
Available P, %	0.25	0.34
Bulk density, lb/ft^3	36.2	28.8

[1]Dried distillers grains with solubles.
[2] Table salt with a particle size of 393 μm was used.

Table 2. Effects of diet type and mixing time on feed uniformity[1]

	CV, %	
Item	Corn-soybean meal diet	High-fiber diet
Mixing time, sec		
60	8	33
120	9	15
240	7	7
Discharge	5	9

[1]Values represent the mean of 3 replicates per diet and mix time.

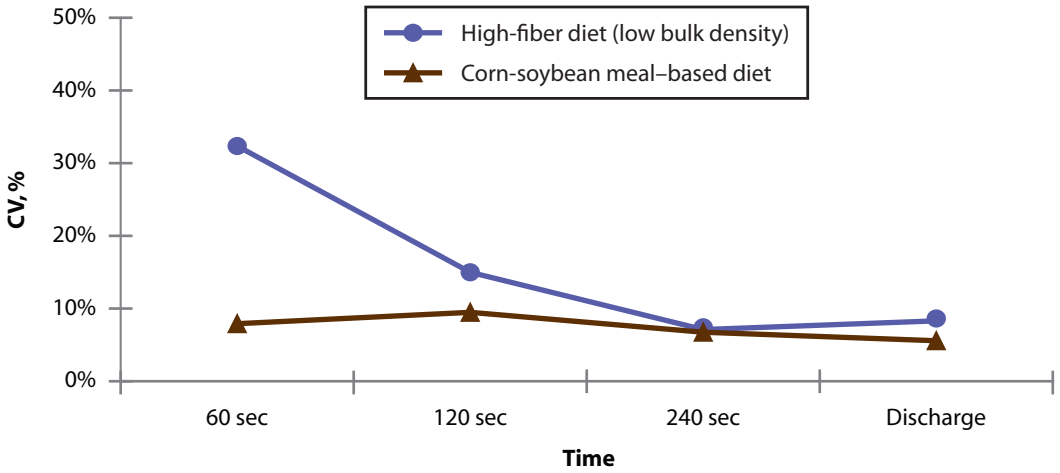

Figure 1. Effects of mixing time on feed uniformity. Coefficient of variation (CV) was measured by collecting ten 10-g samples at each mix time and analyzing for Cl concentration (Quantabs, Environmental Test Systems, Elkhart, IN). Values represent the mean of 3 batches (replications) for each diet. The discharge samples were collected as the diet exited the mixer from a slide on the bottom of the mixer after 240 sec of mixing. The time required to discharge the diet was approximately 120 sec.

Figure 2. The 60-lb double-ribbon mixer with the corn-soybean meal–based diet. The ribbons are visible when the mixer is filled to capacity.

Figure 3. The 60-lb double-ribbon mixer with the low-bulk-density ingredients. Unlike the corn-soybean meal–based diet, the ribbons are less visible, illustrating the extra volume that the low-bulk-density diet consumes in the mixer.

Index of Key Words

Page numbers in parentheses

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