KANSAS STATE UNIVERSITY
SWINE INDUSTRY DAY
2013

Swine Day 2013

Report of Progress 1092

K-STATE
Research and Extension

Kansas State University Agricultural Experiment Station and Cooperative Extension Service

SWINE DAY 2013

Contents

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Foreword

It is with great pleasure that we present the 2013 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.

2013 Swine Day Report of Progress Editors

Bob Goodband Mike Tokach Steve Dritz Joel DeRouchey

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.

Evaluation of the Effects of Added Vitamin D_3 in Maternal Diets on Sow and Pig Performance[1]

J.R. Flohr, M.D. Tokach, S.S. Dritz[2], J.M. DeRouchey, J.L. Nelssen, and J.R. Bergstrom[3]

Summary

A total of 84 sows (PIC 1050) and their litters were used to determine the effects of supplementing high levels of dietary maternal vitamin D_3 on sow and pig performance, serum 25(OH)D_3, milk vitamin D_3, neonatal bone mineralization, and neonatal tissue vitamin D_3. After breeding, sows were randomly assigned to 1 of 3 dietary vitamin D_3 treatments (680, 1,360, or 2,720 IU/lb of complete diets). Sows were bled on d 0 and 100 of gestation, and at farrowing and weaning (d 21). Pig BW was recorded at birth and weaning, and serum was collected from 2 pigs/litter at birth, on d 10, and at weaning. A total of 54 piglets (18/treatment) were euthanized at birth and necropsied to sample bones and tissues. Sow and suckling pig performance and neonatal bone ash and bone density did not differ ($P > 0.10$) among maternal vitamin D_3 treatments, but sow serum 25(OH)D_3 and milk vitamin D_3 increased (linear, $P < 0.01$) with increasing maternal vitamin D_3 supplementation. Piglet serum 25(OH)D_3 increased (quadratic, $P < 0.03$) with increased maternal vitamin D_3. Neonatal kidney vitamin D_3 tended (quadratic, $P = 0.08$) to decrease with increasing maternal vitamin D_3, but liver vitamin D_3 tended (linear, $P = 0.09$) to increase with increasing maternal vitamin D_3; however, physiological concentrations of vitamin D within these tissues were low regardless of statistical tendencies.

At weaning, a subsample of 180 pigs (PIC 327 × 1050) were used in a 3 × 2 split plot design for 35 d to determine the effects of maternal vitamin D_3 and 2 levels of dietary vitamin D_3 (816 or 8,160 IU/lb) from d 0 to 10 postweaning on piglet growth and serum 25(OH)D_3. Overall (d 0 to 35), nursery ADG and F/G were not affected by either source of vitamin D_3, but ADFI tended (quadratic, $P < 0.06$) to decrease with increasing maternal vitamin D_3 because pigs from sows fed 1,360 IU of vitamin D_3/lb had lower ADFI compared with pigs from sows fed 680 or 2,720 IU vitamin D_3/lb. Nursery pig serum 25(OH)D_3 increased (linear, $P < 0.01$) with increasing maternal vitamin D_3 on d 0 (weaning), and maternal × diet interactions ($P < 0.01$) were observed on d 10 and 21 because pigs from sows fed 680 IU vitamin D_3/lb had greater increases in serum 25(OH)D_3 when fed 8,160 IU vitamin D_3/lb compared with pigs from sows fed 1,360 IU vitamin D_3/lb. In conclusion, sow and pig serum 25(OH)D_3 and milk vitamin D_3 can be increased by increasing maternal vitamin D_3, and nursery pig serum 25(OH)D_3 can be increased by increasing dietary vitamin D_3; however, sow and pig performance and neonatal bone mineralization was not influenced by increasing vitamin D_3 dietary levels.

[1] Appreciation is expressed to Heartland Assays, DSM Nutritional Products, and Iowa State University College of Veterinary Medicine for providing funding and laboratory analysis for this project.
[2] Diagnostic Medicine and Pathobiology, College of Veterinary Medicine, Kansas State University.
[3] DSM Nutritional Products, Parsippany, NJ.

Introduction

Speculation has surfaced recently about serum 25(OH)D_3 concentrations of nursery pigs reared in modern swine production facilities, mainly because of documented cases in which vitamin D_3 has been absent from vitamin premixes fed to pigs (Feedstuffs, 2010[4]). In these cases, large percentages of pigs developed metabolic bone disease, which is categorized as a disturbance of normal bone formation and remodeling and can lead to bone fractures and clinical signs of rickets. In an effort to reduce these signs, guidelines for serum 25(OH)D_3 concentrations have been advocated. A recent survey of swine across different classes indicate that a significant proportion of pigs have serum 25(OH)D_3 concentrations below these guidelines (Madson, 2011[5]). Because most pigs are housed and raised in confinement facilities, pigs no longer have access to direct sunlight, which is needed for the endogenous production of vitamin D_3; therefore, these surveys seem to indicate additional vitamin D_3 supplementation is warranted, but little direct evidence characterizes these levels with production parameters such as weaning performance, subsequent nursery performance, or metabolic indicators such as bone ash or density.

For the suckling pig, vitamin D is supplied from maternal sources until after weaning. Previous research by Goff et al. (1984[6]) reported increased piglet serum 25(OH)D_3 concentrations in newborn pigs from sows dosed with vitamin D_3 intramuscularly 20 d prior to farrowing, suggesting vitamin D and its metabolites are transferred transplacentally. Surprisingly little research has quantified the effects of maternal feeding vitamin D_3 on piglet serum 25(OH)D_3 concentration. In addition, previous research conducted at Kansas State University (Flohr et al., 2011[7] and 2012[8]) concluded that supplementing vitamin D_3 to the suckling and nursery pig can increase serum 25(OH)D_3 concentrations but observed no effects on bone mineralization or growth performance. Finally, because feed is a low-cost method of D_3 supplementation, maternal supplementation may be a lower-cost and less labor-intensive method of manipulating serum 25(OH)D_3 concentrations in offspring compared with oral dosing. Therefore, the objectives in this experiment were to evaluate the effects of supplementing high levels of vitamin D_3 to sows on maternal performance, milk vitamin D_3 concentrations, sow and pig serum 25(OH)D_3, Ca and P concentrations, subsequent pig performance, neonatal bone mineralization, and neonatal tissue (liver and kidney) vitamin D_3 concentrations.

Procedures

Experimental procedures and animal care were approved by the K-State Institutional Animal Care and Use Committee. This experiment was conducted at the K-State Swine Teaching and Research Facility in Manhattan, KS, and was conducted from the months of January through August of 2012.

A total of 84 sows (PIC 1050) from 3 consecutive farrowing groups and their litters were used in this study. Following breeding, sows were randomly assigned to 1 of 3

[4] Feedstuffs. 2010. Kent feeds recalls certain swine feeds. Accessed April 4, 2011. http://www.feedstuffs.com.
[5] Madson, D.M. 2011. Metabolic bone disease in swine: a diagnostic dilemma. Pages 8–18 in Proc. 52nd Ann. George A. Young Swine Health and Management Conference. Sioux City, NE.
[6] Goff, J.P., R.L. Horst, and E.T. Littledike. 1984. Effect of sow vitamin D status at parturition on the vitamin D status of neonatal piglet. J. Nutr. 114:163–169.
[7] Flohr et al. Swine Day 2011. Report of Progress 1056, pp. 34–45.
[8] Flohr et al. Swine Day 2012. Report of Progress 1074, pp. 35–47.

dietary vitamin D_3 treatments (680, 1,360, or 2,720 IU/lb) throughout 3 consecutive farrowing groups. There were 27 sows per treatment and 7 to 11 replications per farrowing group. During d 0 through 100 of gestation, sows were fed 4.4 lb/d of the gestation diets. From d 100 to farrowing, sows were fed 5.5 lb/d of the gestation diets. During d 0 through 110, sows were housed in gestation stalls (7.0 × 2.0 ft). On d 110, sows were transported to the farrowing house and were housed in farrowing crates. Both the gestation and farrowing barns were totally enclosed, environmentally controlled, and mechanically ventilated buildings. The farrowing barn contained 29 farrowing crates (7.0 × 2.0 ft for the sow and 7.0 × 3.2 ft for the pigs) that were each equipped with a single feeder and nipple waterer. After farrowing, sows were switched to lactation diets. Gestation and lactation diets were formulated to contain 0.56% and 0.94% standardized ileal digestible (SID) lysine, respectively (Table 1), and contained 40% and 20% dried distillers grains with solubles (DDGS), respectively. For the first 3 d after farrowing, sows were gradually provided increased feed according to appetite. After d 3, all sows were allowed ad libitum access to the lactation diet. Temperature in the farrowing house was maintained at a minimum of 68°F, and supplemental heat was provided to piglets with heat lamps.

Lactation feed intake was determined by measuring feed disappearance on d 0, 7, 14, and 21 (weaning). Sow BW was measured at breeding, d 110 of gestation, within 24 h after farrowing, and at weaning to determine gestation weight gain and lactation weight loss. Sows were bled on d 0 and 100 of gestation, within 12 h after farrowing, and on d 10 and 21 (weaning) in lactation to determine serum 25(OH)D_3, Ca, and P concentrations. Milk samples were collected within 12 h after farrowing, and on d 10 and d 21 (weaning) to determine milk vitamin D_3 concentrations. Milk samples were obtained by an intravenous injection of oxytocin (1 mL, Agrilabs, St. Joseph, MO), and milk was collected from all functional glands.

At birth, all piglets were weighed individually and ear tagged for identification. The second and fifth pigs born within each litter were bled prior to suckling on d 0, on d 10, and at weaning to determine piglet serum 25(OH)D_3, Ca, and P. The seventh pig born from 54 litters (18 pigs per treatment, 6 replications per farrowing group) was euthanized prior to suckling and necropsied for bone and tissue sample analysis to determine neonatal pig bone ash content, bone density, and tissue vitamin D_3 concentrations. Mummified and stillborn pigs were recorded to calculate total born and live born piglets. Although minimal, cross-fostering was conducted within 24 h postfarrowing to help standardize litter size within vitamin D_3 dietary treatments. Pigs were weighed after fostering to measure fostered litter weight. At weaning, piglet weights and piglet counts were recorded to determine individual and litter weight gains, along with survivability.

At weaning, a subsample of 180 multi-sex pigs (PIC 327 × 1050) from the first sow group were used in a 3 × 2 split plot design for 35 d to determine the effects of maternal vitamin D_3 concentration and 2 levels of dietary vitamin D_3 (816 or 8,160 IU/lb; from d 0 to 10 postweaning) on growth performance and serum 25(OH)D_3, Ca, and P. At weaning, pigs were allotted to pens based on their previously administered maternal vitamin D_3 treatments to maintain the integrity of weaning weights consistent with maternal vitamin D_3 effects. Pens were then randomly assigned to dietary vitamin D_3 treatments. There were 6 pigs/pen and 5 pens per treatment. Dietary vitamin D_3 treat-

ments were provided from d 0 to 10 in the nursery and were fed in a pellet form (Table 2). Common Phase 2 and 3 diets were provided to pigs from d 10 to 21 and d 21 to 35, respectively. Common diets were formulated to contain 1,800 IU/kg vitamin D_3 and were fed in a meal form. All pens (4 × 5 ft) had woven wire flooring, one 3-hole, dry self-feeder, and a nipple waterer to allow for ad libitum access to feed and water. All pigs and feeders were weighed on d 0, 5, 10, 17, 21, 28, and 35 after weaning to determine ADG, ADFI, and F/G. Blood samples were collected from 10 pigs/treatment on d 0, 10, 24, and 35 to determine serum 25(OH)D_3, Ca, and P. All blood, milk, and tissue sample analyses was conducted by Heartland Assays (Ames, IA) to determine serum 25(OH)D_3, Ca and P, and milk and tissue vitamin D_3 concentrations.

To achieve the dietary vitamin D_3 concentrations, a premix was made containing a vitamin D_3 supplement (Rovimix D_3, 500,000 IU/g; DSM Nutritional Products Inc., Parsippany, NJ). This supplement was then mixed into a rice hull carrier to form the premix and was added to the control diet (625 IU vitamin D_3/lb) by replacing corn. Vitamin premixes and complete diet samples were analyzed for vitamin D_3 concentration by DSM Nutritional Products.

Necropsies were performed onsite and in compliance with the college's standard operating procedures. Pigs were euthanized with an intravenous overdose of sodium pentobarbital (Fatal Plus, Vortech Pharmaceuticals, Dearborn, MI). Right femurs and second ribs were collected to determine bone ash content, and left second ribs were used to determine bone density. Whole liver and kidney tissues were collected and frozen immediately at -4°F until samples were prepared for specific analysis.

Bone densities were determined at the Iowa State University College of Veterinary Medicine (Ames, IA). All left second ribs were stripped to the periosteum, submerged in water for 4 h under 12.09 psi vacuum, and blotted dry prior to recording bone weight. Bone volume was determined using weight in air minus weight under water according to the Archimedes principle. Bone density values were then expressed as ounces of bone/in.^{3} volume.

Bone ash analysis, which was performed on the right femurs and right second rib, was conducted at the K-State Swine Nutrition Laboratory in Manhattan, KS. Bones were cleaned to the periosteum and were split perpendicular to the long axis of the diaphysis. Fat extraction was conducted by placing bones in cellulose thimbles and inserting thimbles in the main chambers of soxhlet extractors. The extraction solvent was petroleum ether. Fat extraction was conducted for 7 d. At the completion of the extraction period, bone samples were dried in a forced-air oven at 212°F until a consistent dry weight was achieved. Then bones were ashed at 1,112°F for 24 h. Ash weights were recorded and expressed as a percentage of dry fat-free bone.

Data were analyzed using the MIXED procedure in SAS (SAS Institute, Inc., Cary, NC). Maternal performance data were analyzed with sow as the experimental unit, treatment as a fixed effect, and farrowing group as a random effect. Nursery performance was analyzed as a 3 × 2 split plot design, and pen was used as the experimental unit. Additional contrasts were used to determine the effects of early nursery vitamin D_3 treatments and the interaction of maternal vitamin D_3 and early nursery dietary vitamin D_3 treatments. Serum 25(OH)D_3, Ca, P, and milk vitamin D_3 data were analyzed

using the repeated measures function to determine the effects of treatment variables over time, and individual pig was the experimental unit. Bone ash, bone density, and tissue vitamin D_3 concentrations were analyzed using individual pig as the experimental unit. Differences among treatments were considered significant with $P \leq 0.05$ and trends if $P > 0.05$ and ≤ 0.10.

Results and Discussion

Analysis of vitamin D_3 concentrations in the diets verified that they were within acceptable analytical variation of formulated dietary values (Table 3). For maternal performance, increasing supplementation of vitamin D_3 from 680 to 2,720 IU/lb of the complete diet did not influence ($P > 0.05$; Table 4) sow BW gain in gestation, lactation ADFI, or sow BW loss in lactation. In addition, maternal vitamin D_3 treatments used in this study did not affect ($P > 0.05$) litter performance criteria or piglet BW at birth or weaning.

A maternal × day interaction ($P < 0.01$; Table 5) was observed for sow serum 25(OH)D_3 because 25(OH)D_3 was not different among sows on d 0 of gestation serum, but increasing maternal vitamin D_3 increased (linear, $P < 0.01$) serum 25(OH)D_3 on d 100 of gestation, at farrowing, and at weaning. Milk vitamin D_3 concentrations were not influenced by sampling day ($P = 0.56$); however, milk vitamin D_3 increased (linear, $P < 0.01$) with increasing maternal dietary vitamin D_3 at farrowing, on d 10 in lactation, and at weaning. A day effect was observed ($P < 0.01$) for piglet serum 25(OH)D_3 as serum concentrations increased through time from birth to weaning, and serum 25(OH)D_3 increased (quadratic, $P < 0.03$) with increasing maternal vitamin D_3 at birth, on d 10 in lactation, and at weaning.

No differences ($P > 0.05$) in neonatal bone ash values were observed for femurs or second ribs. Rib bone density was not influenced ($P > 0.05$) by maternal vitamin D_3 concentrations. Kidney vitamin D_3 concentrations tended to decrease (quadratic, $P = 0.09$) with increasing maternal vitamin D_3 because pigs from sows fed 1,360 IU vitamin D_3/lb had much lower tissue vitamin D_3 concentrations compared with pigs from sows fed 680 or 2,720 IU vitamin D_3/lb. Liver tissue vitamin D_3 concentrations tended to increase (linear, $P = 0.08$) with increased maternal dietary vitamin D_3. Overall, means associated with tissue vitamin D_3 concentrations were low because many samples were below the lower detectable limit of 0.001 ng/mg, which suggests that the neonatal liver and kidney are not high in vitamin D_3 content at birth and that newborn pigs do not store vitamin D_3 in the liver and kidney, perhaps the result of little to no hepatic or renal fat development within the newborn animal. Previous research (Clements and Fraser, 1988[9]) concluded that fetal rats store 25(OH)D_3 in muscle tissue at birth, and this is the primary source of vitamin D available to the animal for the first 3 weeks of its life.

During the nursery portion of the study, no interactions between maternal vitamin D_3 and dietary vitamin D_3 were observed ($P > 0.05$; Table 6) in growth performance. Overall (d 0 to 35), ADFI tended (quadratic, $P = 0.06$) to decrease with increasing vitamin D_3, with pigs from sows fed 1,360 IU vitamin D_3/lb having lower ADFI compared with pigs

[9] Clements, M.R., and D.R. Fraser. 1988. Vitamin D supply to the rat fetus and neonate. J. Clin. Invest. 81:1768–1773.

from sows fed either 680 or 2,720 IU vitamin D_3/lb; however, maternal and nursery vitamin D_3 supplementation did not influence ($P > 0.05$) overall (d 0 to 35) ADG or F/G.

A day effect ($P < 0.01$) was observed for nursery pig serum 25(OH)D_3. At weaning (d 0), pig serum 25(OH)D_3 increased (linear, $P < 0.01$) with increasing maternal vitamin D_3. Maternal × diet interactions ($P < 0.01$) were observed on d 10 and 21 because pigs from sows fed 680 IU vitamin D_3/lb had greater increases in serum 25(OH)D_3 when fed 8,160 IU vitamin D_3/lb compared with pigs from sows fed 1,360 IU vitamin D_3/lb. On d 35, serum 25(OH)D_3 concentrations did not differ among maternal treatments, but a diet effect ($P < 0.04$) was observed with increased nursery diet vitamin D_3 increasing serum 25(OH)D_3.

A day effect ($P < 0.01$; Figure 1) was observed for sow serum Ca. Sow serum Ca tended (linear, $P = 0.07$) to be higher on d 0 of gestation for sows assigned to the 2,720 IU vitamin D_3/lb treatment compared with sows assigned to lower maternal vitamin D_3 treatments, which reflects potential differences prior to initiation of maternal vitamin D_3 treatments. On d 100 of gestation, increasing maternal dietary vitamin D_3 tended to decrease (quadratic, $P = 0.09$) serum Ca. Serum P concentrations were not influenced ($P > 0.10$) by maternal vitamin D_3 treatments or by sampling day ($P = 0.18$). In terms of piglet serum Ca, a day effect was observed ($P < 0.01$; Figure 2) for serum Ca concentrations. Serum Ca also tended to decrease (linear, $P = 0.08$) with increasing maternal vitamin D_3 on d 10 of lactation. Serum P concentrations were not influenced ($P > 0.10$) by maternal vitamin D_3 treatments, but they tended to be different based on day of sampling ($P = 0.08$). Nursery pig serum Ca concentrations were not influenced by maternal or nursery vitamin D_3 concentrations, but for serum P a tendency was observed (quadratic, $P = 0.08$; Figure 3) for P concentrations to increase within increasing maternal vitamin D_3 on d 10 after weaning was observed, and day of blood collection influenced serum P concentrations ($P < 0.01$). Although several statistical tendencies were observed within several collection days, all serum Ca and P means collected fell within previously described physiological ranges (Friendship et al., 1984[10]) associated with normal healthy pigs of similar stages of production.

In summary, supplementing vitamin D_3 via the maternal diet is an effective way to increase serum 25(OH)D_3 of the young pig by increasing transplacental transfer of 25(OH)D_3 from the sow to the fetus, along with increased transfer during lactation from the increased milk vitamin D_3 concentrations. In addition, maternal supplementation and increased vitamin D_3 in nursery diets can increase nursery pig serum 25(OH)D_3 concentrations, but the increase in maternal supplementation did not influence sow or pig performance, sow or pig serum Ca and P, or neonatal bone traits. Future research is needed to determine optimal serum 25(OH)D_3 levels for proper bone development and ideal Ca and P absorption in pigs. More work examining potential impacts of vitamin D on the immune system or other novel biological processes in pigs may offer additional insights into possible benefits of vitamin D supplements for pigs.

[10] Friendship et al. 1984. Hematology and biochemistry reference values for Ontario swine. Can. J. Comp. Med. 48:390–393.

Table 1. Composition of sow diets (as-fed basis)[1,2]

Item	Gestation	Lactation
Ingredient, %		
Corn	52.96	52.19
Soybean meal (46.5% CP)	2.99	23.88
Dried distillers grains with solubles	40.00	20.00
Monocalcium P (21% P)	0.65	0.90
Limestone	1.90	1.60
Salt	0.50	0.50
Vitamin premix[3]	0.50	0.50
Trace mineral premix	0.15	0.15
L-lysine HCl	0.23	0.15
Phytase[4]	0.13	0.13
Total	100	100
Calculated analysis		
ME, kcal/lb	1,492	1,488
CP, %	17.0	21.1
Total lysine, %	0.72	1.13
Standardized ileal digestible lysine, %	0.56	0.97
Ca, %	0.88	0.88
P, %	0.59	0.64
Available P, %[5]	0.50	0.48

[1] A total of 84 sows and litters were used to determine the effects of supplemental vitamin D_3 on maternal performance, subsequent pig performance, sow and piglet serum 25(OH)D_3, Ca and P, milk vitamin D_3, neonatal bone mineralization, and piglet tissue vitamin D_3 concentrations.

[2] Vitamin D_3 premixes were mixed to contain 1,000,000 IU vitamin D_3/lb of premix by blending vitamin D_3 (Rovimix D; DSM Nutritional Products, Parsippany, NJ) with rice hulls. Premix replaced a percentage of corn to achieve the desired treatment vitamin D_3 concentrations.

[3] Vitamin premix provided 625 IU vitamin D_3/lb of the complete diet.

[4] Natuphos 600, BASF, Florham Park, NJ. Provided 341 phytase units (FTU)/lb of diet.

[5] Phytase provided 0.12% available P to gestation and lactation diets.

Table 2. Composition of nursery diets (as-fed basis)[1]

Item	Phase 1[2]	Phase 2[3]	Phase 3[4]
Ingredient, %			
Corn	39.58	44.73	65.78
Soybean meal (46.5% CP)	17.33	23.41	30.67
Dried distillers grains with solubles	5.00	15.00	---
Spray-dried porcine plasma	5.00	---	---
Spray-dried blood cells	1.25	---	---
Spray-dried whey	25.00	10.00	---
Select menhaden fish meal	---	4.50	---
Soybean oil	3.00	---	---
Monocalcium P (21% P)	0.85	0.15	1.03
Limestone	1.00	0.70	0.98
Salt	0.30	0.30	0.35
Zinc oxide	0.39	0.25	---
Trace mineral premix	0.15	0.15	0.15
Vitamin premix[5]	0.25	0.25	0.25
L-lysine HCl	0.20	0.28	0.36
DL-methionine	0.13	0.05	0.13
L-threonine	0.05	0.05	0.13
L-isoleucine	0.10	---	---
Phytase[6]	0.13	0.17	0.17
Acidifier[7]	0.20	---	---
Vitamin E, 20,000 IU	0.05	---	---
Choline chloride 60%	0.04	---	---
Vitamin D_3 premix[8]	0.02	0.02	0.02
Total	100	100	100
Calculated analysis			
ME, kcal/lb	1,549	1,506	1,503
CP, %	21.2	23.1	20.4
Standardized ileal digestible lysine, %	1.35	1.30	1.25
Ca, %	0.80	0.70	0.68
P, %	0.71	0.63	0.61
Available P, %[9]	0.63	0.50	0.42

[1] A total of 180 pigs (PIC 327 × 1050; initially 21 d of age) were used in a 3 × 2 split plot design for 35 d to determine the effects of maternal vitamin D_3 and early nursery dietary vitamin D_3 on nursery growth performance and serum 25(OH) D_3 concentrations.

[2] Phase 1 diets were fed from d 0 to 10.

[3] Common Phase 2 diets were fed from d 10 to 24.

[4] Common Phase 3 diets were fed from d 24 to 35.

[5] Vitamin premix provided 625 IU vitamin D_3/lb of the complete diet.

[6] Natuphos 600 (BASF, Florham Park, NJ) provided 354, 463, and 463 phytase units (FTU)/lb of the complete diet for Phase 1, 2, and 3 diets, respectively.

[7] KemGest (Kemin Industries Inc., Des Moines, IA).

[8] Vitamin D_3 premixes were mixed to contain 1,000,000 IU vitamin D_3/lb of premix by blending vitamin D_3 (Rovimix D; DSM Nutritional Products, Parsippany, NJ) with rice hulls. Premix replaced a percentage of corn to achieve the desired treatment vitamin D_3 concentrations.

[9] Phytase provided 0.12, 0.13, and 0.12% available P for Phase 1, 2, and 3 diets, respectively.

Table 3. Analyzed dietary vitamin D_3 concentrations (as-fed)[1]

Maternal diets, IU/lb				
Formulated composition	680	1,360	2,720	
Analyzed composition				
Gestation	683	1,529	3,640	
Lactation	669	1,538	2,817	
	Phase 1[2]		Phase 2[3]	Phase 3[4]
Nursery diets, IU/lb				
Formulated composition	816	8,160	816	816
Analyzed composition	848	8,754	841	867

[1] Vitamin D_3 analysis was performed by DSM Nutritional Products (Parsippany, NJ), and values represent the average of 2 pooled samples per diet.
[2] Phase 1 diets were fed from d 0 to 10.
[3] Common Phase 2 diets were fed from d 10 to 24.
[4] Common Phase 3 diets were fed from d 24 to 35.

Table 4. The effects of high maternal vitamin D3 on sow and litter performance[1,2]

	Vitamin D_3, IU/lb				Probability, $P <$	
Item	680	1,360	2,720	SEM	Linear	Quadratic
Sows, n	28	26	26			
Sow BW, lb						
Gestation						
d 0	425.7	427.9	423.7	19.29	0.91	0.89
d 110	510.2	518.5	522.7	13.21	0.52	0.80
Change	+84.5	+90.6	+99.0	11.99	0.24	0.92
Lactation						
d 0	489.2	501.7	494.0	13.17	0.89	0.50
d 21 (weaning)	468.1	485.6	479.2	16.59	0.67	0.42
Change	-21.1	-16.1	-14.8	6.14	0.24	0.43
ADFI, lb						
d 0 to wean (d 21)	12.46	12.96	13.18	0.747	0.27	0.63
Piglets						
Litter size, n						
Mummies	0.3	0.2	0.3	0.12	0.88	0.86
Stillborn	0.6	0.4	0.8	0.34	0.60	0.37
Total born alive	13.0	12.5	13.2	0.88	0.74	0.57
Fostered	12.3	12.1	13.0	0.70	0.50	0.48
Weaned	11.2	10.8	11.5	0.652	0.48	0.32
Survivability, %[3]	91.2	89.2	88.5	2.02	0.88	0.58
Piglet BW, lb						
Birth	2.88	2.99	2.96	0.091	0.63	0.47
Weaning	11.71	12.23	12.18	0.364	0.43	0.42

[1] A total of 84 sows (PIC 1050) and their litters were used. Two sows were removed from the 1,360 IU/kg vitamin D_3 treatment because of lameness and illness, and two sows were removed from the 2,720 IU/kg vitamin D_3 treatment because of late-term abortion and farrowing complications.

[2] Sow group was used as a random effect in the statistical model.

[3] Survivability was calculated by dividing the weaned litter size by the fostered litter size.

Table 5. Effects of high maternal vitamin D_3 on sow and pig serum 25(OH)D_3, milk vitamin D_3, neonatal bone traits, and tissue vitamin D_3[1,2]

	Maternal vitamin D_3, IU/lb				Probability, $P <$	
	680	1,360	2,720	SEM	Linear	Quadratic
Sow						
Serum 25(OH)D_3, ng/mL						
d 0	30.1	26.2	32.0	4.65	0.54	0.27
d 100	33.2	36.5	57.9	4.65	0.01	0.23
Farrowing	30.1	35.4	56.9	4.65	0.01	0.38
Weaning	39.3	52.5	66.3	4.65	0.01	0.31
Milk vitamin D_3, ng/g						
Farrowing	1.02	2.33	3.97	0.31	0.01	0.37
d 10	0.78	2.33	3.73	0.31	0.01	0.13
Weaning	1.02	1.98	3.53	0.31	0.01	0.73
Piglet						
Serum 25(OH)D_3, ng/mL						
Birth	4.5	5.9	9.4	0.75	0.01	0.03
d 10	4.4	6.2	10.6	0.75	0.01	0.01
Weaning	5.6	8.0	14.0	0.81	0.01	0.01
Bone ash content, %						
2nd rib	43.6	43.6	43.5	0.80	0.95	0.96
Femur	44.9	44.5	44.8	0.55	0.76	0.66
Bone density, g/mL						
2nd rib	1.30	1.30	1.31	0.02	0.64	0.56
Tissue vitamin D_3, ng/g						
Kidney	1.68	0.10	1.37	0.842	0.99	0.09
Liver	0.04	0.04	0.19	0.050	0.08	0.16

[1] A total of 84 sows (PIC 1050) and their litters were used to determine the effects of high maternal vitamin D_3 on sow and pig serum 25(OH)D_3, milk vitamin D_3, and neonatal bone traits and tissue vitamin D_3.

[2] Day effects were $P < 0.01$, $P = 0.56$, and $P < 0.01$ for sow 25(OH)D_3, milk vitamin D_3, and piglet 25(OH)D_3, respectively. Maternal × day interactions were $P < 0.01$, $P = 0.87$, and $P = 0.13$ for sow 25(OH)D_3, milk vitamin D_3, and piglet 25(OH)D_3, respectively.

Table 6. The effects of maternal and early nursery vitamin D_3 supplementation on nursery pig growth performance and serum 25(OH)D_3[1]

	Maternal vitamin D_3, IU/lb						Probability, $P <$				
	680		1,360		2,720			Maternal × diet	Maternal		
Early nursery vitamin D_3:[2]	816	8,160	816	8,160	816	8,160	SEM	interaction	Linear	Quadratic	Diet
d 0 to 35											
ADG, lb	0.92	0.92	0.86	0.88	0.92	0.87	0.03	0.56	0.56	0.12	0.75
ADFI, lb	1.32	1.36	1.27	1.25	1.33	1.27	0.04	0.39	0.47	0.06	0.69
F/G	1.43	1.48	1.48	1.42	1.45	1.45	0.03	0.17	0.96	0.71	0.90
Serum 25(OH)D_3, ng/mL											
d 0	6.3		10.5		17.6		3.09		0.01	0.91	
d 10	20.0	53.5	21.9	49.6	24.0	60.9	2.16	0.01	0.01	0.04	0.01
d 21	13.2	26.7	13.6	23.9	14.4	31.6	2.16	0.01	0.16	0.15	0.01
d 35	16.7	18.0	14.5	19.3	14.9	19.5	2.16	0.42	0.94	0.83	0.04

[1] A total of 180 mixed-sex pigs (PIC 327 × 1050; initially 21 d of age) were weaned from the first sow group and used in a 3 × 2 split plot design for 35 d to determine the effects of maternal and early nursery dietary vitamin D_3 on growth performance.

[2] Dietary vitamin D_3 treatments were fed in Phase 1 diets from d 0 to 10. Common Phase 2 and 3 diets were fed from d 10 to 21 and d 21 to 35, respectively. Common diets were formulated to contain 1, 800 IU/kg vitamin D_3. Treatments are expressed as IU/kg of the complete diet.

[3] Ten pigs/treatment were bled to determine serum 25(OH)D_3. Day effect, $P < 0.01$ and maternal × diet × day interaction, $P = 0.32$.

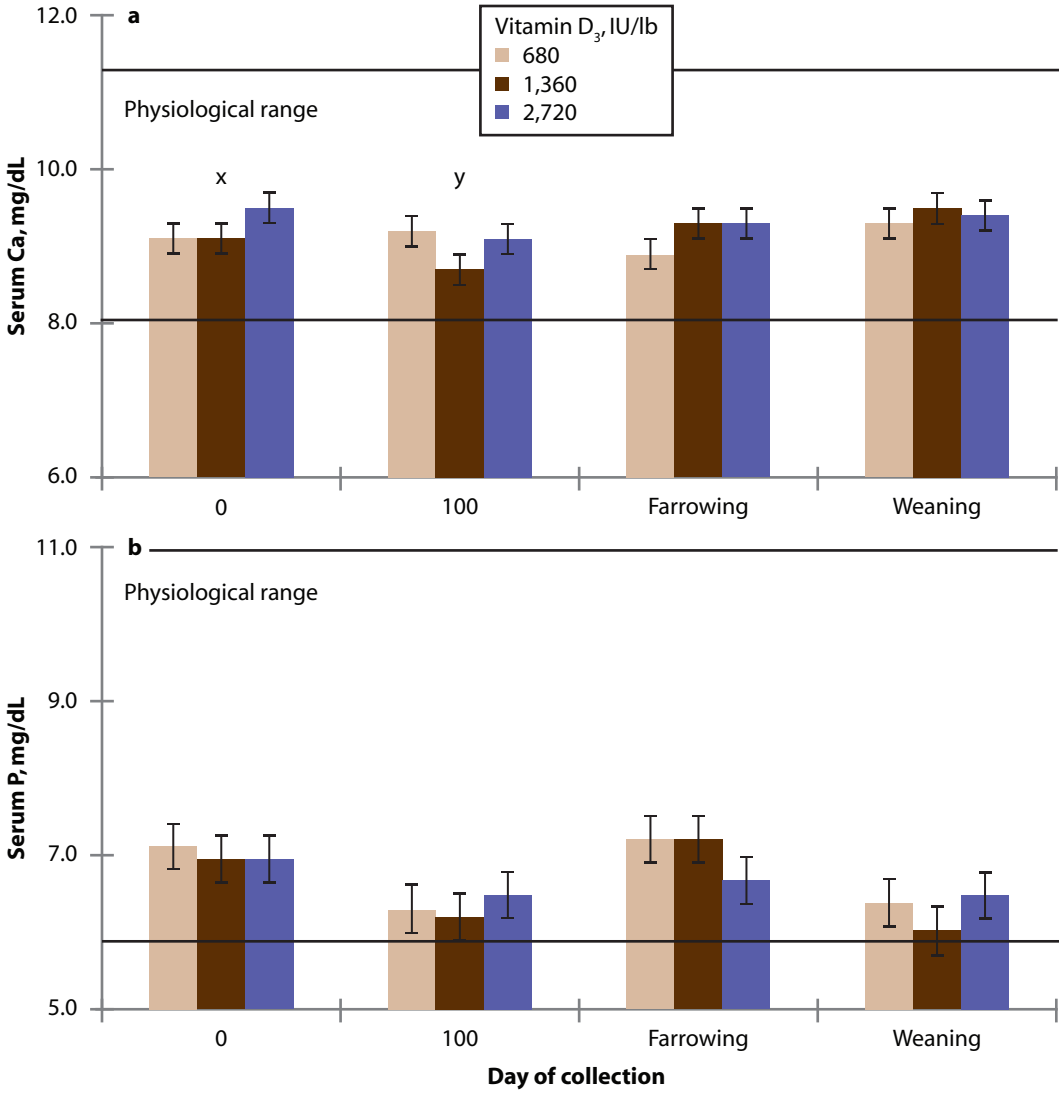

Figure 1. Serum Ca and P concentrations (mg/dL) at d 0 and 100 of gestation, farrowing, and weaning (d 21 of lactation) in sows fed diets formulated to supply 680, 1,320, or 2,720 IU vitamin D_3/lb of the complete diet. Superscripts denote differences ($P < 0.05$) due to: a, linear dietary effect; and b, a quadratic dietary effect. Superscripts denote tendencies ($0.05 < P \leq 0.10$) due to: x, linear dietary effects; and y, quadratic dietary effects. Physiological range based on Friendship et al. (1984).

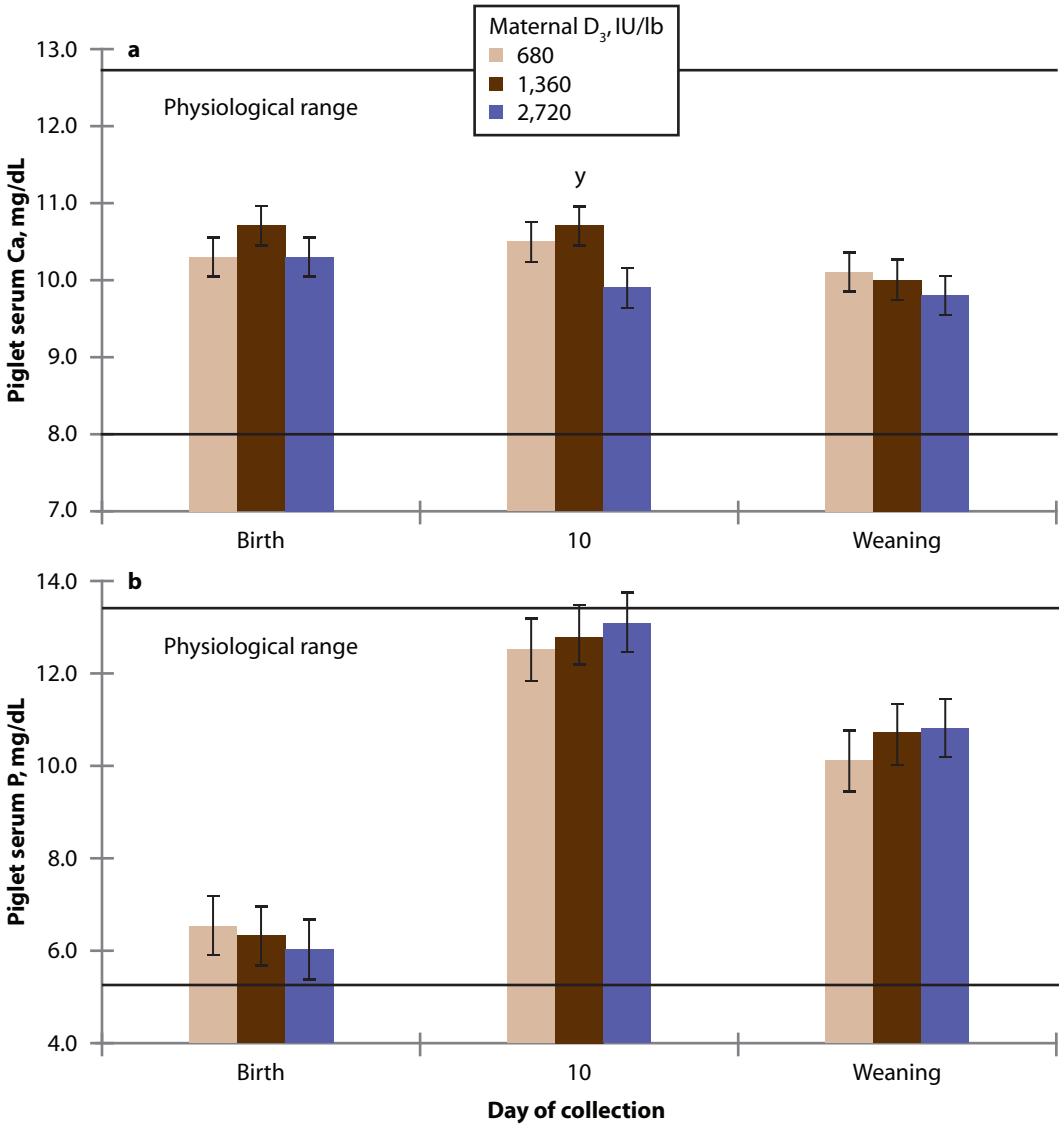

Figure 2. Serum Ca and P concentrations (mg/dL) at birth, d 10, and weaning (d 21) in pigs from sows fed diets formulated to supply 680, 1,320, or 2,720 IU vitamin D_3/lb of the complete diet. Superscripts denote differences ($P < 0.05$) due to: a, linear maternal diet effect; and b, quadratic maternal diet effect. Superscripts denote tendencies ($0.05 < P \leq 0.10$) due to: x, linear maternal diet effect; and y, quadratic maternal diet effect. Physiological range is based on Friendship et al. (1984).

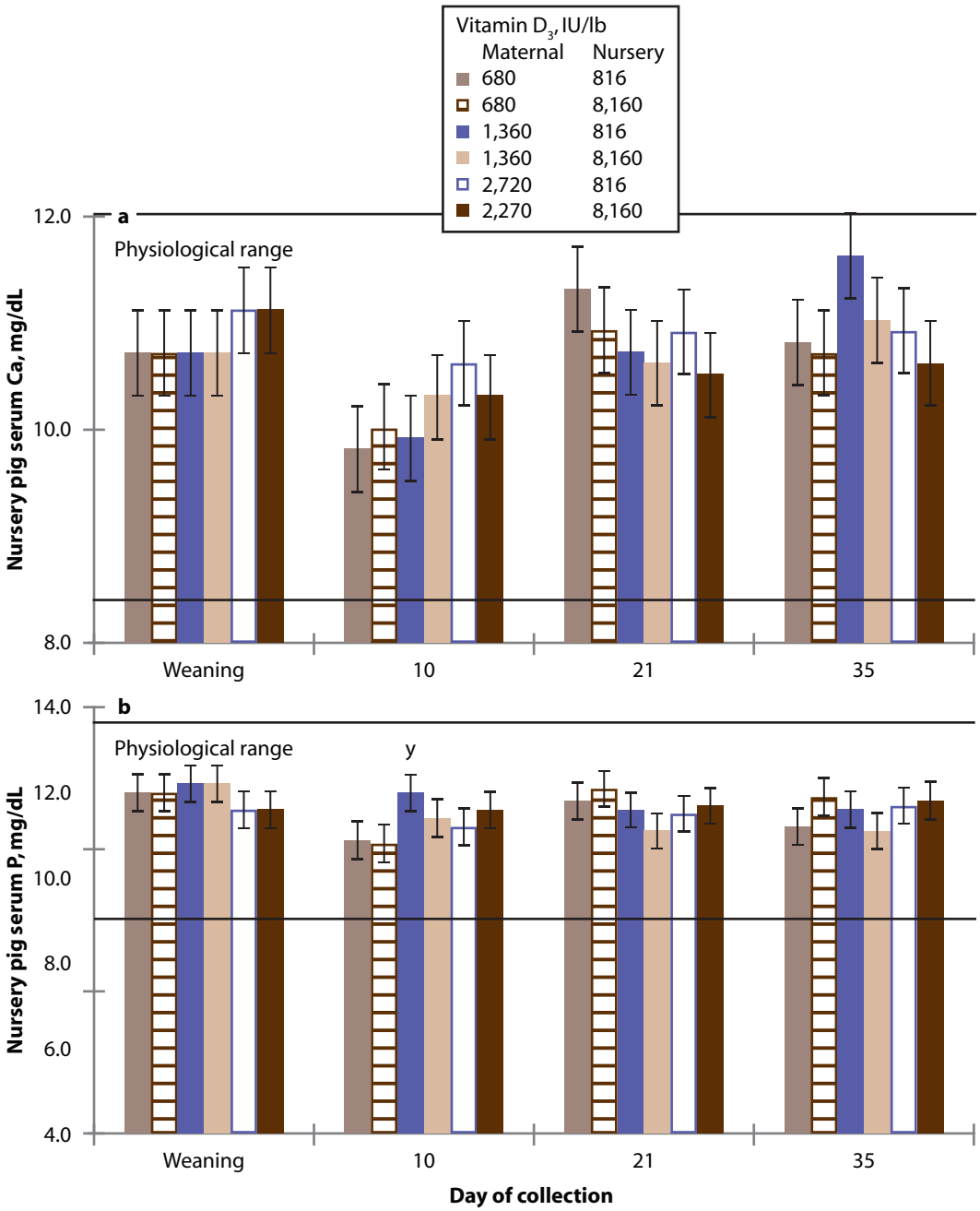

Figure 3. Serum Ca and P concentrations (mg/dL) at weaning, d 10, d 21, and d 35 in nursery pigs from sows fed diets formulated to supply either 680, 1,320 or 2,720 IU vitamin D_3/lb of the complete diet, and fed diets formulated to either 816 or 8,160 IU vitamin D_3/lb from weaning until d 10. Superscripts denote differences ($P < 0.05$) due to: a, linear maternal diet effect; b, a quadratic maternal diet effect; and c, diet effect. Superscripts denote tendencies ($0.05 < P \leq 0.10$) due to: x, linear maternal diet effect; and y, quadratic maternal diet effect; z, diet effect. Physiological range is based on Friendship et al. (1984).

Stimulation of Estrus and Ovulation in Lactating Sows

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Summary

A total of 53 sows were used to determine the effects of a lactational estrus stimulation strategy on reproductive and litter growth performance. Treatment differences within parity group, multiparous and primiparous, were also considered. Litter size was equalized to 11.6 ± 1.2 pigs at d 2 postfarrowing. At d 18 of lactation, sows were allotted to the control or an altered suckling method (ALT). The ALT sows were placed in adjacent pairs within parity so pigs could be moved between litters by temporarily lifting the divider between the two litters. On d 18, all but the 5 lightest weight pigs from each ALT litter were weaned. The 5 lightweight pigs for each pair of litters formed a combined litter that nursed each sow of the pair 12 h/d from d 18 to 25. Therefore, pigs had nursing access 24 h/d, but each ALT sow was suckled only 12 h/d. Boar exposure was provided to ALT sows for 15 min/d by removing sows to a pen outside the farrowing room. Control and ALT sows were weaned at d 21 and d 25, respectively. Sow weights and litter growth performance during lactation was similar between treatments, although ALT sows had 16% greater total feed intake ($P < 0.01$) due to the extended lactation length. Primiparous sows lost a greater percentage (7.4 vs. 3.4%) of BW and consumed less feed ($P < 0.01$) than multiparous sows. A total of 26 ALT sows (93%) were detected in estrus and mated in lactation. Although duration from initiating ALT to estrus was greater ($P < 0.001$) than the wean-to-estrus interval for controls, ALT sows were in estrus earlier (23.0 vs. 24.6 d; $P < 0.001$) than controls postfarrowing, with primiparous sows responding more slowly (5.4 vs. 3.8 d; $P < 0.01$) than multiparous sows for both treatments. Pregnancy rate and subsequent reproductive performance were similar between treatments. In conclusion, ALT sows expressed lactational estrus and performed reproductively similar to sows with conventionally weaned litters.

Key words: boar exposure, lactating sow, lactational estrus, split weaning

Introduction

Sows experience a period of lactational anestrus driven by suckling-induced suppression of gonadotropin secretion. The sow's reproductive tract requires a minimum of 14 to 21 d for uterine involution and resumption of reproductive activity; consequently, weaning currently takes place at least 2 weeks after parturition and has moved closer to 3 weeks to support better performance of the weaned pigs.

Producers have significant economic incentives to shorten the interval from farrowing to conception. One approach to circumvent the negative impact of early weaning is to uncouple weaning and breeding by breeding during lactation. In theory, this could reduce sow non-productive days while simultaneously increasing lactation length to the

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benefit of the litter. Another potential advantage would be easing the transition into group gestation housing. Shifting the breeding procedures to the farrowing facility also may help reassign duties and improve preweaning survival.

Several strategies have been evaluated to elicit a fertile estrus in lactating sows. Although results have been inconsistent, separating the sow from the litter for longer than 6 hours/d and exposure to a boar clearly are important stimuli. Researchers in Europe[2] and Australia[3] have recently revisited these ideas to address welfare and production issues in modern production systems. This recent work suggests that some maternal sow genotypes are more responsive to temporary litter separation and boar exposure than previously thought.

We designed a treatment that combined early weaning of the heavier pigs in each litter and created combined litters to give small pigs access to 24 h/d nursing but restricted sows to 12 h/d of sucking. We also provided boar exposure. This unique treatment was compared with conventionally weaned sows. We assigned the sows to treatment by parity (multiparous vs. primiparous) in anticipation that the primiparous sows would be less likely to respond with lactational estrus.

Procedures

Animals and housing

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The trial was conducted at the Kansas State University Swine Teaching and Research Center in Manhattan, KS. A total of 53 sows (PIC 1050) were used in two farrowing groups. Parity ranged from 1 to 5 and averaged 2.6 ± 1.5. Prior to farrowing, pregnant sows were moved into a single farrowing room (29 individual farrowing crates; 7.0 × 2.0 ft for the sow and 7.0 × 5.2 ft for pigs). Sows not farrowing by d 115 of gestation were induced to farrow by injecting Lutalyse (dinoprost tromethamine, 10 mg; Zoetis Animal Health, Florham Park, NJ). Litter size at birth varied from 3 to 18 live pigs and was equalized within 2 d after farrowing by cross-fostering pigs within each parity group, resulting in an average litter size of 11.6 ± 1.2 pigs. Within 1 d after farrowing, piglet BW was determined and pigs were individually ear-notched and injected with 2 mL iron dextran and 1 mL of antibiotic (Naxcel (ceftiofur sodium); Zoetis Animal Health). Male pigs were castrated approximately 7 d after birth. The day on which most of the litters were born was considered d 0 of lactation for the group, and all treatment procedures were performed on the same calendar day for all litters in the farrowing group. Litters were born from 4 d before to 3 d after d 0. Sows were fed a common lactation diet (1,472 kcal/lb, 21.6% CP, and 0.97% lysine) based on corn, soybean-meal, and 20% DDGS, which was provided ad libitum beginning the day after farrowing. Lactation feed was delivered using individual Gestal Solo (JYGA Technologies, St-Nicolas, Quebec, Canada) electronic sow feeders. Water was available ad libitum. Creep feed was not offered during lactation.

[2] Kemp, B., and N.M. Soede. 2012. Should weaning be the start of the reproductive cycle in hyper-prolific sows? A Physiological view. Reprod. Dom. Anim. 47:320–326.

[3] Downing, J.A., and L.R. Giles. 2009. Induction of estrus in lactating sows. Australian Pork CRC Report. 2009.

Treatments

Sows were allotted to treatments within parity group on d 18 of lactation with BW. Suckled litter size and date farrowed equalized as nearly as possible. A total of 25 control sows (16 multiparous and 9 primiparous) and 28 ALT sows (20 multiparous and 8 primiparous) were used. Per normal farm procedures, control sows were continuously suckled by their litters until weaning. The ALT sows were placed in adjacent pairs within parity group such that two litters could be combined and switched between sows by temporarily lifting the separating divider. On d 18, all but the 5 lightest-weight pigs from each ALT litter were split-weaned and moved to the nursery. The remaining 5 lightweight pigs on paired ALT litters were combined to form a new litter of 10 pigs. These combined litters were rotationally suckled between paired sows at 12-h intervals (0600 and 1800), such that pigs had access to a sow 24 h/d, but each ALT sow was suckled for only 12 h/d. Lights were left on for 24 h/d throughout lactation.

The ALT sows were provided daily exposure to a boar by moving the sow to a pen adjacent to the farrowing room. Each sow received approximately 5 min of nose-to-nose contact followed by 5 min of full physical contact and a final 5 min of nose-to-nose contact with a boar. To maximize stimulation, one of three mature boars was used for full physical contact on each day with a second boar providing nose-to-nose contact, and boars were rotated each day to minimize individual boar effects. Boar exposure was from d 18 of lactation until ovulation or at weaning on d 25. Control sows were weaned on the afternoon of d 21. At weaning, sows were moved into a group pen environment, but sows were moved into individual gestation stalls each day for transrectal ultrasound. Estrus detection was also performed at this time in the presence of a boar.

Measurements

Sow BW and backfat (BF) were recorded at entry, after farrowing, and on d 18, 21, and 25 postfarrowing. Pigs were weighed at d 18, on the afternoon of d 21, and on d 25. Feed disappearance was also measured in sows from their individual farrowing date until weaning.

Standing estrus was confirmed using a back-pressure test in the presence of a boar. Sows were artificially inseminated at first observed estrus and again 24 h later. Starting on d 17, transrectal ultrasound was performed using an Aloka 500V ultrasound with a 5.0-MHz probe (Aloka, Wallingford, CT). Ultrasound was performed daily for ALT sows and every other day for control sows until d 21, after which all sows were scanned daily until ovulation, defined as 12 h prior to the ultrasound exam where fewer than 4 total intact follicles remained on the ovaries. The number of follicles per ovary were recorded along with the follicle diameter, calculated by the average diameter of the three largest follicles on each ovary.

A blood sample was obtained by jugular venipuncture from all sows on d 18, 21, and 25. Two additional samples were collected 8 to 12 and 18 to 21 d postestrus to verify ovulation and confirm establishment of pregnancy, respectively. Serum from these samples was assayed for concentrations of progesterone (P4). Progesterone concentrations greater than 4.0 ng/mL at d 8 to 12 after estrus confirmed ovulation and at d 18 to 21 confirmed the establishment of pregnancy. Pregnancy was confirmed approximately 28 d after insemination by ultrasound examination. Farrowing rate, total born, number born live, stillbirths, mummies, and birth weights were recorded for all resulting litters.

Statistical analysis

All normally distributed data were analyzed using the MIXED procedure of SAS, version 8.1 (SAS Institute, Inc., Cary, NC). Sow was the experimental unit and farrowing replicate was included in the model as a random effect. Pregnancy and farrowing rate were evaluated by chi-square analysis using the LOGISTIC procedure of SAS. Statistical significance and tendencies were set at $P < 0.05$ and $P < 0.10$.

Results and Discussion

No treatment × parity group interactions were observed for sow or piglet growth performance. The ALT sows were heavier and had greater BF ($P < 0.01$) at d 25, which probably resulted from feed restriction for control sows after weaning on d 21, whereas ALT sows continued to have ad libitum access to feed until d 25 (Table 1). Control and ALT sows had similar BW and backfat losses during lactation. Average daily feed intake was similar between treatments, but ALT sows had 16% greater ($P < 0.01$) total feed intake during lactation due to a longer lactation length. Despite different weaning times between and within treatments, pig BW remained similar at d 18, 21, or 25, and no differences were detected in piglet mortality during the 7-d experimental period.

Primiparous sows had lighter ($P < 0.001$) BW than multiparous sows before farrowing and remained lower throughout lactation (Table 2). Primiparous sows also lost a greater ($P < 0.01$) percentage of BW during lactation and tended ($P < 0.06$) to lose more BW than multiparous sows. Both ADFI and total feed intake decreased ($P < 0.001$) for primiparous sows compared with multiparous sows, but no backfat differences were detected during lactation. Moreover, pigs nursing primiparous sows were similar in BW to pigs from multiparous sows at d 18, 21, and 25, and their postweaning performance is reported in a separate paper (see "Effects of an Altered Suckling Method on Piglet Performance during Late Lactation and the Nursery Period," pp. 27).

The wean-to-estrus interval was shorter (3.6 vs. 5.0; $P < 0.001$) for controls than the time from initiation of ALT to estrus, but when expressed as the day in estrus postfarrowing, ALT sows were detected in estrus more quickly (23.0 vs. 24.6 d: $P < 0.001$) than controls (Table 3). Of the 28 ALT sows, 26 were detected in estrus and mated during lactation, including all 20 multiparous sows and 6 of 8 primiparous sows (Table 4). The remaining 2 primiparous ALT sows were detected in estrus and mated at 9 and 12 d after the initiation of the ALT treatment (2 and 5 d after weaning). For controls, 15 of 16 multiparous and all 9 primiparous sows were detected in estrus and mated postweaning. The remaining multiparous control sow had more than 4 follicles with diameter greater than 15 mm without ovulating for 3 d and appears to have had cystic ovarian follicles. For both treatments, primiparous sows were in estrus later (5.4 vs. 3.8 d; $P < 0.01$) than multiparous sows. Figure 1 shows the estrus response comparison between treatments, whereas Figure 2 illustrates the cumulative percentage of sows in estrus by treatment over time. Analysis of P4 in sows at 8 to 12 and 18 to 21 d postestrus explained that a total of 2 sows failed to establish pregnancy after ovulation. No treatment differences were detected for pregnancy rate.

Ultrasound observations of follicular development matched observed estrus differences between treatments and parity groups (Table 5). The ALT sows reached maximum follicle diameter and ovulated more quickly than control sows after initiation of ALT or

weaning. The growth of follicles between control and ALT sows is shown in Figure 3, and the delayed follicular development of primiparous versus multiparous sows is illustrated in Figure 4.

For subsequent farrowing traits, a total of 20 control and 20 ALT sows were retained and farrowing data were collected (Table 6). Reproductive performance was similar for control and ALT sows. There was a tendency for a treatment × parity interaction ($P < 0.07$) for the percentage of mummified fetuses, but the limited number of sows and variation in this trait make interpretation unclear. Pigs farrowed by formerly primiparous sows also tended ($P < 0.08$) to be lighter than pigs from multiparous sows.

Our results provide evidence that the ALT treatment can induce estrus in lactating sows at rates comparable to conventionally weaned sows with no detrimental effects on farrowing rate or litter size. The lactational estrus we observed is greater than many reports in the literature, and this may be due to the sow line and unique aspects of the ALT treatment. In addition to reduced hours of nursing each day, the ALT sows were nursed by a combined litter of foreign and own pigs that were lightweight compared with the litter nursing before treatment. These foreign pigs may be perceived in a way that contributes to the occurrence of estrus, but further work will be required to evaluate individual components of the treatment. Another objective of this work was to benefit the lightweight pigs, and that is the subject of another report in this publication (see "Effects of an Altered Suckling Method on Piglet Performance during Late Lactation and the Nursery Period," p. 27).

The ALT sows were detected in estrus more quickly after farrowing than the controls. Previous lactational estrus work with primiparous sows is limited, and the present data suggest that estrus in lactation also can be stimulated in these sows; moreover, the altered suckling method did not affect litter performance prior to weaning.

Additional research may help develop practical protocols that allow breeding during lactation, but additional work is necessary to confirm these results in larger populations of sows and to determine the most effective and practical presentation of stimuli. Treatment similar to this study may benefit lightweight pigs in large litters, and breeding during lactation could help enhance group sow housing management. Because individual farrowing stalls are more accepted for the welfare advantages to the nursing pigs, this last benefit is worth exploring; groups in Australia and Europe are also researching treatments to induce lactational estrus for this reason.

Table 1. The effects of boar exposure and an altered suckling method (ALT) on the growth of lactating sows and their litters[1]

Item	Control	ALT	SEM
Sows, n	25	28	
Parity	2.44	2.68	
Litter size at d 18	11.60	11.54	0.44
Sow BW, lb			
Entry	548.4	560.5	22.92
Farrowing	525.3	530.7	24.59
d 18	503.6	513.9	15.39
d 21	499.0	507.3	18.35
d 25	453.1[a]	502.4[b]	16.86
Lactation BW loss, lb[2]	26.2	28.3	6.77
Lactation BW loss, %	5.19%	5.89%	1.106
Backfat, mm			
Entry	14.1	14.4	0.85
d 18	13.1	13.1	0.57
d 21	13.2	12.6	0.62
d 25	11.6[a]	13.5[b]	0.55
Backfat loss, mm[2]	0.82	0.84	1.179
Sow ADFI, lb[3]	12.12	11.85	0.490
Sow intake, lb	254.6	304.0	13.60
Pig BW[4]			
d 18	12.43	12.46	0.340
d 21	14.21	13.59	0.363
d 25	15.57	15.67	0.358

[a, b] Means without a common superscript differ $P < 0.05$.

[1] Data were collected from a total of 53 sows (PIC 1050) across two replicate farrowing groups. Sows were allotted to treatments on d 18 (average 18.8 d) of lactation. Control sows were weaned on d 21, whereas the altered suckling method (ALT) consisted of split-weaning (SW) all but the 5 lightest-weight pigs on d 18. The ALT sows were then paired, and the lightweight pigs from 2 litters were combined and rotationally suckled between the pair of sows at 12-h intervals until weaning on d 25.

[2] Lactation weight and backfat loss were measured from d 0 to 21 for control sows and 0 to 25 for ALT sows.

[3] Incorporates feed intake from actual farrowing date for each sow.

[4] Litter size was similar ($P > 0.78$) at d 18, and no differences in pig mortality were detected ($P > 0.94$) between treatments.

Table 2. The interactive effects of an altered suckling method (ALT) and parity group on the growth of lactating sows and their litters[1]

	Control		ALT			Probability, $P <$[2]	
Item Parity:[3]	Mult	Prim	Mult	Prim	SEM	Trt	Parity
Sows, n	16	9	20	8			
Parity	3.3	1.0	3.4	1.0			
Sow BW, lb							
Entry	580.8	491.0	591.6	482.6	23.42	0.82	<0.001
Farrowing	559.4	464.6	561.4	454.1	24.98	0.86	<0.001
Lactation d 18	537.9	442.4	546.4	432.6	15.89	0.88	<0.001
Lactation d 21	534.8	435.6	542.7	418.9	18.80	0.97	<0.001
Lactation d 25	483.8	398.6	536.4	405.4	17.84	0.01	<0.001
Lactation BW loss, lb[4]	24.7	29.0	25.0	48.7	6.77	0.85	0.06
Lactation BW loss, %	4.26%	6.13%	3.08%	8.69%	1.110	0.98	<0.01
Backfat, mm							
Entry	13.3	15.4	14.2	14.8	0.86	0.62	0.13
d 18	12.7	13.8	13.3	12.6	0.60	0.99	0.80
d 21	12.6	14.4	12.6	12.8	0.65	0.53	0.27
d 25	11.3	12.3	13.8	12.6	0.58	0.02	0.97
Backfat loss, mm[4]	0.72	1.00	0.35	2.17	1.201	0.11	0.56
Sow ADFI, lb[5]	12.87	10.79	12.7	9.5	0.50	0.32	<0.001
Sow total intake, lb	270.4	226.5	324.1	246.4	13.78	0.00	<0.001
Pig BW[6]							
d 18	12.59	12.14	12.64	12.01	0.360	0.98	0.29
d 21	14.37	13.91	13.79	13.10	0.385	0.20	0.29
d 25	15.80	15.15	15.84	15.20	0.377	0.94	0.16

[1] Data were collected from a total of 53 sows (PIC 1050) across two replicate farrowing groups. Sows were allotted to treatments on d 18 (average 18.8 d) of lactation. Control sows were weaned on d 21, whereas the altered suckling method (ALT) consisted of split-weaning all but the 5 lightest-weight pigs on d 18. The ALT sows were then paired, and the lightweight pigs from 2 litters were combined and rotationally suckled between the pair of sows at 12-h intervals until weaning on d 25.

[2] No interactions were detected ($P > 0.11$) between treatment and parity group.

[3] Multiparous (Mult) or primiparous (Prim).

[4] Lactation weight and backfat loss were measured from d 0 to 21 for control sows and 0 to 25 for ALT sows.

[5] Incorporates feed intake from actual farrowing date for each sow.

[6] Litter size was similar ($P > 0.26$) across treatment and parity at d 18, and no differences in pig mortality were detected ($P > 0.24$).

Table 3. The effects of boar exposure and an altered suckling regimen (ALT) on the reproductive performance of lactating sows[1]

Item	Control	ALT	SEM
Weaning or beginning of ALT to estrus, d	3.6[a]	5.0[b]	0.54
Day in estrus after farrowing	24.6[b]	23.0[a]	0.54
Inseminated in lactation, %	---	89.3%	---
Inseminated after weaning, %	96.0%	10.7%	---
Pregnancy rate, %[2]	92.0%	89.0%	---

[a, b] Means without a common superscript differ $P < 0.05$.

[1] Data were collected from 53 sows (PIC 1050) used across two replicate farrowing groups. Sows were allotted to treatments on d 18 (average 18.8 d) of lactation. Control sows were weaned on d 21, whereas the altered suckling method (ALT) consisted of split-weaning all but the 5 lightest-weight pigs on d 18. The ALT sows were then paired, and the lightweight pigs from 2 litters were combined and rotationally suckled between the pair of sows at 12-h intervals until weaning on d 25.

[2] Chi-square analysis was conducted using PROC LOGISTIC in SAS (SAS Institute, Inc., Cary, NC) to compare treatment means. Transabdominal ultrasound (Aloka 500V, 5.0 MHz) was used for pregnancy detection at approximately 28 d after mating.

Table 4. The interactive effects of an altered suckling method (ALT) and parity group on the reproductive performance of lactating sows[1]

	Control		ALT			Probability, $P <$[2]	
Item Parity:[3]	Mult	Prim	Mult	Prim	SEM	Trt	Parity
Sows, n	16	9	20	8			
Parity	3.25	1.00	3.35	1.00	0.468	0.82	<0.001
Litter size at d 18	11.8	11.3	11.6	11.3	0.44	0.78	0.26
Weaning or beginning of ALT to estrus, d	3.1	4.4	4.5	6.4	0.54	<0.001	<0.001
Day in estrus after farrowing	24.1	25.4	22.5	24.4	0.54	<0.001	<0.01
Mated in lactation, %	---	---	100.0%	75.0%	---	---	---
Mated after weaning, %	93.8%	100.0%	0.0%	25.0%	---	---	---
Pregnancy rate, %[4]	93.8%	88.9%	90.0%	86.0%	---	0.71	0.69
Progesterone, ng/mL[5]							
8 to12 d postestrus, % >4 ng/ml	93.8% (15/16)	100.0% (9/9)	100.0% (20/20)	100.0% (8/8)			
18 to 21 d postestrus, % >4 ng/ml	100.0% (16/16)	88.9% (8/9)	95.0% (19/20)	100.0% (8/8)			

[1] Data were collected from a total of 53 sows (PIC 1050) across two replicate farrowing groups. Sows were allotted to treatments on d 18 (average 18.8 d) of lactation. Control sows were weaned on d 21, whereas the altered suckling method (ALT) consisted of split-weaning all but the 5 lightest-weight pigs on d 18. The ALT sows were then paired, and the lightweight pigs from 2 litters were combined and rotationally suckled between the pair of sows at 12 h intervals until weaning on d 25.

[2] No interactions were detected ($P > 0.54$) between treatment and parity group.

[3] Multiparous (Mult) or primiparous (Prim).

[4] Chi-square analysis was conducted using PROC LOGISTIC in SAS (SAS Institute, Inc., Cary, NC) to compare treatment means. Transabdominal ultrasound (Aloka 500V, 5.0 MHz) was used for pregnancy detection at approximately 28 d after mating.

[5] Samples were collected at 8 to 12 and 18 to 21 d postestrus to confirm ovulation and establishment of pregnancy, respectively. 4 ng/mL was used as a qualitative threshold to signify the presence of a functional corpus luteum.

Table 5. Follicle development and ovulation response of sows with ovulation within 7 d after initiation of boar exposure and an altered suckling method (ALT) or weaning[1]

		Control			ALT		
Item	Parity:[2]	Mult	Prim	Total	Mult	Prim	Total
Follicle development[3]							
Initial follicle diameter, mm		4.0	5.0	4.3	3.9	3.6	3.8
Maximum follicle diameter, mm		8.3	8.4	8.3	8.4	7.9	8.3
Follicle diameter at ovulation, mm		8.0	8.0	8.0	8.2	7.5	8.0
Day of max. follicle diameter after ALT or weaning		2.9	4.7	3.6	5.0	6.6	5.4
Day of max. follicle diameter after farrowing		23.9	25.7	24.6	23.0	24.6	23.4
Time to ovulation after ALT or weaning, h[4]		92.0	137.3	109.0	135.6	183.4	148.0

[1] Data shown from the 24 control and 24 ALT sows that ovulated within 7 d after weaning or initiation of ALT treatment.
[2] Multiparous (Mult) or primiparous (Prim).
[3] Daily transrectal ultrasound (500V, 5.0 MHz; Aloka, Wallingford, CT) measurements were collected from d 17 until 7 d postweaning. Follicle diameter reported as the average of the three largest follicles on each ovary.
[4] Time of ovulation was defined as 12 h prior to the ultrasound exam when fewer than 4 follicles remained between both ovaries.

Table 6. The effects of boar exposure and an altered suckling method (ALT) on subsequent reproductive performance of sows[1]

		Control		ALT			Probability, *P* <		
Item	Parity:[2]	Mult	Prim	Mult	Prim	SEM	Trt × parity	Trt	Parity
Sows retained, n[3]		13	7	14	6				
Total born		13.6	12.1	13.4	12.2	1.58	0.90	0.66	0.32
Number born live		12.8	11.4	12.1	11.7	1.54	0.83	0.63	0.42
Stillbirths, %		6.1%	5.3%	7.8%	3.3%	3.93	0.58	0.87	0.44
Mummies, %		2.1%	4.0%	4.3%	0.0%	1.95	0.07	0.97	0.50
Piglet BW, lb		3.03	3.47	3.25	3.48	0.232	0.59	0.40	0.08
Litter weight, lb		38.70	39.67	39.23	40.64	4.091	0.65	0.74	0.85

[1] Data were collected from a total of 53 sows (PIC 1050) across two replicate farrowing groups. Sows were allotted to treatments on d 18 (average 18.8 d) of lactation. Control sows were weaned on d 21, whereas the altered suckling method (ALT) consisted of split-weaning all but the 5 lightest-weight pigs on d 18. The ALT sows were then paired, and the lightweight pigs from 2 litters were combined and rotationally suckled between the pair of sows at 12-h intervals until weaning on d 25.
[2] Multiparous (Mult) or primiparous (Prim).
[3] Following pregnancy confirmation by transabdominal ultrasound at 25 to 35 d post-artificial insemination, sows were culled or retained according to the operation's normal culling procedures.

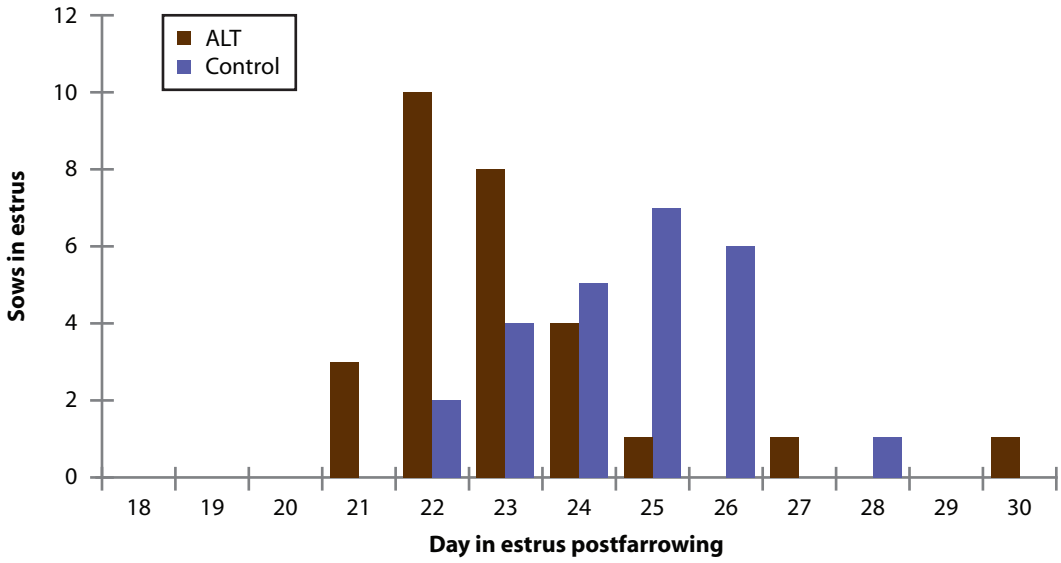

Figure 1. The day of first detected estrus for control sows and sows given boar exposure and an altered suckling method (ALT).

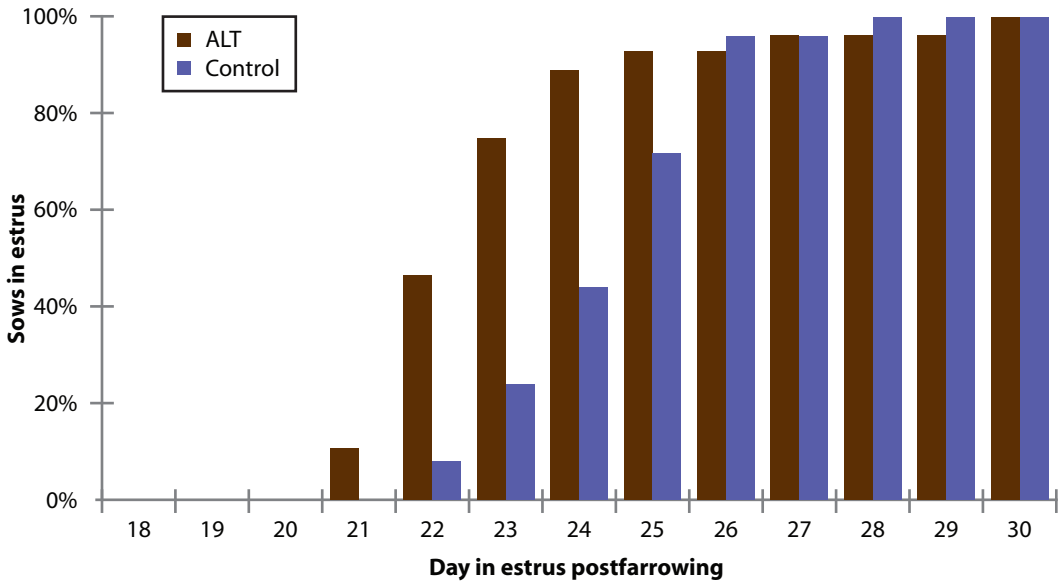

Figure 2. The cumulative percentage of sows in estrus postfarrowing between control sows and sows given boar exposure and an altered suckling method (ALT).

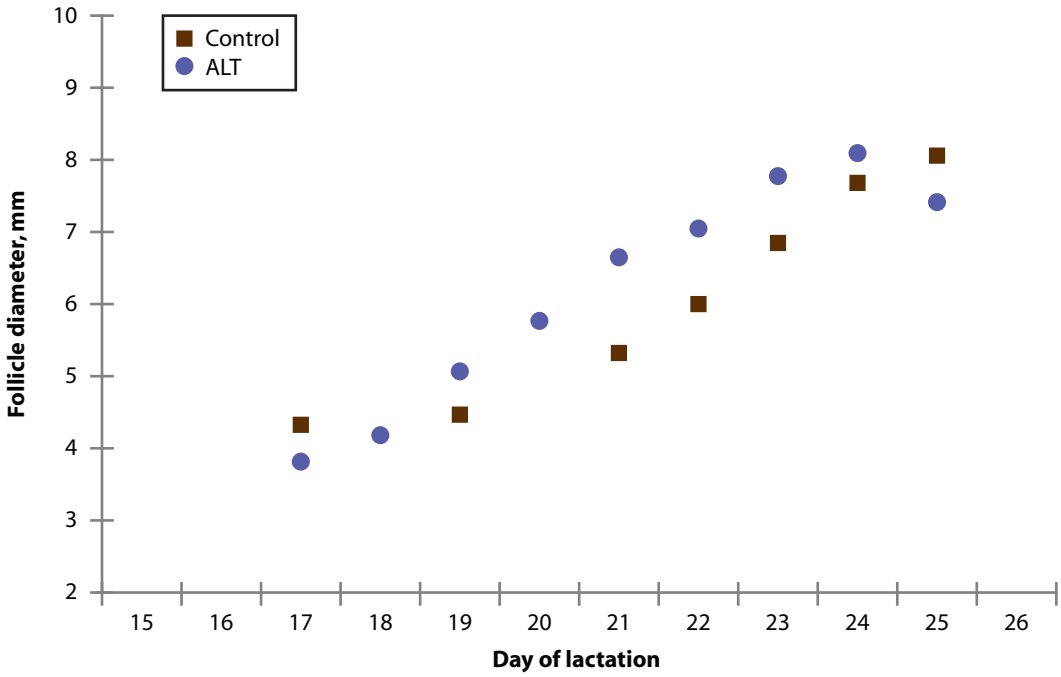

Figure 3. Change in mean follicle diameter of the largest follicles after treatment (d 18 of lactation) for control sows and sows given boar exposure and an altered suckling method (ALT). Control sows were not ultrasounded on d 18 or 20.

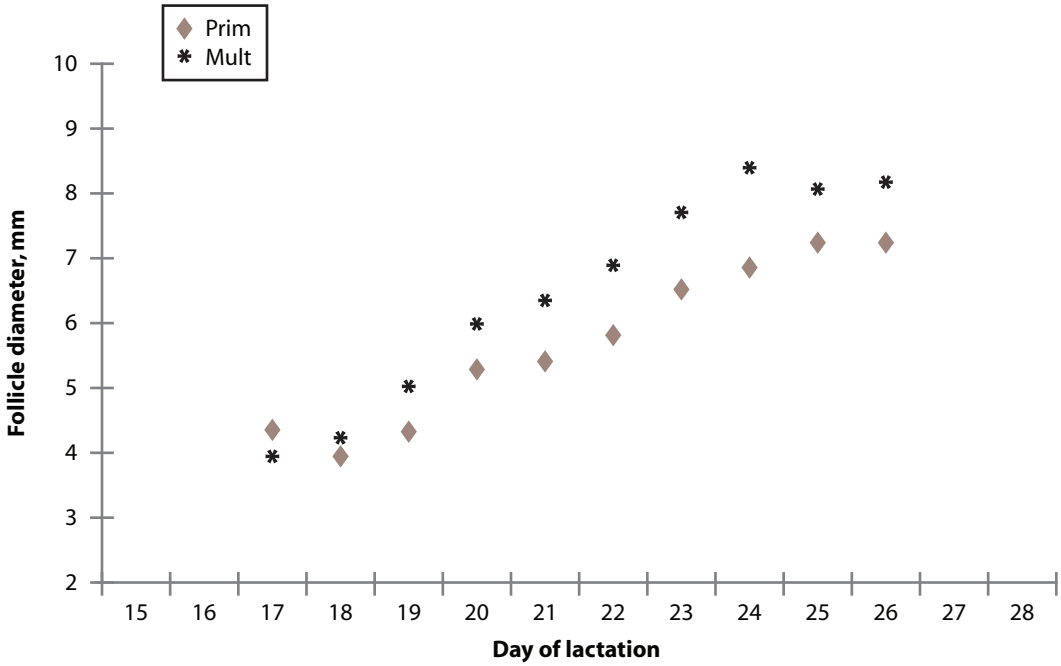

Figure 4. Change in mean follicle diameter of the largest follicles after treatment (d 18 of lactation) for multiparous (Mult) and primiparous (Prim) sows.

Effects of an Altered Suckling Method on Piglet Performance during Late Lactation and the Nursery Period

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Summary

The effects of an altered suckling method (ALT) on nursery pig performance were studied in a 14-d experiment encompassing late lactation and the early nursery period. A total of 611 pigs (PIC 327 × 1050) nursing 54 sows were used in 2 farrowing groups. Sows were allotted to treatments on d 18 of lactation when all but the 5 lightest-weight pigs from each ALT litter were split-weaned (SW) and moved to the nursery. The lightweight pigs in the ALT litters were paired within parity group such that two litters were combined. These combined litters rotationally suckled (RS) each sow of the pair for 12 h/d from d 18 until weaning on d 25. Pigs in control litters were weaned on d 21. At weaning, pigs were randomly assigned to pens (7 pigs/pen). All weaned pigs received a common feed budget of 4 lb of Phase 1 followed by a Phase 2 diet. Pigs were weighed on d 18, 21, 25, 28, and 32 of age. Differences in weight gain, variation in growth within litter, and the association between piglet weight category on d 18 and treatment effects were evaluated. An interaction was detected ($P < 0.01$) for pig weights and weight gain from d 18 to 32 because the RS pigs gained 15% more than lightweight controls, whereas SW pigs were 15% lighter than heavyweight controls on d 32. Overall variation as measured by the changes in CV and SD was 50% less ($P < 0.01$) within ALT litters compared with controls. When pig weight groups were compared, the ALT treatment benefited ($P < 0.001$) growth of light (<10 lb) pigs but decreased ($P < 0.01$) the weight gain of heavy (>14 lb) pigs. Overall, performance was similar between ALT and control pigs, but the apparent improvement in weight variation observed within ALT litters warrants additional investigation.

Key words: intermittent suckling, litter variation, nursery pig, split weaning

Introduction

Mounting U.S. consumer pressure to transition away from individual stall housing in gestation necessitates consideration of alternative management strategies during lactation and gestation. Recent research has demonstrated that current sow lines may be more responsive to stimulation of estrus during lactation than reports from 20 years ago. In a concurrent study, we evaluated a lactational estrus stimulation strategy in which the duration of daily nursing was reduced beginning on d 18 of lactation by weaning the heaviest pigs early and creating combined litters that nursed each sow only 12 h/d. Because reducing the suckling stimulus seems to be a critical component in motivating lactational estrus expression, characterizing the effects of this practice on piglet performance is important.

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Here we report the effects of combining SW and RS on piglet performance during an extended lactation and the early nursery period. This treatment provides additional nursing time for lightweight pigs but requires larger littermates to be weaned earlier. The effects of this altered weaning strategy on both weight groups are reported.

Procedures

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

A total of 611 pigs (PIC 327 × 1050) originating from 54 sows in 2 farrowing groups were used. Parity ranged from 1 to 5 and averaged 2.6 ± 1.5. Prior to farrowing, pregnant sows were moved into a single farrowing room (29 individual farrowing crates; 7.0 × 2.0 ft for the sow and 7.0 × 5.2 ft for pigs). Litter size at birth varied from 3 to 18 live pigs and was approximately equalized within 2 d after farrowing by cross-fostering pigs within each parity group (primiparous or multiparous), resulting in an average litter size of 11.6 ± 1.2 pigs. Within 1 d after farrowing, piglet BW was determined, pigs were individually ear-notched, and pigs received an injection of 2 mL iron dextran and 1 mL of antibiotic (Naxcel; Zoetis Animal Health, Florham Park, NJ). Male pigs were castrated approximately 7 d after birth. Within each farrowing group, the day on which most of the litters were born was considered d 0 of lactation for the group, and all treatment procedures were performed on the same calendar day for all litters in the farrowing group. Litters were born from 4 d before to 3 d after d 0. Sows were fed a common lactation feed based on corn, soybean meal and 20% DDGS (1,472 kcal/lb, 21.6% CP, and 0.97% lysine), which was provided ad libitum after d 1 postfarrowing. Creep feed was not offered during lactation.

Control and altered suckling treatments (ALT) were implemented. Sows were allotted to treatments on d 18 of lactation by parity, BW, suckled litter size, and date farrowed. ALT sows were placed in adjacent pairs so litters could be combined and switched between sows by temporarily lifting the separating divider. On d 18, all but the 5 lightest-weight pigs from each ALT litter were split weaned (SW) and moved to the nursery. The remaining 5 lightweight pigs on paired ALT litters were then combined to form a new litter of 10 pigs. These combined litters were rotationally suckled (RS) between each of the paired sows at 12-h intervals (0600 and 1800), such that pigs had access to a sow 24 h/d, but each ALT sow was suckled for only 12 h/d. The farrowing room lights were left on for 24 h/d throughout lactation. This strategy was implemented from d 18 of lactation until ALT sows were weaned on d 25. Control sows were managed according to the farm's normal protocol, with weaning taking place on the afternoon of d 21.

At weaning on d 18 (SW), the afternoon of d 21 (control), or d 25 (RS), pigs were assigned to pens by BW with 7 pigs per pen. All weaned pigs were fed according to the same feed budget consisting of 4 lb/pig of a commercial Phase 1 diet followed by a Phase 2 diet until the end of the experiment. Each pen contained a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water. Pigs were weighed individually at birth, at d 18, and at 3.5-d intervals (d 21.5, 25, 28.5, and d 32) to assess weight gain between different weaning ages.

All experimental data were analyzed using the MIXED procedure of SAS, version 8.1 (SAS Institute, Inc., Cary, NC). To assess treatment differences, weight gain (Table 1), variation in growth within litter (Table 2), and the association between piglet weight group and treatment (Table 3) were evaluated. For weight gain, pigs originating from both control and ALT sows were compared by retrospectively breaking control pigs into heavy- or lightweight categories based on d-18 weight, thus matching the proportion of ALT pigs allotted to RS or SW treatments. Pig was the experimental unit, and both nursery pen and farrowing group were included in the model as random effects. For variation in growth within litter, SD, CV, and the changes in SD and CV throughout the 14-d experiment were compared between control and ALT litters using litter as the experimental unit. For evaluating the association between piglet weight group and treatment, pig was the experimental unit, and pigs were assigned to 1 of 4 weight classifications based on d-18 weights: <10 lb, 10 to 12 lb, 12 to 14 lb, or >14 lb. Total weight gain and the average weight of pigs within each weight group were then compared across treatments with unequal replications. Least squares means were calculated for each independent variable, and treatment means were separated using preplanned CONTRAST statements in SAS. Statistical significance and tendencies were set at $P < 0.05$ and $P < 0.10$, respectively.

Results

Pigs assigned to control or ALT suckling treatments were similar in weight at allotment on d 18; however, an interaction was detected ($P < 0.01$) for each subsequent time point and for weight gain from d 18 to 32 in which RS pigs gained more weight than lightweight control pigs but SW pigs were lighter compared with the initially heavyweight controls. Comparing the collective performance of ALT pigs versus controls showed that although control pigs were heavier than ALT pigs at d 21.5, weights were similar at each subsequent time point, and the total gain from d 18 to 32 did not differ between the two suckling treatments. Finally, RS pigs were lighter ($P < 0.001$) than their SW counterparts at each time point, and the lightweight pigs within the control group remained lighter ($P < 0.001$) than the heavyweight control pigs.

The variation in pig weights within each litter was expressed as CV and SD. Litters where the ALT suckling treatment was applied had decreased CV ($P < 0.03$) at d 21.5 and d 32 corresponding to a greater reduction ($P < 0.01$) of CV relative to control litters over the 14-d experiment. Standard deviation decreased ($P < 0.03$) in ALT litters at d 21.5 and d 32 and tended to be lower on d 28.5. These reductions in SD led to a greater ($P < 0.001$) change in SD from d 18 to 32.

For pigs under 10 lb on d 18, ALT pigs were heavier ($P < 0.01$) than controls on d 25 and 32 and experienced greater ($P < 0.001$) BW gain from d 18 to 32. Conversely, ALT pigs >14 lb were lighter ($P < 0.01$) at d 21.5, d 28.5, and d 32 and experienced less ($P < 0.01$) BW gain compared with controls. The 12- to 14-lb controls were heavier ($P < 0.02$) on d 21.5 than their ALT counterparts, but otherwise pigs within the 10- to 12-lb and 12- to 14-lb categories performed similarly regardless of the suckling treatment applied.

Discussion

The application of an ALT suckling treatment during late lactation illustrates how piglet performance can be altered by weaning age and manipulation of suckling competition. Although overall performance of ALT pigs did not differ from controls, SW pigs experienced a more marked postweaning growth check, resulting in 15% poorer total gain compared with heavyweight controls. This reduced growth rate may be explained in part by the earlier weaning age, but it also may be related to the fact that SW pigs were grouped together whereas heavyweight control pigs were housed alongside lightweight controls at weaning. Nonetheless, the additional growth RS pigs experienced prior to weaning on d 25 resulted in a heavier BW at d 32 and a 15% improvement in total weight gain relative to lightweight controls.

The lighter SW pigs and heavier RS pigs potentiated a 50% reduction in the change in CV and SD for ALT versus control litters. Additional research is needed to determine whether these decreases in variation are maintained through time.

Further evaluation of d-18 weight categories revealed that overall differences between treatments occurred primarily because of changes in the weight of pigs in the <10 and >14 lb categories. As seen in Figure 1, <10-lb ALT pigs experienced 15% more gain than controls, but for the >14 lb group, ALT pigs were 8% lighter. It is logical that the lightest pigs may benefit most from the additional time on the sow with reduced competition from their heavier littermates, but it is intriguing that of the heavier-weight groups, pigs greater than 14 lb experienced the biggest setback in performance by weaning at d 18 rather than d 21.5.

In conclusion, the altered suckling method used to stimulate lactational estrus in sows did not appear to improve overall pig performance during late lactation and the early nursery period. However, variation in pig weight was reduced by both increasing gain and reducing the postweaning growth check of lightweight pigs, which simultaneously negatively affecting growth of the heavyweight pigs in the altered suckling treatment. Additional research is needed to determine whether this reduction in variation is sustained to market and its economic implications. Additional lactational strategies are also worth evaluating for their effects on pig performance.

Table 1. The effects of an altered suckling treatment (ALT) on piglet weights during late lactation and the nursery period[1]

	Control[2]			ALT[2]				Probability $P <$		
Item	Heavy[3]	Light[3]	Total	SW	RS	Total	SEM	Treatment × weight	Treatment	Weight
Pigs, n	164	125	289	183	139	322				
Weaning age, d	21.5	21.5	21.5	18.0	25.0	---				
Pig BW, lb										
d 18	13.78	10.59	12.19	13.87	10.69	12.28	0.172	0.98	0.62	< 0.001
d 21.5	15.74	12.17	13.95	14.43	12.60	13.51	0.161	< 0.001	0.03	< 0.001
d 25	17.06	13.46	15.26	16.79	14.42	15.61	0.215	< 0.01	0.12	< 0.001
d 28.5	19.12	15.24	17.18	18.37	15.79	17.08	0.253	< 0.01	0.68	< 0.001
d 32	21.52	17.28	19.40	20.86	18.23	19.55	0.588	< 0.01	0.60	< 0.001
Gain d 18 to 32, lb	7.74	6.69	7.21	6.99	7.55	7.27	0.727	< 0.001	0.67	0.08

[1] A total of 611 pigs (PIC 327 × 1050) originating from 54 litters in 2 farrowing replicates were used in this 14-d study with 7 pigs per pen after weaning. Birth weights of pigs averaged 3.25 lb and were similar between control and ALT treatments.

[2] Sows were allotted to 1 of 2 treatments at d 18 of lactation based on parity, sow weight, suckled litter size, and average piglet weight. The altered suckling treatment (ALT) involved split-weaning (SW) all but the 5 lightest-weight pigs on d 18. The ALT sows were then paired, and the lightweight pigs from 2 litters were combined and rotationally suckled (RS) between the pair of sows at 12 h intervals until weaning on d 25.

[3] Pigs from control sows were weaned on d 21.5 (afternoon of d 21) and allotted to nursery pens by weight and gender. Even though litters remained intact until weaning, control pigs are represented by heavy and lightweight categories using d-18 weights so comparisons can be made to the ALT treatment.

Table 2. The effects of an altered suckling treatment (ALT) on piglet weight variation within litter during late lactation and the early nursery period[1,2]

Item	Control	ALT	SEM	*P* <
Litters	25	28		
Pigs per litter	11.56	11.50		
Litter SD				
d 18	2.19	2.12	0.178	0.74
d 21.5	2.51	1.87	0.173	<0.01
d 25	2.51	2.27	0.171	0.27
d 28.5	2.80	2.38	0.170	0.07
d 32	3.11	2.55	0.290	0.03
SD change, d 18 to 32	0.92	0.43	0.133	<0.001
Litter CV, %				
d 18	17.9	17.2	1.64	0.70
d 21.5	17.9	13.9	1.39	0.02
d 25	16.4	14.6	1.11	0.22
d 28.5	16.2	13.9	1.05	0.12
d 32	16.0	13.0	1.14	0.03
CV change, d 18 to 32	-1.90	-4.20	0.628	<0.01

[1] A total of 611 pigs (PIC 327 × 1050) originating from 54 litters in 2 farrowing replicates were used in this 14-d study with 7 pigs per pen.

[2] Sows were allotted to 1 of 2 treatments at d 18 of lactation based on parity, sow weight, suckled litter size, and average piglet weight. The altered suckling treatment (ALT) involved split-weaning (SW) all but the 5 lightest-weight pigs on d 18. The ALT sows were then paired and the lightweight pigs from 2 litters were combined and rotationally suckled (RS) between the pair of sows at 12-h intervals until weaning on d 25.

Table 3. The association between piglet weight group and an altered suckling treatment (ALT) on piglet growth performance during late lactation and the early nursery period[1,2]

	Control				ALT					Probability $P <$			
Item	<10 lb	10–12 lb	12–14 lb	>14 lb	<10 lb	10–12 lb	12–14 lb	>14 lb	SEM	<10 lb	10–12 lb	12–14 lb	>14 lb
Pigs, d 18	58	65	68	98	52	77	91	102					
% of total	20%	22%	24%	34%	16%	24%	28%	32%					
Pig BW, lb													
d 18	8.36	10.95	12.84	15.46	8.30	11.05	12.95	15.32	0.194	0.75	0.56	0.51	0.33
d 21.5	9.66	12.62	14.74	17.55	9.97	12.31	14.24	15.98	0.250	0.21	0.17	0.02	<0.001
d 25	10.76	14.12	16.14	18.80	11.60	14.18	16.50	18.43	0.300	0.01	0.82	0.15	0.10
d 28.5	12.32	15.90	18.11	21.05	12.84	15.62	17.89	20.18	0.320	0.11	0.32	0.42	<0.01
d 32	14.10	17.90	20.50	23.64	15.06	18.04	20.32	22.84	0.375	0.01	0.67	0.56	<0.01
Gain d 18 to 32, lb	5.72	6.91	7.63	8.16	6.71	6.97	7.40	7.57	0.302	<0.001	0.81	0.37	<0.01

[1] A total of 611 pigs (PIC 327 × 1050) originating from 54 litters in 2 farrowing replicates were used in this 14-d study with 7 pigs per pen.

[2] Sows were allotted to 1 of 2 treatments at d 18 of lactation based on parity, sow weight, suckled litter size, and average piglet weight. The altered suckling treatment (ALT) involved split-weaning (SW) all but the 5 lightest-weight pigs on d 18. The ALT sows were then paired, and the lightweight pigs from 2 litters were combined and rotationally suckled (RS) between the pair of sows at 12-h intervals until weaning on d 25.

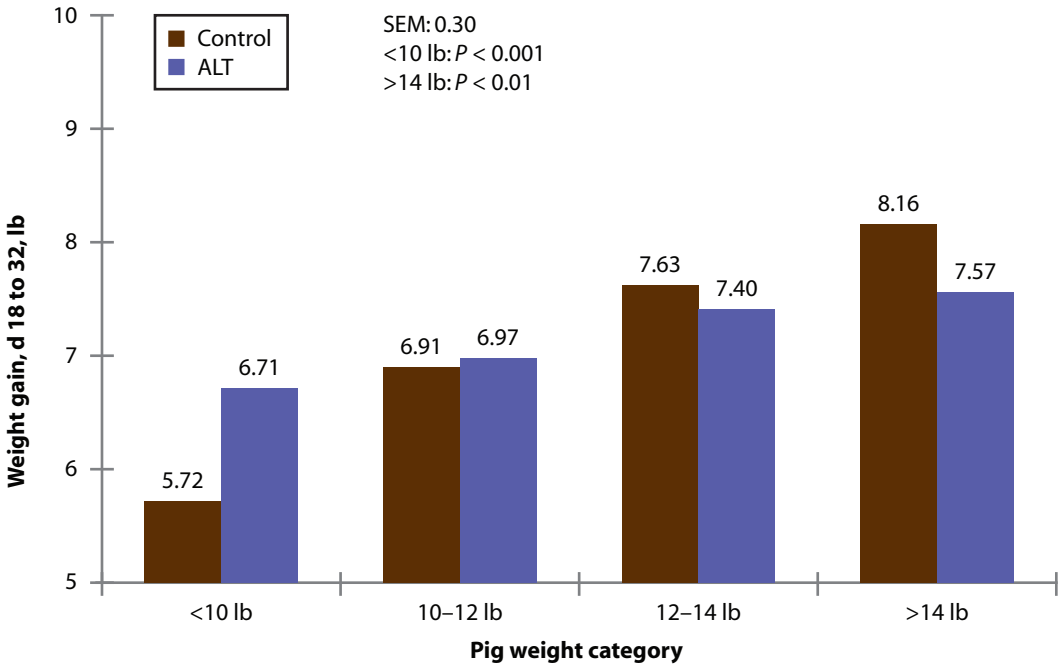

Figure 1. Weight gain from d 18 to 32 for pigs of different weight categories between control and altered suckling treatments (ALT).

Evaluation of Diet Complexity and Benzoic Acid on Growth Performance of Nursery Pigs[1]

J.E. Nemechek, M.D. Tokach, S.S. Dritz[2], R.D. Goodband, J.M. DeRouchey, and J.R. Bergstrom[3]

Summary

A total of 280 weanling pigs (PIC 327 × 1050, initially 15.4 lb, 3 d postweaning) were used in a 28-d trial to evaluate the effects of benzoic acid and diet complexity on growth performance. Treatments were arranged as a 2 × 2 factorial with 2 diet complexities and 2 benzoic acid levels (0 vs. 0.5%) fed for the first 14 d. Diet complexity treatments were either a simple diet that did not contain any lactose, zinc oxide, or specialty protein sources or a complex diet that contained 10% dried whey, 1.25% select menhaden fish meal, 1.25% spray-dried blood cells, and 0.25% zinc oxide. From d 14 to 28, pigs were fed a common diet with and without 0.5% benzoic acid, with pigs continuing to receive benzoic acid if they received it from d 0 to 14.

No growth performance interactions ($P > 0.33$) were detected between diet complexity and benzoic acid. From d 0 to 14, when different diet complexities were fed, pigs fed simple diets had decreased ($P < 0.001$) ADG and ADFI and poorer ($P < 0.001$) F/G compared with pigs fed complex diets. From d 14 to 28, pigs previously fed simple diets showed compensatory growth and tended to have increased ($P < 0.06$) ADG and improved ($P < 0.003$) F/G compared with pigs previously fed the complex diets. Overall (d 0 to 28), pigs fed simple diets during Phase 1 had decreased ($P < 0.001$) ADG and ADFI from d 0 to 28 compared with pigs fed complex diets. For the main effect of benzoic acid, no differences ($P > 0.10$) were observed in ADG, ADFI, or F/G. In conclusion, as expected, early nursery pig growth performance was reduced when pigs were fed simple diets. Benzoic acid had no impact on pig growth performance regardless of diet complexity.

Key words: benzoic acid, diet complexity, nursery pig

Introduction

Benzoic acid is an acidifier that is most commonly utilized in nursery pig diets. Vevovitall is a source of benzoic acid that may become available to the North American swine industry; however, it has been used by European swine nutritionists for a number of years. Data from European trials indicate that adding Vevovitall to the nursery pig diet may improve growth performance, but little research has been conducted with the product in typical U.S. diet formulations, which are corn and soybean meal–based and often contain pharmacological levels of zinc oxide. The possible introduction of Vevovitall to the North American market justifies the need for research to demonstrate its efficacy using typical U.S. diet formulation techniques and to determine whether the

[1] Appreciation is expressed to DSM Nutritional Products (Parsippany, NJ), for providing the benzoic acid (Vevovitall) utilized in this study and for partial financial support.
[2] Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University.
[3] DSM Nutritional Products (Parsippany, NJ).

response is influenced by diet complexity. Thus, the objective of this experiment was to determine the effects of diet complexity and Vevovitall (as a source of benzoic acid) on growth performance of nursery 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 Kansas State University Swine Teaching and Research Center in Manhattan, KS.

A total of 280 weanling pigs (PIC 327 × 1050, initially 15.4 lb, 3 d postweaning) were used in a 28-d trial. Pigs were weaned at approximately 21 d of age and allotted to pens by initial BW to achieve the same average pen weight for all pens. Pigs were fed a common pelleted transition diet for 3 d after weaning before the beginning of the study. On d 3 postweaning, pens were allotted to 1 of 4 dietary treatments, arranged as a 2 × 2 factorial with 7 pigs per pen and 7 pens per treatment. Each pen contained a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water. Pigs and feeders were weighed on d 0, 7, 14, 21, and 28 to calculate ADG, ADFI, and F/G.

Diets were formulated and fed in 2 phases with decreasing nutrient concentrations in the second phase (Table 1). The first phase was fed from d 0 to 14, and the experimental treatments were organized in a 2 × 2 factorial with main effects of diet complexity (simple vs. complex) and benzoic acid (Vevovitall; DSM Nutritional Products, Parsippany, NJ; 0 vs. 0.5%). All diets were corn-soybean meal–based, with the simple diets containing no lactose, zinc oxide, or specialty protein sources. The complex diets contained 10% dried whey, 1.25% select menhaden fish meal, 1.25% spray-dried blood cells, and 0.25% zinc oxide. Phase 2 was fed from d 14 to 28, and the 2 treatment diets were corn-soybean meal–based with no specialty protein sources, either with or without 0.5% benzoic acid. All pigs fed benzoic acid from d 0 to 14 were also fed benzoic acid from d 14 to 28, regardless of diet complexity during Phase 1. Similarly, pigs fed diets without benzoic acid during Phase 1 were fed diets without benzoic acid during Phase 2. All experimental diets were in meal form and were prepared at the K-State Animal Science Feed Mill.

Experimental data were analyzed as a completely randomized design using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Treatments were arranged as a 2 × 2 factorial with 2 diet complexities and 2 benzoic acid levels. Differences between treatments were determined using the PDIFF option of SAS. Significant differences were declared at $P < 0.05$ and trends at $P < 0.10$.

Results and Discussion

No interactions ($P > 0.33$) were detected between diet complexity and benzoic acid on growth performance (Table 2).

From d 0 to 14, when different diet complexities were fed, pigs fed simple diets had decreased ($P < 0.001$) ADG and ADFI, and poorer ($P < 0.001$) F/G compared with pigs fed complex diets (Table 3). This response was expected because the simple diet did not contain any lactose, animal protein, or zinc oxide. From d 0 to 14, benzoic acid did not affect ($P > 0.26$) ADG, ADFI, or F/G.

From d 14 to 28, pigs previously fed simple diets tended to have increased ($P < 0.06$) ADG and improved ($P < 0.003$) F/G compared with pigs previously fed the complex diets. These differences appear to be a compensatory growth response from the pigs previously fed simple diets. When benzoic acid was added to the diet, there were no differences ($P > 0.13$) in ADG or F/G. Pigs fed diets containing benzoic acid in Phase 2 had a tendency for increased ($P < 0.10$) ADFI.

Decreased growth during the first phase in pigs fed simple diets carried over into the overall data, causing decreased ($P < 0.001$) ADG and ADFI from d 0 to 28 compared with pigs fed complex diets. Because of the differences in overall ADG, feeding complex diets from d 0 to 14 resulted in a 2-lb heavier ($P < 0.001$) nursery pig at the end of the trial. Overall, F/G did not differ ($P > 0.31$) between pigs fed different diet complexities because of the compensatory F/G exhibited by pigs from d 14 to 28 after they were fed the simple diet from d 0 to 14. From d 0 to 28, there were no differences ($P > 0.28$) in ADG, ADFI, or F/G when benzoic acid was added to the diet.

In conclusion, the current experiment confirmed that feeding simple, corn-soybean meal–based diets did not allow for optimal growth of early nursery pigs. Although compensatory growth did occur during Phase 2, it was inadequate to compensate for the poorer ADG and ADFI exhibited in Phase 1. Contrary to previous European data, our study suggests that there were no improvements in growth or efficiency when benzoic acid was included in the diet, regardless of diet complexity.

Table 1. Diet composition (as-fed basis)

	Phase 1[1]		
Item	Complex	Simple	Phase 2[2]
Ingredient, %			
Corn	59.93	63.17	64.50
Soybean meal (46.5% CP)	26.39	32.27	32.15
Select menhaden fish meal	1.25	---	---
Spray-dried blood cells	1.25	---	---
Spray-dried whey	10.0	---	---
Monocalcium phosphate (21% P)	0.85	1.30	1.05
Limestone	0.80	0.90	1.00
Salt	0.30	0.30	0.35
Zinc oxide	0.25	---	---
Trace mineral premix	0.15	0.15	0.15
Vitamin premix	0.25	0.25	0.25
L-lysine HCl	0.295	0.375	0.325
DL-methionine	0.140	0.125	0.100
L-threonine	0.125	0.140	0.110
Phytase[3]	0.019	0.019	0.019
Diatomacious earth[4]	1.00	1.00	---
Benzoic acid	---	---	---
Total	100.00	100.00	100.00

continued

Table 1. Diet composition (as-fed basis)

	Phase 1[1]		
Item	Complex	Simple	Phase 2[2]
Calculated analysis			
Standardized ileal digestible amino acids (SID), %			
Lysine	1.30	1.30	1.26
Isoleucine:lysine	56	60	62
Leucine:lysine	129	125	130
Methionine:lysine	33	32	31
Met & Cys:lysine	56	56	56
Threonine:lysine	62	62	62
Tryptophan:lysine	17.0	17.0	18
Valine:lysine	69	66	68
Total lysine, %	1.43	1.43	1.39
ME, kcal/lb	1,480	1,488	1,504
SID lysine:ME, g/Mcal	3.99	3.96	3.80
CP, %	20.7	20.9	20.9
Ca, %	0.71	0.71	0.70
P, %	0.63	0.67	0.62
Available P, %	0.47	0.46	0.41

[1] Pigs were fed complex or simple diets from d 0 to 14. Within each diet complexity, pigs were fed diets either without or with 0.5% benzoic acid. Vevovitall was used as a source of benzoic acid (DSM Nutritional Products, Parsippany, NJ).
[2] From d 14 to 28, 2 treatment diets were fed, without or with 0.5% benzoic acid.
[3] Ronozyme P CT (10,000) (International Nutrition, Omaha, NE), providing 840 phytase units (FTU)/lb and an estimated release of 0.10% available P.
[4] Indigestible marker (Perma-Guard, Inc., Corrales, NM).

Table 2. Effect of diet complexity and benzoic acid on growth performance of nursery pigs[1]

Complexity:[2]	Complex	Simple	Complex	Simple		Probability, $P <$		
Benzoic acid:[3]	0	0	0.5%	0.5%	SEM	Complexity × benzoic acid	Complexity	Benzoic acid
d 0 to 14								
ADG, lb	0.60	0.41	0.62	0.42	0.023	0.78	0.001	0.55
ADFI, lb	0.84	0.67	0.84	0.66	0.028	0.82	0.001	0.96
F/G	1.41	1.65	1.37	1.61	0.037	0.95	0.001	0.26
d 14 to 28								
ADG, lb	1.25	1.27	1.25	1.31	0.021	0.33	0.06	0.37
ADFI, lb	1.88	1.86	1.95	1.93	0.041	0.88	0.57	0.10
F/G	1.51	1.46	1.57	1.48	0.021	0.39	0.003	0.13
d 0 to 28								
ADG, lb	0.92	0.84	0.93	0.86	0.019	0.72	0.001	0.40
ADFI, lb	1.36	1.26	1.39	1.30	0.031	0.99	0.003	0.28
F/G	1.48	1.51	1.50	1.51	0.019	0.56	0.31	0.62
Weight, lb								
d 0	15.4	15.4	15.4	15.4	0.178	0.95	0.97	0.99
d 14	23.7	21.1	24.1	21.2	0.378	0.72	0.001	0.54
d 28	41.2	38.9	41.5	39.5	0.592	0.80	0.001	0.40

[1] A total of 280 weanling pigs (PIC 327 × 1050, initially 15.4 lb and 3 d postweaning) were used with 7 pigs per pen and 10 pens per treatment.
[2] Pigs were fed complex or simple diets from d 0 to 14. From d 14 to 28, pigs were fed the same basal diet formulation with or without benzoic acid.
[3] Pigs were fed diets without or with benzoic acid from d 0 to 28. Vevovitall (DSM Nutritional Products, Parsippany, NJ) was used as the source of benzoic acid.

Table 3. Main effects of diet complexity and benzoic acid on growth performance of nursery pigs[1]

	Complexity[2]			Benzoic acid[3]			Probability, $P <$	
	Complex	Simple	SEM	0	0.5%	SEM	Complexity	Benzoic acid
d 0 to 14								
ADG, lb	0.61	0.41	0.013	0.51	0.52	0.013	0.001	0.55
ADFI, lb	0.84	0.67	0.019	0.76	0.75	0.019	0.001	0.96
F/G	1.39	1.63	0.024	1.53	1.49	0.024	0.001	0.26
d 14 to 28								
ADG, lb	1.25	1.29	0.011	1.26	1.28	0.011	0.06	0.37
ADFI, lb	1.92	1.90	0.030	1.87	1.94	0.030	0.57	0.10
F/G	1.54	1.47	0.011	1.49	1.53	0.011	0.003	0.13
d 0 to 28								
ADG, lb	0.92	0.85	0.010	0.88	0.90	0.010	0.001	0.40
ADFI, lb	1.38	1.28	0.023	1.31	1.35	0.023	0.003	0.28
F/G	1.49	1.51	0.010	1.50	1.51	0.010	0.31	0.62
Weight, lb								
d 0	15.4	15.4	0.120	15.4	15.4	0.120	0.97	0.99
d 14	23.9	21.1	0.239	22.4	22.7	0.239	0.001	0.54
d 28	41.4	39.2	0.391	40.1	40.5	0.391	0.001	0.40

[1] A total of 280 weanling pigs (PIC 327 × 1050, initially 15.4 lb) were used with 7 pigs per pen and 20 pens per diet complexity main effect.
[2] Pigs were fed complex or simple diets from d 0 to 14. From d 14 to 28, a common diet was fed that did not differ in complexity.
[3] Pigs were fed diets without or with 0.5% Vevovitall from d 0 to 28.

Evaluation of Antibiotics and Benzoic Acid on Growth Performance of Nursery Pigs[1]

J.E. Nemechek, M.D. Tokach, S.S. Dritz[2], R.D. Goodband, J.M. DeRouchey, and J.R. Bergstrom[3]

Summary

A total of 240 weanling pigs (PIC 327 × 1050, initially 16.1 lb, 3 d postweaning) were used in a 28-d trial to evaluate the effects of benzoic acid and antibiotics on growth performance. Treatments were arranged as a 2 × 2 factorial (with or without 0.5% Vevovitall, a source of benzoic acid; DSM Nutritional Products, Parsippany, NJ), and with or without carbadox (Mecadox; Philbro Animal Health Corp., Ridgefield Park, NJ). The 4 dietary treatments included a control (1) without Mecadox or Vivovitall, (2) without Mecadox and with Vevovitall, (3) with Mecadox and without Vevovitall, and (4) with Mecadox and Vevovitall. No interactions ($P > 0.57$) were observed between Mecadox and Vevovitall on growth performance. From d 0 to 14, there were no differences ($P > 0.12$) in ADG or ADFI between pigs fed diets with or without Mecadox, but pigs fed Mecadox tended to have poorer ($P < 0.07$) F/G than pigs fed diets without Mecadox. From d 14 to 28, pigs fed Mecadox had improved ($P < 0.01$) ADG, ADFI, and F/G compared with pigs fed diets without Mecadox. Overall (d 0 to 28), pigs fed Mecadox had increased ($P < 0.02$) ADG and ADFI. For the main effect of Vevovitall, there were no differences ($P > 0.11$) in ADG, ADFI, or F/G during either phase or for the overall data. In conclusion, feeding Mecadox increased ADG and ADFI, but no improvements in growth were found when benzoic acid was included in the diets.

Key words: benzoic acid, carbadox, nursery pig

Introduction

Vevovitall, a source of benzoic acid, has been included in European swine diets and may become available for use in the North American swine industry. This experiment is the second in a series of trials that were conducted at K-State to evaluate Vevovitall in nursery pig diets. In the previous experiment, the effect of Vevovitall in simple and complex diets was tested. Although no significant improvements in growth were observed when Vevovitall was fed, the response was not influenced by diet complexity; therefore, complex diets, which are more representative of a typical diet fed in the U.S., were used in the current experiment to further test the effects of Vevovitall.

Weaning and early nursery phases are often associated with higher stress, particularly with regards to intestinal health and development. Antibiotics are most commonly fed during this time in an attempt to lessen any negative effects on growth, but acidifiers also have been investigated as beneficial feed additives due to the potential for antibiotic-

[1] Appreciation is expressed to DSM Nutritional Products (Parsippany, NJ), for providing the Vevovitall used in diet formulation and partial financial support.
[2] Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University.
[3] DSM Nutritional Products (Parsippany, NJ).

like effects. The objective of the current experiment was to determine the effect of antibiotics on the response to Vevovitall in nursery pig diets.

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.

A total of 240 weanling pigs (PIC 327 × 1050, initially 16.1 lb, 3 d postweaning) were used in a 28-d trial. Pigs were weaned at approximately 21 d of age and allotted to pens by initial BW to achieve the same average pen weight. Pigs were fed a common pelleted transition diet for 3 d. On d 3 postweaning, pens were allotted to 1 of 4 dietary treatments, arranged as a 2 × 2 factorial. Thus, d 3 after weaning was d 0 of the experiment. There were 7 pigs per pen and 7 pens per treatment. Each pen contained a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water. Pigs and feeders were weighed on d 0, 7, 14, 21, and 28 to calculate ADG, ADFI, and F/G.

A 2-phase diet series was used. All diets were corn-soybean meal–based. From d 0 to 14, all diets contained 10% dried whey, 1.25% select menhaden fish meal, 1.25% spray-dried blood cells, and 2,000 ppm of Zn from zinc oxide (Table 1). From d 14 to 28, no specialty protein sources or additional zinc oxide were included in any diets. There were 4 dietary treatments, including a control (1) without Mecadox or Vivovitall, (2) without Mecadox and with Vevovitall, (3) with Mecadox and without Vevovitall, (4) with Mecadox and Vevovitall. For treatments 3 and 4, Mecadox was included at 50 g/ton from d 0 to 14 and 25 g/ton from d 14 to 28. Vevovitall was included in treatments 2 and 4 at 0.5%

Experimental data were analyzed as a completely randomized design using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Treatments were arranged as a 2 × 2 factorial (with or without Mecadox and with or without Vevovitall). Differences between treatments were determined using the PDIFF statement in SAS. Significant differences were declared at $P < 0.05$ and trends at $P < 0.10$.

Results and Discussion

No interactions ($P > 0.57$) were observed among pigs fed Mecadox and Vevovitall on growth performance (Table 2).

From d 0 to 14, there were no differences ($P > 0.12$) in ADG and ADFI between pigs fed diets with or without Mecadox, but pigs fed Mecadox tended to have poorer ($P < 0.07$) F/G than those fed diets without Mecadox (Table 3). The inclusion of dietary Vevovitall had no effect ($P > 0.33$) on ADG, ADFI, or F/G from d 0 to 14.

Although the addition of Mecadox in Phase 1 had little effect on growth, from d 14 to 28, pigs fed Mecadox had improved ($P < 0.01$) ADG, ADFI, and F/G compared with pigs fed diets without Mecadox. Similar to the previous period, feeding Vevovitall from d 14 to 28 did not affect ($P > 0.11$) ADG, ADFI, or F/G.

For the overall trial (d 0 to 28), the inclusion of Mecadox increased ($P < 0.02$) ADG and ADFI but did not influence ($P > 0.21$) F/G. Consistent with the previous periods, no differences ($P > 0.14$) were observed in ADG, ADFI, or F/G when Vevovitall was fed for the overall experiment.

In conclusion, no interactive effects of feeding Mecadox and Vevovitall to nursery pigs were observed. The inclusion of Mecadox alone improved ADG, ADFI, and F/G, which was driven primarily by improvements observed in pigs from d 14 to 28 of the trial (25 to 45 lb). Feeding acidifiers has resulted in improved growth performance in several trials, but the current experiment showed only numerical improvements in growth.

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

	Phase 1	Phase 2
Item	Negative control[3]	Negative control[4]
Ingredient, %		
Corn	59.93	64.50
Soybean meal (46.5% CP)	26.39	32.15
Select menhaden fish meal	1.25	---
Spray-dried blood cells	1.25	---
Spray-dried whey	10.0	---
Monocalcium phosphate (21% P)	0.85	1.05
Limestone	0.80	1.00
Salt	0.30	0.35
Zinc oxide	0.25	---
Trace mineral premix	0.15	0.15
Vitamin premix	0.25	0.25
L-lysine HCl	0.295	0.325
DL-methionine	0.140	0.100
L-threonine	0.125	0.110
Phytase[5]	0.019	0.019
Diatomacious earth[6]	1.00	---
Total	100.00	100.00

continued

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

	Phase 1	Phase 2
Item	Negative control[3]	Negative control[4]
Calculated analysis		
Standardized ileal digestible amino acids (SID), %		
Lysine	1.30	1.26
Isoleucine:lysine	56	62
Leucine:lysine	129	130
Methionine:lysine	33	31
Met & Cys:lysine	56	56
Threonine:lysine	62	62
Tryptophan:lysine	17.0	17.5
Valine:lysine	69	68
Total lysine, %	1.43	1.39
ME, kcal/lb	1,480	1,504
SID lysine:ME, g/Mcal	3.99	3.80
CP, %	20.7	20.9
Ca, %	0.71	0.70
P, %	0.63	0.63
Available P, %	0.47	0.47

[1] A total of 240 weanling pigs (PIC 327 × 1050) were used in a 28-d trial to evaluate the effects of benzoic acid and antibiotics on growth performance.
[2] Vevovitall was used as the source of benzoic acid (DSM Nutritional Products, Parsippany, NJ). Mecadox 2.5 was used as the source of antibiotic (Philbro Animal Health Corp., Ridgefield Park, NJ).
[3] Pigs were fed Phase 1 diets from d 0 to 14. Diets contained 0 or 0.5% Vevovitall and 0 or 50 g/ton of Mecadox.
[4] Pigs were fed Phase 2 diets from d 14 to 28. Diets contained 0 or 0.5% Vevovitall and 0 or 25 g/ton of Mecadox.
[5] Ronozyme CT (10,000) (International Nutrition, Omaha, NE) provided 840 phytase units (FTU)/lb, with a release of 0.10% available P.
[6] Indigestible marker (Perma-Guard, Inc., Corrales, NM).

Table 2. Effect of benzoic acid and antibiotics on growth performance of nursery pigs[1]

Benzoic acid:[2]	---	Vevovitall	---	Vevovitall		Probability, $P <$		
Antibiotic:[3]	---	---	Mecadox	Mecadox	SEM	Benzoic acid × antibiotic	Benzoic acid	Antibiotic
d 0 to 14								
ADG, lb	0.64	0.65	0.64	0.67	0.026	0.61	0.33	0.57
ADFI, lb	0.87	0.88	0.91	0.95	0.033	0.60	0.51	0.12
F/G	1.38	1.36	1.42	1.41	0.026	0.95	0.46	0.07
d 14 to 28								
ADG, lb	1.20	1.24	1.31	1.36	0.026	0.79	0.11	0.001
ADFI, lb	1.87	1.91	1.97	2.01	0.037	0.99	0.23	0.01
F/G	1.56	1.55	1.51	1.49	0.018	0.75	0.32	0.003
d 0 to 28								
ADG, lb	0.92	0.94	0.97	1.01	0.022	0.72	0.14	0.01
ADFI, lb	1.37	1.39	1.44	1.48	0.032	0.86	0.32	0.02
F/G	1.50	1.48	1.48	1.46	0.016	0.76	0.28	0.21
Weight, lb								
d 0	16.1	16.1	16.1	16.1	0.153	0.96	0.98	0.96
d 14	25.0	25.2	25.0	25.6	0.447	0.67	0.43	0.63
d 28	41.9	42.5	43.3	44.7	0.748	0.57	0.20	0.02

[1]A total of 240 weanling pigs (PIC 327 × 1050, initially 16.1 lb) were used in a 28-d trial to evaluate the effects of benzoic acid and antibiotics on growth performance. There were 6 pigs per pen and 10 pens per treatment.

[2] Vevovitall (DSM Nutritional Products, Parsippany, NJ) was included in from d 0 to 14 and d 14 to 28 at 0.5% of the diet.

[3] Mecadox (Philbro Animal Health Corp., Ridgefield Park, NJ) was added at 50 g/ton from d 0 to 14 and 25 g/ton from d 14 to 28.

Table 3. Main effect of Mecadox and Vevovitall on growth performance of nursery pigs[1]

	Antibiotic[2]			Benzoic acid[3]			Probability, $P <$	
	None	Mecadox	SEM	None	Vevovitall	SEM	Antibiotic	Benzoic acid
d 0 to 14								
ADG, lb	0.64	0.66	0.018	0.64	0.66	0.018	0.57	0.33
ADFI, lb	0.87	0.93	0.024	0.89	0.91	0.024	0.12	0.51
F/G	1.37	1.42	0.018	1.40	1.38	0.018	0.07	0.46
d 14 to 28								
ADG, lb	1.22	1.33	0.019	1.25	1.30	0.019	0.001	0.11
ADFI, lb	1.89	1.99	0.026	1.92	1.96	0.026	0.01	0.23
F/G	1.56	1.50	0.013	1.54	1.52	0.013	0.003	0.32
d 0 to 28								
ADG, lb	0.93	0.99	0.016	0.94	0.98	0.016	0.01	0.14
ADFI, lb	1.38	1.46	0.023	1.40	1.44	0.023	0.02	0.32
F/G	1.49	1.47	0.011	1.49	1.47	0.011	0.21	0.28
Weight, lb								
d 0	16.1	16.1	0.109	16.1	16.1	0.109	0.96	0.98
d 14	25.1	25.3	0.316	25.0	25.4	0.316	0.63	0.43
d 28	42.2	44.0	0.529	42.6	43.6	0.529	0.02	0.20

[1]A total of 240 weanling pigs (PIC 327 × 1050, initially 16.1 lb) were used in a 28-d trial to evaluate the effects of benzoic acid and antibiotics on growth performance. There were 6 pigs per pen and 10 pens per treatment.
[2]Pigs were fed diets without or with Mecadox (Philbro Animal Health Corp., Ridgefield Park, NJ) from d 0 to 28.
[3]Pigs were fed diets without or with 0.5% Vevovitall (DSM Nutritional Products, Parsippany, NJ) from d 0 to 28.

Evaluation of Dietary Acidifiers on Growth Performance of Nursery Pigs[1]

J.E. Nemechek, M.D. Tokach, S.S. Dritz[2], R.D. Goodband, J.M. DeRouchey, and J.R. Bergstrom[3]

Summary

Three 28-d experiments were conducted to determine the effects of dietary acidifiers on the growth performance of nursery pigs housed under both university and field conditions. All diets were corn-soybean meal–based and fed in meal form. Each experiment consisted of a 2-phase diet series with decreasing nutrient concentrations in the second phase. The same 4 dietary treatments were evaluated in all 3 experiments, including a control with (1) no acidifier, (2) 0.5% Vevovitall (DSM Nutritional Products, Parsippany, NJ), (3) 0.2% Kem-Gest (Kemin Americas, Des Moines, IA), or (4) 0.05% Buti-Pearl (Kemin Americas). In Exp. 1, 280 weanling pigs (PIC 327 × 1050, initially 16.1 lb, 3 d postweaning) were used with 7 pigs per pen and 10 pens per treatment. From d 0 to 14, pigs fed the Kem-Gest diet tended to have increased ($P < 0.07$) ADG compared with pigs fed the other 3 treatments. From d 14 to 28 and for the overall data (d 0 to 28), no differences ($P > 0.64$) were observed in ADG, ADFI, or F/G among treatments. In Exp. 2, 1,728 nursery pigs (PIC 327 × 1050, initially 12.8 lb, 10 d postweaning) were used with 48 pigs per feeder (24 pigs per pen) and 9 feeders per treatment. Treatment diets were fed from d 0 to 14, and a common diet was fed from d 14 to 28. From d 0 to 14, pigs fed the control diet had decreased ($P < 0.001$) ADG and poorer ($P < 0.001$) F/G compared with pigs fed diets with acidifiers. From d 14 to 28, when a common diet was fed, there were no differences ($P > 0.60$) in ADG, ADFI, or F/G among treatments. Overall (d 0 to 28), there were no differences in ADG, ADFI, or F/G ($P > 0.11$), but pigs fed diets containing acidifiers were approximately 2 lb heavier at the conclusion of the trial. In Exp. 3, 1,800 nursery pigs (PIC 327 × 1050, initially 16.3 lb, 13 d postweaning) were used with 50 pigs per feeder (25 pigs per pen) and 9 feeders per treatment. Treatment diets were fed throughout the entire trial (d 0 to 28), but there were no differences ($P > 0.12$) in ADG, ADFI, or F/G among pigs fed the different dietary treatments from d 0 to 14, d 14 to 28, or for the overall trial.

Overall, the responses to dietary acidification were inconsistent across experiments, but the reasons are unclear. Pigs fed acidifiers had improved growth performance in Exp. 2, but not Exp. 1 and 3. Further research is needed to determine the reason for the inconsistent responses so dietary acidifiers can be used effectively to improve the performance of nursery pigs.

Key words: acidifiers, benzoic acid, butyric acid, nursery pig

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[1] Appreciation is expressed to DSM Nutritional Products (Parsippany, NJ) for providing the benzoic acid (Vevovitall) used in diet formulation and partial financial support.

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

[3] DSM Nutritional Products (Parsippany, NJ).

Introduction

With decreasing use of antibiotics in swine diets, potential alternatives are a growing area of interest. Among these alternatives are various types of acidifiers that are increasingly being incorporated in nursery pig diets, both in Europe and North America. Acidifiers have resulted in improved performance in some trials, but not in others. Explanations for the varying responses have been proposed but are not fully understood.

Many sources of acidifiers are available, and they often vary in pH and potency depending on the form of acid. Kem-Gest (phosphoric, fumaric, lactic, and citric acid blend; Kemin Americas, Des Moines, IA) and ButiPearl (encapsulated butyric acid; Kemin Americas) are 2 common sources of acidifiers that are currently available in the U.S. Vevovitall (DSM Nutritional Products Parsippany, NJ) is a source of benzoic acid that may become available to the North American swine industry and has been shown to provide growth and health benefits for swine in experiments from other countries. Previous experiments at K-State have shown no improvements in growth performance when Vevovitall was fed, regardless of diet complexity or antibiotic inclusion; however, previous trials were conducted in a university research nursery where pigs often maintain a higher health status and improved growth rate. With increasing interest in feeding dietary acidifiers, the objective of these trials was to determine the effect of 3 commercial acidifiers (Vevovitall, Kem-Gest, and Butipearl) on growth performance of nursery pigs housed in both university and field facilities.

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.

Experiment 1

A total of 280 weanling pigs (PIC 327 × 1050, initially 16.1 lb, 3 d postweaning) were used in a 28-d trial to evaluate the effects of Vevovitall, Kem-Gest, and ButiPearl on growth performance in a university research nursery. Pigs were weaned at approximately 21 d of age and allotted to pens by initial BW to achieve the same average pen weight for all pens. Pigs were fed a common, pelleted, transition diet for 3 d. On d 3 postweaning, pens were allotted to 1 of 4 dietary treatments; thus, d 3 after weaning was d 0 of the experiment. There were 7 pigs per pen and 10 pens per treatment. Each pen contained a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water. Pigs and feeders were weighed on d 0, 7, 14, 21, and 28 to calculate ADG, ADFI, and F/G. A 2-phase diet series was used, with decreasing nutrient concentrations in the second phase. All diets were corn-soybean meal–based. From d 0 to 14, all diets contained 10% dried whey, 1.25% select menhaden fish meal, 1.25% spray-dried blood cells, and 2,000 ppm of zinc oxide (Table 1). From d 14 to 28, no specialty protein sources or additional zinc oxide were included in any diets. There were 4 dietary treatments, including a control with (1) no acidifier, (2) 0.5% Vevovitall, (3) 0.2% Kem-Gest, or (4) 0.05% ButiPearl. Inclusion rates were based on the recommendations of the manufacturer. All experimental diets were in meal form and were prepared at the K-State Animal Science Feed Mill.

Experiments 2 and 3

In Exp. 2 and 3, a total of 1,728 and 1,800 nursery pigs (PIC 327 × 1050) were used, respectively, in 28-d trials conducted at a commercial research nursery facility. Each feeder was available to 2 adjacent pens (1 barrow and 1 gilt pen per feeder), resulting in 48 pigs per feeder (24 pigs per pen) for Exp. 2 and 50 pigs per feeder (25 pigs per pen) in Exp. 3. There were 9 replicate feeders per treatment. Treatment diets were fed starting on d 10 (Exp. 2) or d 13 (Exp. 3) after weaning, and these days were considered d 0 of the experiments. The 4 dietary treatments were the same as in Exp. 1 and included a control with (1) no acidifier, (2) 0.5% Vevovitall, (3) 0.2% Kem-Gest, or (4) 0.05% ButiPearl. A 2-phase diet series was used in each trial, with decreasing nutrient concentrations in the second phase. All diets were corn-soybean meal–based. Treatment diets were identical from d 0 to 14 for both experiments and were formulated to 1.35% standardized ileal digestible (SID) lysine (Table 2). In Exp. 2, a common diet with no acidifiers was fed from d 14 to 28 to monitor subsequent performance and was formulated to 1.30% SID lysine. In Exp. 3, instead of a common diet, a second phase of treatment diets (Control, 0.5% Vevovitall, 0.2% Kem-Gest, or 0.05% ButiPearl) was fed from d 14 to 28 and was formulated to 1.30% SID lysine. Pigs and feed disappearance were measured on d 0, 7, 14, 21, and 28 to calculate ADG, ADFI, and F/G. All experimental diets were in meal form and were manufactured at a commercial feed mill.

Statistical analysis

At the conclusion of the experiment, data were analyzed as a completely randomized design with pen (Exp. 1) or feeder (Exp. 2 and 3) as the experimental unit. Analysis of variance was performed using the PROC MIXED option of SAS (SAS Institute, Inc., Cary, NC). Differences between treatments were determined using the PDIFF statement in SAS, with differences declared at $P < 0.05$ and trends declared at $P < 0.10$.

Results and Discussion

Experiment 1

From d 0 to 14, pigs fed the Kem-Gest diet had a tendency for increased ($P < 0.07$) ADG compared with pigs fed the other 3 treatments (Table 3). No differences were observed ($P > 0.33$) in ADFI or F/G among pigs fed any of the treatment diets. From d 14 to 28 and for the overall period (d 0 to 28), no differences were observed ($P > 0.64$) in ADG, ADFI, or F/G among treatments; therefore, feeding acidifiers did not influence growth performance in a university research setting.

Experiments 2 and 3

For Exp. 2, when the treatment diets were fed from d 0 to 14, pigs fed the control diet had decreased ($P < 0.001$) ADG and poorer ($P < 0.001$) F/G compared with pigs fed all diets with acidifiers (Table 4), and ADFI did not differ ($P > 0.29$) among treatments. When a common diet was fed from d 14 to 28, there were no differences ($P > 0.60$) in ADG, ADFI, or F/G among treatments. These results indicate that no compensatory growth occurred when pigs were taken off diets containing acidifiers. Because growth was similar from d 14 to 28, there were no differences in overall (d 0 to 28) ADG, ADFI, or F/G ($P > 0.11$). Although no differences were found in growth for the overall data, pigs fed diets containing any of the 3 acidifiers were approximately 2 to 2.5 lb heavier in BW on d 14 compared with pigs fed the control diet. This difference was

maintained to d 28, resulting in a 2-lb heaver nursery pig at the end of the trial for pigs fed acidifiers.

Unlike in Exp. 2, no differences were observed ($P > 0.12$) in ADG, ADFI, or F/G in Exp. 3 among pigs fed the different dietary treatments from d 0 to 14, d 14 to 28, or for the overall trial (Table 5).

In conclusion, the responses to dietary acidifiers varied among experiments. In Exp. 1, including acidifiers in the diets had no beneficial effects on growth performance, which agrees with previous experiments conducted under university research conditions. Pigs fed acidifiers in Exp. 2 (a commercial nursery), however, had improved ADG and F/G, but only numerical differences were found in Exp. 3. The reason for the inconsistent responses among trials is unclear, but results may be influenced by health status, age, or starting weight of pigs. Pigs housed in university research facilities are often considered to have a higher health status than those in a commercial facility, which may mitigate any potential antimicrobial effects of the acids. This does not, however, fully explain the varying responses between Exp. 2 and Exp. 3, which were conducted in the same facility. Due to the inconsistent responses among trials, further investigation is needed to effectively incorporate acidifiers in diets for nursery pigs.

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

	Control	
Item	Phase 1[2]	Phase 2[3]
Ingredient, %[4]		
Corn	59.93	64.50
Soybean meal (46.5% CP)	26.39	32.15
Select menhaden fish meal	1.25	---
Spray-dried blood cells	1.25	---
Spray-dried whey	10.0	---
Monocalcium phosphate (21% P)	0.85	1.05
Limestone	0.80	1.00
Salt	0.30	0.35
Zinc oxide	0.25	---
Trace mineral premix	0.15	0.15
Vitamin premix	0.25	0.25
L-lysine HCl	0.295	0.325
DL-methionine	0.140	0.100
L-threonine	0.125	0.110
Phytase[5]	0.019	0.019
Diatomacious earth	1.00	---
Total	100.0	100.0

continued

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

	Control	
Item	Phase 1[2]	Phase 2[3]
Calculated analysis		
Standardized ileal digestible (SID) amino acids, %		
Lysine	1.30	1.26
Isoleucine:lysine	56	62
Leucine:lysine	129	130
Methionine:lysine	33	31
Met & Cys:lysine	56	56
Threonine:lysine	62	62
Tryptophan:lysine	17.0	17.5
Valine:lysine	69	68
Total lysine, %	1.43	1.39
ME, kcal/lb	1,480	1,504
SID lysine:ME, g/Mcal	3.99	3.80
CP, %	20.7	20.9
Ca, %	0.71	0.70
P, %	0.63	0.62
Available P, %	0.47	0.41

[1] In addition to the control diet, pigs were fed 0.5% Vevovitall (DSM Nutritional Products, Parsippany, NJ), 0.2% Kem-Gest (Kemin Americas, Des Moines, IA), or 0.05% ButiPearl (Kemin Americas) for both phases.
[2] Phase 1 diets were fed from d 0 to 14.
[3] Phase 2 diets were fed from d 14 to 28.
[4] Vevovitall was used as a source of benzoic acid; Kem-Gest was used as a source of phosphoric, fumaric, lactic, and citric acid blend; and ButiPearl was used as a source of encapsulated butyric acid.
[5] Ronozyme P-CT (10,000) (International Nutrition, Omaha, NE), providing 840 phytase units (FTU)/lb and an estimated release of 0.10% available P.

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

	Control	
Item	Phase 1[2]	Phase 2[3]
Ingredient, %[4]		
Corn	42.29	51.34
Soybean meal (46.5% CP)	27.55	29.54
Dried distillers grains with solubles	15.00	15.00
Spray-dried blood cells	1.00	---
Spray-dried whey	10.0	---
Dicalcium phosphate (18.5% P)	0.75	1.13
Limestone	1.45	1.50
Salt	0.35	0.50
Zinc oxide	0.25	---
Vitamin-trace mineral premix	0.30	0.30
L-lysine HCl	0.400	0.450
DL-methionine	0.160	0.135
L-threonine	0.125	0.115
Denagard 10	0.175	---
CTC-100	0.200	---
Total	100.0	100.0
Calculated analysis		
Standardized ileal digestible (SID) amino acids, %		
Lysine	1.35	1.30
Isoleucine:lysine	59	61
Leucine:lysine	137	136
Methionine:lysine	35	35
Met & Cys:lysine	58	58
Threonine:lysine	63	61
Tryptophan:lysine	17.4	17.2
Valine:lysine	70	68
Total lysine, %	1.53	1.48
ME, kcal/lb	1,462	1,474
SID lysine:ME, g/Mcal	4.19	4.00
Ca, %	0.90	0.93
P, %	0.60	0.64
Available P, %	0.46	0.46

[1] In addition to the control diet, pigs were fed 0.5% Vevovitall (DSM Nutritional Products, Parsippany, NJ), 0.2% Kem-Gest (Kemin Americas, Des Moines, IA), or 0.05% ButiPearl (Kemin Americas).
[2] Phase 1 diets were fed from d 0 to 14.
[3] Phase 2 diets were fed from d 14 to 28. For Phase 2, only the control diet was fed in Exp. 1, and all 4 treatment diets were fed in Exp. 2.
[4] Vevovitall was used as a source of benzoic acid; Kem-Gest was used as a source of phosphoric, fumaric, lactic, and citric acid blend; and ButiPearl was used as a source of encapsulated butyric acid.

Table 3. Effects of acidifiers on growth performance of nursery pigs under university research conditions, Exp. 1[1]

		Acidifier[2]				
	Control	Vevovitall	Kem-Gest	Butipearl	SEM	Probability, *P* <
d 0 to 14						
ADG, lb	0.54	0.52	0.58	0.53	0.017	0.07
ADFI, lb	0.76	0.74	0.81	0.77	0.026	0.33
F/G	1.41	1.43	1.39	1.45	0.035	0.61
d 14 to 28						
ADG, lb	1.06	1.05	1.02	1.05	0.024	0.68
ADFI, lb	1.70	1.71	1.67	1.66	0.039	0.81
F/G	1.60	1.63	1.64	1.59	0.032	0.64
d 0 to 28						
ADG, lb	0.82	0.80	0.82	0.81	0.017	0.90
ADFI, lb	1.26	1.26	1.27	1.25	0.029	0.97
F/G	1.54	1.57	1.55	1.54	0.024	0.87
BW, lb						
d 0	15.2	15.2	15.2	15.2	0.126	0.99
d 14	22.3	21.9	22.8	22.1	0.277	0.47
d 28	38.3	37.7	38.1	37.8	0.506	0.81

[1] A total of 280 weanling pigs were used with 7 pigs per pen and 10 pens per treatment. Treatment diets were fed starting on d 3 after weaning.
[2] Acidifiers were fed from d 0 to 28.

Table 4. Effects of acidifiers on growth performance of nursery pigs fed under field conditions, Exp. 2[1]

		Acidifier[2]				
	Control	Vevovitall	Kem-Gest	Butipearl	SEM	Probability, $P <$
d 0 to 14						
ADG, lb	0.66[a]	0.81[b]	0.78[b]	0.80[b]	0.026	0.001
ADFI, lb	0.90	1.00	0.96	0.97	0.036	0.29
F/G	1.36[a]	1.23[b]	1.22[b]	1.21[b]	0.015	< 0.001
d 14 to 28						
ADG, lb	1.03	1.04	1.03	1.02	0.026	0.97
ADFI, lb	1.25	1.29	1.30	1.29	0.029	0.64
F/G	1.22	1.26	1.27	1.27	0.027	0.60
d 0 to 28						
ADG, lb	0.84	0.92	0.91	0.91	0.023	0.10
ADFI, lb	1.07	1.14	1.13	1.13	0.028	0.37
F/G	1.28	1.24	1.24	1.24	0.016	0.35
BW, lb						
d 0	12.8	12.9	12.8	12.9	0.263	0.99
d 14	22.3[a]	24.7[b]	24.3[b]	24.4[b]	0.543	0.01
d 28	36.7	39.3	38.8	38.8	0.817	0.15

[ab] Within a row, means without a common superscript differ ($P < 0.05$).

[1] A total of 1,728 nursery pigs (PIC 327 × 1050) were used. Each number represents the mean of 9 feeders. Each feeder was accessible by 2 adjacent pens (1 barrow and 1 gilt pen per feeder). There were 24 pigs per pen. Treatment diets were fed starting on d 10 after weaning.

[2] Treatment diets were fed from d 0 to 14 of the trial. A common diet with no acidifiers was fed from d 14 to 28 to determine any effects on subsequent performance.

Table 5. Effects of acidifiers on growth performance of nursery pigs fed under field conditions, Exp. 3[1]

		Acidifier[2]				
	Control	Vevovitall	Kem-Gest	Butipearl	SEM	Probability, $P <$
d 0 to 14						
ADG, lb	0.79	0.80	0.80	0.76	0.017	0.18
ADFI, lb	1.20	1.18	1.15	1.12	0.030	0.32
F/G	1.52	1.47	1.44	1.48	0.022	0.14
d 14 to 28						
ADG, lb	0.98	0.97	0.93	0.99	0.023	0.25
ADFI, lb	1.65	1.65	1.53	1.61	0.047	0.27
F/G	1.68	1.69	1.65	1.63	0.022	0.28
d 0 to 28						
ADG, lb	0.89	0.89	0.86	0.87	0.016	0.65
ADFI, lb	1.42	1.41	1.34	1.37	0.031	0.23
F/G	1.61	1.59	1.55	1.57	0.016	0.12
BW, lb						
d 0	16.3	16.3	16.3	16.4	0.261	0.99
d 14	27.6	27.7	27.5	26.9	0.450	0.64
d 28	41.6	41.4	40.9	40.8	0.606	0.78

[1] A total of 1,800 nursery pigs (PIC 327 × 1050) were used. Each number represents the mean of 9 feeders. Each feeder was accessible by 2 adjacent pens (1 barrow and 1 gilt pen per feeder). There were 25 pigs per pen. Treatment diets were fed starting on d 13 after weaning.
[2] Acidifiers were fed from d 0 to 28.

Effects of Hydrolyzed Vegetable Protein or Hydrolyzed Vegetable and Meat Protein Blend on Nursery Pig Performance from 15 to 40 lb[1]

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

Summary

A total of 280 pigs (PIC 327 × 1050, initially 16.7 lb BW) were used in a 28-d trial to evaluate the effects of hydrolyzed vegetable protein or a blend of hydrolyzed vegetable and meat protein for nursery pigs. Three days after weaning, pigs were allotted to 1 of 4 dietary treatments in a completely randomized design, balancing for initial BW and gender. There were 10 pens per treatment with 7 pigs per pen. The 4 treatment diets were: (1) no added specialty protein source (negative control); (2) 6% select menhaden fish meal; (3) 5% hydrolyzed vegetable protein (Hydr SF 52, International Ingredient Corporation, St. Louis, MO), or (4) 6.5% hydrolyzed vegetable and meat protein blend (HDSF Protein; International Ingredient Corporation). Diets were fed in 2 phases, with Phase 1 from d 0 to 17 (treatment diets) and Phase 2 from d 17 to 28 (common diet). From d 0 to 17, pigs fed the negative control diet had improved ($P \leq 0.05$) F/G compared with pigs fed diets with Hydr SF 52 or HDSF Protein. No differences in ADG and ADFI were detected among treatments. From d 17 to 28 (common period), no difference was observed in growth performance between pigs previously fed any of the treatment diets. Overall (d 0 to 28), no differences were observed in ADG, ADFI, or F/G among pigs fed any of the treatment diets. Because performance did not differ from pigs fed the negative control diet, definitive conclusions regarding these specialty protein sources cannot be made.

Key words: hydrolyzed vegetable and meat protein blend, hydrolyzed vegetable protein, nursery pig, protein sources

Introduction

Including specialty proteins such as fish meal, blood products, poultry meal, or further processed soy proteins is a common industry practice in pig diets fed from weaning until pigs reach approximately 25 lb. Including these ingredients helps reduce the level of dietary soybean meal and provides a highly digestible amino acid source for newly weaned nursery pigs. In addition, nursery diets containing specialty protein sources of animal origin often result in improved feed intake. Although using specialty protein sources in nursery diets has many advantages, they increase diet costs; thus, new specialty protein sources are developed continually to moderate increasing diet costs while improving growth of nursery pigs.

[1] The authors wish to thank International Ingredient Corporation, St. Louis, MO, for providing the protein and lactose sources used in diet formulation and partial financial support.
[2] Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University.

Two new specialty protein sources contain either hydrolyzed vegetable protein (Hydr SF 52, International Ingredient Corporation, St. Louis, MO) or a combination of hydrolyzed vegetable and meat protein (HDSF Protein; International Ingredient Corporation), but no research has determined their effects in nursery diets. Therefore, the objective of this study was to determine the effects of fish meal, hydrolyzed vegetable protein, or a blend of hydrolyzed vegetable and meat protein in nursery pigs from 15 to 40 lb.

Procedures

The protocol for this experiment was approved by the Kansas State University Institutional Animal Care and Use Committee. The experiment was conducted at the K-State Swine Teaching and Research Center in Manhattan, KS. The facility is a totally enclosed, environmentally controlled, mechanically ventilated barn.

A total of 280 pigs (PIC 327 × 1050, initially 16.7 lb BW) were used in a 28-d trial. Pigs were weaned at 21 d of age and were fed a common pelleted diet for 3 d. On d 3, pigs were weighed and pens of pigs were allotted to 1 of 4 dietary treatments in a completely randomized design, balancing for initial BW and gender, with 10 pens per treatment with 7 pigs per pen. All dietary treatments were corn-soybean meal–based. The 4 dietary treatments (Table 1) contained either: (1) no added specialty protein source (negative control); (2) 6% select menhaden fish meal; (3) 5% hydrolyzed vegetable protein (Hydr SF 52), or (4) 6.5% hydrolyzed vegetable and meat protein blend (HDSF Protein). Hydr SF 52 is a drum-dried hydrolyzed vegetable protein. HDSF Protein is a co-dried product containing hydrolyzed vegetable protein, meat by-product, and animal fat. Diets were fed in 2 phases, with treatment diets fed during Phase 1 from d 0 to 17 and a common diet fed to all pigs in Phase 2 from d 17 to 28. All Phase 1 diets contained 12.5% DairyLac 80 (International Ingredient Corporation), which provided 10% lactose in the complete diets. Treatment diets 2, 3, and 4 contained 28.2% soybean meal during Phase 1, whereas the negative control diet contained 36.5% soybean meal. All diets were formulated to be isocaloric on an ME basis. For Hydr SF 52 and HDSF Protein, estimated energy, amino acid concentrations, and standardized ileal digestibility (SID) coefficients (Table 2) were based on the proportions of ingredients and values for enzymatic soy and meat meal from the NRC (2012). Diets were fed in meal form and were prepared at the K-State Animal Science Feed Mill.

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, 17, and 28 of the trial to determine ADG, ADFI, and F/G.

Samples of each specialty protein source were collected during the manufacturing process and submitted to Ward Laboratories, Inc. (Kearney, NE) for analysis of DM, CP, Ca, and P (Table 3).

Data were analyzed as a completely randomized design using PROC MIXED in SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Results for treatment criteria were considered significant at $P \leq 0.05$ and tendencies from $P > 0.05$ to $P \leq 0.10$.

Results and Discussion

Chemical analysis of the protein sources (Table 2) showed that most nutrients were similar to formulated values. Crude protein levels were lower in fish meal and Hydr SF 52 than formulated values, whereas the CP level for HDSF Protein was slightly higher than used in diet formulation. Analyzed Ca levels were higher than formulated values for all protein sources, and the P levels were slightly higher than the formulated values for fish meal and HDSF Protein.

From d 0 to 17, there were no differences in ADG and ADFI among pigs fed any of the treatment diets (Table 4); however, pigs fed the negative control diet had improved ($P \leq 0.05$) F/G compared with pigs fed diets containing Hydr SF 52 or HDSF Protein. From d 17 to 28 (common diet period), growth performance did not differ among pigs previously fed the treatment diets. Overall (d 0 to 28), no differences were observed in ADG, ADFI, or F/G among pigs fed any of the treatment diets.

The lack of growth response differences compared with the negative control makes definitive conclusions between specialty protein sources difficult. More research is needed to validate the efficacy of the two newly developed specialty protein sources for nursery pigs.

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

Item	Phase 1				Common Phase 2
	Negative control	Fish meal	Hydr SF 52[2,3]	HDSF Protein[3,4]	
Ingredient, %					
Corn	46.22	50.64	49.63	48.70	64.44
Soybean meal (46.5% CP)	36.55	28.20	28.20	28.20	31.85
Select menhaden fish meal	-	6.00	-	-	-
HDSF Protein	-	-	-	6.45	-
Hydr SF52	-	-	5.00	-	-
DairyLac80[5]	12.50	12.50	12.50	12.50	-
Soybean oil	0.98	-	0.65	0.13	-
Monocalcium P (21.5% P)	1.25	0.53	1.23	1.23	1.03
Limestone	0.90	0.60	0.95	0.95	0.98
Salt	0.25	0.25	0.25	0.25	0.35
L-lysine HCL	0.300	0.270	0.425	0.420	0.34
DL-methionine	0.180	0.150	0.215	0.220	0.13
L-threonine	0.150	0.140	0.190	0.195	0.13
L-tryptophan	0.005	-	0.045	0.040	-
Trace mineral premix	0.15	0.15	0.15	0.15	0.15
Vitamin premix	0.25	0.25	0.25	0.25	0.25
Zinc oxide	0.25	0.25	0.25	0.25	-
Phytase[6]	0.08	0.08	0.08	0.08	0.17
Antibiotic[7]	-	-	-	-	0.20
Total	100.00	100.00	100.00	100.00	100.00

continued

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

Item	Phase 1				Common Phase 2
	Negative control	Fish meal	Hydr SF 52[2,3]	HDSF Protein[3,4]	
Calculated analysis					
Standardized ileal digestible (SID) amino acids, %					
Lysine	1.30	1.30	1.30	1.30	1.22
Isoleucine:lysine	63	61	59	59	62
Leucine:lysine	121	121	103	102	127
Methionine:lysine	36	37	38	38	34
Met & Cys:lysine	58	58	58	58	57
Threonine:lysine	64	64	64	64	63
Tryptophan:lysine	19	18	18	18	18
Valine:lysine	67	67	67	67	67
Total lysine, %	1.46	1.47	1.45	1.45	1.37
ME, kcal/lb	1,513	1,513	1,513	1,513	1,480
SID lysine:ME, g/Mcal	3.90	3.90	3.90	3.90	3.74
CP, %	22.1	22.3	21.1	21.1	21.0
Ca, %	0.70	0.70	0.70	0.70	0.64
P, %	0.69	0.66	0.67	0.67	0.61
Available P, %	0.48	0.48	0.48	0.48	0.43

[1] Treatment diets were fed from d 0 to 17, then a common diet was fed from d 17 to 28.
[2] Hydr SF 52 (International Ingredient Corporation, St. Louis, MO). Hydr SF 52 is a drum-dried hydrolyzed vegetable protein.
[3] For Hydr SF 52 and HDSF Protein, estimated energy, amino acid values, and SID coefficients were based on the proportions of ingredients and values for enzymatic soy and meat meal from the 2012 NRC.
[4] HDSF Protein (International Ingredient Corporation). HDSF Protein is co-dried product containing hydrolyzed vegetable protein, meat by-product and animal fat.
[5] DairyLac80 (International Ingredient Corporation).
[6] Nutrase 600 (Consumers Supply Distributing, North Sioux City, SD). Provided 205 and 450 phytase units (FTU)/lb with a release of 0.10% and 0.13% of available P for Phase 1 and Phase 2 diets, respectively.
[7] Aureo-50 (Pfizer Animal Health, New York City, NY) provided 200 g/ton of chlortetracycline.

Table 2. Metabolizable energy (ME), amino acid concentrations and standardized ileal digestibility (SID) coefficients for Hydr SF 52 and HDSF Protein used in diet formulation

Item	Hydr SF 52[1]	HDSF Protein[2]
ME, kcal/lb	1,593	1,776
Amino acid concentration, %		
Lysine	2.68	2.20
Met & Cys:lysine	1.26	0.93
Threonine	1.86	1.43
Tryptophan	0.71	0.56
Isoleucine	2.25	1.82
Valine	2.41	2.05
SID coefficients, %		
Lysine	86	85
Met & Cys:lysine	82	81
Threonine	83	82
Trpyptophan	83	82
Isoleucine	89	87
Valine	89	87

[1] Hydr SF 52 (International Ingredient Corporation, St. Louis, MO) is a drum-dried hydrolyzed vegetable protein.
[2] HDSF Protein (International Ingredient Corporation) is a co-dried product containing hydrolyzed vegetable protein, meat by-product, and animal fat.

Table 3. Chemical analysis of fish meal, hydrolyzed vegetable protein, and hydrolyzed vegetable and meat protein blend (as fed-basis)

Item	Fish meal[1]	Hydr SF 52[2]	HDSF Protein[3]
DM, %	93.67 (93.70)	87.32 (93.0)	84.92 (88.0)
CP, %	59.30 (63.28)	46.60 (50.4)	40.10 (39.3)
Ca, %	7.34 (4.28)	0.50 (0.38)	0.35 (0.23)
P, %	3.98 (2.93)	0.70 (0.70)	0.67 (0.56)

[1] Values in parentheses indicate those used in diet formulation and are from NRC, 2012. (Nutrient Requirements of Swine, 11th ed. Natl. Acad. Press, Washington DC).
[2,3] Values in parentheses indicate those used in diet formulation and are from International Ingredient Corporation, St. Louis, MO.

Table 4. Evaluation of specialty protein sources for nursery pigs[1,2]

Item	Negative control	Fish meal	Hydr SF 52[3]	HDSF protein[4]	SEM	*P* <
d 0 to 17						
ADG, lb	0.56	0.53	0.54	0.54	0.023	0.68
ADFI, lb	0.78	0.77	0.80	0.80	0.052	0.55
F/G	1.41[a]	1.46[ab]	1.51[b]	1.51[b]	0.047	0.09
d 17 to 28						
ADG, lb	1.19	1.21	1.19	1.13	0.034	0.27
ADFI, lb	2.05	2.09	2.04	2.00	0.052	0.43
F/G	1.73	1.73	1.71	1.77	0.037	0.69
d 0 to 28						
ADG, lb	0.81	0.80	0.80	0.77	0.015	0.40
ADFI, lb	1.29	1.30	1.30	1.28	0.021	0.96
F/G	1.59	1.63	1.63	1.66	0.027	0.34
BW, lb						
d 0	16.7	16.7	16.7	16.7	0.190	1.00
d 7	17.8	17.6	17.5	17.6	0.152	0.58
d 17	26.2	26.0	25.8	25.8	0.609	0.87
d 28	39.5	39.5	39.1	38.4	0.484	0.34

[a,b] Means within the same row with different superscripts differ ($P \leq 0.05$).
[1] A total of 280 nursery pigs (PIC 327 × 1050, initially 16.7 lb BW) were used in a 28-d growth trial with 7 pigs per pen and 10 pens per treatment.
[2] Treatment diets were fed from d 0 to 17, then a common diet was fed from d 17 to 28.
[3] Hydr SF 52 (International Ingredient Corporation, St. Louis, MO) is a drum-dried hydrolyzed vegetable protein.
[4] HDSF Protein (International Ingredient Corporation) is a co-dried product containing hydrolyzed vegetable protein, meat by-product, and animal fat.

Evaluation of Increasing Peptone Blend on Nursery Pig Performance from 15 to 40 lb[1]

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Summary

A total of 270 pigs (PIC 327 × 1050, initially 15.7 lb BW) were used in a 28-d trial to evaluate the effects of increasing levels of a new peptone blend by-product on nursery pig growth performance. The product is the result of the pharmaceutical extraction of chondroitin sulfate from bovine cartilage and processing to form the peptone blend, which was mixed with soybean hulls and drum-dried. Pigs were weaned at 21 d of age and were fed a common pelleted diet for 5 d prior to the start of the experiment. Each treatment had 8 replicate pens and 6 or 7 pigs per pen. The 5 experimental treatments were: (1) a diet with 1% blood meal and 2% select menhaden fish meal (positive control), (2) a diet with no added specialty protein source (negative control), (3) a diet containing 4% peptone blend, (4) a diet containing 8% peptone blend, or (5) a diet containing 12% peptone blend. Experimental diets were fed for 14 d, then a common Phase 2 diet was fed for an additional 14 d to determine the residual treatment effects on growth performance.

From d 0 to 14, pigs fed increasing peptone blend had increased (linear, $P < 0.001$) ADFI but poorer (linear, $P < 0.001$) F/G. Pigs fed the positive control diet had increased ($P = 0.04$) ADFI compared with pigs fed the negative control diet. From d 14 to 28, when pigs were fed a common diet, pigs previously fed increasing peptone blend had increased (linear, $P = 0.03$) ADFI and poorer (linear, $P = 0.001$) F/G. Similar to d 0 to 14 data, pigs previously fed the positive control diet had increased ($P = 0.05$) ADFI compared with pigs previously fed the negative control diet from d 14 to 28. Overall (d 0 to 28), pigs fed diets with increasing peptone blend for the first 14 d had increased ($P < 0.001$) ADFI and poorer F/G ($P < 0.001$) with no differences in ADG ($P = 0.87$). Pigs fed the positive control diet had increased ($P = 0.01$) overall ADFI compared with pigs fed negative control diet, with no differences ($P > 0.17$) in ADG or F/G. Based on these results, the peptone blend is not a suitable replacement for blood meal and select menhaden fish meal in nursery pig diets from 15 to 24 lb. Up to 4% of the peptone blend was a suitable replacement for soybean meal in the negative control diet, which contained no specialty protein sources.

Key words: growth performance, nursery pig, peptone blend, specialty protein sources

Introduction

Providing high-quality specialty protein to weanling pigs is known to improve performance and help piglets start on feed, but rising prices of some of the most common sources used by swine nutritionists have encouraged the industry to search for alterna-

[1] The authors thank Sioux Biochemical Inc., Sioux Center, IA, for providing the peptone blend used in diet formulation and for partial financial support.

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

tive ingredients capable of replacing specialty proteins at lower costs without negatively affecting performance.

Previous research conducted at Kansas State University (Myers et al., 2010[3]; 2011[4]) found that a peptone blend by-product of the heparin production industry that is derived from porcine intestinal mucosa is a suitable replacement for fish meal and poultry meal in nursery diets. A new potential peptone blend by-product of the pharmaceutical extraction of chondroitin sulfate from bovine cartilage is now available for consideration (Sioux Biochemical Inc., Sioux Center, IA). To create this new peptone blend product, the bovine cartilage is processed to remove the chondroitin sulfate, and the resulting product is further processed to form a peptone blend that is mixed with soybean hulls and drum-dried. Little to no research has been conducted to determine how this new peptone blend product will affect nursery pig performance. Thus, the objective of this study was to evaluate the effects of different inclusion levels of peptone blend on growth performance of weanling 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 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 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.

A total of 270 pigs (PIC 327 × 1050, initially 15.7 lb BW) were used in a 28-d trial. Pigs were weaned at 21 d of age and were initially fed a common pelleted diet for 5 d prior to the start of this experiment. On d 5 after weaning, pigs were weighed and pens of pigs were allotted to 1 of 5 dietary treatments in a randomized complete block design. Each treatment had 8 replicate pens and 6 or 7 pigs per pen balanced for gender. Pig weight and feed disappearance were measured on d 0, 7, 14, and 28 of the trial to determine ADG, ADFI, and F/G.

All dietary treatments were corn-soybean meal–based. Experimental diets contained 10% spray-dried whey providing 7.2% lactose in the complete diets. The 5 experimental treatments (Table 1) were: (1) 1% blood meal and 2% select menhaden fish meal (positive control), (2) no added specialty protein source (negative control), (3) 4% peptone blend, (4) 8% peptone blend, or (5) 12% peptone blend. For diet formulation, the energy and standardized ileal digestible (SID) amino acid coefficients (Table 2) used were from previous trials conducted in our lab evaluating an enteric mucosa peptone blend product. Experimental diets were fed for 14 d, followed by a 14-d period in which all pigs were fed the same common diet. Diets were fed in meal form and were manufactured at the K-State Animal Science Feed Mill.

Samples of the peptone blend were collected during diet manufacturing and submitted to Ward Laboratories, Inc. (Kearney, NE) for analysis of DM, CP, Ca, and P. To determine the amino acid content from the peptone blend, samples were analyzed at

[3] Myers et al., Swine Day 2010, Report of Progress 1038, pp. 27–34.
[4] Myers et al., Swine Day 2011, Report of Progress 1056, pp. 81–89.

the University of Missouri Agricultural Experiment Station Chemical Laboratories (Columbia, MO).

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 increasing dietary peptone blend level on performance criteria were determined by linear and quadratic polynomial contrasts. Single degree of freedom contrasts were used to compare performance of positive and negative controls. 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 peptone blend (Table 3) revealed that most nutrients were similar to those use in diet formulation. Crude protein, P, lysine, and methionine and cystine were slightly lower than those used for formulated values. Tryptophan, isoleucine, and valine were higher than those used for formulated values.

From d 0 to 14, pigs fed increasing peptone blend had increased (linear, $P < 0.001$) ADFI and poorer (linear, $P < 0.001$) F/G (Table 4). No differences were observed in ADG among treatments ($P > 0.19$). Pigs fed the positive control diet had increased ($P = 0.04$) ADFI compared with pigs fed the negative control diet, with no changes ($P > 0.19$) in F/G or ADG. From d 14 to 28, pigs previously fed diets with increasing peptone blend had increased (linear, $P = 0.03$) ADFI and poorer (linear, $P = 0.001$) F/G, with no changes ($P > 0.28$) in ADG. Similar to the first 14 d, pigs previously fed the positive control diet had increased ($P = 0.05$) ADFI compared with pigs previously fed the negative control diet, with no changes ($P > 0.15$) in F/G or ADG.

Overall (d 0 to 28), pigs fed diets with increasing peptone blend for 14 d had increased ($P < 0.001$) ADFI and poorer ($P < 0.001$) F/G, with no difference ($P > 0.20$) in ADG. Pigs fed the positive control diet had increased ($P = 0.01$) overall ADFI compared with pigs fed the negative control diet, with no differences ($P > 0.17$) in ADG or F/G.

In conclusion, in this experiment up to 4% of the peptone blend could replace soybean meal in the negative control diet without negatively affecting growth performance, but the peptone blend was not a suitable replacement for blood meal and select menhaden fish meal in nursery pig diets from 15 to 24 lb. In our study, actual digestibility coefficients were not available for the new product, so we used values from a previously researched peptone blend that originated from enteric mucosa. As a result, the coefficients utilized for diet formulation in this study might not reflect the actual coefficients of the product we tested. Therefore, further research is needed to characterize the energy and digestible amino acid coefficients of this specific peptone blend so diets can be formulated more accurately.

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

	Phase 1					
Item	Pos. control	Neg. control	Peptone 4%	Peptone 8%	Peptone 12%	Common Phase 2
Ingredient, %						
Corn	56.49	52.93	51.07	49.20	47.33	64.44
Soybean meal (46.5% CP)	27.15	33.42	31.29	29.17	27.05	31.85
Blood meal	1.00	--	--	--	--	--
Select menhaden fish meal	2.00	--	--	--	--	--
Spray-dried whey	10.00	10.00	10.00	10.00	10.00	--
Monocalcium P (21.5% P)	0.90	1.13	1.15	1.15	1.18	1.03
Limestone	0.83	0.90	0.85	0.83	0.78	0.98
Salt	0.30	0.30	0.30	0.30	0.30	0.35
L-lysine HCl	0.30	0.30	0.30	0.30	0.30	0.34
DL-methionine	0.165	0.165	0.165	0.165	0.165	0.13
L-threonine	0.145	0.130	0.130	0.130	0.130	0.13
L-tryptophan	--	--	--	0.005	0.013	--
L-valine	--	0.010	0.015	0.025	0.035	--
Trace mineral premix	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
Phytase[2]	0.08	0.08	0.08	0.08	0.08	0.17
Zinc oxide	0.25	0.25	0.25	0.25	0.25	--
Peptone blend[3]	--	--	4.00	8.00	12.00	--
Antibiotic[4]	--	--	--	--	--	0.20
Total	100.00	100.00	100.00	100.00	100.00	100.00

continued

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

Item	Phase 1					Common Phase 2
	Pos. control	Neg. control	Peptone 4%	Peptone 8%	Peptone 12%	
Calculated analysis						
Standardized ileal digestible (SID) amino acids, %						
Lysine	1.30	1.30	1.30	1.30	1.30	1.22
Isoleucine:lysine	58	63	62	60	59	62
Leucine:lysine	125	124	122	119	116	127
Methionine:lysine	36	35	36	36	36	34
Met & Cys:lysine	58	58	58	58	58	57
Threonine:lysine	64	64	64	64	64	63
Tryptophan:lysine	18	19	18.3	18.1	18.1	18
Valine:lysine	68	68	68	68	68	67
Total lysine, %	1.45	1.45	1.45	1.45	1.46	1.37
ME, kcal/lb	1,492	1,482	1,464	1,446	1,429	1,480
SID lysine:ME, g/Mcal	3.95	3.98	4.03	4.08	4.13	3.74
CP, %	21.4	21.9	22.7	23.5	24.3	21.0
Ca, %	0.70	0.70	0.70	0.70	0.70	0.64
P, %	0.66	0.69	0.68	0.66	0.65	0.61
Available P, %	0.48	0.48	0.48	0.48	0.48	0.43

[1] Treatment diets were fed from d 0 to 14, and then a common diet was fed from d 14 to 28.
[2] Nutrase 600 (Consumers Supply Distributing, North Sioux City, SD) provided phytase at 205 and 450 phytase units (FTU)/lb with a release of 0.10% and 0.13% of available P for Phase 1 and Phase 2 diets, respectively.
[3] Peptone blend (Sioux Biochemical Inc., Sioux Center, IA).
[4] Aureo-50 (chlortetracycline, Pfizer Animal Health, New York City, NY) provided 200 g/ton of chlortetracycline.

Table 2. Estimated ME and standardized ileal digestibility (SID) coefficients for peptone blend used in diet formulation

Item	Peptone blend
ME, kcal/lb[1]	1,061
SID coefficients, %[2]	
Lysine	82
Methionine	84
Cysteine	66
Threonine	75
Tryptophan	83
Isoleucine	83
Valine	81

[1] ME calculated by Midwest Laboratories (Omaha, NE).
[2] SID coefficients used were from a previous study originating from swine enteric mucosa.

Table 3. Chemical analysis of peptone blend (as fed-basis)[1]

Item	Peptone blend
DM, %	92.98 (93.00)
CP, %	44.3 (48.80)
Ca, %	0.51 (0.52)
P, %	0.09 (0.14)
Total amino acid concentration, %	
Lysine	1.75 (1.80)
Met & Cys:lysine	0.80 (0.93)
Threonine	1.21 (1.22)
Tryptophan	0.31 (0.18)
Isoleucine	1.06 (0.85)
Valine	1.41 (1.17)

[1] Values in parentheses were provided by the manufacturer from analysis at Midwest Laboratories (Omaha, NE) and were used in diet formulation.

Table 4. Evaluation of increasing peptone blend on nursery pig performance from 15 to 40 lb[1,2,3]

Item	Positive control	Negative control	4% peptone	8% peptone	12% peptone	SEM	Probability, *P*<		
							Peptone inclusion[4]		
							Linear	Quadratic	Pos. control × Neg. control
d 0 to 14									
ADG, lb	0.62	0.58	0.58	0.57	0.62	0.028	0.31	0.19	0.19
ADFI, lb	0.88	0.82	0.85	0.94	1.02	0.030	0.001	0.32	0.04
F/G	1.41	1.40	1.47	1.71	1.66	0.062	0.001	0.31	0.87
d 14 to 28									
ADG, lb	1.21	1.18	1.16	1.14	1.16	0.021	0.28	0.33	0.37
ADFI, lb	2.00	1.87	1.90	1.93	2.01	0.044	0.03	0.59	0.05
F/G	1.65	1.58	1.63	1.70	1.73	0.031	0.001	0.84	0.15
d 0 to 28									
ADG, lb	0.92	0.88	0.87	0.85	0.89	0.019	0.87	0.20	0.17
ADFI, lb	1.43	1.34	1.37	1.43	1.51	0.029	0.001	0.39	0.01
F/G	1.57	1.52	1.57	1.69	1.70	0.027	0.001	0.42	0.19
BW, lb									
d 0	15.7	15.6	15.7	15.7	15.7	0.125	0.44	0.94	0.66
d 14	24.5	24.0	23.8	23.8	24.6	0.452	0.21	0.13	0.25
d 28	41.5	40.6	40.1	39.7	40.8	0.602	0.86	0.15	0.24

[1] A total of 270 nursery pigs (PIC 327 × 1050, initially 15.7 lb BW) were used in a 28-d growth trial with 6 or 7 pigs per pen and 8 pens per treatment.
[2] Treatment diets were fed from d 0 to 14, then a common diet was fed from d 14 to 28.
[3] Peptone blend (Sioux Biochemical Inc., Sioux Center, IA). Peptone blend is a by-product of pharmaceutical extraction from bovine cartilage.
[4] Contrasts were determined using negative control and the different levels of peptone inclusion.

Evaluating the Effects of an Algae-Modified Montmorillonite Clay in Diets Contaminated with Deoxynivalenol on Nursery Pig Growth Performance[1]

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Summary

A total of 280 nursery pigs (PIC 327 × 1050, initially 21.9 lb and 35 d of age) were used in a 21-d growth trial to evaluate the effects of an algae-modified montmorillonite clay (MMi) on nursery pig performance when fed diets contaminated with deoxynivalenol (DON). Pigs were allotted to pens by weight, and pens were randomly assigned to 1 of 5 dietary treatments arranged in a 2 × 2 + 1 factorial with 7 pigs per pen and 8 pens per treatment. All experimental diets were pelleted. Mycotoxin analyses were conducted on the main ingredients at NDSU[3] and LDA labs[4], and these results were used in diet formulation. Naturally contaminated wheat (10.7 ppm DON) was used to produce diets with approximately 5 ppm DON. The 5 treatments consisted of 2 positive control diets that did not contain DON contamination with or without 0 or 0.50% MMi and 3 negative control diets that were contaminated with 5 ppm of DON and contained 0, 0.25%, or 0.50% MMi. No DON × MMi interactions were observed for the entire study. Overall (d 0 to 21), ADG, ADFI, and d 21 BW decreased ($P < 0.001$) in pigs fed DON-contaminated diets regardless of MMi addition. Feed efficiency was poorer ($P < 0.001$) for pigs fed diets with DON due, primarily to poor feed efficiency in the initial period (d 0 to 7). Pigs fed diets contaminated with DON had greater ($P < 0.05$) BW variation (CV) within pen on d 21. Although the addition of 0.5% MMi to diets restored ($P < 0.02$) ADFI from d 14 to 21, no other treatment differences were observed for MMi inclusion. In conclusion, this study suggests that including MMi will not offset reductions in nursery pig performance caused by high DON levels (> 5 ppm) when diets are fed in pellet form.

Key words: deoxynivalenol, montmorillonite clay, nursery pig, vomitoxin

Introduction

Deoxynivalenol (DON), also known as vomitoxin, develops in cereal grains when excess moisture is present during the flowering stage. It is one of the most detrimental mycotoxins because it occurs frequently in cereal grains, often at levels of toxicological relevance. Pigs are the most DON-susceptible livestock species, with negative effects consisting of decreased feed intake and growth performance, immune suppression, and, at high DON concentrations, vomiting and complete feed refusal.

[1] Appreciation is expressed to Advanced Management Solutions (Black River Falls, WI) and Olmix S.A. (Brehan, France) 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.

Deoxynivalenol presents significant challenges for pork producers because conventionally used detoxification agents such as bentonite clay and activated aluminosilicates provide little to no benefit to DON-contaminated grains. Such adsorbent products have successfully bound mycotoxins with smaller molecular size such as aflatoxin, allowing the toxin to pass through the body without negative effects, but the large diameter of DON prevents it from being adsorbed within the structure of available clay adsorbents. A new algae-modified montmorillonite clay (MMi) product is available that has not been previously studied. This MMi is produced using a patented processing method in which algae polysaccharides are used to expand the layers of the montmorillonite clay. This expansion of the clay layers may provide a substrate for increased adsorption, which could mitigate the negative effects of DON on pig performance; therefore, the aim of this study was to determine the influence of MMi in DON-contaminated feeds 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 280 mixed-sex pigs (PIC 327 × 1050; 21.9 ± 0.2 lb BW and 35 d of age) were used in a 21-d experiment with 8 replicate pens per treatment and 7 pigs in each pen. At weaning, pigs were allotted to pens by initial weight and fed a common diet for 7 d, at which time they were reweighed and pens were assigned to 1 of 5 treatments in a completely randomized design. Each pen contained a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water.

Treatments were arranged in a 2 × 2 + 1 factorial with DON and MMi inclusion as main effects. The experimental treatments consisted of 2 positive control diets that had no DON contamination and contained either 0 or 0.50% MMi and 3 negative control diets formulated to contain 5 ppm DON and either 0, 0.25%, or 0.50% MMi (Table 1). Diets exceeded 2012 NRC[5] nutrient requirements, and apart from the inclusion of DON and MMi were formulated to be identical in nutrient composition.

Diets were manufactured in pellet form at the K-State Animal Science Feed Mill in Manhattan, KS. All diets were pelleted in an attempt to minimize segregation of dietary ingredients. A naturally contaminated source of high-DON wheat (10.7 ppm DON; Table 2) was used to provide diets with 5 ppm DON. 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 replicate samples, which were then sent for mycotoxin analysis at NDSU and LDA Labs. The lab at NDSU conducted an 18-component toxin screen using a combination of mass spectrometry, ELISA, and high-pressure liquid chromatography. LDA Labs performed a 43-component toxin screen using liquid chromatography/mass spectrometry analysis. Due to concerns that high-DON wheat may also have a different amino acid profile than DON-free wheat, both were analyzed for amino acid content (Table 3) at the University of Missouri Agricultural Experiment Station Chemical Laboratories (Columbia, MO), and diet formulation was adjusted to account for the differences. Following final diet manufac-

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

turing, diet samples were sent to NDSU and the University of Missouri for mycotoxin and amino acid analysis, respectively (Table 4).

Average daily gain, ADFI, and F/G were determined by weighing pigs and determining feed disappearance on d 0, 7, 14, and 21 (Table 5). Each pen contained a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water.

Results were analyzed as a completely randomized design. Treatment means were analyzed using the LSMEANS statement and preplanned CONTRAST statements in SAS (SAS Institute, Inc., Cary, NC). The fixed factors in the model included DON level and MMi inclusion. Preplanned contrasts included: (1) the interaction between DON contamination and MMi inclusion, (2) DON contaminated diets vs. non-contaminated diets, (3) 0 vs. 0.5% MMi, and (4) the linear effects of MMi inclusion within DON-contaminated diets. Least squares means were calculated for each independent variable, and means were considered significant at $P < 0.05$.

Results and Discussion

In the present study, the amino acid concentrations of DON-free wheat were generally higher than that of the DON-contaminated wheat. Although DON contamination clearly alters nutrient content,[6] previous research has shown that the alterations are not consistent. This fact reinforces the importance of accounting for these changes in diet formulation to assess the true impact of a mycotoxin contamination on animal performance.

All negative control diets averaged 6.6 ppm DON, approximately 20% higher than targeted concentrations (5 ppm DON). Although fumonisin B_1 was detected at 2.0 ppm in the DON-free diet without MMi, analyses confirmed that no other mycotoxins were detected in positive control diets above the practical quantification limit (PQL; <0.5 ppm). Aflatoxin B_1 was detected at low levels (20 and 28 ppb) in two of three negative control diets, but no other mycotoxins were detected above PQL in DON-contaminated diets. Although the presence of low levels of fumonisin and aflatoxin in several test diets is concerning, according to EFSA (2009[7]) these levels remain below critical concentrations in nursery pig diets.

No DON × MMi interactions were observed for the entire study. As expected, ADFI was reduced ($P < 0.03$) in pigs fed DON-contaminated diets in all periods and for the overall study, with the greatest impact observed in the first 7 d. The almost 24% reduction in ADFI resulted in pigs fed DON-contaminated diets having decreased ($P < 0.001$) ADG and BW for every period and the entire study. Although F/G was poorer ($P < 0.001$) from d 0 to 7 and d 0 to 21, no impact ($P > 0.12$) of DON contamination was observed from d 7 to 14 and d 14 to 21. The approximately 40% poorer F/G during the initial period might correspond with the DON-associated upregulation of immune system function during the initial exposure to the toxin. Finally, pigs fed

[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.

[7] EFSA, 2009. Pages 141–142 in: Review of mycotoxin-detoxifying agents used as feed additives: mode of action, efficacy and feed/food safety. Scientific report submitted to the European Food Safety Association.

DON-contaminated diets had greater ($P < 0.05$) BW CV within pen on d 21, which indicates more variation in pig weights within a pen.

An unforeseen challenge that arose during the execution of this trial was the management of feeders for pigs fed DON-contaminated diets. Although not previously described in the literature, anecdotal visual evidence from this experiment suggests that significant feed sorting may have occurred for pigs consuming DON-contaminated diets despite attempts to manage feeders carefully. The increased variation in pig BW within pens offered the DON-contaminated diets may also suggest that some pigs were more affected by DON than others.

Although the addition of 0.5% MMi to diets restored ($P < 0.02$) ADFI from d 14 to 21, no other differences due to MMi inclusion were detected for any response variable; moreover, within DON-contaminated diets, no ($P > 0.14$) linear effects of added MMi for ADG, ADFI, F/G or pig BW were observed. These data suggest that the processing techniques for the algae-modified montmorillonite clay (MMi) do not significantly increase its adsorption capabilities for DON. Furthermore, the lack of MMi response in the DON-free diet suggests that no other beneficial responses can be expected from including MMi in diets without DON contamination.

In conclusion, this study showed that MMi failed to offset reductions in nursery pig performance caused by high DON levels (>5 ppm) when diets were fed in pelleted form. Future research to define feed-processing effects on the MMi response should be conducted to determine if a better response would be observed with diets fed in meal form.

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

	Positive control (0 ppm DON[1])		Negative control (5 ppm DON)		
Item MMi[2] inclusion:	None	0.50%	None	0.25%	0.50%
Ingredient, %					
Corn	16.90	16.40	16.35	16.25	15.90
Soybean meal (46.5% CP)	30.93	31.00	31.45	31.35	31.45
Hard red winter (HRW) wheat	46.75	46.75	---	---	---
High-DON HRW wheat[3]	---	---	46.75	46.75	46.75
Soybean oil	2.00	2.00	2.00	2.00	2.00
Monocalcium P, 21% P	1.05	1.05	1.05	1.05	1.05
Limestone	1.05	1.00	1.05	1.03	1.00
Salt	0.35	0.35	0.35	0.35	0.35
Vitamin premix with phytase[4]	0.25	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15	0.15
L-lysine HCl	0.33	0.33	0.33	0.33	0.33
DL-methionine	0.10	0.10	0.15	0.15	0.15
L-threonine	0.14	0.14	0.14	0.14	0.14
MMi montmorillonite clay	---	0.50	---	0.25	0.50
Total	100	100	100	100	100
Calculated composition, %					
Standardized ileal digestible amino acids, %					
Lysine	1.28	1.28	1.28	1.28	1.28
Isoleucine:lysine	65	65	62	62	62
Leucine:lysine	120	120	115	115	115
Methionine:lysine	31	31	33	33	33
Met & Cys:lysine	58	58	58	58	58
Threonine:lysine	64	64	64	64	64
Tryptophan:lysine	20.7	20.7	18.9	18.9	18.9
Valine:lysine	72	72	69	69	69
Total lysine, %	1.42	1.42	1.42	1.42	1.42
ME, kcal/lb	1,505	1,498	1,505	1,501	1,498
SID Lysine:ME, g/Mcal	3.86	3.89	3.87	3.87	3.89
CP, %	22.3	22.3	21.2	21.2	21.3
Ca, %	0.73	0.73	0.73	0.73	0.74
P, %	0.65	0.65	0.66	0.66	0.66
Available P, %	0.48	0.48	0.49	0.48	0.48
DON, ppm	<0.5	<0.5	5.0	5.0	5.0

[1] Deoxynivalenol (DON).
[2] MMi algae-modified montmorillonite clay product (Olmix, Brehan, France).
[3] Analyzed DON concentration in DDGS was 10.7 ppm.
[4] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 750 phytase units 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[1]	High-DON
NDSU[2]			
DON	<0.50	<0.50	10.60[3]
LDA Labs[4]			
DON	---[5]	---	10.70
15-Acetyl DON	---	---	0.12
Zearalenone	---	---	0.35
Fumonisin B_1	---	---	0.03

[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] Mean of two duplicate samples sent to NDSU. Individual samples had DON levels of 10.0 and 11.1 ppm, respectively.
[4] 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.
[5] (---) indicates samples were not tested.

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

	Hard red winter wheat	
Item	DON-free[2]	High-DON
Lysine	0.40	0.37
Isoleucine	0.47	0.36
Leucine	0.91	0.72
Methionine	0.21	0.16
Cysteine	0.28	0.22
Threonine	0.37	0.30
Tryptophan	0.18	0.12
Valine	0.62	0.50

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

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

	Positive control (0 ppm DON[2])		Negative control (5 ppm DON)		
Item MMi inclusion:[3]	None	0.50%	None	0.25%	0.50%
DON, ppm	<0.5	<0.5	6.6	6.7	6.4
Fumonisin $B_{1,}$ ppm	2.0	<2.0	<2.0	<2.0	<2.0
Aflatoxin B_1, ppb	<20	<20	20	28	<20

[1] 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 in at least one diet.
[2] Deoxynivalenol (DON).
[3] MMi algae-modified montmorillonite clay product (Olmix, Brehan, France).

Table 5. The effects of deoxynivalenol (DON) and an algae-modified montmorillonite clay (MMi) on nursery pig performance[1,2]

	Positive control (DON 0 ppm)[3]		Negative control (DON 5 ppm)[4]				Probability, $P <$[5]	
Item MMi:[2]	None	0.50%	None	0.25%	0.50%	SEM	DON	MMi
d 0 to 7								
ADG, lb	0.68[b]	0.65[b]	0.31[a]	0.35[a]	0.33[a]	0.07	0.001	0.77
ADFI, lb	1.01[b]	0.99[b]	0.81[a]	0.85[ab]	0.80[a]	0.16	0.01	0.74
F/G	1.57[a]	1.58[a]	2.69[b]	2.54[b]	2.51[b]	0.19	0.001	0.68
d 7 to 14								
ADG, lb	1.16[b]	1.17[b]	0.92[a]	0.87[a]	1.01[a]	0.04	0.001	0.18
ADFI, lb	1.55[b]	1.62[b]	1.23[a]	1.29[a]	1.35[a]	0.10	0.001	0.16
F/G	1.35	1.40	1.35	1.48	1.35	0.06	0.71	0.60
d 14 to 21								
ADG, lb	1.16[b]	1.29[b]	1.05[ab]	1.02[a]	1.07[ab]	0.07	0.001	0.14
ADFI, lb	1.79[b]	1.89[b]	1.61[a]	1.62[a]	1.80[b]	0.08	0.03	0.02
F/G	1.55[ab]	1.46[a]	1.52[ab]	1.60[ab]	1.69[b]	0.06	0.12	0.54
d 0 to 21								
ADG, lb	1.00[b]	1.03[b]	0.76[a]	0.74[a]	0.80[a]	0.05	0.001	0.18
ADFI, lb	1.45[b]	1.50[b]	1.21[a]	1.26[a]	1.31[ab]	0.11	0.001	0.16
F/G	1.46[a]	1.46[a]	1.61[b]	1.67[b]	1.65[b]	0.05	0.001	0.67
Pig BW, lb								
d 0	21.9	21.9	21.9	22.0	22.0	0.20	0.25	0.33
d 7	26.7[b]	26.4[b]	24.0[a]	24.4[a]	24.2[a]	0.54	0.001	0.84
d 14	34.7[b]	34.6[b]	30.5[a]	30.6[a]	31.2[a]	0.76	0.001	0.47
d 21	42.8[b]	43.6[b]	37.7[a]	37.7[a]	38.6[a]	1.20	0.001	0.16
Pen CV, %								
d 0	14.1	13.8	14.2	14.4	14.7	1.00	0.23	0.76
d 21	13.6[ab]	12.1[a]	16.6[b]	15.2[ab]	14.7[ab]	0.015	0.05	0.22

[a, b] Values without a common superscript are statistically different ($P < 0.05$).

[1] A total of 280 pigs (PIC 327 × 1050; 35 d of age) were used in this 21-d study, with 7 pigs per pen and 8 pens per treatment.

[2] MMi (Olmix S.A., Brehan, France).

[3] Formulated mycotoxin levels. Deoxynivalenol (DON)-contaminated wheat was used to produce diets with 5 ppm DON.

[4] Analyzed DON levels averaged 6.6 ppm for negative control diets.

[5] No interactions were detected ($P > 0.05$) between mycotoxin level and inclusion of MMi, and no linear effects ($P > 0.05$) due to MMi inclusion within DON contaminated diets were found. 'MMi' contrast compares diets without MMi to those containing MMi at 0.50%.

Effects of Non-Starch Polysaccharide Enzymes (Roxazyme G2G and/or Ronozyme VP) on Growth Performance of Nursery Pigs Fed Normal or Drought-Stressed Corn[1]

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Summary

A total of 360 barrows (PIC 1050 × 337, initially 12.9 lb BW) were used to determine the effects of non-starch polysaccharide enzymes (Roxazyme G2G and/or Ronozyme VP; DSM Nutritional Products, Inc., Parsippany, NJ) on growth performance and nutrient digestibility of nursery pigs fed normal or drought-stressed corn. Initially, corn samples were collected from 34 separate lots and analyzed to find representatives of normal and drought-stressed corn. These same lots were also used in a separate experiment measuring the impact of drought stress on diet manufacturing characteristics. The lot selected to represent the normal corn had a test weight of 55.9 lb/bu, <5 ppb aflatoxin, 15.0% moisture, and contained 0.77% β-glucan. The lot selected to represent drought-stressed corn had a test weight of 54.3 lb/bu, 6 ppb aflatoxin, 14.3% moisture, and 0.83% β-glucan. Pigs were allotted to pens at weaning (d 0) and were acclimated to a common diet for 10 d prior to the start of this experiment. On d 10 post-placement, pigs were weighed and pens of pigs randomly allotted to 1 of 8 dietary treatments in a completely randomized design. Treatments were arranged in a 2 × 4 factorial with main effects of corn (normal vs. drought-stressed) and enzyme inclusion (none vs. 100 ppm Roxazyme G2G vs. 250 ppm Ronozyme VP vs. 100 ppm Roxazyme G2G + 250 ppm Ronozyme VP). Pigs were fed experimental treatments from d 10 to 35 postweaning in two phases. Feed and fecal samples were collected on d 30 postweaning and analyzed to determine apparent total tract digestibility of nutrients.

The nutrient concentrations of normal and drought-stressed corn were similar, which resulted in few treatment or main effects differences of corn type or enzyme inclusion. No interactions were observed ($P > 0.24$) between corn source and enzyme inclusion. Overall (d 10 to 35), there was no effect on ADG or ADFI, but enzyme inclusion tended to improve ($P = 0.09$) F/G, which was primarily driven by the improved ($P = 0.04$) feed efficiency of pigs fed Roxazyme G2G in Phase 1 (d 10 to 25 postweaning). In conclusion, drought stress did not alter the non-starch polysaccharide concentration of corn. Because non-starch polysaccharide substrates were similar across treatments, it was not surprising that enzyme inclusion showed little benefit to nursery pig growth performance; however, improved feed efficiency of pigs fed diets containing Roxazyme G2G from d 10 to 25 postweaning warrants further investigation.

[1] Appreciation is expressed to DSM Nutritional Products (Parsippany, NJ) for providing enyzmes and partial financial assistance.

[2] Department of Grain Science and Industry, Kansas State University.

[3] DSM, Nutritional Products, Parsippany, NJ.

Introduction

Drought conditions are known to affect corn test weight and may affect swine growth performance, but whether commercially available carbohydrase enzymes can mitigate this effect is unknown. When water-stressed, the ratio of corn endosperm (starch-containing portion) to germ (protein and oil-containing portion) decreases, which in turn increases the protein percentage of the grain. In addition, as the endosperm fraction decreases, the pericarp, or hull, portion increases proportionally. This pericarp fraction is primarily composed of non-starch polysaccharides, such as arabinoxylan, β-glucans, α-galactosidans, and galactomannans, which pigs cannot digest.

Although commercial carbohydrase enzymes have not been consistently effective in corn-based diets, the hypothesized increase in non-starch polysaccharide substrate in drought-stressed corn could create an opportunity to realize beneficial enzyme responses. A commercial carbohydrase enzyme could improve the digestibility of these non-starch polysaccharides and thus help restore nutrient availability in drought-stressed corn. Therefore, the objectives of this experiment were to determine how drought stress affects corn composition and the effects of two commercially available carbohydrase enzymes on growth performance and nutrient digestibility of nursery pigs fed diets containing normal or drought-stressed corn.

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 Segregated Early Weaning Facility in Manhattan.

Initially, 34 samples of corn were collected and analyzed to determine those that would represent the normal and drought-stressed corn used in this experiment. The two lots were selected based on comparisons of growing season temperatures and precipitation as well as β-glucan concentration. The selected corn samples originated from either Harlan, IA (normal corn) or Lewis, IA (drought-stressed corn; Table 1).

A total of 360 barrows (PIC 1050 × 337, initially 12.9 lb and 21 d of age) were allotted to pens at weaning (d 0) and were acclimated to a common diet for 10 d. Starting on d 10 postweaning, pigs were utilized in a 25-d growth and nutrient digestibility experiment. Dietary treatments were arranged in a 2 × 4 factorial with main effects of corn (normal vs. drought-stressed) and enzyme inclusion (none vs. 100 ppm Roxazyme G2G vs. 250 ppm Ronozyme VP vs. 100 ppm Roxzayme G2G + 250 ppm Ronozyme VP). Roxazyme G2G is a multipurpose enzyme cocktail containing cellulase, β-glucanase, and xylanase enzymes, and Ronozyme VP is a multipurpose enzyme cocktail containing β-glucanase, hemicellulase, and pectinase enzymes. On d 10 post-placement, pigs were weighed and pens of pigs randomly allotted to 1 of 8 dietary treatments in a completely randomized design with 5 pigs per pen and 9 pens per treatment. Pigs were provided unlimited access to feed and water through a 4-hole dry self-feeder and a cup waterer in each pen (5 × 5 ft). Treatments were fed in in two phases: Phase 1 from d 10 to 25 postweaning and Phase 2 from d 25 to 35 postweaning. Pigs were weighed and feed disappearance was measured on d 10, 25, and 35 postweaning.

Normal and drought-affected corn were ground in a hammer mill to a common particle size and similar SD. Within phase, all diets were manufactured from the same formulation (Table 2), with both corn types given equal nutritive value. The enzymes were included at the expense of corn. Diets included 0.4% titanium dioxide as an indigestible marker to determine apparent total tract digestibility of nutrients. Diets were analyzed for proximate analysis and carbohydrate composition. Feed and fecal samples were collected on d 30 post-placement, stored at 0°F, then oven-dried and analyzed for DM, ash, CP, crude fat, crude fiber, and titanium to calculate DM and apparent total tract digestibility.

Data were analyzed using the GLIMMIX procedure of SAS with the main effects and their interaction serving as fixed effects. There were no random effects. All interactions were insignificant ($P > 0.24$) and thus removed from the model. Preplanned orthogonal contrasts included enzyme vs. no enzyme inclusion (regardless of enzyme type or corn type), Roxazyme G2G inclusion vs. no enzyme inclusion (regardless of corn type), and Ronozyme VP inclusion vs. no enzyme inclusion (regardless of corn type). Results were considered significant if $P < 0.05$ and trends if $0.05 < P < 0.10$.

Results and Discussion

Total precipitation during the growing season for drought-stressed corn was 58% of the 5-year average compared with 83.5% for normal corn (Table 1). Average temperatures during the growing season for drought-stressed corn were 1.8°F warmer than normal corn. Normal corn substantially outyielded drought-stressed corn (140 vs. 87 bu/acre) and had a slightly heavier test weight (55.9 vs. 54.3 lb/bu). Chemical analysis of the grains showed that drought-stressed corn had 0.9% greater CP concentration as well as 21% greater lignin and 7% greater β-glucan concentration than normal corn, but other chemical components were similar (Table 2). These results partially confirmed our hypothesis because the increased CP concentration in drought-stressed corn suggests that the endosperm:germ ratio shifted; however, starch concentrations were actually 1.4% greater in drought-stressed grains, and differences in cellulose and hemicellulose concentrations were minimal.

Diet chemical analysis revealed that Phase 1 diets with Roxazyme G2G had an average of 1.6% more CP than other diets (Table 3). Diets manufactured with normal corn and no enzyme had 4.4% more starch than diets manufactured with drought-stressed corn and no enzyme, but this was reversed in Phase 2 diets. Interestingly, diets manufactured with drought-stressed corn and no enzyme had greater lignin concentrations than all other diets, particularly those with Roxazyme G2G or Ronozyme VP; however, neither starch nor any other non-starch polysaccharide concentrations were different, including cellulose, β-glucan, or hemicellulose.

During the overall period of both phases (d 10 to 35), dietary treatment did not affect BW, ADG, ADFI, or F/G (Table 4; $P > 0.10$). Preplanned orthogonal contrasts showed that, regardless of corn type, enzyme inclusion did not affect BW or ADFI. Pigs fed Roxazyme G2G tended to have greater ($P = 0.09$) overall ADG compared with those fed diets not containing enzymes. Pigs fed diets with Roxazyme G2G had improved ($P = 0.04$) feed efficiency compared with those not supplemented with Roxa-

zyme from d 10 to 25 postweaning, but the overall effect on feed efficiency was insignificant ($P = 0.11$).

Similar to the treatment and contrast effects, there were few main effects of corn or enzyme type on growth performance (Table 5). Neither corn type nor enzyme inclusion affected BW, ADG, or ADFI. Enzyme inclusion tended to affect ($P = 0.09$) overall F/G, which again reflected improved feed efficiency in pigs fed diets including Roxazyme G2G.

Apparent total tract digestibility of ash and fat tended to be affected ($P = 0.10$) by treatment, but no other impacts on digestibility of DM, CP, or crude fiber were observed. Preplanned contrasts found significant improvement ($P = 0.03$) in ash digestibility in diets containing enzyme compared with those not containing enzyme, which was primarily driven by the improved ($P = 0.01$) ash digestibility of pigs fed diets containing Roxazyme G2G compared with those fed diets with no enzyme. Enzyme inclusion had no effects on digestibility of other nutrients ($P > 0.10$).

Pigs fed normal corn had improved fat digestibility compared with those fed drought-stressed corn ($P = 0.01$, 53.7 vs. 48.0%), but digestibility of other nutrients was not affected ($P > 0.47$) by corn type.

In conclusion, drought-stressed corn appears to have altered CP and starch content compared with normal corn, but the non-starch polysaccharide concentrations are not different, thereby disproving our hypothesis that they would be increased due to changes of the endosperm:pericarp ratio. Because non-starch polysaccharide substrates were similar across treatments, it was not surprising that enzyme inclusion showed little benefit to nursery pig growth performance. Still, the improved feed efficiency of pigs fed diets containing Roxazyme G2G during Phase 1 warrants further investigation.

Table 1. Growing conditions, characteristics, and nutrient composition of corn types

Item	Normal corn[1]	Drought corn[2]
Growing conditions (March through September 2012)		
Temperature		
Average actual temperature, °F[3]	63.9	65.7
Difference from normal average temperature, °F	-3.5	-1.7
Percentage of normal average temperature, %	94.8	97.5
Precipitation		
Total actual rainfall, in.[4]	21.8	14.0
Difference from total normal rainfall, in.	-4.3	-12.1
Percentage of total normal rainfall, %	83.5	58.0
Average actual soil moisture, in.[3]	11.8	7.9
Characteristics		
Yield, bu/acre	140	87
Aflatoxin, ppb	< 5	6
Test weight, lb/bu	55.9	54.3
Moisture, %	15.0	14.3
Total damaged kernels, %	2.9	0.2
Broken corn and foreign material, %	0.5	0.8
Ground corn particle size mean (dgw), μm	404	403
Ground corn SD (sgw)	2.15	2.03
Analyzed nutrient composition, %		
CP	8.5	9.4
Moisture	12.6	12.4
Crude fat	3.2	3.2
Crude fiber	1.4	1.5
Ash	1.4	1.3
Starch	64.3	65.7
ADF	2.9	3.0
NDF	10.6	10.6
Cellulose	2.5	2.5
β-glucan	0.77	0.83
Calculated nutrient composition, %		
Lignin[5]	0.38	0.48
Hemicellulose[6]	7.8	7.6

[1] Grown in Lewis, IA.
[2] Grown in Harlan, IA.
[3] Calculated by the Climate Prediction Center, National Oceanic and Atmospheric Administration.
[4] As reported by the Advanced Hydrologic Prediction Service, National Oceanic and Atmospheric Administration.
[5] Calculated using the equation: ADF - cellulose = lignin.
[6] Calculated using the equation: NDF - ADF = hemicellulose.

Table 2. Diet composition (as-fed basis)

Item	Phase 1[1]	Phase 2[2]
Ingredient, %		
Corn	55.15	64.30
Soybean meal, 46.5%	27.15	30.40
Select menhaden fish meal	3.00	---
Spray-dried whey	10.00	---
Soy oil	2.00	2.00
Monocalcium P, 21% P	0.65	1.05
Limestone	0.89	1.00
Salt	0.35	0.35
Vitamin premix	0.25	0.25
Trace mineral premix	0.15	0.15
Lysine HCl	0.24	0.31
DL-methionine	0.12	0.12
L-threonine	0.11	0.12
Phytase[3]	0.02	0.02
Total	100	100
Calculated analyses		
Standardized ileal digestible (SID) amino acids, %		
Lysine	1.25	1.20
Isoleucine:lysine	62	62
Leucine:lysine	129	131
Methionine:lysine	34	33
Met & Cys:lysine	58	58
Threonine:lysine	64	63
Tryptophan:lysine	17.5	17.5
Valine:lysine	69	69
Total lysine, %	1.38	1.33
CP, %	20.8	20.0
ME, kcal/lb	1,547	1,550
Ca, %	0.80	0.70
P, %	0.64	0.61
Available P, %	0.50	0.43

[1] Phase 1 diets were fed from d 10 to 25 postweaning.
[2] Phase 2 diets were fed from d 25 to 35 postweaning.
[3] Ronozyme P-CT, DSM Nutritional Products, Parsipanny, NJ, provided 839 phytase units (FTU)/lb, with a release of 0.10% available P.

Table 3. Analyzed or calculated nutrient composition of nursery pig diets

Item	Normal + no enzyme	Drought + no enzyme	Normal + Roxazyme G2G	Drought + Roxazyme G2G	Normal + Ronozyme VP	Drought + Ronozyme VP	Normal + G2G + VP	Drought + G2G + VP
Phase 1 diet analyzed composition, %[1]								
CP	20.5	21.0	22.7	22.5	20.7	20.3	20.3	20.0
Moisture	9.9	9.7	9.0	9.8	9.7	9.4	9.8	9.5
Crude fat	3.4	4.4	3.8	3.6	4.2	4.7	4.6	4.3
Crude fiber	1.9	2.0	2.2	2.2	2.0	2.2	1.9	2.2
Ash	6.1	6.1	6.2	5.8	6.4	6.4	5.7	6.3
Starch	39.2	34.8	37.3	41.1	39.8	40.2	37.4	37.0
ADF	3.1	3.2	3.2	3.2	3.5	3.4	3.5	3.7
NDF	9.0	9.1	9.0	9.1	8.9	8.3	9.7	9.5
Cellulose	2.6	2.7	2.9	2.7	3.0	2.9	2.9	3.1
β–glucan	0.48	0.42	0.45	0.50	0.49	0.49	0.45	0.45
Phase 1 calculated composition, %[1]								
Lignin[1]	0.46	0.47	0.38	0.51	0.54	0.51	0.64	0.65
Hemicellulose[2]	5.9	5.9	5.8	5.9	5.4	4.9	6.2	5.7
Phase 2 analyzed composition, %[2]								
CP	21.0	17.8	21.2	18.7	18.1	20.0	19.9	19.8
Moisture	10.5	10.4	10.1	10.3	10.0	10.3	10.7	9.9
Crude fat	4.2	3.8	4.2	4.1	4.5	4.1	4.1	4.0
Crude fiber	2.5	2.2	2.3	2.7	2.2	2.6	2.3	2.3
Ash	4.9	5.3	5.6	5.9	5.5	5.4	5.7	5.3
Starch	40.2	43.3	45.4	47.2	46.9	45.8	46.4	41.4
ADF	3.6	3.7	3.4	3.7	3.2	3.8	3.4	3.8
NDF	9.8	9.8	9.3	10.3	10.0	10.8	9.8	9.3
Cellulose	3.3	3.3	3.2	3.4	2.9	3.5	3.2	3.5
β–glucan	0.49	0.53	0.55	0.58	0.57	0.56	0.57	0.50
Phase 2 calculated composition, %[2]								
Lignin[3]	0.35	0.42	0.17	0.29	0.31	0.31	0.29	0.28
Hemicellulose[4]	6.2	6.1	5.9	6.5	6.8	7.1	6.4	5.5

[1] Phase 1 diets were fed from d 10 to 25 postweaning.
[2] Phase 2 diets were fed from d 25 to 35 postweaning.
[3] Calculated using the equation: ADF - cellulose = lignin.
[4] Calculated using the equation: NDF - ADF = hemicellulose.

Table 4. Treatment effects of drought-affected corn and/or carbohydrase enzyme inclusion on nursery pig growth performance and nutrient digestibility[1]

Item	Normal + no enzyme	Drought + no enzyme	Normal + G2G	Drought + G2G	Normal + VP	Drought + VP	Normal + G2G + VP	Drought + G2G + VP	SEM	*P* = Treatment	Enzyme vs. none[2]	Roxazyme G2G vs. none[2]	Roxazyme VP vs. none[2]
Body weight, lb													
d 0	12.9	12.9	12.9	12.9	12.9	12.8	12.9	12.9	0.01	0.92	0.26	0.63	0.20
d 10	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	0.21	1.00	0.76	0.99	0.50
d 25	25.8	25.3	26.6	26.2	25.8	25.4	25.9	25.9	0.67	0.92	0.50	0.23	0.95
d 35	38.7	37.4	39.0	38.9	37.5	37.8	38.6	37.5	0.91	0.80	0.83	0.33	0.65
d 10 to 25													
ADG, lb	0.74	0.70	0.79	0.76	0.71	0.71	0.74	0.71	0.036	0.67	0.58	0.14	0.78
ADFI, lb	1.01	1.01	1.03	1.01	1.01	1.00	1.00	0.98	0.039	0.99	0.91	0.77	0.94
F/G	1.36	1.44	1.30	1.33	1.42	1.41	1.35	1.38	0.020	0.24	0.28	0.04	0.66
d 25 to 35													
ADG, lb	1.21	1.21	1.24	1.27	1.17	1.24	1.27	1.17	0.048	0.66	0.74	0.38	0.82
ADFI, lb	1.85	1.74	1.88	1.84	1.81	1.82	1.85	1.74	0.058	0.62	0.57	0.28	0.73
F/G	1.53	1.44	1.52	1.45	1.55	1.47	1.46	1.49	0.023	0.73	0.93	0.99	0.60
d 10 to 35													
ADG, lb	0.92	0.91	0.97	0.96	0.89	0.92	0.95	0.89	0.030	0.41	0.49	0.09	0.77
ADFI, lb	1.34	1.30	1.37	1.34	1.33	1.33	1.34	1.28	0.042	0.89	0.73	0.40	0.82
F/G	1.46	1.43	1.41	1.40	1.49	1.45	1.41	1.44	0.012	0.22	0.19	0.11	0.35
ATTD, %[3]													
DM	85.3	85.9	85.3	85.9	85.2	84.9	85.3	84.2	0.78	0.85	0.51	0.94	0.51
Ash	47.1	49.4	54.2	58.5	50.3	49.6	54.9	54.1	2.82	0.10	0.03	0.01	0.57
CP	80.0	78.0	80.3	79.1	75.6	78.6	78.6	78.3	1.28	0.17	0.60	0.57	0.16
Fat	52.6	48.2	49.9	46.5	58.3	49.8	54.0	47.0	3.11	0.10	0.85	0.47	0.27
Fiber	58.4	43.9	51.6	66.9	60.0	59.6	63.2	45.5	8.82	0.54	0.37	0.35	0.35

[1] After a 10-d acclimation period, a total of 360 pigs were fed 1 of 8 treatment diets. There were 5 pigs per pen and 9 pens per treatment. Pigs were fed Phase 1 treatment diets from d 10 to 25 postweaning and Phase 2 diets from d 25 to 35 postweaning.

[2] Preplanned orthogonal contrasts to compare Roxazyme inclusion (regardless of or corn type) vs. no enzyme.

[3] Apparent total tract digestibility. Calculated from analyzed feed and fecal samples collected on d 30 of the experiment and analyzed using titanium dioxide as an indigestible marker.

Table 5. Main effects of drought-affected corn and/or carbohydrase enzyme inclusion on nursery pig growth performance and nutrient digestibility[1,2]

	Normal vs. drought				Enzyme inclusion					
Item	Normal	Drought	SEM	*P* =	None	Roxazyme G2G	Ronozyme VP	Roxazyme G2G + VP	SEM	*P* =
Body weight, lb										
d 0	12.9	12.9	0.01	0.78	12.9	12.9	12.9	12.9	0.01	0.53
d 10	14.8	14.8	0.11	0.87	14.8	14.8	14.8	14.8	0.15	1.00
d 25	26.0	25.7	0.33	0.48	25.8	26.2	25.6	25.9	0.46	0.82
d 35	38.4	37.9	0.44	0.46	38.3	38.7	37.6	38.1	0.63	0.66
d 10 to 25										
ADG, lb	0.74	0.72	0.017	0.40	0.73	0.77	0.71	0.73	0.025	0.43
ADFI, lb	1.01	1.00	0.019	0.64	1.02	1.01	1.01	0.99	0.027	0.89
F/G	1.38	1.39	0.019	0.65	1.39	1.33	1.43	1.37	0.027	0.11
d 25 to 35										
ADG, lb	1.22	1.22	0.025	0.93	1.22	1.25	1.20	1.22	0.034	0.80
ADFI, lb	1.85	1.79	0.029	0.15	1.81	1.85	1.81	1.79	0.041	0.82
F/G	1.52	1.47	0.026	0.20	1.49	1.49	1.52	1.48	0.037	0.89
d 10 to 35										
ADG, lb	0.92	0.93	0.015	0.61	0.93	0.96	0.91	0.92	0.021	0.33
ADFI, lb	1.34	1.31	0.021	0.30	1.33	1.35	1.33	1.31	0.029	0.86
F/G	1.44	1.42	0.013	0.32	1.44	1.40	1.47	1.42	0.019	0.09
ATTD, %[3]										
DM	85.3	85.2	0.39	0.85	85.6	85.6	85.1	84.8	0.55	0.65
Ash	51.6	53.1	1.38	0.47	48.2	56.3	50.2	54.7	1.95	0.02
CP	78.6	78.4	0.64	0.82	79.1	79.7	76.6	78.5	0.91	0.10
Fat	53.7	48.0	1.52	0.01	50.3	48.1	54.4	50.7	2.14	0.21
Fiber	85.3	85.2	0.39	0.85	85.6	85.6	85.1	84.8	0.55	0.65

[1] After a 10-d acclimation period, a total of 360 pigs were fed 1 of 8 treatment diets. Pigs were fed Phase 1 treatment diets from d 10 to 25 postweaning and Phase 2 diets from d 25 to 35 postweaning.
[2] Main effect interactions were not significant for any measured variable ($P > 0.24$) and were thus removed from the model.
[3] Apparent total tract digestibility. Calculated from analyzed feed and fecal samples collected on d 30 of the experiment and analyzed using titanium dioxide as an indigestible marker.

Feed Processing Parameters and Their Effects on Nursery Pig Growth Performance

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Summary

A total of 180 nursery pigs (PIC 327 × 1050; initially 27.8 lb) were used in an 18-d study to determine the effects of conditioning parameters and feed form on pig performance. All diets were the same corn, dried distillers grains with solubles (DDGS), and soybean meal-based formulation with different processing parameters used to create the experimental treatments. Treatments included: (1) negative control mash diet, (2) positive control pelleted diet conditioned at 60 rpm, (3) pelleted diet conditioned at 30 rpm and reground, (4) pelleted diet conditioned at 60 rpm and reground, and (5) pelleted diet conditioned at 90 rpm and reground. The different rpm values among treatments represent the time in the conditioner during processing. The lower the rpm value, the longer time feed was in the conditioner. Pigs were weaned and fed a common acclimation diet for 21 d prior to the start of the experiment. Average daily gain and F/G did not differ ($P > 0.12$) between treatments overall, but ADFI decreased ($P = 0.03$) for pigs fed the pelleted, positive control diet compared with all other diets. Although no overall treatment effects were significant for ADG or F/G, the experiment was designed more specifically to evaluate treatment differences using preplanned comparisons. When considering preplanned contrasts, we observed that pigs fed mash diets tended to have greater ($P = 0.10$) ADG than those fed pelleted and reground diets, suggesting that processing may have had a negative influence on feed utilization, a hypothesis that is further supported because pigs fed mash diets tended to have greater ($P = 0.06$) ADG compared with those fed diets that were heat-processed, regardless of regrinding. Considering these results, it was not surprising that pigs fed mash diets had greater ($P = 0.05$) ADG and ADFI ($P = 0.01$) than those fed pelleted diets. When directly comparing diets conditioned at 60 rpm, fed either as whole pellets or reground to mash consistency, pigs fed pelleted diets had improved ($P = 0.01$) F/G due to lower ADFI ($P = 0.004$) but similar ADG ($P = 0.60$). This unexpected negative impact of pelleting on ADG may be due to a negative influence of heat treatment on palatability. The expected improvement in F/G from pelleting (6.8%) was observed but lost when diets were reground to near original mash particle size. This result may indicate that diet form (high-quality pellets vs. mash) affects F/G more than degree of starch gelatinization or other intrinsic factors associated with conditioning ingredients.

Key words: conditioning, feed processing, growth performance, pelleting, nursery pig

Introduction

Although pelleting diets is generally accepted as a method to improve feed efficiency, whether the improvement is due to enhancements in nutrient utilization or changes

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in diet form that minimize potential feed wastage is subject to disagreement. The role of starch gelatinization on efficiency of nutrient use and its impact on animal growth performance has not been consistently demonstrated in previous studies. Discrepancies among past experiments may be influenced by differences in diet formulation or processing conditions; furthermore, much of the previous research was conducted more than 10 years ago, when animals possessed less genetic potential for lean growth performance than those today. Thus, testing processing effects with current genetics may yield improvements in animal performance. Factors such as degree of starch gelatinization may now be both statistically and biologically significant with faster-growing and more efficient pigs; therefore, the objective of this experiment was to determine if conditioning retention time affects nursery pig performance regardless of diet form.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used for this experiment. The study was conducted at the Kansas State University Segregated Early Weaning Facility in Manhattan.

A total of 180 nursery pigs (PIC 327 × 1050; initially 27.8 lb) were utilized in an 18-d growth experiment. Pigs were weaned at 21 d of age and fed common diets for 21 d until the start of the experiment. There were 6 pigs per pen and 6 replicates per treatment. Each pen contained 1 nipple waterer and 1 self-feeder to allow for ad libitum access to water and feed. At 42 d of age, pigs were weighed and treatments were randomly assigned to pens in a completely randomized design.

All diets were corn, dried distillers grains with solubles (DDGS), and soybean meal–based (Table 1), but they were processed differently to form the experimental treatments. The 5 treatments consisted of a negative control diet that was fed in mash form, a positive control diet that was pelleted and conditioned at 60 rpm and fed in pellet form, and 3 diets that were pelleted but conditioned at 30, 60, or 90 rpm then reground and fed in mash form. The rpm difference represents the number of rotations of the central shaft and paddles inside the conditioner. Lowering the rpm slows the speed of the rotating paddles, and thus increases the retention time of the feed in the conditioner. The lower the rpm, the longer the feed remains in the conditioner. All pelleted diets were pelleted at 190°F. Samples of diets were collected after processing and analyzed for particle size and bulk density (Table 2). Pigs were weighed and feed disappearance was determined on d 0 and 18 to determine ADG, ADFI, and F/G.

Data were analyzed using the GLIMMIX procedure in SAS (SAS Institute, Inc., Cary, NC) with pen as experimental unit. Treatment was the fixed effect, and no random effects were observed. Preplanned orthogonal contrasts included the 3 reground diets vs. mash diet, the 4 heat-processed diets vs. mash diet, pellet diet vs. mash diet, and pelleted diet conditioned at 60 rpm vs. reground diet processed at 60 rpm. The results were considered significant if $P \leq 0.05$ and trends if $P \leq 0.10$.

Results and Discussion

As expected, ADFI was greater ($P = 0.03$) in pigs fed the mash diet, but this did not affect BW, ADG, or F/G ($P > 0.13$; Table 3). Because ADFI is determined by measur-

ing feed disappearance, we suspect that this response is a reflection of increased wastage rather than actual feed consumption.

Our intention was to regrind pelleted diets to a particle size similar to that of the negative control mash diet, but the reground diets had average particle sizes that were 66 to 100 μm smaller and average bulk densities that were 0.9 to 1.5 lb/bu heavier than mash diets (Table 2). Wondra et al. (1995[4]) reported that a 200-μm difference in particle size (400 vs. 600 μm) affected ($P < 0.05$) ADG. No research has evaluated if a difference of 100-μm particle size will affect pig growth performance, but using the Wondra et al. (1995) data, one can extrapolate that a 100-μm decrease in particle size yields a 1.3% improvement in feed efficiency. We observed no significant impact of mash vs. reground diets in BW, ADFI, or F/G in our study, but we saw a trend toward increased ADG ($P = 0.10$) for pigs fed mash diets compared with those fed pelleted and reground diets.

Based on the work of Lundblad et al. (2011[5]), one would expect pigs fed pelleted diets to have reduced ADFI and a 6 to 7% improvement in F/G compared with those fed mash diets; however, pigs fed pelleted diets in our study had reduced ADFI ($P = 0.01$), which was not correlated to an improvement in F/G ($P = 0.30$) because ADG was also negatively affected ($P = 0.05$). The cause of the reduction in ADFI is unknown but may be partially attributable to feed wastage; nevertheless, the overall ADG was greater, so feed intake and subsequent growth of nursery pigs eating mash diets was inexplicably greater than those fed pelleted diets. The expected improvement in feed efficiency was observed when comparing pelleted diets to those that were pelleted and processed at the same rpm but reground and fed in meal form. Pigs fed pelleted diets had the expected reduction ($P = 0.004$) in ADFI with similar ADG, which translated into improved F/G ($P = 0.01$; 1.49 vs. 1.70 for pelleted vs. reground, respectively).

In this experiment, we observed an unexpected negative impact of pelleting on ADG, which may be due to a negative impact of heat treatment on palatability. We observed the expected improvement in F/G from pelleting (6.8%), but this improvement was lost when diets were reground to near-original mash particle size. This result may indicate that diet form (high-quality pellets vs. mash) affects F/G more than degree of starch gelatinization or other intrinsic factors associated with conditioning ingredients.

[4] Wondra, K.J., J.D. Hancock, K.C. Behnke, R.H. Hines, and C.R. Stark.1995. Effects of particle size and pelleting on growth performance, nutrient digestibility, and stomach morphology in finishing pigs. J. Anim. Sci. 73:757–763.

[5] Lundblad, K.K., S. Issa, J.D. Hancock, K.C. Behnke, E. Prestløkken, L.J. McKinney, S. Alavi, J. Fledderus, and M. Sørensen. 2011. Effects of steam conditioning at low and high temperature, expander conditioning, and extruder processing prior to pelleting on growth performance and nutrient digestibility of nursery pigs and broiler chickens. Anim. Feed. Sci. Technol. 169:209–217.

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

Ingredient, %	
Corn	40.55
Soybean meal	25.25
Corn DDGS[2]	30.00
Poultry fat	0.50
Monocalcium phosphate	1.03
Limestone	1.30
Salt	0.35
L-lysine-HCL	0.45
DL-methionine	0.07
L-threonine	0.09
Vitamin premix	0.25
Trace mineral premix	0.15
Total	100.00
Calculated analysis	
Standardized ileal digestible (SID) amino acids, %	
Lysine	1.26
Isoleucine:lysine	65
Leucine:lysine	156
Methionine:lysine	33
Met & Cys:lysine	58
Threonine:lysine	62
Tryptophan:lysine	17.0
Valine:lysine	74
Total lysine, %	1.47
ME, kcal/lb	1,495
SID lysine:ME, g/Mcal	3.82
CP, %	24.1
Ca, %	0.76
P, %	0.69
Available P, %	0.41

[1] Diets were fed for 18 d beginning when the pigs were 42 d old.
[2] Dried distillers grains with solubles.

Table 2. Particle size and bulk density in treatment diets[1]

Form:	Mash	Pelleted	Pelleted then reground		
Conditioning rpm:[2]	n/a	60	30	60	90
Particle size					
Mean (dgw, µm)	592	-	526	492	508
SD, (sgw)	2.4	-	2.1	2.1	2.1
Bulk density, lb/bu	41.0	48.6	41.9	42.3	42.5

[1] All samples were collected at the feeders during the trial. Particle size was run on a Ro-Tap E Test Sieve Shaker (Tyler Industrial Group, Mentor, OH) with 13 sieves and a pan. Bulk density was calculated in g/qt then converted to lb/bu.
[2] Rpm was preset using the automation system during pelleting and verified manually.

Table 3. Effects of processing parameters on nursery pig performance[1]

Form:	Mash	Pelleted	Pelleted then reground				
Conditioning rpm:[2]	n/a	60	30	60	90	SEM	*P* =
BW, lb							
d 0	27.8	27.8	27.9	27.9	27.9	0.46	1.00
d 18	47.9	45.9	46.8	46.4	46.7	0.90	0.63
ADG, lb[3,4]	1.12	1.01	1.05	1.03	1.05	0.04	0.34
ADFI, lb	1.78[b]	1.50[a]	1.72[b]	1.82[b]	1.77[b]	0.07	0.03
F/G[5]	1.60	1.49	1.65	1.76	1.70	0.07	0.13

[ab] Means within a row that lack a common superscript differ $P < 0.05$.
[1] A total of 180 pigs (42 d of age; initially 27.8 lb) were used, with 6 pigs per pen and 6 pens per treatment.
[2] Rpm was preset using the automation system during pelleting and verified manually.
[3] Pigs fed mash diets had greater ADG than those fed the pelleted but not reground diet ($P = 0.05$).
[4] Pigs fed mash diets tended to have greater ADG than those fed pelleted then reground diets ($P = 0.10$).
[5] Pigs fed diets pelleted at 60 rpm and fed as pellets had improved F/G compared with those fed the diet as reground ($P = 0.01$).

Effects of Corn Particle Size, Complete Diet Grinding, and Diet Form on 24- to 50-lb Nursery Pig Growth Performance[1,2]

J.A. De Jong, J.M. DeRouchey, M.D. Tokach, R.D. Goodband, C.W. Hastad[3], and S.S. Dritz[4]

Summary

A total of 996 pigs (PIC TR4; initially 24.5 lb BW and 40 d of age) were used in a 21-d study to determine the effects of corn particle size, complete diet grinding, and diet form on nursery pig growth performance and caloric efficiency. Pens of pigs were balanced by initial BW and randomly allotted to 1 of 6 dietary treatments with 6 replications per treatment and 28 pigs per pen. The same corn-soybean meal–based diet containing 30% corn dried distillers grains with solubles (DDGS) and 10% wheat middlings (midds) was used for all treatments. The 6 treatments were: (1) roller mill–ground corn (737 µ) fed in meal form; (2) treatment 1 fed in pellet form; (3) hammer mill–ground corn (324 µ) fed in meal form; (4) treatment 3 fed in pellet form; (5) complete mixed diet reground through a hammer mill (541 µ) fed in meal form; and (6) treatment 5 in pellet form.

Overall (d 0 to 21), ADG and ADFI decreased when corn was finely ground and fed in meal form but increased when fed in pelleted form, resulting in a tendency ($P < 0.09$) for a diet form × corn particle size interaction. Fine-grinding the complete mixed diet had no effects. Pelleting diets improved ($P < 0.04$) ADG, F/G, ME and NE energetic efficiencies, and final BW.

In conclusion, pelleting diets significantly improved performance, and reducing the particle size of corn from 737 to 324 µ improved nursery pig performance when fed in pelleted form.

Key words: nursery pig, fine-grinding, pelleting

Introduction

Cereal grains are ground to improve nutrient digestibility and pig growth performance. A wide range of ingredient particle sizes can be obtained by grinding through 1-, 2-, 3-, or even 4-high roller mills or hammer mills equipped with various screen sizes, hammer configurations, and operating conditions. Although numerous research studies have been conducted to investigate the impact of grinding cereal grains, little research has reported the effects of grinding complete diets after initial mixing.

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[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] New Fashion Pork, Jackson, MN.
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Pelleting is another feed processing technology used throughout the swine industry to improve nutrient utilization and pig performance, but few data are available on the interactions of pelleting diets in the presence of different particle sizes for individual ingredients or the entire diet. Therefore, the objective of this experiment was to determine the interactive effects of fine-grinding corn or complete diet grinding and diet form (pellet vs. meal) on nursery pig growth performance and caloric efficiency.

Procedures

The protocol for this experiment was approved by the Kansas State University Institutional Animal Care and Use Committee. The study was conducted at New Fashion Pork's nursery research facility in Buffalo Center, IA. Pens (6 × 13 ft) contained a 5-hole dry self-feeder and nipple waterer to allow for ad libitum access to feed and water. All pigs were fed common pelleted starter diets for the 19 d between weaning and the start of the experiment.

A total of 996 pigs (PIC TR4; initially 24.5 lb BW and 40 d of age) were used in a 21-d study to determine the effects of corn particle size, complete diet grinding, and diet form on nursery pig growth performance and caloric efficiency. Pens of pigs (28 pigs per pen) were balanced by initial BW and randomly allotted to 1 of 6 dietary treatments with 6 replications per treatment. The same corn-soybean meal–based diet containing 30% corn DDGS and 10% wheat midds was used for all treatments. The 6 treatments were: (1) roller mill–ground corn (737 µ) fed in meal form; (2) treatment 1 fed in pellet form; (3) hammer mill–ground corn (324 µ) fed in meal form; (4) treatment 3 fed in pellet form; (5) treatment 3 reground through a hammer mill (541 µ) fed in meal form; and (6) treatment 5 fed in pellet form.

All ingredients were ground and mixed at New Fashion Pork's feed mill in Estherville, IA. All 737-µ corn (treatments 1 and 2) was ground by a 2-high roller mill (RMS Roller Grinder, Tea, SD). Corn used in treatments 3 and 4 was finely ground using a full-circle hammer mill (Jacobsen Machine Works, Minneapolis, MN) equipped with a 1/16-in. screen. The complete diets used for treatments 5 and 6 were ground using a hammer mill (Easy Automation, Welcome, MN) equipped with a 1/16-in. screen. All pelleted diets were processed using a CPM pellet mill (California Pellet Mill, San Francisco, CA) equipped with a 1/6-in. die.

Pig weight and feed disappearance were measured on d 0, 7, 14, and 21 of the experiments to calculate ADG, ADFI, and F/G. Caloric efficiency of pigs was determined on both an ME and NE basis. Caloric efficiencies were determined using calculated dietary ingredient values for ME from NRC (2012) and for NE from INRA (2004). Values provided by the commercial producer were used for the ME and NE of DDGS. 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.

Multiple samples of each diet were collected from feeders, blended and subsampled, then submitted to Ward Laboratories, Inc. (Kearney, NE) for analysis of DM, CP, crude fat, crude fiber, ash, Ca, P, ADF, NDF, and NFE.

Bulk density was determined for all ingredients pre- and post-grind as well as for the complete diets. Particle size of the corn, soybean meal, DDGS, midds, and complete meal diets 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. A geometric mean particle size (dgw) and the log-normal SD (sgw) were calculated by measuring the amount of grain remaining on each screen. Pellets were analyzed for standard pellet durability index (PDI), and a modified PDI was determined by adding five 13-mm hexagonal nuts prior to tumbling. Percentage fines and angle of repose were also determined for all pellet and meal diets, respectively.

Data were analyzed as a completely randomized design using PROC MIXED in SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Contrasts were used to compare the effects of diet form, corn particle size, diet particle size, and the interactions of diet form × corn particle size and diet form × diet particle size. Results were considered significant at $P \leq 0.05$ and a trend at $P \leq 0.10$.

Results and Discussion

Chemical analysis of corn, soybean meal, midds, and DDGS confirmed that nutrients were similar to those used for diet formulation (Tables 1 and 2). The minor differences were not expected to influence the results of the experiment. Nutrient analysis of treatment diets (Table 3) showed that the concentrations were similar to formulated values. As expected, as the particle size of the diets decreased, the angle of repose increased, which illustrates reduced flowability with the finer particle sizes (Table 4). Bulk densities of meal diets were relatively similar. Diets that were pelleted were higher in bulk density compared with the meal diets. Across all treatments, PDI, modified PDI, and percentage fines were similar.

Overall (d 0 to 21), ADG and ADFI decreased when corn was finely ground and fed in meal form but increased when fed in pelleted form, resulting in a tendency ($P < 0.09$) for a diet form × corn particle size interaction. Fine-grinding the complete diet did not influence pig performance or the response to pelleting. Pelleting diets improved ($P < 0.04$) ADG, F/G, ME and NE energetic efficiencies, and final BW (Tables 5 and 6).

The interaction of diet form × corn particle size and numerical decreases in intake of pigs fed the fine-ground complete diet suggests that finely ground feed fed in meal form may reduce palatability of the diet; however, improved performance from fine-grinding may be realized if the diet is fed in pelleted form. In conclusion, pelleting diets significantly improved performance, and fine-grinding corn numerically improved performance when fed in pelleted form. No additional improvements were found when the complete diet with fibrous ingredients was finely ground compared with grinding only the corn.

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

Ingredient, %	
Corn	33.33
Soybean meal (46.5% CP)	22.82
Wheat middlings	10.00
DDGS[2]	30.00
Beef tallow	1.00
Monocalcium phosphate	0.30
Limestone	1.50
Salt	0.35
L-lysine HCl	0.45
Methionine hydroxy analog	0.08
L-threonine	0.08
Vitamin and mineral premix	0.10
Total	100.00
Calculated analysis	
Standardized ileal digestible (SID) amino acids, %	
Lysine	1.23
Isoleucine:lysine	64
Leucine:lysine	150
Methionine:lysine	33
Met & Cys:lysine	58
Threonine:lysine	62
Tryptophan:lysine	17.4
Valine:lysine	74
Total lysine, %	1.44
ME, kcal/lb[3]	1,522
NE, kcal/lb[4]	1,094
SID lysine:ME, g/Mcal	3.88
CP, %	3.66
Crude fiber, %	4.06
NDF, %	19.49
ADF, %	8.04
Ca, %	0.71
P, %	0.59
Available P, %	0.42

[1] Experimental diets were fed for 21 d beginning when pigs weighed 24.5 lb.
[2] Dried distillers grains with solubles.
[3] NRC. 2012. Nutrient Requirements of Swine. 11th ed. Natl. Acad. Press, Washington DC.
[4] 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 ingredients (as-fed basis)[1,2]

Item	DDGS	Soybean meal	Corn	Wheat middlings
DM, %	89.56	90.06	87.67	89.34
CP, %	29.4 (27.2)	47.7 (46.5)	7.7 (8.50)	16.1 (15.90)
ADF, %	10.4	4.2	2.5	12.1
NDF, %	25.9	6.1	6.0	34.2
Crude fiber, %	8.0 (7.3)	3.1 (3.9)	1.6 (2.2)	8.9 (7.00)
NFE, %	37.5	31.4	73.6	53.6
Ca, %	0.05 (0.03)	0.56 (0.03)	0.06 (0.03)	0.25 (0.12)
P, %	0.91 (0.71)	0.70 (0.69)	0.25 (0.28)	1.15 (0.93)
Fat, %	9.9	0.9	3.2	4.2
Ash, %	4.39	6.62	1.20	5.75
Starch	3.1	1.7	61.9	16.3
Particle size, μ[3]	483	786	737; 324[3]	590
Particle size, SD[4]	2.07	2.01	1.89; 2.00	2.15
Bulk density, lb/bu	50.0	64.4	49.8; 48.2[4]	22.8

[1] Values in parentheses for dried distillers grains with solubles (DDGS) are taken from Stein (2007).
[2] Values in parentheses from NRC (1998).
[3] Values listed first are initial particle sizes, values listed second are particle sizes post–hammer mill grinding.
[4] Values listed first are roller mill–ground SD; values listed second are hammer mill–ground SD.

Table 3. Chemical analysis of diet[1]

Item	
DM, %	88.97
CP, %	19.7
ADF, %	4.9
NDF, %	11.2
Crude fiber, %	3.6
NFE, %	55.8
Ca, %	0.88
P, %	0.47
Fat, %	5.1
Ash, %	4.48
Starch, %	39.0

[1] Diet 1 was used for analysis.

Table 4. Physical characteristic of diets

Treatment:	1	2	3	4	5	6
Ingredient processed:	---	---	Corn[1]	Corn	Diet[2]	Diet
Item Diet form:	Meal	Pellet	Meal	Pellet	Meal	Pellet
Particle size, µ	656	---	425	---	540	---
Bulk density, lb/bu	51.8	62.6	52.8	59.0	52.0	59.4
Angle of repose, °	46.9	---	54.4	---	51.8	---
Standard pellet durability index	---	91.6	---	93.5	---	92.1
Modified pellet durability index	---	89.4	---	91.5	---	90.1
Fines, %	---	1.3	---	1.3	---	1.2

[1] Corn was fine-ground to approximately 324 µ.
[2] Diet was fine-ground to approximately 540 µ.

Table 5. Effects of corn particle size, complete diet grinding, and diet form on 24- to 50-lb nursery pig growth performance[1]

Treatment:	1	2	3	4	5	6	
Ingredient finely ground:	---	---	Corn[2]	Corn	Diet[3]	Diet	
Item Diet form:	Meal	Pellet	Meal	Pellet	Meal	Pellet	SEM
d 0 to 21							
ADG, lb	0.93	0.95	0.89	1.00	0.92	0.99	0.03
ADFI, lb	1.22	1.19	1.18	1.24	1.20	1.23	0.03
F/G	1.54	1.46	1.57	1.45	1.54	1.43	0.21
Caloric efficiency[4]							
ME	5.18	4.90	5.28	4.87	5.17	4.79	32.71
NE	3.72	3.53	3.80	3.50	3.72	3.44	23.51
Wt, lb							
d 21	44.2	44.6	43.1	45.5	44.0	45.4	0.8

[1] A total of 996 pigs (initially 24.5 lb BW and 40 d of age) were used in a 21-d study with 28 pigs/pen and 6 pens/treatment.
[2] Corn was fine-ground to approximately 324 µ.
[3] Diet was fine-ground to approximately 540 µ.
[4] Caloric efficiency is expressed as kcal/lb gain.

Table 6. Effects of corn particle size, complete diet grinding, and diet form on 24- to 50-lb nursery pig growth performance

	Probability, *P* <				
Item Contrast:	Pelleting × Corn μ[1]	Pelleting × portion ground[2]	Diet form[3]	Corn μ[4]	324-μ corn vs. 540-μ diet[5]
d 0 to 21					
ADG, lb	0.07	0.45	0.002	0.84	0.61
ADFI, lb	0.09	0.42	0.84	0.65	0.88
F/G	0.33	0.82	0.001	0.61	0.20
Caloric efficiency[6]					
ME	0.34	0.82	0.001	0.61	0.20
NE	0.34	0.82	0.001	0.61	0.20
Wt, lb					
d 21	0.23	0.55	0.04	0.90	0.62

[1] Interactive effects of diet form and corn μ.
[2] Interactive effects of diet form and corn or complete diet grinding.
[3] Treatments 1, 3, and 5 vs. 2, 4, and 6.
[4] Treatments 1 and 2 vs. 3 and 4.
[5] Treatments 3 and 4 vs. 5 and 6.
[6] Caloric efficiency is expressed as kcal/lb gain.

Effects of Fine-Grinding Corn or Dried Distillers Grains with Solubles and Diet Form on Growth Performance and Caloric Efficiency of 25- to 50-lb Nursery Pigs[1,2]

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Summary

A total of 687 pigs (PIC 1050 barrows; initially 25.5 lb BW and 37 d of age) were used in a 21-d study to determine the effects of fine-grinding corn or dried distillers grains with solubles (DDGS) and diet form on nursery pig performance and caloric efficiency. Pens of pigs were balanced by initial BW and randomly allotted to 1 of 10 dietary treatments with 14 replications per treatment. There were 5 pigs per pen in two groups of nursery pigs. The 10 experimental diets included 4 corn-soybean meal–based diets consisting of: (1) corn ground to ~638 µ, in meal form; (2) treatment 1 in pellet form; (3) corn ground to ~325 µ, in meal form, and (4) treatment 3 in pellet form. The remaining 6 diets contained 30% DDGS. Diets 5 through 10 consisted of: (5) corn and DDGS ground to ~638 and 580 µ, in meal form; (6) diet 5 in pellet form; (7) corn and DDGS ground to ~638 and 391 µ, in meal form; (8) diet 7 in pellet form; (9) corn and DDGS ground to ~325 and 391 µ, in meal form; and (10) diet 9 in pellet form.

Overall (d 0 to 21), a corn particle size (regardless of DDGS addition) × diet form interaction was observed ($P < 0.01$) as a result of increased ADFI when corn was finely ground and fed in pellet form but decreased intake when corn was finely ground and fed in meal form. Pelleting diets decreased ($P < 0.001$) ADG, ADFI, and final BW but improved ($P < 0.001$) F/G and caloric efficiency on both an ME and NE basis. Fine-grinding corn decreased ($P < 0.04$) ADG as a result of numerically decreased ADFI ($P < 0.16$). Feeding 30% DDGS also decreased ($P < 0.01$) ADG, ADFI, and NE caloric efficiency and tended to decrease ($P < 0.07$) final BW. In conclusion, pelleting diets and fine-grinding ingredients reduced ADG as a result of decreased ADFI, but pelleting improved feed efficiency. Feeding 30% DDGS was detrimental to nursery pig growth performance.

Key words: DDGS, nursery pig, particle size, pelleting

Introduction

Feed processing and manufacturing technologies allow for more efficient nutrient utilization of grains used in swine diets. Two primary technologies help improve ingredient utilization: fine-grinding and pelleting. The primary grain source (i.e., corn or sorghum)

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

typically is the only ingredient ground because other dietary ingredients arrive at the feed mill in processed form, and feed mills are not normally designed to grind non-cereal ingredients either pre- or post-mixing. Little is known about the effects of fine-grinding other ingredients in combination with the cereal grain source or the effect that the whole-diet particle size may have on nursery pig performance.

Previous research with pelleting corn-soybean meal–based diets has shown an improvement in ADG and feed efficiency of nursery pigs; however, few data are available on the interaction between pelleting high-fiber diets and particle size of ingredients on nursery pig performance. Therefore, the objective of this experiment was to determine the effects of fine-grinding corn, DDGS, or both and diet form (pellet vs. meal) on nursery pig growth performance.

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 K-State Segregated Early Weaning Facility in Manhattan, KS. Pens (4 × 4 ft) had wire-mesh floors and deep pits 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. All pigs were fed common starter diets for approximately 18 d before the start of the experiment.

A total of 687 pigs in two consecutive groups (PIC 1050 barrows; initially 25.5 lb BW and 37 d of age) were used in a 21-d study. Pens of pigs were balanced by initial BW and randomly allotted to 1 of 10 dietary treatments with 14 replications per treatment and 5 pigs per pen. The 10 experimental diets included 4 corn-soybean meal–based diets consisting of: (1) corn ground to ~638 µ in meal form; (2) treatment 1 in pellet form; (3) corn ground to ~325 µ, in meal form; and (4) treatment 3 in pellet form. The remaining 6 diets contained 30% DDGS. Diets 5 through 10 consisted of: (5) corn and DDGS ground to ~638 and 580 µ, in meal form; (6) diet 5 in pellet form; (7) corn and DDGS ground to ~638 and 391 µ, in meal form; (8) diet 7 in pellet form, (9) corn and DDGS ground to ~325 and 391 µ, in meal form; and (10) diet 9 in pellet form.

All ingredients were ground and mixed at the K-State Grain Science and Industry Feed Mill. All 638-µ corn was ground by a 3-high roller mill (Model TP 912, Roskamp Manufacturing, Cedar Falls, IA). All finely ground ingredients were processed using a full-circle teardrop hammer mill (P-240D Pulverator, Jacobsen Machine Works, Minneapolis, MN) with a 1/16-in. screen. Diets were pelleted in a 30-horsepower pellet mill (30 HD Master Model, California Pellet Mill, San Francisco) with a 1/8-in.-thick die with 3/20-in. openings. Corn was from the same lot and was split at the mill to be ground through the hammer mill or roller mill.

All diets were formulated to meet or exceed the nutrient requirement estimates as defined by the NRC (1998; Table 1). Diets were not balanced for energy, so as DDGS increased in the diet, dietary energy increased slightly. All diets were formulated to a constant standardized ileal digestible (SID) lysine concentration.

Caloric efficiency of pigs were determined on both an ME and NE basis. Caloric efficiencies of pigs were determined using dietary ingredient values for ME (DDGS value

used was equal to corn) from NRC (1998)[4] and for NE from INRA (2004)[5]. 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. Values from NRC (1998) were used because the NRC (2012) had not been published at the time of diet formulation. Pig weight and feed disappearance were measured on d 0, 7, 14, and 21 of the experiments to calculate ADG, ADFI, and F/G.

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, crude fiber, ash, Ca, P, ADF, NDF, and NFE.

Bulk density was determined for all ingredients pre- and post-grind as well as for the complete diets. Particle size of the corn, soybean meal, DDGS, and complete meal diets also were determined using a standard method for determining particle size. Tyler sieves, with screen numbers 6, 8, 10, 14, 20, 28, 35, 48, 65, 100, 150, 200, 270, and a pan were used. A Ro-Tap shaker (W.S. Tyler, Mentor, OH) was used to sift the 100-g samples for 10 min. A geometric mean particle size (dgw) and the log-normal SD (sgw) were calculated by measuring the amount of grain remaining on each screen. For all diets in pelleted form, pellet durability index (PDI) and percentage fines were determined. Pellets were analyzed for PDI (ASAE, 1987) and modified PDI by altering the procedure by adding five 13-mm hexagonal nuts prior to tumbling. Percentage fines and angle of repose were also determined for all pellet and meal diets, respectively.

Data from both groups were combined and analyzed as a completely randomized design using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Treatment was considered a fixed effect and group as a random effect in the statistical model. Contrasts were used to compare the effects of diet form, corn particle size, DDGS particle size, and diet type (corn soybean meal vs. high by-product). Results were considered significant at $P \leq 0.05$ and a trend at $P \leq 0.10$.

Results and Discussion

Nutrient chemical analysis of corn, soybean meal, and DDGS used were verified to be similar to those used in formulation (Table 2). The minor differences were not expected to influence the results of the experiment. Nutrient analysis of treatment diets (Table 3) showed that the concentrations were similar to formulated values. The only exception was ADF and NDF, which were all slightly lower than formulated values. As expected, as the portion of the diet that was ground increased, the particle size of the diet decreased, which led to an increase in the diet angle of repose (Table 4). Bulk densities of meal diets were all relatively similar. Diets that were pelleted were higher in bulk density compared with the meal diets. Across all treatments, PDI and modified PDI, percentage fines, mill throughput, and hot pellet temperature were all similar.

Overall (d 0 to 21), a corn particle size (regardless of DDGS addition) × diet form interaction was observed ($P < 0.01$) as a result of increased ADFI when corn was finely

[4] NRC. 1998. Nutrient Requirements of Swine, 10th ed. Natl. Acad. Press, Washington DC.
[5] 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.

ground and fed in pellet form, but intake decreased when corn was finely ground and fed in meal form. Pelleting the diets decreased ($P < 0.001$) ADG, ADFI, and final BW and improved ($P < 0.001$) F/G and caloric efficiency on both an ME and NE basis. Fine-grinding corn decreased ($P < 0.04$) ADG as a result of numerically decreased ADFI ($P < 0.016$). Also, feeding 30% DDGS decreased ($P < 0.01$) ADG and ADFI, resulted in poorer NE caloric efficiency, and tended to decrease ($P < 0.07$) final BW (Tables 5 and 6).

Why pelleting and fine-grinding had few positive, and even some negative, effects on nursery pig performance in the current experiment is not clear. Some reasons could include decreased palatability of finely ground ingredients, limited or no benefit to grinding grain finer than 600 µ for nursery pigs, or limited biological benefits of fine-grinding other ingredients for nursery pigs. The lack of growth improvement with pelleting may have been a result of increased pellet hardness supported by high measured PDI values. The negative effects of DDGS on nursery pig growth performance also were not expected.

More research clearly needs to be conducted to determine the optimum particle size of cereal grains and complete diets when fed to nursery pigs as well as the effects of pellet hardness on nursery pig performance.

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

	DDGS, %[2]	
Item	0	30
Ingredient, %		
Corn	63.23	39.14
Soybean meal (46.5% CP)	32.83	27.39
DDGS	---	30.00
Monocalcium phosphate (21% P)	1.63	0.93
Limestone	0.98	1.35
Salt	0.35	0.35
Vitamin premix	0.25	0.25
Trace mineral premix	0.15	0.15
L-lysine HCl	0.33	0.40
DL-methionine	0.14	---
L-threonine	0.13	0.05
Phytase[3]	0.13	0.13
Total	100.00	100.00
Calculated analysis		
Standardized ileal digestible (SID) amino acids		
Lysine, %	1.28	1.28
Ise:lysine	61	66
Leu:lysine	129	160
Methionine:lysine	34	28
Met & Cys:lysine	58	58
Threonine:lysine	63	63
Tryptophan:lysine	17.5	17.5
Valine:lysine	68	77
Total lysine, %	1.42	1.47
ME, kcal/lb[4]	1,496	1,501
NE, kcal/lb[5]	1,067	1,086
SID lysine:ME, g/Mcal	3.88	3.87
CP, %	21.1	24.6
Crude fiber, %	2.7	1.9
NDF, %	10	17.6
ADF, %	3.9	7.5
Ca, %	0.80	0.80
P, %	0.74	0.71
Available P, %	0.42	0.42

[1] Experimental diets were fed from d 0 to 21.
[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] NRC. 1998. Nutrient Requirements of Swine, 10th ed. Natl. Acad. Press, Washington DC.
[5] 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 ingredients (as-fed basis)[1]

Item	DDGS[2]	Soybean meal[3]	Corn[3]
DM, %	91.16	89.34	89.06
CP, %	31.2 (27.2)	44.8 (46.5)	9.3 (8.50)
ADF, %	10.6	6.1	2.5
NDF, %	25.4	7.5	5.9
Crude fiber, %	7.3(7.3)	3.5(3.9)	2(2.2)
Crude fat, %	9.4	1.6	3.2
NFE, %	38.3	33	73.2
Ca, %	0.09 (0.03)	0.51 (0.03)	0.06 (0.03)
P, %	0.91 (0.71)	0.66 (0.69)	0.26 (0.28)
Ash, %	4.87	6.5	1.39
Starch	3.1	4.3	61.9
Particle size, μ[4]	580; 391	780	638; 325
Particle size, SD[5]	1.90; 1.86	2.13	2.18; 2.21
Bulk density, lb/bu[6]	48.2	55.1	49.6

[1] All values are averages of the ingredients used for the 2 groups used in this experiment.
[2] Dried distillers grains with solubles. Values in parentheses for DDGS are taken from Stein (2007).
[3] Values in parentheses from NRC (1998).
[4] Values listed first are initial particle sizes; values listed second are particle sizes post–hammer mill grinding.
[5] Values listed first are roller mill–ground SD; values listed second are hammer mill–ground SD.
[6] Bulk density was determined from hammer mill–ground samples for DDGS and corn.

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

	Control[2]	30% DDGS[3]
DM, %	90.81	91.93
CP, %	21.3	25.6
ADF, %	3.8	6.2
NDF, %	6.3	12.9
Crude fiber, %	2.1	3.5
Crude fat, %	2.3	4.0
NFE, %	59.5	52.5
Ca, %	0.97	1.04
P, %	0.71	0.75
Ash, %	5.8	6.4

[1] A composite sample consisting of 6 subsamples from each of 2 groups within each experiment.
[2] Control diet was a corn-soybean meal–based diet.
[3] Dried distillers grains with solubles.

Table 4. Analysis of diets

Treatment:	1	2	3	4	5	6	7	8	9	10
Diet:[1]	C	C	C	C	DDGS	DDGS	DDGS	DDGS	DDGS	DDGS
Ingredient processed:[2]	---	---	Corn	Corn	---	---	DDGS	DDGS	Both	Both
Item Diet form:	Meal	Pellet	Meal	Pellet	Meal	Pellet	Meal	Pellet	Meal	Pellet
Diet particle size, µ	724	---	619	---	709	---	703	---	550	---
Bulk density, lb/bu	54.0	55.6	49.0	57.4	51.4	53.7	52.1	53.9	53.4	53.2
Angle of repose, °	50.1	---	52.8	---	50.9	---	51.0	---	55.3	---
Standard pellet durability index	---	96.0	---	94.6	---	93.3	---	96.9	---	95.4
Modified pellet durability index	---	91.2	---	92.3	---	90.3	---	92.5	---	92.8
Fines, %	---	6.4	---	8.0	---	4.5	---	5.0	---	1.2
Production rate, lb/h	---	2,564		2,839		2,421		2,784		2,828
Hot pellet temperature, °F	---	190	---	192	---	190	---	190	---	190

[1] C = Control diet was a corn-soybean meal–based diet. DDGS = 30% dried distillers grains with solubles.
[2] Corn ground to ~638 µ and fine-ground to ~325 µ. DDGS received at ~580 µ and fine-ground to ~391 µ .

Table 5. Effects of fine-grinding corn and/or dried distillers grains with solubles (DDGS) and diet forms on 25- to 50-lb nursery pig performance[1]

Treatment:	1	2	3	4	5	6	7	8	9	10	
Diet:[2]	C	C	C	C	DDGS	DDGS	DDGS	DDGS	DDGS	DDGS	
Ingredient processed:[3]	---	---	Corn	Corn	---	---	DDGS	DDGS	Both	Both	
Item Diet form:	Meal	Pellet	Meal	Pellet	Meal	Pellet	Meal	Pellet	Meal	Pellet	SEM
d 0 to 21											
ADG, lb	1.37	1.31	1.30	1.23	1.30	1.20	1.31	1.18	1.27	1.25	0.05
ADFI, lb	2.18	1.98	2.05	1.93	2.11	1.84	2.10	1.84	2.04	1.93	0.08
F/G	1.59	1.51	1.58	1.58	1.63	1.53	1.61	1.56	1.61	1.55	0.02
Caloric efficiency[4]											
ME	2,384	2,255	2,368	2,359	2,445	2,300	2,414	2,342	2,417	2,328	34.5
NE	1,700	1,609	1,689	1,683	1,770	1,664	1,747	1,695	1,749	1,684	24.9
Wt, lb											
d 0	25.59	25.58	25.56	25.57	25.61	25.56	25.55	25.54	25.58	25.54	0.69
d 21	53.66	52.54	52.16	50.69	52.18	50.98	52.46	49.94	51.76	51.06	1.14

[1] A total of 687 pigs (initially 25.5 lb BW and 37 d of age) were used in a 21-d study with 5 pigs/pen and 14 pens/treatment.
[2] C = Control diet was a corn-soybean meal–based diet. DDGS = 30% dried distillers grains with solubles.
[3] Corn ground to ~638 µ and fine-ground to ~325 µ. DDGS received at ~580 µ and fine-ground to ~391 µ.
[4] Caloric efficiency is expressed as kcal/lb of gain.

Table 6. Effects of fine-grinding corn and/or dried distillers grains with solubles (DDGS) and diet form on 25- to 50-lb nursery pig performance

	Diet:	Probability, $P <$				
Item	Contrast:	Corn μ × diet form[1,2]	Diet form[3]	Corn μ[4]	DDGS μ[5]	Diet[6]
d 0 to 21						
ADG, lb		0.15	0.001	0.04	0.95	0.001
ADFI, lb		0.01	0.001	0.16	0.95	0.008
F/G		0.13	0.001	0.43	0.87	0.19
Caloric efficiency[7]						
ME		0.14	0.001	0.42	0.88	0.13
NE		0.14	0.001	0.44	0.87	0.01
Wt, lb						
d 21		0.62	0.008	0.21	0.64	0.07

[1] Interactive effects of corn particle size and diet form.
[2] No interactive effects ($P > 0.20$) of diet × diet form, or DDGS μ × diet form.
[3] Pellet vs. meal (treatments 1, 3, 5, 7, and 9 vs. 2, 4, 6, 8, and 10).
[4] Corn particle size effect (treatments 1, 2, 7, and 8 vs. 3, 4, 9, and 10).
[5] DDGS particle size effect (treatments 5 and 6 vs. 7 and 8).
[6] DDGS effect (treatments 1 and 2 vs. 5 and 6).
[7] Caloric efficiency is expressed as kcal/lb gain.

Effects of Corn Particle Size and Diet Form on Finishing Pig Growth Performance and Carcass Characteristics[1,2]

J.E. Nemechek, M.D. Tokach, K.F. Coble, J.M. DeRouchey, R.D. Goodband, and S.S. Dritz[3]

Summary

A total of 960 pigs (PIC TR4 × Fast Genetics York-AND × PIC Line 02, initially 75.7 lb BW) were used in a 101-d trial to determine the effect of corn particle size and diet form on finishing pig growth performance and carcass characteristics. Pens were randomly allotted to 1 of 6 experimental treatments by initial BW with 8 pens per treatment and 20 pigs per pen. All diets were fed in four phases with the same corn-soybean meal–based diet containing 30% dried distillers grains with solubles (DDGS; Phases 1 to 3) or 15% DDGS (Phase 4) used for all diets. The 6 experimental treatments were arranged in a 2 × 3 factorial with main effects of final feed form (meal vs. pellet) and corn particle size (650 µ, 350 µ, or an equal blend of the 650 µ and 350 µ ground corn). Overall (d 0 to 101), linear particle size × diet form interactions were observed ($P < 0.02$) for ADFI and F/G due to ADFI decreasing and F/G improving as particle size was reduced for pigs fed meal diets but not for pigs fed pelleted diets. Pigs fed pelleted diets had increased ($P < 0.001$) ADG and final BW and improved ($P < 0.001$) F/G. As corn particle size decreased, ADG and ADFI decreased ($P < 0.02$) linearly. Pigs fed pelleted diets had increased ($P < 0.001$) HCW compared with pigs fed meal diets. Yield, backfat, and loin depth were not influenced by particle size or diet form.

In summary, pigs fed pelleted diets had improved growth performance compared with those fed meal diets, with the greatest improvement in F/G observed from pigs fed coarse-ground (650 µ) corn. Feed efficiency improved as corn particle size decreased for pigs fed meal diets but not for those fed pelleted diets, suggesting that there was no benefit to grinding corn finer than 650 µ for pelleted diets.

Key words: finishing pig, particle size, pelleting

Introduction

Previous research at Kansas State University has shown that growth performance can be improved if corn particle size is reduced or if the diets are fed in pellet form, but grinding the complete diets was not beneficial (De Jong et al., 2012[4]). In this previous trial, the entire corn fraction of each experimental diet was ground to a specific particle size using either a roller mill (650 µ) or a hammer mill (320 µ). By feeding a blend of corn

[1] Appreciation is expressed to New Fashion Pork for the use of pigs and facilities and to Chad Hastad and Ryan Cain for technical assistance.
[2] This project was supported by National Research Initiative Competitive Grand 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] De Jong et al., Swine Day 2012, Report of Progress 1074, pp. 316–324

varying in particle size, the throughput of some feed mills could be increased, but little research has been conducted to determine the impact on finishing pig growth performance. Therefore, the objective of the current experiment was to determine the effect of corn particle size (650 μ, 350 μ, or an equal blend of the 650 μ and 350 μ ground corn) and diet form (meal vs. pellet) on finishing pig growth performance 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 New Fashion Pork Research Facility (Round Lake, MN) in a commercial research-finishing barn located in northwestern Iowa. The double-curtain-sided barn was tunnel-ventilated with completely slatted flooring and deep pits for manure storage. Each pen was equipped with a 5-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 deliveries for individual pens.

A total of 960 pigs (PIC TR4 × Fast Genetics York-AND × PIC Line 02, initially 75.7 lb BW) were used in a 101-d trial. Pens were randomly allotted by initial BW to 1 of 6 experimental treatments with 8 pens per treatment with 20 pigs per pen. Diets were fed in 4 phases, with Phases 1 through 4 fed from d 0 to 26, 26 to 46, 46 to 73, and 73 to 101, respectively (Table 1). Within each phase, the same corn-soybean meal–based diet containing 30% DDGS (Phases 1 through 3) or 15% DDGS (Phase 4) was used for all 6 experimental treatments. The 6 experimental treatments were arranged in a 2 × 3 factorial with main effects of final feed form (meal vs. pellet) and corn particle size (650 μ, 350 μ, or an equal blend of the 650 μ and 350 μ ground corn). All diets were prepared at New Fashion Pork's commercial feed mill in Estherville, IA.

Pigs were weighed and feed disappearance measured approximately every 2 weeks to calculate ADG, ADFI, and F/G. On d 87 of the trials, pens were weighed and the 6 heaviest pigs (selected by the marketing serviceman) were removed and transported 350 miles to Triumph Foods (St. Joseph, MO) for harvest. The remaining pigs were transported to Triumph Foods on d 101 for harvest. Pigs were weighed and feed disappearance was determined approximately every 21 d to calculate ADG, ADFI, and F/G. Yield was calculated using live weight at the farm and HCW at the plant. At the plant, backfat and loin depth were measured, and percentage lean was calculated using NPPC (1991) guidelines for lean containing 5% fat: Lean % = (2.83 + (0.469 × (HCW)) – (18.47 × (fat depth)) + (9.824 × loin depth))/(HCW).

Samples of corn and complete diets were collected during each phase. Particle size of corn samples and diets in meal form was determined using Tyler sieves (numbers 6, 8, 10, 14, 20, 28, 35, 48, 65, 100, 150, 200, 270, and a pan) and a Ro-Tap shaker (W.S. Tyler, Mentor, OH). One hundred-gram samples were sifted for 10 min without a flow agent, and the weight on each screen was used to calculate the mean particle size (Table 2). 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, and fines were characterized as material that would pass through a #6 sieve (3,360 µ opening).

Data were analyzed as a completely randomized design using PROC MIXED in SAS (SAS Institute, Inc., Cary, NC), with pen as the experimental unit. Treatments were analyzed as a 2 × 3 factorial with main effects of corn particle size and diet form. Linear and quadratic effects of decreasing particle size were determined as well as interactive effects of corn particle size and diet form. Results were considered significant at $P < 0.05$ and considered a trend at $P < 0.10$.

Results and Discussion

Particle size and pellet quality measurements

Particle size of corn was similar to expectations with corn targeted at 650 µ ranging from 616 to 681 µ and corn targeted at 350 µ ranging from 336 to 359 µ (Table 2). Because corn particle size of the diets containing a 50:50 mixture of 650 and 350 µ ground corns could not be determined, whole diet particle size was measured. These data found that whole diets of the 50:50 mixture were intermediate between high– and low–particle size corn diets, which was expected. High-quality pellets were produced as reflected by the PDI being greater than 90% and the percentage fines being 20% or less for all diets and phases.

Growth performance and carcass measurements

Overall (d 0 to 101), linear particle size × diet form interactions were observed ($P < 0.02$) for ADFI and F/G because ADFI decreased and F/G improved as particle size was reduced for pigs fed meal diets, but not for pigs fed pelleted diets (Table 3). Pigs fed pelleted diets had increased ($P < 0.001$) ADG and improved ($P < 0.001$) F/G. As corn particle size decreased, ADG and ADFI decreased ($P < 0.02$) linearly. Pigs fed pelleted diets had increased ($P < 0.001$) HCW compared with pigs fed meal diets, but no other effects ($P > 0.12$) on carcass characteristics were observed.

In summary, pigs fed pelleted diets had improved growth performance compared with those fed meal diets, with the greatest magnitude of F/G improvement to pellets occurring when pigs were fed 650-µ corn. Feed efficiency improved as corn particle size decreased for pigs fed meal diets but not for those fed pelleted diets, suggesting that grinding corn finer than 650 µ for pelleted diets conferred no benefit. Further research is needed to understand why F/G did not improve in pelleted diets as particle size was reduced from 650 to 350 µ.

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

Item	Phase 1	Phase 2	Phase 3	Phase 4
Ingredient, %				
Corn	48.45	53.13	56.33	63.28
Soybean meal (46.5% CP)	17.88	13.36	10.39	18.42
Dried distillers grains with solubles	30.00	30.00	30.00	15.00
Beef tallow	1.50	1.50	1.50	1.50
Limestone	1.36	1.22	1.06	1.05
Salt	0.35	0.35	0.35	0.35
Vitamin-trace mineral premix	0.100	0.100	0.075	0.050
L-lysine HCl	0.365	0.340	0.305	0.275
L-threonine	---	---	---	0.050
Ractopamine HCl[2], 9 g/lb	---	---	---	0.025
Total	100	100	100	100
Calculated analysis				
Standardized ileal digestible (SID) amino acids, %				
Lysine	1.01	0.88	0.78	0.90
Isoleucine:lysine	68	70	72	68
Leucine:lysine	172	185	200	166
Methionine:lysine	30	33	35	30
Met & Cys:lysine	58	62	67	58
Threonine:lysine	60	62	65	65
Tryptophan:lysine	17	17	17	18
Valine:lysine	80	83	87	79
Total lysine, %	1.20	1.06	0.95	1.05
ME, kcal/lb	1,559	1,563	1,567	1,551
CP, %	21.3	19.5	18.3	18.5
Ca, %	0.58	0.52	0.45	0.46
P, %	0.43	0.41	0.40	0.39
Available P, %	0.32	0.31	0.30	0.32

[1] Phase 1 diets were fed from d 0 to 26, Phase 2 from d 26 to 46, Phase 3 from d 46 to 73, and Phase 4 from d 73 to 101.
[2] Paylean; Elanco Animal Health (Greenfield, IN).

Table 2. Analysis of pellet quality and particle size[1]

Corn particle size:	650 µ		50:50 blend		350 µ	
Item	Meal	Pellet	Meal	Pellet	Meal	Pellet
Corn particle size, µ						
Phase 1	675	675	---	---	350	350
Phase 2	616	616	---	---	336	336
Phase 3	681	681	---	---	359	359
Phase 4	656	656	---	---	355	355
Diet particle size, µ						
Phase 1	610	---	541	---	425	---
Phase 2	595	---	480	---	483	---
Phase 3	611	---	483	---	455	---
Phase 4	622	---	500	---	496	---
Standard pellet durability index, %[2]						
Phase 1	---	92.8	---	94.1	---	96.0
Phase 2	---	97.6	---	93.2	---	94.5
Phase 3	---	94.1	---	91.7	---	95.8
Phase 4	---	96.8	---	92.4	---	97.8
Modified pellet durability index, %[3]						
Phase 1	---	89.5	---	87.4	---	86.5
Phase 2	---	91.4	---	91.6	---	89.0
Phase 3	---	90.2	---	92.0	---	89.3
Phase 4	---	90.1	---	90.2	---	91.4
Fines, %						
Phase 1	---	9.2	---	11.7	---	11.3
Phase 2	---	9.7	---	10.5	---	8.8
Phase 3	---	18.2	---	11.9	---	10.7
Phase 4	---	20.0	---	8.6	---	11.2

[1] A composite sample of 3 subsamples was used for analysis.
[2] Pellet durability index was determined using the standard tumbling-box technique.
[3] Procedure was altered by adding 5 hexagonal nuts prior to tumbling.

Table 3. The effect of corn particle size and diet form (meal vs. pellet) on finishing pig performance[1]

Corn particle size:	650 µ		50:50 blend[2]		350 µ			Probability, P <				
								Diet form × particle size			Particle size	
Diet form:	Meal	Pellet	Meal	Pellet	Meal	Pellet	SEM	Linear	Quadratic	Diet form	Linear	Quadratic
d 0 to 101												
ADG, lb	1.97	2.07	1.96	2.05	1.91	2.03	0.021	0.58	0.72	< 0.001	0.01	0.58
ADFI, lb	5.31	5.19	5.22	5.23	4.99	5.18	0.065	0.02	0.82	0.60	0.02	0.28
F/G	2.69	2.51	2.67	2.55	2.62	2.56	0.020	0.005	0.94	< 0.001	0.65	0.34
Weight, lb												
d 0	75.7	75.7	75.7	75.7	75.8	75.7	0.989	0.99	0.99	0.99	0.99	0.99
d 101	263.9	275.5	264.8	274.1	260.5	268.1	2.860	0.50	0.96	0.002	0.07	0.33
Carcass characteristics[3]												
HCW, lb	195.4	205.3	193.4	199.4	197.4	203.6	2.017	0.34	0.63	< 0.001	0.12	0.23
Yield, %	74.1	74.5	74.3	74.4	74.6	74.3	0.402	0.68	0.41	0.80	0.94	0.77
Backfat, in.	0.72	0.74	0.72	0.72	0.72	0.75	0.026	0.32	0.62	0.33	0.42	0.56
Loin depth, in.	2.62	2.61	2.58	2.65	2.60	2.57	0.029	0.32	0.35	0.82	0.92	0.42
Lean, %[4]	55.6	55.2	55.2	55.9	55.3	55.1	0.326	0.26	0.39	0.95	0.87	0.49

[1] A total of 960 pigs (PIC TR4 × Fast Genetics York-AND × PIC Line 02, initially 75.7 lb BW) were used in a 101-d trial with 8 pens per treatment and 20 pigs per pen.
[2] Equal blend of the 650-µ and 350-µ ground corn.
[3] The 6 largest pigs were marketed from each pen on d 87. All remaining pigs were marketed from each pen on d 101. Carcass characteristics other than yield were adjusted by using HCW as a covariate.
[4] Calculated using NPPC (1991) guidelines for lean containing 5% fat. Lean % = (2.83) + (0.469 × (HCW)) – (18.47 × (fat depth)) + (9.824 × loin depth)) / (HCW).

Influence of a Superdose of Phytase (Optiphos) on Finishing Pig Performance and Carcass Characteristics[1]

R.D. Goodband, K.B. Langbein, M.D. Tokach, S.S. Dritz[2], and J.M. DeRouchey

Summary

A total of 1,188 finishing pigs (PIC 337 × 1050, initially 80.1 lb) were used in a 92-d experiment to determine the influence of providing phytase above that needed to meet the P requirement for growth performance and carcass characteristics. There were 27 pigs per pen and 11 pens per treatment. Each pen contained a similar number of barrows and gilts. Pens were randomly assigned to treatment based on initial BW. Basal diets contained corn, soybean meal, dried distillers grains with solubles (DDGS), and bakery meal and were formulated to meet or exceed the nutrient requirements of the pigs in each of the four phases. The four dietary treatments were formed by adding increasing levels of phytase (Optiphos 2000, Enzyvia LLC) at 0.25 (control), 0.5, 1.0 and 2.0 lb/ton. Diets were formulated such that the addition of the first 0.25 lb/ton of phytase was needed to meet the P requirement of the pigs, with further additions exceeding the P requirement. Pigs were weighed and feed disappearance was determined approximately every 14 d to determine ADG, ADFI, and F/G. On d 92, pigs were tattooed by pen number and harvested to collect carcass data.

Overall (d 0 to 92), increasing dietary phytase did not influence ADG but reduced (cubic, $P < 0.01$) ADFI, resulting in an improvement in F/G (cubic, $P < 0.01$). The cubic response occurred because F/G improved as phytase inclusion increased from 0.25 to 0.5 lb/ton, with no further improvement when phytase was increased to 1.0 or 2.0 lb/ton. Phytase addition to the diet did not influence carcass measurements. These results suggest that providing phytase at levels above that needed to meet the pig's requirement for P has the potential to improve feed efficiency.

Key words: finishing pig, phosphorus, phytase

Introduction

Phytase has been included in swine diets as a means of improving the digestibility of the P in the diet. Previous research illustrates that increasing the phytase dose results in a quadratic increase in P digestibility when diets are formulated to be at or below the requirement of the pig. Some recent research has also suggested that additions of phytase at levels much greater than that needed to meet pigs' P requirements may lead to improvements in the digestibility of other dietary nutrients, such as amino acids, trace minerals, and energy. Therefore, the objective of this experiment was to confirm if

[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.

providing a high dose (superdose) of phytase, above that needed to meet the P requirement, would influence pig growth performance and carcass characteristics.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in these experiments. The 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 self-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.

A total of 1,188 pigs (PIC 337 × 1050; initially 80.1 lb) were used in the 92-d study. There were 27 pigs per pen, with a similar number of barrows and gilts in each pen. Pens were randomly assigned to the 4 dietary treatments with 11 pens per treatment.

The 4 dietary treatments were increasing levels of phytase (Optiphos 2000, Enzyvia LLC) at 0.25, 0.5, 1.0, and 2.0 lb/ton (Table 1). Diets were formulated such that the addition of the first 0.25 lb/ton of phytase was needed to meet the pigs' P requirements, with further additions exceeding the phosphorus requirement. Corresponding phytase levels in the 4 diets were 113.5, 227, 454, and 908 phytase units (FTU)/lb (250, 500, 1,000, and 2,000 FTU/kg). The basal diet was corn-soybean meal–based and contained 15% bakery meal and decreasing levels of DDGS by phase and was formulated to meet or exceed the nutrient requirements of the pigs as defined by NRC (2012). Diets were fed in 4 phases from approximately 80 to 130, 130 to 180, 180 to 240, and 240 to 288 lb BW.

Pigs and feeders were weighed approximately every 14 d to determine ADG, ADFI, and F/G. On d 72, the 3 heaviest pigs from each pen (determined visually) were marketed following normal farm procedures. On d 92, the remaining pigs were harvested for carcass data collection. Pigs were tattooed by pen and transported to JBS Swift and Company (Worthington, MN) for processing and carcass data collection.

All data were analyzed as a completely randomized design using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Statistical significance was determined at $P < 0.05$, and P-values falling between $P > 0.05$ and $P < 0.10$ were considered trends. Contrast statements were used to test for linear, quadratic, and cubic effects. Polynomials for the unequally spaced treatments were determined and used in the contrast statements.

Results and Discussion

Overall (d 0 to 92), growth performance was excellent in this trial, with pigs gaining 2.3 lb/d; however, increasing added phytase did not influence ADG (Table 2). Increasing phytase dose reduced (cubic, $P < 0.01$) ADFI, resulting in an improvement in F/G (cubic, $P < 0.01$). The cubic response was a reflection of F/G improving as phytase inclusion increased from 0.25 to 0.5 lb/ton, with no further improvement

when phytase increased to 1.0 or 2.0 lb/ton. Quadratic responses are often observed when data respond in this manner, but in this study the unequally spaced treatments and lowest F/G for pigs fed the 0.5 lb/ton phytase level resulted in the cubic response. Phytase addition to the diet did not influence any of the carcass characteristics measured in this study.

The improvement in F/G as phytase level increased above that needed to meet the P requirement of the pigs demonstrates that providing a "superdose" of phytase can improve pig performance. The phytase used in this experiment is thought to provide a release of approximately 0.12% available P at 0.25 lb/ton. Providing additional phytase may release more P; however, with diets formulated to meet the P requirement at the 0.25 lb/ton inclusion, the additional phytase is thought to improve F/G through improved digestibility of the other nutrients in the diet, specifically amino acids and/or energy. Because diets should have met the amino acid requirements of the pigs, the extra energy availability is the most logical explanation for improved feed efficiency.

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

Item	Phase 1	Phase 2	Phase 3	Phase 4
Corn[2]	37.10	41.15	53.10	51.30
Soybean meal (46.5% CP)	15.50	11.50	9.75	16.40
Bakery meal	15.00	15.00	15.00	15.00
Corn DDGS, 9.6% oil[3]	30.00	30.00	20.00	15.00
Limestone	1.40	1.36	1.23	1.21
Salt	0.35	0.35	0.35	0.35
L-threonine	0.013	-	0.02	0.075
Biolys (lysine sulfate)	0.555	0.51	0.45	0.52
Methionine hydroxy analog	-	-	-	0.05
Ractopamine HCl[4]	-	-	-	0.025
Vitamin/trace mineral premix[5]	0.10	0.10	0.10	0.075
Total	100	100	100	100
Calculated analysis				
Standardized ileal digestible (SID) amino acids, %				
Lysine	0.97	0.85	0.74	0.92
Isoleucine:lysine	72	74	73	68
Methionine:lysine	32	35	35	34
Met & cys:lysine	60	65	65	61
Threonine:lysine	61	62	64	65
Tryptophan:lysine	18	18	18	18
Valine:lysine	83	87	86	77
Total lysine, %	1.16	1.03	0.89	1.07
CP, %	20.93	19.32	16.69	18.47
ME, kcal/lb	1,538	1,540	1,543	1,540
SID lysine:ME, g/Mcal	2.86	2.50	2.18	2.71
Ca, %	0.60	0.58	0.52	0.54
P, %	0.42	0.41	0.37	0.38
Available P, %	0.29	0.28	0.24	0.23

[1] Diets were fed in meal form during the experiment.
[2] The 4 dietary treatments were obtained by replacing corn in each diet with Optiphos 2000 (Enzyvia, Sheridan, IN) at a rate of 0.25, 0.50, 1.0, or 2.0 lb/ton.
[3] Dried distillers grains with solubles.
[4] Provided 9 g/lb (10 ppm) of Ractopamine HCl (Paylean; Elanco Animal Health, Greenfield, IN).
[5] Provided per pound of premix: 2,000,000 IU vitamin A; 250,000 IU vitamin D_3; 8,000 IU vitamin E; 800 mg vitamin K; 1,500 mg riboflavin; 5,000 mg pantothenic acid; 9,000 mg niacin; 7 mg vitamin B_{12}; 12 g Mn from manganese oxide; 50 g Fe from iron sulfate; 50 g Zn from zinc sulfate; 5 g Cu from copper sulfate; 90 mg I from calcium iodate; and 90 mg Se from sodium selenite.

Table 2. Effects of increasing levels of Optiphos 2000 in growth performance of finishing pigs[1]

	Phytase, lb/ton:					Probability, *P*<		
	0.25	0.50	1.00	2.00	SEM	Linear	Quadratic	Cubic
d 0 to 92								
ADG, lb	2.28	2.28	2.30	2.26	0.017	0.25	0.27	0.54
ADFI, lb	5.81[b]	5.59[a]	5.75[ab]	5.67[ab]	0.062	0.49	0.72	0.01
F/G	2.54[b]	2.45[a]	2.50[ab]	2.51[ab]	0.023	0.90	0.19	0.01
Wt, lb								
d 0	80.2	80.1	80.2	80.0	1.198	0.94	1.00	0.94
d 92	288.6	286.9	288.6	285.5	2.320	0.42	0.68	0.52
Carcass characteristics								
HCW, lb	210.7	211.0	212.2	207.9	1.566	0.16	0.18	0.76
Yield, %[2]	75.1	74.9	74.7	74.7	0.448	0.49	0.64	0.94
Backfat, in.[3]	0.67	0.66	0.65	0.67	0.011	0.75	0.16	0.92
Loin depth, in.[3]	2.59	2.60	2.57	2.57	0.018	0.33	0.89	0.42
Lean, %[3]	56.4	56.6	56.6	56.3	0.180	0.60	0.19	0.67
Fat-free lean index[3]	50.7	50.8	50.9	50.7	0.128	0.67	0.13	0.90

[a,b] Means with different superscripts differ ($P > 0.05$)

[1] A total of 1,188 finisher pigs (initially 80.1 lb) were used in a 92-d trial with 27 pigs per pen and 11 pens per treatment.

[2] Yield was determined by dividing carcass weight by live weight at the plant.

[3] HCW was used as a covariate.

Effects of High Levels of Phytase (Ronozyme HiPhos) in Low-Lysine Diets on the Growth Performance of Nursery Pigs[1]

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Summary

Two studies were conducted to determine the effects of added phytase in nursery pig diets formulated at or below their dietary lysine requirements. In Exp. 1, a total of 360 nursery pigs (PIC 327 × 1050, initially 27.3 lb) were used in an 18-d study with 5 pigs per pen and 18 pens per treatment in a university research facility. Pens of pigs were randomly allotted to 1 of 4 dietary treatments arranged in a 2 × 2 factorial with main effects of lysine level (adequate; 1.2% standardized ileal digestible [SID] lysine vs. marginal; 1.05% SID lysine) and phytase level (500 vs. 3,000 phytase units [FTU]/kg) with Ronozyme HiPhos (DSM Nutritional Products, Parsippany, NJ) as the source of phytase. Overall (d 0 to 18), no ($P > 0.37$) lysine × phytase interactions and no differences ($P > 0.14$) were observed among phytase levels. Pigs fed adequate lysine diets had greater ($P < 0.01$) ADG and BW and better F/G than those fed marginal lysine diets. In Exp. 2, 2,592 nursery pigs (PIC 1050 × 337, initially 23 lb) were fed 1 of 6 dietary treatments over 2 phases in a 36-d study in a commercial research barn. Dietary treatments included an adequate lysine (1.20 and 1.10% SID lysine in Phases 1 and 2, respectively) positive control diet containing 250 FTU/kg of phytase, or 5 low-lysine (1.10 and 1.00% SID lysine in Phases 1 and 2, respectively) diets with 250, 500, 1,000, 2,000, or 3,000 FTU/kg of phytase. Overall, pigs fed the positive control had greater ($P < 0.02$) ADG and better F/G than pigs fed the low-lysine diet with the same amount of phytase. Increasing phytase in the low-lysine diets increased (quadratic, $P < 0.02$) ADG, with the optimum response observed in pigs fed 1,000 FTU/kg. Phytase did not affect F/G.

In summary, these studies confirmed the importance of feeding adequate lysine to optimize gain and feed efficiency. These studies also illustrate the differences between studies conducted in university vs. commercial settings because only the commercial study yielded a detectable phytase response. In the commercial study, pigs fed the low-lysine diet with 1,000 FTU/kg of phytase had performance similar to pigs fed high-lysine diets containing 250 FTU/kg of phytase.

Key words: phosphorous, phytase, nursery pig

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Introduction

Phytase is an enzyme routinely added to swine diets to enhance phosphorus utilization. Phytase acts by catalyzing the stepwise removal of phosphates from phytic acid or phytate, thus making the P from phytic acid more available to the pig. This increase in availability of P allows for less inorganic phosphorus addition to the diet, which ultimately results in reduced diet cost and less mineral excretion. Ronozyme HiPhos is suggested to release a greater portion of the phytate-bound phosphorus in the diet than other phytase sources.

Adding greater amounts of phytase than that needed to meet the P requirement, a practice called "super-dosing," could potentially increase digestibility of nutrients other than P and result in improved gain and efficiency; however, this added benefit has not been observed consistently. Because lysine is the first limiting amino acid in swine diets, feeding a diet below the lysine requirement, phytase is provided an opportunity to improve performance. Therefore, the objective of these experiments was to determine the effects of phytase beyond releasing P in diets formulated to be adequate or low in standardized ileal digestible lysine on nursery pig performance.

Procedures

The protocols for these experiments were approved by the Kansas State University Institutional Animal Care and Use Committee. Experiment 1 was conducted in a University research barn at the K-State Segregated Early Weaning Facility in Manhattan, KS. Experiment 2 was conducted in a commercial research barn at the New Horizon Farms Nursery Research Center in Pipestone, MN.

In Exp. 1, a total of 360 nursery pigs (PIC 327 × 1050, initially 27.3 lb) were used in an 18-d study with 5 pigs per pen and 18 pens per treatment (Table 1). Each pen had metal slatted floors, one 4-hole self-feeder, and a cup waterer to allow for ad libitum access to feed and water. Pigs were initially weaned at approximately 21 d of age. After arrival to the nursery, pigs were fed common pretest diets for the first 14 d after weaning. The pretest diet met all nutrient requirements, including P. On d 14 after weaning, pens of pigs were weighed and randomly allotted to 1 of 4 dietary treatments arranged in a 2 × 2 factorial with main effects of lysine level (adequate, 1.2% SID vs. low, 1.05% SID lysine) and added phytase (500 vs. 3,000 FTU/kg). The phytase used in these studies was Ronozyme HiPhos and was assumed to release 0.13% available P with an inclusion of 500 FTU/kg. Basal diets were formulated to contain 0.33% available P. Average daily gain, ADFI, and F/G were determined by weighing pigs and measuring feed disappearance on d 0, 7, 14, and 18.

In Exp. 2, a total of 2,592 nursery pigs (PIC 1050 × 337, initially 23.2 lb) were used in a 36-d study (Table 2). Pigs were initially weaned at approximately 21 d of age. After arrival to the nursery, pigs were fed common pre-test diets for 21 d before the start of the experiment. The barn was mechanically ventilated and had completely slatted flooring and deep pits for manure storage. Each pen was equipped with a 5-hole stainless steel dry self-feeder (STACO, Inc., Schaefferstown, PA) 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. Pigs were weighed and

allotted to pens with 27 pigs per pen and 16 pens per treatment. Pigs were fed in two phases (d 0 to 22 and d 22 to 36). There were 6 dietary treatments consisting of an adequate lysine (1.20 and 1.10% SID lysine in Phases 1 and 2, respectively) positive control diet containing 250 FTU/kg of phytase, or 5 low-lysine (1.10 and 1.00% SID lysine in Phases 1 and 2, respectively) diets with 250, 500, 1,000, 2,000, or 3,000 FTU/kg of phytase. The same phytase source was used as that in Exp. 1. To manufacture the low-lysine treatments, the diet with 250 FTU and the diet with 3,000 FTU were first manufactured then blended together to form the intermediate phytase treatments. Average daily gain, ADFI, and F/G were determined by weighing pigs and measuring feed disappearance on d 0, 7, 14, 22, 29, and 36.

In both experiments, data were analyzed as a completely randomized design using PROC MIXED in SAS (SAS Institute Inc., Cary, NC) with pen as the experimental unit. In Exp. 1, the main effects of phytase, lysine and their interactions were tested. In Exp. 2, the positive control diet was compared with the low-lysine diet that contained the same amount of phytase. Within the low-lysine diets, linear and quadratic contrasts were used to compare phytase levels. Differences between treatments were determined using least squares means with results considered significant at $P \leq 0.05$ and trends at $P \leq 0.10$.

Results and Discussion

In Exp. 1, no ($P > 0.38$) lysine × phytase interactions were observed for any period or response criteria, and no ($P > 0.14$) effects of super-dosing phytase were observed for any period or response. From d 0 to 7 and 7 to 14, increasing lysine improved ($P < 0.01$) ADG and F/G. Average daily feed intake tended to increase ($P < 0.08$) from d 14 to 18 for pigs fed low-lysine diets. Overall (d 0 to 18), ADG and F/G improved ($P < 0.01$) in pigs fed the high-lysine diet. Pig BW was greater ($P < 0.05$) on d 14 and 18 for pigs fed the high-lysine diets (Table 3).

In Exp. 2, from d 0 to 22, ADG tended to increase (quadratic, $P < 0.06$) with increasing levels of phytase in the low-lysine diet, with the greatest improvement coming from 1,000 FTU/kg of phytase. From d 22 to 36, ADG increased (linear, $P < 0.03$), ADFI tended to increase (quadratic, $P < 0.06$), and F/G tended to improve (linear, $P < 0.08$) with increasing levels of added phytase in low-lysine diets (Table 4). In addition, ADG and F/G improved ($P < 0.01$) for pigs fed the adequate lysine diet compared with the low-lysine diet when the same level of phytase was used. Overall, from d 0 to 36, ADG increased (quadratic, $P < 0.02$) when phytase addition increased in the low lysine diets. Pigs fed the positive control diet containing adequate lysine had better ($P < 0.02$) ADG and F/G compared with pigs fed the low-lysine diet that contained the same amount of phytase.

In conclusion, these experiments emphasize the importance of formulating diets with adequate lysine to promote growth performance. These studies also illustrate the differences between studies conducted in university vs. commercial settings because a phytase response was detected only in the commercial study. In the commercial study, pigs fed the low-lysine diet with 1,000 FTU/kg of phytase had performance similar to pigs fed high-lysine diets containing 250 FTU/kg of phytase.

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

	Lysine level	
Ingredient, %	Adequate	Low
Corn[2]	53.28	58.26
Soybean meal (46.5% CP)	28.22	23.29
Dried distillers grains with solubles	15.00	15.00
Monocalcium P (21% P)	0.90	0.93
Limestone	1.36	1.39
Salt	0.35	0.35
L-lysine HCl	0.35	0.31
DL-methionine	0.06	0.02
L-threonine	0.08	0.05
Vitamin premix	0.25	0.25
Trace mineral premix	0.15	0.15
Total	100	100
Calculated analysis		
Standardized ileal digestible (SID) amino acids, %		
Lysine	1.20	1.05
Isoleucine:lysine	65	66
Methionine:lysine	32	30
Met & Cys:lysine	56	56
Threonine:lysine	62	62
Tryptophan:lysine	18	18
Valine:lysine	72	75
Total lysine, %	1.38	1.22
CP, %	22.4	20.4
ME, kcal/lb	1,483	1,483
SID Lysine:ME, g/Mcal	3.67	3.21
Ca, %	0.76	0.76
P, %	0.62	0.61
Available P, % (without phytase)	0.33	0.33
Available P, % (with 500 FTU phytase)	0.46	0.46

[1] Diets were fed for 18 d to pigs initially 27.3 lb and 35 d of age.
[2] Phytase (Ronozyme HiPhos, DSM Nutritional Products, Parsippany, NJ) replaced corn to provide 500 or 3,000 phytase units (FTU)/kg with 500 FTU/kg releasing 0.13% available P.

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

	Phase 1 diets			Phase 2 diets		
Lysine content:	High	Low[2]		High	Low	
Phytase, FTU/kg[3]:	250	250	3,000	250	250	3,000
Ingredient, %						
Corn	53.64	56.95	56.94	57.77	61.06	61.07
Soybean meal (46.5% CP)	27.89	24.62	24.63	24.57	21.31	21.30
Dried distillers grains with solubles	15.00	15.00	15.00	15.00	15.00	15.00
Monocalcium P (21% P)	0.90	0.93	0.93	0.36	0.38	0.38
Limestone	1.35	1.38	1.38	1.20	1.23	1.23
Salt	0.35	0.35	0.35	0.35	0.35	0.35
L-lysine sulfate	0.56	0.52	0.52	0.52	0.48	0.48
Methionine hydroxy analog	0.08	0.04	0.04	0.03	-	-
L-threonine	0.08	0.06	0.06	0.05	0.04	0.04
Vitamin trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15
Total	100	100	100	100	100	100
Calculated analysis						
Standardized ileal digestible (SID) amino acids, %						
Lysine	1.20	1.10	1.10	1.10	1.00	1.00
Isoleucine:lysine	65	66	66	66	67	67
Methionine:lysine	32	31	31	30	29	29
Met & cys:lysine	56	56	56	55	56	56
Threonine:lysine	62	62	62	61	61	61
Tryptophan:lysine	18	18	18	18	18	18
Valine:lysine	72	74	74	74	76	76
Total lysine, %	1.38	1.27	1.27	1.27	1.16	1.16
CP, %	22.3	21.0	21.0	21.0	19.7	19.7
ME, kcal/lb	1,487	1,488	1,486	1,499	1,500	1,498
SID lysine:ME, g/Mcal	3.66	3.35	3.36	3.33	3.02	3.03
Ca, %	0.76	0.76	0.76	0.60	0.60	0.60
P, %	0.62	0.61	0.61	0.49	0.48	0.48
Available P, % (without phytase)	0.33	0.33	0.33	0.21	0.21	0.21
Available P, % (with 250 FTU phytase)	0.43	0.43	>0.43	0.31	0.31	>0.31

[1] Diets were fed to pigs initially 35 d of age and 23 lb with Phase 1 diets fed for 22 d and Phase 2 diets fed for 14 d.
[2] The low-lysine, low-phytase diet was blended with the low-lysine, high-phytase diet to form 5 low-lysine diets containing 250, 500, 1,000, 2,000, or 3,000 phytase units (FTU)/kg of phytase.
[3] Phytase (Ronozyme HiPhos, DSM Nutritional Products, Parsippany, NJ) replaced corn to form the experimental treatments with 250 phytase units (FTU)/kg releasing 0.10% available P.

Table 3. Influence of phytase inclusion in low- or high-lysine diets on growth performance of nursery pigs, (Exp. 1)[1]

SID lysine, %:[2]	1.20		1.05			Probability, *P*<		
Phytase, FTU/kg:[3]	500	3,000	500	3,000	SEM	Interaction	Phytase	Lysine
d 0 to 7								
ADG, lb	0.97	0.95	0.86	0.89	0.03	0.46	0.90	0.01
ADFI, lb	1.62	1.58	1.57	1.60	0.04	0.42	0.82	0.73
F/G	1.67	1.68	1.84	1.81	0.04	0.65	0.78	0.01
d 7 to 14								
ADG, lb	1.45	1.42	1.36	1.31	0.04	0.82	0.30	0.01
ADFI, lb	2.31	2.29	2.24	2.26	0.04	0.75	0.97	0.27
F/G	1.60	1.62	1.66	1.73	0.03	0.41	0.14	0.01
d 14 to 18								
ADG, lb	1.53	1.48	1.51	1.47	0.05	0.95	0.38	0.81
ADFI, lb	2.49	2.37	2.53	2.50	0.05	0.37	0.15	0.08
F/G	1.65	1.63	1.69	1.72	0.05	0.70	0.91	0.15
d 0 to 18								
ADG, lb	1.28	1.25	1.20	1.18	0.02	0.78	0.33	0.01
ADFI, lb	2.08	2.03	2.05	2.06	0.04	0.45	0.58	0.92
F/G	1.62	1.62	1.71	1.74	0.02	0.38	0.39	0.01
Wt, lb								
d 0	27.3	27.3	27.3	27.3	0.37	0.97	0.99	0.98
d 7	34.1	34.0	33.3	33.5	0.50	0.76	0.95	0.23
d 14	44.2	43.9	42.8	42.7	0.66	0.87	0.73	0.05
d 18	50.3	49.8	48.8	48.6	0.70	0.86	0.57	0.05

[1] A total of 360 nursery pigs (initially 35 d of age and 27.3 lb) were used with 5 pigs per pen and 18 pens per treatment. Phytase (Ronozyme HiPhos, DSM Nutritional Products, Parsippany, NJ) replaced corn to form the experimental treatments with 250 phytase units (FTU)/kg releasing 0.10% available P.

[2] Standardized ileal digestible.

[3] Phytase units/kg.

Table 4. Effects of increasing levels of phytase in low-lysine diets on nursery pig growth performance[1]

									Probability, *P*<		
SID lysine, %:	High[2]	Low[3]							Phytase		
Phytase, FTU/kg:[4]	250	250	500	1,000	2,000	3,000	SEM	TRT	Linear	Quadratic	High vs. Low lysine[5]
d 0 to 22											
ADG, lb	1.03	1.03	1.04	1.06	1.06	1.02	0.018	0.52	1.00	0.06	0.81
ADFI, lb	1.56	1.54	1.54	1.56	1.58	1.54	0.035	0.97	0.65	0.60	0.70
F/G	1.51	1.50	1.48	1.47	1.49	1.51	0.020	0.60	0.46	0.13	0.73
d 22 to 36											
ADG, lb	1.59	1.45	1.51	1.55	1.57	1.54	0.033	0.05	0.03	0.09	0.01
ADFI, lb	2.56	2.55	2.57	2.62	2.69	2.56	0.043	0.14	0.32	0.06	0.86
F/G	1.62	1.76	1.70	1.69	1.72	1.67	0.030	0.03	0.08	0.62	0.01
d 0 to 36											
ADG, lb	1.25	1.19	1.22	1.25	1.25	1.22	0.017	0.07	0.10	0.02	0.02
ADFI, lb	1.95	1.93	1.94	1.97	2.01	1.94	0.034	0.57	0.44	0.23	0.74
F/G	1.56	1.62	1.58	1.57	1.60	1.59	0.017	0.19	0.33	0.21	0.01
Wt, lb											
d 0	23.2	23.3	23.3	23.2	23.2	23.2	0.507	1.00	0.96	1.00	0.98
d 22	46.0	45.8	46.1	46.7	46.5	45.6	0.808	0.93	0.98	0.30	0.89
d 36	68.3	66.2	67.4	68.5	68.5	67.2	1.000	0.55	0.33	0.12	0.16

[1] A total of 2,592 nursery pigs (initially 23.2 lb) were used with 27 pigs per pen and 16 pens per treatment.
[2] High-lysine diets had 1.20% standardized ileal digestible (SID) lysine from d 0 to d 22 and 1.10% SID lysine from d 22 to d 36.
[3] Low-lysine diets had 1.10% SID lysine from d 0 to d 22 and 1.00% SID lysine from d 22 to d 36.
[4] Phytase units/kg.
[5] Comparison of the high- and low-lysine diets that contained 250 phytase units (FTU)/kg of phytase. Phytase (Ronozyme HiPhos, DSM Nutritional Products, Parsippany, NJ) replaced corn to form the experimental treatments with 250 FTU/kg releasing 0.10% available P.

Effects of Super-Dosing Phytase in Diets with Adequate Phosphorus on Finishing Pig Growth Performance and Carcass Characteristics

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Summary

A total of 274 finishing pigs (PIC 1050 × 327, initially 129 lb) were used in a 78-d study to compare the effects of adding high levels of three different sources of phytase (super-dosing) on growth performance and carcass characteristics of finishing pigs. Pigs were randomly allotted to pens with 7 or 8 pigs per pen and 9 replications per treatment. Dietary treatments included a corn-soybean meal–based control diet that was formulated to meet the available P requirements of the pigs without any added phytase, or three diets that were formed by adding 2,000 FTU/kg of phytase from 1 of 3 different phytase sources to the basal diet. The three phytase sources were Quantum Blue 5 G (AB Vista, Chesterfield, MO), Ronozyme HiPhos (GT) 2500 (DSM Nutritional Products, Parsippany, NJ), or Optiphos 1000 (Enzyvia, Sheraton, IN). Overall, regardless of source, super-dosing phytase had no effect ($P > 0.26$) on ADG, ADFI, or F/G; furthermore, there were no effects ($P > 0.36$) on any of the carcass criteria measured. In conclusion, in this environment with nutritionally adequate diets, this study suggests that super-dosing phytase had no beneficial effects on finishing pig growth or carcass performance.

Key words: phosphorous, phytase, finishing pig

Introduction

Phytase is routinely added to swine diets to improve phosphorus availability. "Super-dosing," or adding greater amounts of phytase to diets than that needed to meet the P requirement, has been suggested to elicit additional benefits above those attributed to the enhanced P availability. The hypothesis is that the phytase will improve digestibility and availability of other nutrients besides the P; however, previous research has not consistently demonstrated this benefit. Reasons for the inconsistency might be that different sources of phytase do not elicit the same response, differences in diet formulation (below or at the requirement), and differences in environment (university or commercial facilities). Therefore, the objective of this study was to determine the effects of superdosing phytase from three different phytase sources on finishing pig growth and carcass performance in university facilities.

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 Swine Teaching and Research Center in Manhattan, KS. The barn

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

was 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 274 finishing pigs (PIC 1050 × 327, initially 129 lb) were used in a 78-d study with 7 or 8 pigs per pen and 9 replications per treatment. Pigs were randomly allotted to pen by initial BW and pens were assigned to 1 of 4 dietary treatments that were fed in meal form. The dietary treatments included a corn-soybean meal–based control diet that was formulated to meet the available P requirements of the pigs without any added phytase, or three diets that were formed by adding 2,000 FTU/kg of phytase from 1 of 3 different phytase sources to the basal diet. The three phytase sources were Quantum Blue 5 G (AB Vista, Chesterfield, MO), Ronozyme HiPhos (GT) 2500 (DSM Nutritional Products, Parsippany, NJ), or Optiphos 1000 (JBS United, Sheraton, IN). Diets were fed in 3 phases during the study, with 0.27, 0.23, and 0.21% available P formulated for Phases 1, 2, and 3, respectively (Table 1). Average daily gain, ADFI, and F/G were determined by weighing pigs and measuring feed disappearance every 2 wk throughout the study.

On d 78, all pigs were weighed and transported approximately 2.5 h to a commercial packing plant (Triumph Foods LLC, St. Joseph, MO) for harvest under USDA inspection. Before transport to the plant, pigs were individually tattooed according to pen number to allow for carcass data collection at the packing plant and data retrieval by pen. Hot carcass weight was measured immediately after evisceration, and each carcass was evaluated for carcass yield, backfat depth, loin depth, and percentage lean. Carcass yield was calculated by dividing HCW at the plant by final live weight at the farm before transport to the plant. Fat depth and loin depth were measured with an optical probe inserted between the 3rd and 4th last ribs (counting from the ham end of the carcass) at a distance approximately 3 in. from the dorsal midline.

Data were analyzed as a completely randomized design using the MIXED procedure of SAS (SAS Institute Inc., Cary, NC) with pen as the experimental unit. Differences between treatments were determined by using least squares means. Results were considered significant at $P \leq 0.05$ and considered a trend at $P \leq 0.10$.

Results and Discussion

Overall (d 0 to 78), no differences ($P > 0.26$) were observed between treatments for ADG, ADFI, or F/G (Table 2), and no differences ($P > 0.36$) were observed in HCW, carcass yield, backfat depth, loin depth, or percentage lean. When diets were formulated to meet the available P requirements of the pigs in this study, additional phytase from any of the sources did not benefit growth or carcass performance compared with the control. In conclusion, under the conditions of this study, superdosing phytase in diets formulated to be adequate in available P did not elicit additional benefits in pig performance.

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

Ingredient, %	Phase 1	Phase 2	Phase 3
Corn[2]	61.45	65.95	84.80
Soybean meal (46.5% CP)	15.85	11.60	12.55
Dried distillers grains with solubles	20.00	20.00	0.00
Monocalcium P (21% P)	0.60	0.45	0.75
Limestone	1.24	1.17	1.06
Salt	0.35	0.35	0.35
L-lysine HCl	0.26	0.23	0.20
L-threonine	0.00	0.00	0.04
Trace mineral premix	0.12	0.12	0.13
Vitamin premix	0.12	0.12	0.13
Total	100.00	100.00	100.00
Calculated analysis			
Standardized ileal digestible (SID) amino acids, %			
Lysine	0.85	0.72	0.65
Isoleucine:lysine	71	74	67
Methionine:lysine	33	36	31
Met & Cys:lysine	62	69	63
Threonine:lysine	62	65	65
Tryptophan:lysine	18	18	18
Valine:lysine	83	89	79
Total lysine, %	1.01	0.87	0.74
CP, %	18.4	16.7	13.2
ME, kcal/lb	1,496	1,501	1,498
SID lysine:ME, g/Mcal	2.58	2.18	1.95
Ca, %	0.63	0.57	0.57
P, %	0.52	0.47	0.47
Available P, %	0.27	0.23	0.21

[1] All diets were fed in meal from with Phase 1, 2, and 3 fed from d 0 to 20, 20 to 50, and 50 to 78, respectively.
[2] Phytase replaced corn in the basal diet with 2,000 phytase units (FTU)/kg added from either Quantum Blue 5 G (0.8 lb/ton; AB Vista, Chesterfield, MO), Ronozyme HiPhos (GT) 2500 (1.6 lb/ton; DSM Nutritional Products, Parsippany, NJ), or Optiphos 1000 (4.0 lb/ton; Enzyvia, Sheraton, IN) to form the experimental treatments.

Table 2. Influence of high levels of phytase from three different sources on finishing pig growth and carcass performance[1]

		Phytase source, 2,000 FTU/kg[2]				
Item	Control	Quantum Blue	Ronozyme HiPhos	Optiphos	SEM	Trt, *P* <
Wt, lb						
d 0	128.9	129.0	128.9	129.1	1.62	1.00
d 78	296.2	291.6	292.6	291.1	3.00	0.63
d 0 to 78						
ADG, lb	2.13	2.06	2.08	2.08	0.025	0.26
ADFI, lb	6.27	6.06	6.16	6.15	0.087	0.43
F/G	2.95	2.94	2.96	2.96	0.028	0.97
Carcass characteristics						
HCW, lb	212.8	209.9	210.4	208.2	2.49	0.61
Yield, %[3]	73.18	73.51	73.39	73.40	0.204	0.70
Back fat, in.[4]	0.80	0.81	0.80	0.81	0.018	0.98
Loin depth, in.[4]	2.40	2.48	2.45	2.44	0.031	0.36
Lean, %[4]	52.50	52.78	52.66	52.57	0.239	0.85

[1] A total of 274 finishing pigs (PIC 1050 × 327, initially 129 lb) were used in a 78-d study with 7 or 8 pigs per pen and 9 pens per treatment. Basal diets were formulated to adequately meet the pigs available P requirements.

[2] Phytase units per kilogram. Phytase replaced corn in the basal diet with 2,000 phytase units (FTU)/kg added from either Quantum Blue 5 G (0.8 lb/ton; AB Vista, Chesterfield, MO), Ronozyme HiPhos (GT) 2500 (1.6 lb/ton; DSM Nutritional Products, Parsippany, NJ), or Optiphos 1000 (4.0 lb/ton; Enzyvia, Sheraton, IN) to form the experimental treatments.

[3] Percentage yield was calculated by dividing HCW by live weight obtained at the farm before transport to the packing plant.

[4] Carcass characteristics were adjusted by using HCW as a covariate.

Effects of Added Zinc in Diets with Ractopamine HCl on Growth Performance, Carcass Characteristics, and Zinc Concentrations in Plasma, Loin, and Liver of Finishing Pigs[1,2]

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Summary

Two experiments were conducted to determine the effects of added Zn from zinc oxide (ZnO) or Availa-Zn (AZ; Zinpro, Eden Prairie, MN) on growth performance and carcass characteristics of finishing pigs fed ractopamine HCl (RAC; Paylean; Elanco Animal Health, Greenfield, IN). In Exp. 1, a total of 320 pigs (PIC 327 × 1050, initially 215.9 lb) were used in a 35-d study. Pens of pigs were randomly allotted to 1 of 8 dietary treatments, with either 2 barrows or 2 gilts per pen and 20 pens per treatment. Dietary treatments included: a corn-soybean meal–based negative control (0.66% standardized ileal digestible [SID] lysine); a positive control diet (0.92% SID lysine) containing 10 ppm of RAC; and the RAC diet plus 75, 150, or 225 ppm added Zn from ZnO or AZ. The trace mineral premix provided a basal level of 55 ppm Zn from Zn Sulfate ($ZnSO_4$) in all diets. In Exp. 1, overall (d 0 to 35), pigs fed RAC had improved ($P < 0.04$) ADG, F/G, d-35 BW, caloric efficiency on an ME and NE basis, HCW, carcass ADG and F/G, loin depth, percentage lean, and carcass caloric efficiency on an ME and NE basis, and reduced ($P < 0.01$) ADFI and backfat thickness compared with pigs fed the control diet. No evidence of a Zn effect or an interaction between Zn source and level was observed. Performance and IOFC did not differ in pigs fed diets with added Zn from either source.

In Exp. 2, a total of 1,234 pigs (PIC 337 × 1050; initially 228.6 lb) were used in a 28-d study. Pens contained 23 to 28 pigs with either all barrow, all gilt, or mixed-sex allotments. Pens of pigs were blocked by BW, feeder type, and gender and were randomly assigned to diets. The 4 dietary treatments consisted of (1) a corn-soybean meal–based negative control diet (0.70% SID lysine); (2) a positive control diet (0.92% SID lysine) containing 10 ppm RAC; or the RAC diet plus 50 ppm added Zn from ZnO (3) or AZ (4). All diets contained 80 ppm Zn from ZnO provided by the trace mineral premix. On d 14, the 6 heaviest pigs from each pen (determined visually) were individually tattooed by pen and harvested to allow for carcass data collection, and on d 28, the remaining pigs were individually tattooed by pen and harvested to allow for carcass data

[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] Appreciation is expressed to Elanco Animal Health (Greenfield, IN) for providing partial financial support for this experiment.
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[4] Department of Animal Science, College of Agriculture and Natural Resources, Michigan State University.
[5] Elanco Animal Health, Greenfield, IN.

collection. Overall (d 0 to 28), pigs fed RAC had improved ($P < 0.001$) ADG, F/G, final BW, and caloric efficiency on an ME and NE basis. Added Zn or Zn source did not affect ($P > 0.20$) growth performance. For pigs harvested on d 14, pigs fed RAC had improved ($P < 0.001$) carcass ADG, F/G, income over feed cost (IOFC), and carcass caloric efficiency on an ME and NE basis and a tendency for increased HCW, loin depth, and percentage lean compared with those fed the negative control diet. No differences were observed in carcass characteristics ($P > 0.11$) between pigs fed RAC diets and diets containing added Zn; however, pigs fed diets with added Zn from ZnO had increased ($P < 0.05$) carcass F/G, carcass yield, carcass IOFC, and carcass caloric efficiency on an ME and NE basis compared with those fed Zn from AZ. For pigs harvested on d 28, pigs fed RAC had improved ($P < 0.01$) HCW, carcass ADG and F/G, backfat thickness, loin depth, percentage lean, carcass IOFC, and carcass caloric efficiency on an ME and NE basis. No differences were observed in carcass characteristics between pigs fed RAC, and no additional Zn and diets containing added Zn from either source. Carcass characteristics did not differ in pigs fed diets with added Zn from ZnO vs. AZ.

In conclusion, we observed improvements in growth and carcass performance from adding RAC similar to previous studies. In contrast with our previous research, these data indicate that adding Zn to finishing pig diets containing RAC did not improve overall performance. Consistent with the earlier research, income over feed cost (IOFC) was numerically increased with the addition of Zn.

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[6]; Patience, 2011[7]; Paulk et al., 2012[8]). We designed experiments to determine the effects of adding zinc from ZnO or Availa-Zn on growth performance; carcass characteristics; plasma, loin, and liver Zn concentrations; and economics of finishing pigs supplemented with RAC.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in these experiments. Experiment 1 was conducted at the K-State Swine Teaching and Research Center in Manhattan, KS. Experiment 2 was conducted in a commercial research-finishing barn in southwestern Minnesota.

[6] Akey. 2011. Effects of Zinc Source and Level in Paylean Diets on Pig Performance and Carcass Characteristics. Akey Swine Newsletter.
[7] Patience, J. P. 2011. Impact of Zinc Source and Timing of Implementation on Grow-finish Performance, Carcass Composition, and Locomotion Score. IA St. Univ. Anim. Ind. Rep.
[8] Paulk et al., Swine Day 2012, Report of Progress 1074, pp. 348–356.

For Exp. 1, a total of 320 pigs (PIC 327 × 1050, four consecutive groups of 80 pigs) with an initial BW of 215.9 lb were used in this study. Pigs were housed in an environmentally controlled finishing building in 5-ft × 5-ft pens with totally slatted flooring. Each pen was equipped with a 2-hole dry self-feeder and a nipple waterer to provide *ad libitum* access to feed and water. Two consecutive replications of 160 pigs in the same barn were used. Within each replication, there were 80 pens with 2 pigs per pen. Within each replication, the 80 pens were divided into two 40-pen groups with 24 barrow pens and 16 gilt pens or 16 barrow pens and 24 gilt pens per group, which resulted in 4 groups of 40 pens each.

Pens of pigs were randomly allotted to 1 of 8 dietary treatments, with either 2 barrows or 2 gilts per pen and 20 pens per treatment. Dietary treatments were fed for the last 41 d prior to slaughter for group 1 and 35 d for groups 2, 3, and 4. Dietary treatments included: a corn-soybean meal–based negative control diet formulated to 0.66% SID lysine; a positive control diet formulated to contain 0.92% SID lysine and 10 ppm of RAC; and the RAC diet plus 75, 150, or 225 ppm added Zn from ZnO, or Availa-Zn (Zinpro, Eden Prairie, MN; Table 1). All diets contained 55 ppm Zn from $ZnSO_4$ provided by the trace mineral premix. Final analyzed total Zn concentrations were 66 and 74 ppm in the control diets; 134, 241, and 308 ppm in the ZnO diets; and 157, 255, and 318 ppm in Availa-Zn diets, respectively. Experimental diets were fed in meal form, and either ZnO or Availa-Zn (AZ) was added to the RAC diet at the expense of corn. Pigs and feeders were weighed on d 0 and 35 to determine ADG, ADFI, F/G, and caloric efficiency on an ME and NE basis. Caloric efficiency is a method to measure the efficiency of energy utilization and is reported as the ME or NE required per pound of gain. Metabolizable energy values of the feed ingredients were derived from the NRC (1998), and NE values of the feed ingredients were derived from INRA (2004).[9]

One pig was randomly selected from 16 pens per treatment (balanced across gender and group) for collection of blood on d 0, 8, 18, and 32 of the experiment to determine circulating Zn concentrations. Blood samples were chilled for approximately 2 h, then centrifuged at 2,000 × *g* for 15 min at 39.2°F. Plasma was then collected from each sample, frozen at -4°F, and sent to Michigan State University for mineral analysis. Zinc levels were determined by atomic absorption spectrophotometry.

On the final day of the experiment, pigs were harvested at 1 of 2 locations. One pig was randomly selected from each pen and weighed, tattooed, and shipped to the K-State Meat Laboratory for harvest. The remaining pigs were weighed, tattooed, and shipped to a commercial packing plant (Triumph Foods LLC., St. Joseph, MO) for harvest.

Pigs harvested at the commercial packing plant were tattooed to allow individual identification for 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, carcass IOFC, and carcass caloric efficiency on an ME and NE basis were calculated. Percentage carcass yield was calculated by dividing HCW at the packing plant by the

[9] 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.

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[10]):

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

To calculate carcass ADG, the percentage yield was multiplied by ADG. Carcass F/G was calculated by dividing ADFI by carcass ADG. Income over feed cost, a method to measure economic value, was also calculated assuming that other costs, such as utilities and labor, are equal across treatments, and the only variables are carcass ADG and feed usage for the experimental period. Corn was valued at $242/ton, soybean meal at $515/ton, L-lysine at $0.70/lb, phytase at $2.65/lb, RAC at $35.26/lb, zinc oxide at $0.86/lb, Availa-Zn at $1.50/lb; live weight was priced at $75.15/cwt, and carcass price was set at $100.20/cwt.

Pigs harvested at the K-State Meat Laboratory were tattooed to allow for individual carcass data collection. Immediately following evisceration, HCW and liver weight were collected. After a 24-h chilling period, the left side of each carcass was ribbed between the 10th- and 11th-rib interface. At this time, backfat and loin depth were measured with a ruler to mimic data collected at the commercial packing plant. All economic comparisons were calculated as previously described. Liver and loin samples were collected, frozen, and sent to Michigan State University for Zn analysis.

For Exp. 2, the barns were naturally ventilated and double-curtain-sided with completely slatted flooring and deep pits for manure storage. The barn was equipped with two types of Thorp feeders (Thorp Equipment, Inc, Thorp, WI). Both feeder types were a 4-hole stainless steel dry self-feeder (56 in. wide). Pigs were provided 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 1,234 pigs (PIC 337 × 1050; initially 228.6 lb) were used in the 28-d study. Pens consisted of 23 to 28 pigs per pen with either all barrow, all gilt, or mixed-sex pens. Pens of pigs were blocked by BW, feeder type, and gender and were randomly assigned to diets with 12 pens per treatment. Dietary treatments consisted of (1) a corn-soybean meal–based negative control diet (0.70% SID lysine); (2) a positive control diet (0.92% SID lysine) containing 10 ppm RAC; (3) treatment 2 plus 50 ppm added Zn from ZnO, and (4) treatment 2 plus 50 ppm added Zn from AZ. All diets contained 80 ppm Zn from ZnO provided by the trace mineral premix.

Pigs and feeders were weighed on d 0 and 28 to determine ADG, ADFI, F/G, and caloric efficiency on an ME and NE basis. On d 14, the 6 heaviest pigs from each pen (determined visually), and on d 28, the remaining pigs, were sold according to the normal marketing procedures of the farm. Pigs were tattooed by pen and used for collection of carcass measurements. Pigs were transported to JBS Swift and Company

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

(Worthington, MN) for processing and carcass data collection. Carcass data were collected as described in the previous experiment. Additionally, IOFC was calculated including dried distillers grains with solubles valued at $220/ton and bakery meal at $232/ton.

For both experiments, all data were analyzed using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Statistical significance was determined at $P < 0.05$, and P-values falling within $P > 0.05$ and $P < 0.10$ will be termed trends or tendencies. For Exp. 1, data were analyzed as a generalized randomized complete block design. Dietary treatment served as the fixed effect, and gender within group within barn were random effects. Hot carcass weight was used as a covariate for analyses of backfat thickness, loin depth, and percentage lean. Contrast statements consisted of: (1) negative control vs. positive control RAC diet, (2) interaction between increasing Zn level and Zn source, (3) increasing Zn linear and quadratic polynomials, and (4) added Zn from ZnO vs. Availa-Zn. For Exp. 2, data were analyzed as a randomized complete block design. In addition to dietary treatment, the effects of gender (barrow, gilt, or mixed gender) were included as fixed effects in the model. Average initial pen weight and feeder type were included as random factors. Hot carcass weight was used as a covariate for analyses of backfat thickness, loin depth, and percentage lean. Contrast statements consisted of: (1) negative control vs. positive control RAC diet, (2) RAC vs. added Zn, and (3) added Zn from ZnO vs. Availa-Zn.

Results and Discussion

In Exp. 1, overall (d 0 to 35), pigs fed RAC had improved ($P < 0.01$) ADG, F/G, d-35 BW, and caloric efficiency on an ME and NE basis and reduced ($P < 0.01$) ADFI compared with pigs fed the control diet (Table 3). Adding increasing levels of Zn to RAC diets did not affect ($P > 0.25$) growth performance and IOCF, and no differences ($P > 0.17$) were observed between Zn sources.

For carcass measurements, pigs fed RAC had improved ($P < 0.04$) HCW, carcass ADG and F/G, backfat thickness, loin depth, percentage lean, and carcass caloric efficiency on an ME and NE basis compared with those fed the control diet (Table 4). No differences were observed in carcass characteristics ($P > 0.3$) between pigs fed the RAC diet and diets containing added Zn. Carcass characteristics did not differ ($P > 0.25$) in pigs fed diets with added Zn from ZnO vs. Availa-Zn.

Pigs fed the RAC diets had increased ($P = 0.04$) liver weights compared with those fed the control diet. No evidence for a Zn-level effect, or an interaction between Zn source and level ($P > 0.18$) for liver weights (Table 5), was observed. Pigs fed RAC diets with added Zn from ZnO had numerically heavier ($P = 0.09$) liver weights than pigs fed the RAC diet with added Zn from AZ. No difference ($P > 0.29$) was observed in Zn concentrations in liver or loin from pigs fed either the RAC or control diet. A Zn level × source interaction (quadratic, $P = 0.02$) was observed in liver Zn concentrations on both a DM and as-is basis, resulting from liver Zn concentrations plateauing at 150 ppm of added Zn from ZnO but continuing to increase to 225 ppm added Zn from AZ. Zinc concentrations in the loin did not differ ($P > 0.25$) due to Zn source.

There was no plasma Zn interaction between dietary treatment and day ($P > 0.17$), no difference between pigs fed the RAC vs. control diet, no difference in Zn source, and no interaction between Zn source and level ($P > 0.16$) on any of the collection days (Table 6). Pigs fed RAC diets with up to 225 ppm added Zn had increased ($P < 0.02$) plasma Zn levels on day 18 and 32.

In Exp. 2, overall (d 0 to 28), pigs fed RAC had improved ($P < 0.001$) ADG, F/G, final BW, and caloric efficiency on an ME and NE basis (Table 7). No differences were observed in performance ($P > 0.33$) between pigs fed RAC and diets containing added Zn. Performance did not differ ($P > 0.20$) between pigs fed diets with added Zn from ZnO vs. AZ.

For carcass measurements on d 14, pigs fed RAC had improved ($P < 0.001$) carcass ADG, F/G, IOFC, and carcass caloric efficiency on an ME and NE basis and a tendency for increased HCW, loin depth, and percentage lean compared with those fed the diet without RAC (Table 8). No differences were observed in carcass characteristics ($P > 0.11$) between pigs fed RAC diets and diets containing added Zn; however, pigs fed diets with added Zn from ZnO had increased ($P < 0.05$) carcass F/G, carcass yield, carcass IOFC, and carcass caloric efficiency on an ME and NE basis.

For carcass measurements on d 28, pigs fed RAC had improved ($P < 0.01$) HCW, carcass ADG and F/G, backfat thickness, loin depth, percentage lean, carcass IOFC, and carcass caloric efficiency on an ME and NE basis (Table 8). No differences were observed in carcass characteristics ($P > 0.21$) between pigs fed RAC and diets containing added Zn and carcass characteristics did not differ ($P > 0.14$) between Zn sources.

In conclusion, additional Zn did not significantly improve the performance of pigs fed diets containing RAC, but pigs fed 50 to 75 ppm of added Zn from ZnO had a 3% reduction in F/G. This numeric improvement in F/G resulted in a numeric increase in IOFC of $1.30 to $1.45 when pigs in a commercial environment were fed 50 ppm of added Zn from ZnO and $1.26 on a live weight basis (35 d) and $0.54 on a carcass basis when pigs in K-State research facilities were fed 75 ppm added Zn from ZnO. Although these values were not significant, the numerical increase in IOFC was consistent with previous data conducted in our lab (Paulk et al., 2012a[11]; Paulk et al., 2012b[12]). The response to added Zn is not consistent, but only small improvements in performance are needed to overcome the cost of inclusion when adding Zn from ZnO.

[11] Paulk et al., Swine Day 2012, Report of Progress 1074, pp. 348–355.
[12] Paulk et al., Swine Day 2012, Report of Progress 1074, pp. 356–364.

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

Item	Control	RAC
Ingredient, %		
Corn	83.06	74.24
Soybean meal, (46.5% CP)	15.22	23.97
Monocalcium P, (21% P)	0.25	0.20
Limestone	0.75	0.78
Salt	0.35	0.35
Vitamin premix	0.075	0.075
Trace mineral premix[3]	0.075	0.075
L-lysine HCl	0.15	0.15
DL-methionine	---	0.015
L-threonine	---	0.025
Phytase[4]	0.075	0.075
Ractopamine HCl[5]	---	0.05
Total	100	100
Calculated analysis, %		
Standardized ileal digestible (SID) amino acids, %		
Lysine	0.70	0.92
Isoleucine:lysine	71	70
Leucine:lysine	179	158
Methionine:lysine	31	30
Met & Cys:lysine	65	60
Threonine:lysine	63	64
Tryptophan:lysine	19	19
Valine:lysine	84	79
Total lysine, %	0.79	1.03
CP, %	14.3	17.6
ME, kcal/lb[6]	1,525	1,523
NE, kcal/lb[7]	1,044	1,029
SID lysine: ME, g/Mcal	2.08	2.74
Ca, %	0.41	0.44
P, %	0.39	0.42
Available P, %	0.21	0.21

[1] Diets were fed in meal form during the experiment.
[2] Dietary treatments were obtained by replacing corn in the ractopamine HCl diet to achieve 75, 150, and 225 ppm added Zn from ZnO (Zinc Nacional S.A., Monterrey, Mexico) or Availa-Zn (Zinpro, Eden Prairie, MN).
[3] Trace mineral premix provided 55 ppm Zn from $ZnSO_4$.
[4] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 204 phytase units (FTU)/lb, with a release of 0.10% available P.
[5] Provided 9 g/lb (10 ppm) of Ractopamine HCl (Paylean; Elanco Animal Health, Greenfield, IN).
[6] ME values for ingredients were derived from NRC (1998).
[7] NE values for all ingredients were derived from INRA (2004).

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

Item	Control	RAC
Ingredient, %		
Corn	54.68	45.83
Soybean meal, (46.5% CP)	13.63	22.39
Bakery meal	15.00	15.00
DDGS[3]	15.00	15.00
Limestone	1.03	1.08
Salt	0.35	0.35
Vitamin trace mineral premix[4]	0.08	0.08
L-lysine[5]	0.23	0.23
Phytase[6]	0.005	0.005
Ractopamine HCl[7]	---	0.05
Total	100	100
Calculated analysis, %		
Standardized ileal digestible (SID) amino acids, %		
Lysine	0.70	0.92
Isoleucine:lysine	80	77
Leucine:lysine	207	180
Methionine:lysine	38	33
Met & Cys:lysine	73	65
Threonine:lysine	72	68
Tryptophan:lysine	20.3	20.5
Valine:lysine	96	89
Total lysine, %	0.83	1.07
CP, %	16.9	20.2
ME, kcal/lb[8]	1,546	1,543
NE, kcal/lb[9]	1,129	1,102
SID lysine: ME, g/Mcal	2.05	2.70
Ca, %	0.48	0.52
P, %	0.39	0.43
Available P, %	0.21	0.21

[1] Diets were fed in meal form for the final 28 d prior to slaughter.
[2] Dietary treatments were obtained by replacing corn in the ractopamine HCl diet to achieve 50 ppm of added Zn from ZnO or from Availa-Zn (Zinpro, Eden Prairie, MN).
[3] Dried distillers grains with solubles.
[4] Provided 80 ppm Zn from ZnO.
[5] Biolys (50.7% L-lysine; Evonik Degussa Corporation, Kennesaw, GA)
[6] OptiPhos 2000 (Enzyvla LLC, Sheridan, NJ) provided 113.5 phytase units (FTU)/lb, with a release of 0.08% available phosphorus.
[7] Provided 9 g/lb (10 ppm) of Ractopamine HCl (Paylean; Elanco Animal Health, Greenfield, IN).
[8] ME values for ingredients were derived from NRC (1998).
[9] NE values for all ingredients were derived from INRA (2004).

Table 3. Effects of level and source of added Zn on growth performance of finishing pigs fed ractopamine HCl (RAC; Exp. 1)[1]

			Zn from ZnO[2], ppm			Zn from Availa-Zn[2], ppm				Probability, $P <$[3]			
	Control	RAC[2]	75	150	225	75	150	225	SEM	Control vs. RAC	Zn Linear	Zn Quadratic	Source
d 0 to 35													
ADG, lb	2.29	2.54	2.55	2.57	2.56	2.54	2.51	2.47	0.06	0.01	0.7	0.71	0.19
ADFI, lb	7.38	7.03	6.88	6.99	7.02	6.84	6.92	6.76	0.22	0.05	0.49	0.59	0.23
F/G	3.25	2.80	2.71	2.74	2.76	2.71	2.78	2.75	0.11	0.001	0.67	0.25	0.79
IOFC,[4] $/pig	21.16	22.74	24.00	23.83	23.56	23.65	22.09	21.78	2.04	0.33	0.80	0.44	0.17
Caloric efficiency[5]													
ME	5,021	4,266	4,123	4,164	4,184	4,122	4,225	4,179	174	0.01	0.56	0.32	0.78
NE	3,750	3,118	3,013	3,040	3,057	3,012	3,087	3,054	128	0.01	0.56	0.31	0.78
BW, lb													
d 0	215.9	215.5	216.0	215.8	216.1	216.3	215.9	215.9	3.6	0.87	0.85	0.87	0.94
d 35	289.3	302.9	304.4	304.8	305.3	304.2	301.9	301.3	5.4	0.01	0.97	0.77	0.45

[1] A total of 320 pigs (PIC 327 × 1050) were used with 2 pigs per pen and 20 pens per treatment.
[2] Diets contained 10 ppm of Ractopamine HCl (Paylean; Elanco Animal Health, Greenfield, IN).
[3] No interactive effects ($P > 0.16$) of Zn level × source.
[4] Income over feed cost. Corn was valued at $242/ton, soybean meal at $515/ton, L-lysine at $0.70/lb, phytase at $2.65/lb, and RAC at $35.26/lb, zinc oxide at $0.86/lb, Availa-Zn at $1.50/lb, and live weight was priced at $75.15/cwt.
[5] Caloric efficiency is expressed as kcal/lb gain.

Table 4. Effects of level and source of added Zn on carcass characteristics, economic return, and liver weights of finishing pigs fed ractopamine HCl (RAC; Exp. 1)[1]

			Zn from ZnO[2], ppm			Zn from Availa-Zn[2], ppm				Probability, $P <$[3]			
Item	Control	RAC[2]	75	150	225	75	150	225	SEM	Control vs RAC	Zn Linear	Zn Quadratic	Source
Final wt, lb	300.4	306.1	307.1	307.4	308.5	308.6	304.9	304.6	4.1	0.15	0.97	0.76	0.48
HCW, lb	218.1	223.9	225.7	224.1	226.4	224.5	223.9	222.4	3.1	0.04	0.97	0.81	0.28
Carcass yield, %[4]	72.92	73.27	73.21	72.96	73.58	72.68	73.34	72.89	0.28	0.31	0.92	0.30	0.16
Carcass ADG, lb[5]	1.66	1.84	1.84	1.84	1.86	1.84	1.81	1.78	0.04	0.001	0.60	0.93	0.22
Carcass F/G, lb[6]	4.57	3.86	3.78	3.83	3.79	3.75	3.85	3.83	0.14	0.001	0.79	0.54	0.87
Back fat, in.[7]	0.83	0.69	0.67	0.69	0.73	0.68	0.69	0.67	0.03	0.001	0.68	0.59	0.54
Loin depth, in.[7]	2.64	2.79	2.81	2.88	2.81	2.84	2.81	2.80	0.05	0.02	0.71	0.3	0.67
SFFL, %[7,8]	50.51	52.63	52.90	52.72	52.18	52.77	52.63	52.84	0.47	0.001	0.74	0.56	0.65
Carcass IOFC, $/pig[9]	19.69	21.34	21.88	21.46	22.17	22.07	20.39	19.87	2.02	0.28	0.62	0.75	0.23
Carcass caloric efficiency[10]													
ME	6,963	5,879	5,749	5,828	5,772	5,703	5,855	5,812	208	0.001	0.73	0.56	0.94
NE	5,201	4,296	4,201	4,255	4,217	4,167	4,277	4,247	153	0.001	0.73	0.55	0.93
Liver, lb[10]	4.19	4.50	4.54	4.44	4.40	4.31	4.30	4.34	0.13	0.04	0.28	0.66	0.09

[1] A total of 320 pigs (PIC 327 × 1050) were used with 2 pigs per pen and 20 pens per treatment.
[2] Diets contained 10 ppm of Ractopamine HCl (Paylean; Elanco Animal Health, Greenfield, IN).
[3] No interactive effects ($P > 0.12$) of Zn level × source.
[4] Percentage yield was calculated by dividing HCW by live weight obtained at the farm before transport to the packing plant.
[5] Calculated using carcass yield multiplied by ADG.
[6] Calculated by dividing ADFI by carcass ADG.
[7] Adjusted using HCW as a covariate.
[8] Percentage standardized fat-free lean (SFFL) was calculated by dividing the SFFL by HCW. The equation used for calculation of SFFL was derived from NPPC (2001).
[9] Corn was valued at $242/ton, soybean meal at $515/ton, L-lysine at $0.70/lb, phytase at $2.65/lb, RAC at $35.26/lb, zinc oxide at $0.86/lb, Availa-Zn at $1.50/lb, and carcass priced at $100.2/cwt.
[10] Caloric efficiency is expressed as kcal/lb gain.
[11] Liver weights were measured with the gallbladder intact.

Table 5. Effects of level and source of added Zn on loin and liver Zn concentrations of finishing pigs fed ractopamine HCl (RAC; Exp. 1)[1]

			Zn from ZnO[2], ppm			Zn from Availa-Zn[2], ppm				Probability, $P <$		
Item	Control	RAC[2]	75	150	225	75	150	225	SEM	Control vs. RAC	Level × source linear	Level × source quadratic
As-is basis, (μg/g)												
Liver	84.8	78.1	84.6	92.3	88.7	80.4	89.2	107.4	4.71	0.29	0.01	0.02
Loin	16.8	16.3	17.1	15.8	15.6	16.6	15.2	15.9	0.72	0.56	0.77	0.37
DM basis, (μg/g)												
Liver	306.2	292.8	314.1	345.4	329.3	289.6	326.4	394.8	17.44	0.55	0.01	0.01
Loin	61.5	59.2	62.4	58.1	56.4	60.2	55.8	58.7	2.80	0.50	0.55	0.25

[1]Values represent 160 pigs, 1 pig randomly selected from each pen, selected for harvest at the Kansas State University Meat Laboratory (Manhattan, KS).
[2] Diets contained 10 ppm of Ractopamine HCl (Paylean; Elanco Animal Health, Greenfield, IN).

Table 6. Effects of level and source of added Zn on plasma Zn concentrations of finishing pigs fed Ractopamine HCl (RAC; Exp. 1)[1]

			Zn from ZnO[2], ppm			Zn from Availa-Zn[2], ppm				Probability, $P <$[2,3]			
	Control	RAC	75	150	225	75	150	225	SEM	Control vs. RAC	Zn Linear	Zn Quadratic	Source
Plasma, μg/mL													
d 0	1.06	1.01	1.04	1.05	1.04	1.01	1.06	1.06	0.04	0.33	0.25	0.74	0.85
d 8	1.08	1.07	1.09	1.06	1.15	1.08	1.11	1.16	0.05	0.92	0.11	0.40	0.51
d 18	1.13	1.06	1.12	1.16	1.11	1.10	1.18	1.17	0.04	0.16	0.02	0.16	0.44
d 32	1.08	1.01	1.07	1.07	1.13	1.07	1.09	1.13	0.04	0.19	0.01	0.98	0.77

[1]Values represent 128 pigs, 1 pig randomly selected from 16 pens per treatment.
[2]No interactive effects ($P > 0.17$) of Zn level × source or treatment × day.
[3]There was an increase (quadratic, $P < 0.001$) in plasma Zn from day 0 to 18.

Table 7. Effects of added zinc on growth performance of finishing pigs fed ractopamine HCl (Exp. 2)[1]

						Probability, $P <$		
Item	Control	RAC[2]	ZnO[2]	AZ[2]	SEM	CON vs. RAC	RAC vs. added Zn	ZnO vs. AZ
d 0 to 28								
ADG, lb	2.03	2.42	2.46	2.45	0.030	0.001	0.33	0.78
ADFI, lb	6.44	6.39	6.32	6.44	0.087	0.58	0.93	0.26
F/G	3.19	2.64	2.57	2.63	0.035	0.001	0.33	0.20
Caloric efficiency[3]								
ME	4,931	4,076	3,967	4,060	54.5	0.001	0.32	0.21
NE	3,602	2,912	2,833	2,899	39.4	0.001	0.32	0.22
BW								
d 0	228.4	228.6	228.6	228.7	1.79	0.81	0.94	0.85
d 28	278.0	288.0	289.3	288.6	2.33	0.001	0.55	0.68

[1] A total of 1,263 pigs (PIC 337 × 1050; initially 228.6 lb) were used in a 28-d study with 25 to 27 pigs per pen and 12 pens per treatment.
[2] Diets contained 10 ppm of Ractopamine HCl (Paylean; Elanco Animal Health, Greenfield, IN).
[3] Caloric efficiency is expressed as kcal/lb gain.

Table 8. Effects of added zinc on carcass characteristics of finishing pigs fed ractopamine HCl (RAC; Exp. 2)[1]

						Probability, $P <$		
Item	Control	RAC[2]	ZnO[2]	AZ[2]	SEM	CON vs. RAC	RAC vs. added Zn	ZnO vs AZ
d 14[3]								
Final weight, lb	282.3	288.3	289.9	290.5	3.22	0.16	0.60	0.89
HCW, lb	209.5	214.9	216.2	213.0	2.91	0.07	0.91	0.28
Carcass yield,[4] %	74.21	74.55	74.59	73.33	0.482	0.58	0.27	0.05
Carcass ADG,[5] lb	1.51	1.83	1.91	1.87	0.046	0.001	0.11	0.27
Carcass F/G,[6] lb	4.03	3.39	3.19	3.44	0.080	0.001	0.23	0.001
Backfat thickness,[7] in.	0.70	0.66	0.66	0.64	0.017	0.17	0.52	0.26
Loin depth,[8] in.	2.70	2.79	2.77	2.75	0.036	0.09	0.54	0.73
Lean,[7,8] %	52.81	53.46	53.42	53.78	0.279	0.09	0.63	0.30
Carcass IOFC,[9] $/pig	8.94	10.68	11.98	10.55	0.56	0.001	0.15	0.01
Carcass caloric efficiency[10]								
ME	6,227	5,223	4,927	5,303	124	0.001	0.23	0.001
NE	4,548	3,730	3,519	3,786	89	0.001	0.23	0.001
d 28								
Final weight, lb	277.7	288.3	289.3	288.5	2.38	0.001	0.73	0.72
HCW, lb	207.9	215.6	218.3	216.1	2.53	0.001	0.32	0.22
Carcass yield, %[4]	74.79	74.79	75.47	74.94	0.475	0.99	0.35	0.30
Carcass ADG, lb[5]	1.52	1.81	1.85	1.83	0.026	0.001	0.27	0.54
Carcass F/G, lb[6]	4.26	3.53	3.42	3.52	0.049	0.001	0.27	0.15
Backfat thickness, in.[7]	0.66	0.59	0.60	0.60	0.012	0.001	0.56	0.66
Loin depth, in.[8]	2.72	2.80	2.81	2.81	0.013	0.01	0.89	0.99
Lean, %[7,8]	53.40	54.49	54.34	54.43	0.192	0.001	0.61	0.70
Carcass IOFC, $/pig[9]	16.52	19.77	21.22	20.04	0.57	0.001	0.21	0.14
Carcass caloric efficiency[10]								
ME	6,586	5,448	5,269	5,420	76	0.001	0.26	0.16
NE	4,810	3,891	3,763	3,869	55	0.001	0.26	0.17

[1] 1,263 pigs (PIC 337 × 1050; initially 228.6 lb) were used in a 28-d study with 25 to 27 pigs per pen and 12 pens per treatment.
[2] Diets contained 10 ppm of Ractopamine HCl (Paylean; Elanco Animal Health, Greenfield, IN).
[3] The 6 heaviest pigs from each pen (determined visually) were sold as tops.
[4] Percentage yield was calculated by dividing HCW by live weight obtained at the farm before transport to the packing plant.
[5] Calculated using yield multiplied by ADG.
[6] Calculated by dividing ADFI by carcass ADG.
[7] Adjusted using HCW as a covariate.
[8] Calculated using NPPC (2001) equation: (15.31 + 0.51 × (HCW, lb)-31.277 × (last rib backfat thickness,in.) + 3.813 × (loin muscle depth, in.)) / HCW × 100.
[9] Corn was valued at $242/ton, soybean meal at $515/ton, dried distillers grains with solubles at $220/ton, bakery meal at $232/ton, L-lysine at $0.70/lb, phytase at $2.65/lb, RAC at $35.26/lb, zinc oxide at $0.86/lb, Availa-Zn at $1.50/lb; carcasses priced at $100.2/cwt.
[10] Caloric efficiency is expressed as kcal/lb gain.

Effects of Dietary Zinc Level and Ractopamine HCl on Pork Chop Tenderness and Shelf-Life Characteristics[1]

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Summary

A total of 320 finishing pigs (PIC 327 × 1050; initially 216 lb) were utilized to determine the effects of adding Zn to diets containing ractopamine HCl (RAC) on muscle fiber type distribution, fresh chop color, and cooked meat characteristics. Dietary treatments were fed for approximately 35 d and consisted of: a corn-soybean meal–based negative control (CON); a positive control diet with 10 ppm of RAC (RAC+); and the RAC+ diet plus 75, 150, or 225 ppm added Zn from either ZnO or Availa-Zn. Loins from 80 barrow and 80 gilt carcasses were evaluated. No Zn source effect or Zn source × level interactions we observed during the study ($P > 0.10$). Pigs fed the RAC+ had increased ($P < 0.02$) percentage type IIX and a tendency for increased percentage type IIB muscle fibers. Increasing added Zn decreased (linear, $P = 0.01$) percentage type IIA and tended to increase ($P = 0.09$) IIX muscle fibers. On d 1, 2, 3, 4, and 5 of display, pork chops from pigs fed the RAC+ treatment had greater ($P < 0.03$) L* values (lighter) compared with the CON. On d 0 and 3 of display, increasing added Zn tended to decrease (quadratic, $P = 0.10$) L* values and decreased (quadratic, $P < 0.03$) L* values on d 1, 2, 4, and 5. Pigs fed RAC+ had decreased ($P < 0.05$) a* values (less red) on d 1 and 4 of display and tended to have decreased ($P < 0.10$) a* values on d 0 and 2 compared with CON pork chops. RAC+ decreased ($P < 0.001$) metmyoglobin reducing ability (MRA) of pork chops on d 5. Chops from pigs fed added Zn had increased (quadratic, $P < 0.03$) MRA on d 3 and 5 of the display period. There was a trend for increased (linear, $P = 0.07$) cooking loss as added Zn increased in RAC diets. In conclusion, RAC+ diets produced chops that were lighter and less red but maintained a higher percentage of surface oxymyoglobin throughout a 5-d simulated retail display. RAC+ reduced MRA at the end of the display period, but supplementing Zn to RAC diets restored MRA to near CON treatment levels at the end of the display period.

Key words: ractopamine HCl, pork color, pork quality, fiber type, pork chop shelf life

Introduction

Ractopamine HCl (RAC; Paylean; Elanco Animal Health, Greenfield, IN) is frequently added to finishing pig diets to improve growth performance and carcass leanness. When adding RAC to finishing diets, amino acid concentrations should be increased approximately 30% to maximize growth and carcass lean based on results of

[1] Appreciation is expressed to Elanco Animal Health (Greenfield, IN) for providing partial financial support for this experiment.

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several research trials. Little research has been conducted to determine the effects of additional trace mineral concentrations on the response to RAC, but recent studies have observed that added Zn can increase the response to RAC (Akey, 2011[4], Patience, 2011[5]).

Although these studies provide initial justification to increase the amount of Zn in diets containing RAC, no research has demonstrated the effects of additional Zn in combination with RAC on fresh meat characteristics, including color stability and cooked meat tenderness. Numerous studies have reported that RAC decreases cooked longissimus muscle (LM) tenderness (Dunshea et al., 2005[6]) and alters LM color (Apple et al., 2008[7]), which are the most important variables consumers use when making a purchasing decision and evaluating their eating experience. Both of these characteristics are influenced by muscle fiber type and the metabolic profile associated with these fibers (Ryu and Kim, 2005[8]; Lee et al., 2010[9]). Because RAC has been previously shown to alter muscle fiber types (Aalhus et al., 1992[10]; Depreux et al., 2002[11]), we speculated that the increased growth and carcasses response experienced by pigs supplemented with RAC and Zn may alter the muscle's fiber type distribution and consequently impact shelf-life and tenderness. Therefore, the objective of this study was to evaluate the effects of adding increasing levels of Zn to RAC containing finishing pig diets on muscle fiber type distribution, fresh chop color, and cooked meat characteristics.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment.

A total of 320 finishing pigs (PIC 327 × 1050) with an average initial BW of 216 lb were housed at the Kansas State University Swine Teaching and Research Center. The finishing barn was an environmentally controlled facility with 5-ft^2 slatted-floor pens. Each pen was equipped with a dry self-feeder and a nipple waterer to provide ad libitum access to feed and water. Two consecutive replications of 160 pigs in the same barn were used. Within each replication, there were 80 pens with 2 pigs per pen. Within each replication, the 80 pens were divided into two 40-pen groups with 24 barrow pens

[4] Akey. 2011. Effects of Zinc Source and Level in Paylean Diets on Pig Performance and Carcass Characteristics. Akey Swine Newsletter.
[5] Patience, J.P. 2011.Impact of Zinc Source and Timing of Implementation on Grow-finish Performance, Carcass Composition, and Locomotion Score. Iowa St. Univ. Anim. Ind. Rep.
[6] Dunshea, F.R., D.N. D'Souza, D.W. Pethick, G.S. Harper, and R.D. Warner. 2005. Review: Effects of dietary factors and other metabolic modifiers on quality and nutritional value of meat. Meat Sci. 71:8–38.
[7] Apple, J.K., C.V. Maxwell, B.R. Kutz, L.K. Rakes, J.T. Sawyer, Z.B. Johnson, T.A. Armstrong, S.N. Carr, and P.D. Matzat. 2008. Interactive effect of ractopamine and dietary fat source on pork quality characteristics of fresh pork chops during simulated retail display. J. Anim. Sci. 86:2711–2722.
[8] Ryu, Y.C., and B.C. Kim. 2005. The relationship between muscle fiber characteristics, postmortem metabolic rate, and meat quality of *Longissimus dorsi* muscle. Meat Sci. 71:351–357.
[9] Lee, S.H., S.T. Joo, and Y.C. Ryu. 2010. Skeletal muscle fiber type and myofibrillar proteins in relation to meat quality. Meat Sci. 86:166–170.
[10] Aalhus, J.L., A.L. Schaefer, A.C. Murray, and D.M. Jones. 1992. The effect of ractopamine on myofibre distribution and morphology and their relation to meat quality in swine. Meat Sci. 31:397–409.
[11] Depreux, F.F.S., A.L. Grant, D.B. Anderson, and D.E. Gerrard. 2002. Paylean alters myosin heavy chain isoform content in pig muscle. J. Anim. Sci. 80:1888–1894.

and 16 gilt pens or 16 barrow pens and 24 gilt pens per group, resulting in 4 groups of 40 pens each.

Pens of pigs were allotted to 1 of 8 dietary treatments, with 2 pigs per pen and a total of 20 pens per treatment. Dietary treatments consisted of: a corn-soybean meal–based negative control diet formulated to 0.66% standardized ileal digestible (SID) lysine (CON); a positive control diet formulated to contain 0.92% SID lysine and 10 ppm of RAC (RAC+); the RAC+ diet plus 75, 150, or 225 ppm added Zn from ZnO; and the RAC+ diet plus 75, 150, or 225 ppm added Zn from Availa-Zn (Zinpro, Eden Prairie, MN; Table 1). All diets contained a trace mineral premix that contributed 55 ppm Zn from $ZnSO_4$. Experimental diets were fed in meal form, and ZnO or Availa-Zn was added to the RAC diet at the expense of corn. Diets were fed for the last 41 d before slaughter for group 1 and the last 35 days for groups 2, 3, and 4. Treatment effects on growth and carcass composition are reported in another report (see "Effects of Added Zn in Diets with ractopamine HCl on Growth Performance, Carcass Characteristics, and Zn Concentrations in Plasma, Loin, and Liver of Finishing Pigs," p. 132).

Harvest and sample collection

At the completion of the feeding period, 1 pig was randomly selected from each pen and transported to the Kansas State University Meats Laboratory for harvest under federal inspection. After a 24-h post-slaughter chilling period, a 12-in. portion of the *longissimus lumborum* muscle (beginning at the 10th rib) was collected from the left side for immunohistochemistry and fresh pork quality analysis. Additionally, 24-h pH was measured using a Hanna HI 99163 meat pH probe (Hanna Instruments, Smithfield, RI) inserted into the 11th–12th-rib interface, and a 1-in.-thick chop was collected from this location to be used for immunohistochemical analysis. The remainder of the muscle sample was vacuum-packaged and stored at 36°F for 13 d postmortem.

Immunohistochemistry

A 0.39-in.^{2} portion of muscle was collected from the geometric center of each chop designated for immunohistochemistry. After collection, the muscle was embedded in Optimal Cutting Temperature (OCT) tissue embedding media (Fisher Scientific, Pittsburgh, PA), frozen by submersion in supercooled isopentane, and stored at -112°F until analysis. For each sample, two 10-μm cryosections were collected on frost-resistant slides (Fisher Scientific), and the methods of Gonzalez et al. (2008[12]) were followed for immunodetection with modifications. Non-specific antigen-binding sites were inhibited by incubating cryosections in 5% horse serum and 0.2% TritonX-100 in phosphate-buffered saline (PBS) for 30 min. All sections were incubated with the following primary antibodies in blocking solution for 60 min: 1:50 α-dystrophin (Thermo Scientific, Waltham, MA); 1:10 supernatant myosin heavy-chain, slow IgG2b (BA-D5, Developmental Studies Hybridoma Bank, University of Iowa, Iowa City, IA); 1:10 supernatant myosin heavy-chain type 2A, IgG1 (SC-71, Developmental Studies Hybridoma Bank); and 1:10 supernatant myosin heavy-chain type 2B, IgM (BF-F3, Developmental Studies Hybridoma Bank, University of Iowa, Iowa City, IA). After incubation, sections were washed with PBS 3 times for 5 min, followed by incuba-

[12] Gonzalez, J.M., S.E. Johnson, T.A. Thrift, J.D. Savell, S.E. Ouellette, and D.D. Johnson. 2009. Effect of ractopamine-hydrochloride on the fiber type distribution and shelf-life of six muscles of steers. J. Anim. Sci. 87:1764–1771.

tion in the following secondary antibodies (1:1000) in blocking solution for 30 min: Alexa-Fluor 488 goat anti-mouse IgM for BF-F3 (Invitrogen, San Diego, CA); Alexa-Fluor 594 goat anti-mouse IgG1for SC-71 (Invitrogen); Alexa-Fluor 633 goat anti-mouse IgG2b for BA-D5 (Invitrogen); and Alexa-Flour 594 goat anti-rabbit H&L for α-dystrophin (Invitrogen). In additon, 1:1000 Hoechst Dye 33342 (Invitrogen) was utilized to identify all fiber-associated nuclei. Finally, sections were washed for three 5-min periods in PBS, then covered with 5 μL of 9:1 glycerol in PBS, then coverslipped for imaging.

Cryosections were imaged using a Nikon Eclipse TI-U inverted microscope with 10× working distance magnification (Nikon Instruments Inc., Melville, NY). Four representative photomicrographs per section were captured using a Nikon DS-QiMc digital camera (Nikon Instruments Inc.) calibrated to the 10× objective. For myosin heavy-chain fiber-type data collection, a minimum of 2 photomicrographs per section (minimum 500 fibers per animal) were analyzed for isoform distribution with NIS-Elements Imaging Software (Basic Research, 3.3; Nikon Instruments Inc.). Fibers that were positive for the BA-D5 antibody were counted as type I fibers. Fibers strongly stained only for SC-71 or BF-F3 were labeled as type IIA and type IIB fibers, respectively. Fibers stained weakly for both SC-71 and BF-F3 were labeled as type IIX fibers.

Chop cutting and simulated retail display

At the conclusion of the 13-d aging period, muscles were removed from the package, oriented in the same direction, and cut into five 1-in.-thick chops. The first 4 chops closest to the 10th rib were utilized for simulated retail display. Of these chops, the first 3 were used for d 0, 1, and 3 metmyoglobin reducing ability analysis, and the fourth chop was used for 5-d chop surface color attributes including the collection of L*, a*, and b* values and spectral data for the calculation of surface myoglobin redox forms. The fourth chop was also used for d-5 metmyoglobin reducing ability analysis. The last chop was immediately analyzed for mechanical tenderness by Warner-Bratzler shear force.

All chops allocated to simulate retail display were placed on white 1S Styrofoam trays (Genpack, Glens Falls, NY) with a Dri-Loc 50 (Cryovac Sealed Air Corporation, Duncun, SC) absorbent pad and overwrapped with PVC film (MAPAC M [1,450 cc/23.6 $in.^2$/24 h, 72 gauge], Bordon Packaging and Industrial Products, North Andover, MA). Chops were placed in coffin-style retail cases (Model DMF 8; Tyler Refrigeration Corporation, Niles, MI) at 37.4 ± 3.6°F. Cases were constantly illuminated with fluorescent lights (32 W Del-Warm White 3000°K; Philips Lighting Company, Somerset, NJ) that emitted a 24-h case average intensity of 2,143 ± 113 lx. Every 12 h, chops were rotated from left to right and front to back in the cases to account for variation in temperature and light intensity. Absolute CIE L*, a*, and b*, and spectral reflectance (400 to 700 nm) readings were taken at 3 locations on each 5-d retail display chop using a Hunter Lab Miniscan EZ spectrophotometer (Illuminant A, 1 in diameter aperture, 10° observer; Hunter Associates Laboratory, Reston, VA). Absolute and spectral values from the 3 scans were averaged and reflectance at 473, 525, 572, and 700 nm

were used to calculate surface percentages of metmyoglobin and oxymyoglobin using the equations published in the AMSA Color Guidelines (AMSA, 2012[13]).

Metmyoglobin reducing ability

The procedures of Gonzalez et al. (2009[12]) were followed for metmyoglobin reducing ability (MRA) with modifications. On the day of analysis, chops were pulled from the retail display case and cut into 2 × 2-in. portions that were indicative of the discoloration pattern for the entire chop. Each section was placed in a 400-mL beaker and oxidized in 100 mL of 0.3% sodium nitrite at 77 ± 3.6°F for 20 min. After the samples were blotted of excess solution, they were vacuum-packaged in 10 × 12 in Prime Source Vacuum Pouches (3-mil standard barrier, Bunzl Processor Division, Koch Supplies, Kansas City, MO) that possess an oxygen transmission rate of 4.5 cc/1002/24 h/73°F/65% relative humidity. Reflectance measurements (400 to 700 nm) were collected initially after vacuum-packaging and every 30 min for 2 h using a Hunter Lab Miniscan EZ spectrophotometer (Illuminant A, 1 in diameter aperture, 10° observer; Hunter Associates Laboratory). Average reflectance values at 525, 572, and 700 nm were used to calculate metmyoglobin percentage at all time points using the equations published in the Meat Color Guidelines, AMSA (2012[13]). Metmyoglobin reducing ability was calculated as: (observed decrease in metmyoglobin concentration ÷ initial metmyoglobin concentration) × 100.

Warner-Bratzler shear force analysis and cooking loss

The AMSA (1995[14]) guidelines for instrumental cooked meat tenderness were followed for shear force analysis. Fresh-cut chops were weighed and a thermocouple wire (30-gauge and constantan, Omega Engineering, Stamford, CT) was inserted into the geometric center of each chop for internal temperature monitoring using a Doric Minitrend 205 monitor (VAS Engineering, San Francisco, CA). Chops were cooked on electric, open-hearth Farberware grills (Model 450-A; Yonkers, NY) to an internal temperature of 95°F, then flipped and cooked to a final internal temperature of 160°F. After cooked chops were chilled overnight at 45 ± 1.8°F, six 0.5-in.-diameter cores were extracted from each chop parallel to the muscle fiber orientation. Each core was sheared once through the center of the core perpendicular to the muscle fiber orientation with an Instron Model 5569 Testing Machine (Instron, Canton, MA) with a Warner-Bratzler shear head attached (220.5-lb compression load cell, crosshead speed of 9.8 in./min). Cooking loss was determined by measuring the difference in chop weight before and after cooking and dividing by precooked chop weight.

Statistics

All data were analyzed as a generalized randomized complete block design using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit and animal/chop as the observational unit. For cooked meat analysis and fiber isoform distribution, dietary treatment served as the fixed effect, and gender within group within barn was included as random effects. Contrast statements consisted of: (1) negative control vs. positive control RAC diet, (2) interaction between increasing Zn and Zn source, (3) increasing Zn linear and quadratic polynomials, and (4) added

[13] AMSA (American Meat Science Association). 2012. Meat color measurement guidelines. Am. Meat Sci. Assoc., Champaing, IL.

[14] AMSA (American Meat Science Association). 1995. Research Guidelines for Cookery, Sensory Evaluation, and Instrumental Tenderness Measurements of Fresh Meat. Am. Meat Sci. Assoc., Chicago, IL.

Zn from ZnO vs. Availa-Zn. For shelf-life analysis, the statistical structure was the same, except day of display and the day × treatment interaction served as fixed effects in addition to dietary treatment. Day of display × dietary treatment interaction was evaluated by the following contrast: (1) interaction between negative control vs. positive control RAC diet and day of display, (2) interaction between increasing Zn and day of display, (3) interaction between Zn source and day of display, and (4) interaction between increasing Zn, Zn source, and day of display. Day of display also served as the repeated measure with chop as the subject. Statistical significance was determined at $P < 0.05$, and $P > 0.05$ and $P < 0.10$ were termed trends or tendencies.

Results and Discussion

For all dependent variables observed in the study, there was no evidence of a Zn source effect or an interaction between Zn source and Zn level ($P > 0.10$). Therefore, all data presented will combine the Zn treatment groups by the level of supplementation, making three pooled Zn treatments: 75 (75Zn), 150 (150Zn), and 225 ppm (225Zn) Zn.

Using immunohistochemical techniques, the effects of dietary treatments on myosin heavy-chain isoform distribution were evaluated (Figure 1). This analysis evaluated the four different muscle fiber types: slow-oxidative (type 1), fast oxido-glycolytic (type IIA), and fast glycolytic IIX or IIB. Our method of muscle fiber type determination is in agreement with Lefaucheur et al. (2002), who used the same set of antibodies in the LM of the pig. Similar to our findings, these authors reported that SC-71 recognized both type IIA and IIX fibers, with the IIA fibers staining more intensely than the IIX fibers. In addition, our fiber isoform distribution pattern was similar to the distribution reported by the authors, with a high percentage of type IIB fibers (46 to 50%), a moderate percentage of type IIX fibers (25 to32%), and low percentages of type I (8%) and IIA (14 to 11%) fibers.

Our data indicate that feeding RAC+ or RAC plus added Zn diets did not affect ($P > 0.62$) the percentage of type I muscle fibers. No evidence ($P = 0.16$) was observed for a difference in the percentage of type IIA fibers when comparing muscles from pigs fed CON and RAC+ diets; however, the percentage of type IIA fibers decreased (linear, $P = 0.01$) as dietary Zn increased. Loin muscle samples from pigs fed the RAC+ treatment had a decreased ($P = 0.02$) percentage of type IIX muscle fibers compared with CON; however, adding Zn to the RAC diet tended to increase (linear, $P = 0.09$) the percentage of type IIX fibers. For type IIB fibers, pigs fed the RAC+ treatment had a tendency to possess more ($P = 0.10$) fibers than CON pigs. Finally, no evidence was found ($P > 0.70$) that added Zn affected percentage of type IIB muscle fibers in the loin.

Pork chops from all treatment groups were displayed under simulated retail conditions for 5 d, and daily objective measures of pork color were collected. For L*, a*, and b* values (Figure 2), only a* and b* values were affected by day of display (quadratic, $P < 0.05$). Pork chops of pigs from the RAC+ treatment did not differ ($P > 0.13$) in L* values compared with those from pigs fed the CON on d 0 of the display period. On d 1, 2, 3, 4, and 5, pork chops from pigs fed the RAC+ treatment had greater L* values than those from pigs fed the CON treatment ($P < 0.03$). On d 0 and 3 of display, increasing the Zn content of the diet resulted in a trend for lower L* values (quadratic,

$P = 0.10$). On d 1, 2, 4, and 5 of the display period, increasing Zn reduced the L* values (quadratic, $P < 0.03$). Of the Zn treatment groups, pork chops from pigs fed 150Zn possessed the lowest L* values over the entire display period. Pork chops from pigs fed RAC+ had lower a* values compared with those from the CON fed pigs on d 1 and 4 of display ($P < 0.05$); however, RAC+ produced chops with a* values that tended to be lower on d 0 and 2 of display ($P < 0.10$). On d 4 of display, a* values increased (quadratic, $P = 0.04$) as Zn was added to the diet, with chops from the 150Zn treatment possessing the greatest a* value. For all other display days, there was a lack of evidence ($P > 0.12$) that increasing dietary Zn influenced a* values. On d 0 of display, there was no evidence ($P > 0.28$) for differences in the b* values of pork chops from RAC+ fed pigs compared with CON-fed pigs; however, for the remainder of the display period, chops from RAC+-fed pigs possessed lower b* values than CON-fed pigs ($P < 0.04$). On d 1 of display, adding dietary Zn increased (quadratic, $P = 0.03$) b* values, and on d 2 and 4, added Zn tended to increase b* values ($P < 0.09$). Chops from pigs fed RAC+ from our study appeared less red and less blue than those from CON-fed pigs throughout most of the display period, and chops from pigs fed RAC+ were lighter than the CON chops on d 1–5 of retail display. This result can be explained by a trend toward increased type IIB fibers in chops from pigs fed RAC+ compared with those fed the CON diet. Interesting quadratic Zn effects were detected on d 3 for a* values, d 1–5 for L* values, and d 1, 2, and 4 for b* values. These results indicate that when Zn was added to the RAC diet, values for each parameter shifted away from RAC+ values and toward the CON values. In addition, because Zn supplementation decreased the amount of type IIA fibers and these fibers contain more myoglobin than IIX and IIB fibers, we believe this observed added Zn effect was independent of muscle fiber shifts.

We further explored the effects of RAC on chop shelf-life by utilizing the equations of Krzywicki (1979[15]) to measure the percentage formation of oxymyoglobin and metmyoglobin on the surface of chops and their associated MRA during display. The objective measures of chop surface oxymyoglobin and metmyoglobin percentages indicated a day effect on both redox forms ($P < 0.001$; Figure 3). Oxymyoglobin surface percentages increased (quadratic, $P < 0.001$) from d 0 to d 1, but the surface percentage of oxymyoglobin decreased thereafter. On d 0 of the display period, we observed no evidence ($P = 0.63$) of differences in amount of oxymyoglobin formed on the surface of chops from pigs fed CON or RAC+; however, on the same day of display, as dietary Zn increased from 0 to 225 ppm in RAC diets, formation of pork chop surface oxymyoglobin percentage decreased (linear, $P < 0.01$). For the remaining days of display, RAC+-treated pigs had chops with a tendency toward increased oxymyoglobin percentage compared with chops from CON-fed pigs ($P < 0.08$). As the day of display increased, the surface percentage of metmyoglobin increased (quadratic, $P < 0.001$), but no evidence was found that including dietary RAC or increasing Zn affected chop surface metmyoglobin accumulation ($P > 0.10$). Full bloom for all treatments, as indicated by the peak oxymyoglobin formation, was reached on d 1 of display, which follows the same pattern as a* values. At this time point, RAC+ chops tended to possess more oxymyoglobin on their surface, and this finding was maintained on all days of display except d 3. We attributed these findings to RAC+ chops reaching a

[15] Krzywicki, K. 1979. Assessment of relative content of myoglobin, oxymyoglobin and metmyoglobin at the surface of beef. Meat Sci. 3:1–10.

higher maximum bloom on d 1 and all of the dietary treatments decreasing in surface oxymyoglobin percentage at the same relative rate throughout the display period (Table 2). Our finding that RAC+ chops contain more surface oxymyoglobin than CON chops seems counterintuitive considering RAC+ chops were lighter and less red according to L* and a* values. We attribute the increased surface oxymyoglobin to RAC+ pigs tending to possess more type IIB fibers. Because of this shift, we are certain that the amount of myoglobin and oxygen-scavenging mitochondria present in the muscle was reduced (Aberle et al., 2003[16]). When muscle possesses a copious amount of mitochondria, myoglobin must compete with these organelles for oxygen, which results in less oxymyoglobin formation (Klont, 1998[17]); therefore, because the RAC+ chops possessed a fiber type distribution that favored the presence of fewer mitochondria, more oxygen was available for consumption by the myoglobin in the muscle, which increased the formation of oxymyoglobin.

As expected, all chops exhibited a reduction ($P < 0.001$) in MRA as the day of display increased (Figure 4). At the beginning of the display period, chop reducing ability ranged from 52% to 56%. No evidence of an RAC+ effect was observed on the reducing ability on this day or d 1 and 3 of the display period ($P > 0.10$). By d 5 of display, chop reducing abilities ranged from 31% to 42%. Inclusion of RAC in the diet reduced ($P < 0.001$) metmyoglobin reducing ability compared with the chops from CON-fed pigs. Although there was no evidence of a Zn effect on d 0 and 1 ($P > 0.10$), as dietary Zn increased, reducing ability increased on d 3 (quadratic, $P = 0.03$) and d 5 (quadratic, $P = 0.02$) of the display period. Seventy-five ppm of added Zn was sufficient to maximize the reducing ability of RAC-treated pork chops on d 3 of display, whereas 150 ppm of added Zn resulted in the greatest reducing ability on d 5. The RAC effect on MRA was not detected until d 5 of the display period, when RAC+ chops possessed 11.6% less MRA than CON chops. At this time point, a quadratic Zn effect was observed in which adding 150 ppm of Zn increased MRA by 9.2% over RAC+ chops. This same effect was seen at d 3, where adding 75 ppm of Zn to the diet increased MRA by 6.3% over RAC+ chops. The fact that RAC stimulated a shift toward type IIB fibers and this did not affect MRA until d 5 of display could indicate that the fiber shift influence on MRA does not become important until later in the display period, when this attribute is the most important to a retailer. In addition, the Zn75 treatment group had the highest MRA and type IIA fiber percentage of the Zn treatments. Because type IIA fibers are more glycolytic than IIX or IIB fibers, more mitochondria and NADH could be available, causing this treatment to have a greater MRA. Although the difference between RAC+ and CON MRA detected at d 5 did not translate to increases in chop surface metmyoglobin formation, extending the display period could demonstrate that the RAC-induced reduction in MRA may result in greater metmyoglobin formation on the surface of these chops. Furthermore, if extending the display period proves that RAC reduces color stability during extended display, Zn supplementation can serve as a countermeasure to these effects, as indicated by the ability of the Zn treatments to restore MRA and a* values close to control values.

[16] Aberle, E.D., J.C. Forrest, D.E. Gerrard, and E.W. Mills. 2001. Principles of Meat Science. 4th ed. Kendall/Hunt Publishing Co. Dubuque, IA.
[17] Klont, R.E., L. Brocks and G. Eikelenboom. 1998. Muscle fibre type and meat quality. Meat Sci. 49:S219–S229.

We found no evidence ($P > 0.30$) that RAC+ elicited different pH, cooking loss, or shear force values compared with the CON treatment, but we observed a trend toward increased (linear, $P = 0.07$) cooking loss as dietary Zn increased in RAC containing diets (Table 3).

In summary, feeding pigs 10 ppm of RAC decreased the amount of type IIX fibers while tending to increase the percentage of type IIB fibers in the *Longissimus lumborum*. Supplementing the RAC diets with dietary Zn above that contained in the trace mineral premix decreased the percentage of type IIA fibers and tended to increase the percentage of type IIX fibers, which affected meat color characteristics. Pigs fed RAC produced chops that were lighter and less red, but maintained a higher percentage of surface oxymyoglobin throughout a 5-d simulated retail display. Although RAC improved these shelf-life characteristics, it reduced MRA at the end of the display period. Supplementing Zn to RAC diets restored MRA to near-CON treatment levels at the end of the display period, which is most important to retailers. Zinc supplementation tended to increase chop cook loss, which may affect sensory attributes of the chops and should be explored further.

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

Item	Control	RAC
Ingredient, %		
Corn	83.06	74.24
Soybean meal, (46.5% CP)	15.22	23.97
Monocalcium P, (21% P)	0.25	0.20
Limestone	0.75	0.78
Salt	0.35	0.35
Vitamin premix	0.075	0.075
Trace mineral premix[3]	0.075	0.075
L-lysine HCl	0.15	0.15
DL-methionine	---	0.015
L-threonine	---	0.025
Phytase[4]	0.075	0.075
Ractopamine HCl[5]	---	0.05
Total	100	100
Calculated analysis, %		
Standardized ileal digestible (SID) amino acids, %		
Lysine	0.70	0.92
Isoleucine:lysine	71	70
Leucine:lysine	179	158
Methionine:lysine	31	30
Met & Cys:lysine	65	60
Threonine:lysine	63	64
Tryptophan:lysine	19	19
Valine:lysine	84	79
Total lysine, %	0.79	1.03
CP, %	14.3	17.6
ME, Kcal/lb[6]	1,525	1,523
NE, Kcal/lb[7]	1,044	1,029
SID lysine: ME, g/Mcal	2.08	2.74
Ca, %	0.41	0.44
P, %	0.39	0.42
Available P, %	0.21	0.21

[1] Diets were fed in meal form during the experiment.
[2] Dietary treatments were obtained by replacing corn in the ractopamine HCl diet to achieve 75, 150, and 225 ppm added Zn from ZnO (Zinc Nacional S.A., Monterrey, Mexico) or Availa-Zn (Zinpro, Eden Prairie, MN).
[3] Trace mineral premix provided 55 ppm Zn from $ZnSO_4$.
[4] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 204 phytase units (FTU)/lb, with a release of 0.10% available P.
[5] Provided 9 g/lb (10 ppm) of ractopamine HCl (Paylean; Elanco Animal Health, Greenfield, IN).
[6] ME values for ingredients were derived from NRC (1998).
[7] NE values for all ingredients were derived from INRA (2004).

Table 2. LSMEANS of the daily reduction in surface oxymyoglobin percentage from d 1 of display of pork *Longissimus lumborum* chops from pigs supplemented ractopamine HCl and 3 levels of dietary zinc

			Zinc, ppm[1,2]				*P*-value		
Day of display	Control	RAC+[1]	75	150	225	SEM	RAC	Zn linear	Zn quadratic
2	-7.66	-7.19	-6.88	-6.52	-7.39	1.18	0.72	0.95	0.41
3	-11.63	-10.92	-9.63	-9.53	-10.77	1.18	0.58	0.87	0.08
4	-15.47	-14.90	-13.76	-14.06	-15.11	1.18	0.66	0.80	0.13
5	-18.01	-17.39	-16.73	-16.36	-17.50	1.18	0.63	0.99	0.21

[1] Diets contained 10 ppm of ractopamine-HCl (Paylean; Elanco Animal Health, Greenfield, IN).
[2] Dietary treatments were obtained by replacing corn in the ractopamine HCl diets to achieve 75, 150, and 225 ppm added Zn from ZnO (Zinc Nacional S.A., Monterrey, Mexico) or Availa-Zn (Zinpro, Eden Prairie, MN). Because no Zn × source interaction was observed, means represent the pooled results of both Zn sources.

Table 3. LSMEANS of pork *Longissimus lumborum* chop cooked meat characteristics from pigs supplemented ractopamine HCl and 3 levels of dietary zinc

			Zinc, ppm[1,2]				*P*-value		
Item	Control	RAC+[1]	75	150	225	SEM	RAC	Zn linear	Zn quadratic
Cooking loss, %	24.74	23.54	25.06	24.60	25.63	0.98	0.30	0.07	0.70
Shear force, lb	7.85	7.83	8.29	8.00	8.22	0.31	0.97	0.44	0.59
pH[3]	5.44	5.43	5.44	5.46	5.44	0.02	0.89	0.67	0.43

[1] Diets contained 10 ppm ractopamine HCl (Paylean; Elanco Animal Health, Greenfield, IN).
[2] Dietary treatments were obtained by replacing corn in the ractopamine HCl diets to achieve 75, 150, and 225 ppm added Zn from ZnO (Zinc Nacional S.A., Monterrey, Mexico) or Availa-Zn (Zinpro, Eden Prairie, MN). Because no Zn × source interaction was observed, means represent the pooled results of both Zn sources.
[3] pH collected at 24-h postmortem.

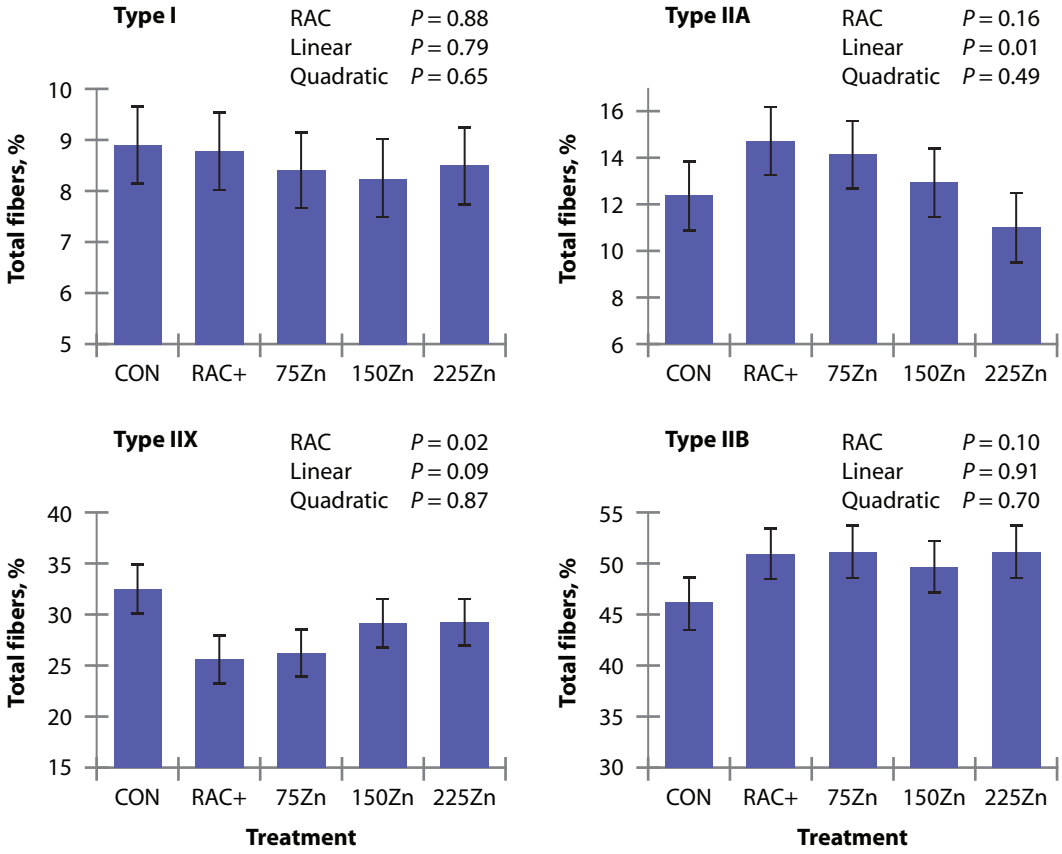

Figure 1. Tenth-rib *Longissimus lumborum* myosin heavy-chain isoform distribution of pigs fed a basal diet containing 0 ppm ractopamine HCl (CON), pigs supplemented 10 ppm ractopamine HCl (RAC+), and pigs supplemented 10 ppm ractopamine HCL and 75 ppm (75Zn), 150 ppm (150Zn), or 225 ppm (225Zn) of zinc.

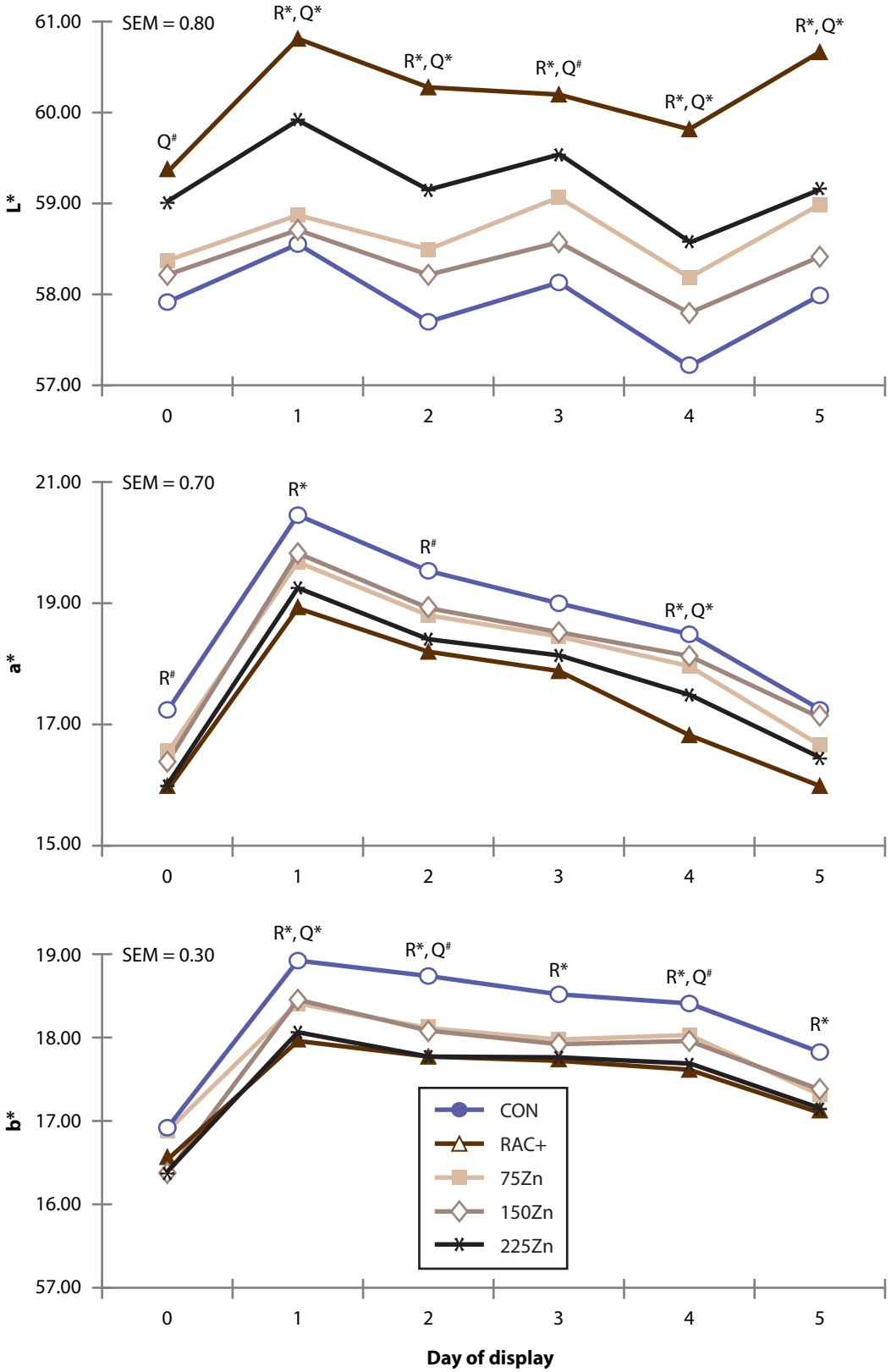

Figure 2. Surface L*, a*, and b* values of loin chops from pigs fed a basal diet containing 0 ppm ractopamine HCl (CON), pigs supplemented 10 ppm ractopamine HCl (RAC+), and pigs supplemented 10 ppm ractopamine HCl and 75 ppm (75Zn), 150 ppm (150Zn), or 225 ppm (225Zn) of zinc. L* = lightness (0 = black; 100 = white), a* = redness (-60 = green; 60 = red), and b* = blueness (-60 = blue; 60 = yellow). R designates a ractopamine-HCl effect and Q designates a quadratic zinc effect. The superscript * indicates a significant effect ($P \leq 0.05$), and the superscript # indicates marginal significance ($P \leq 0.10$).

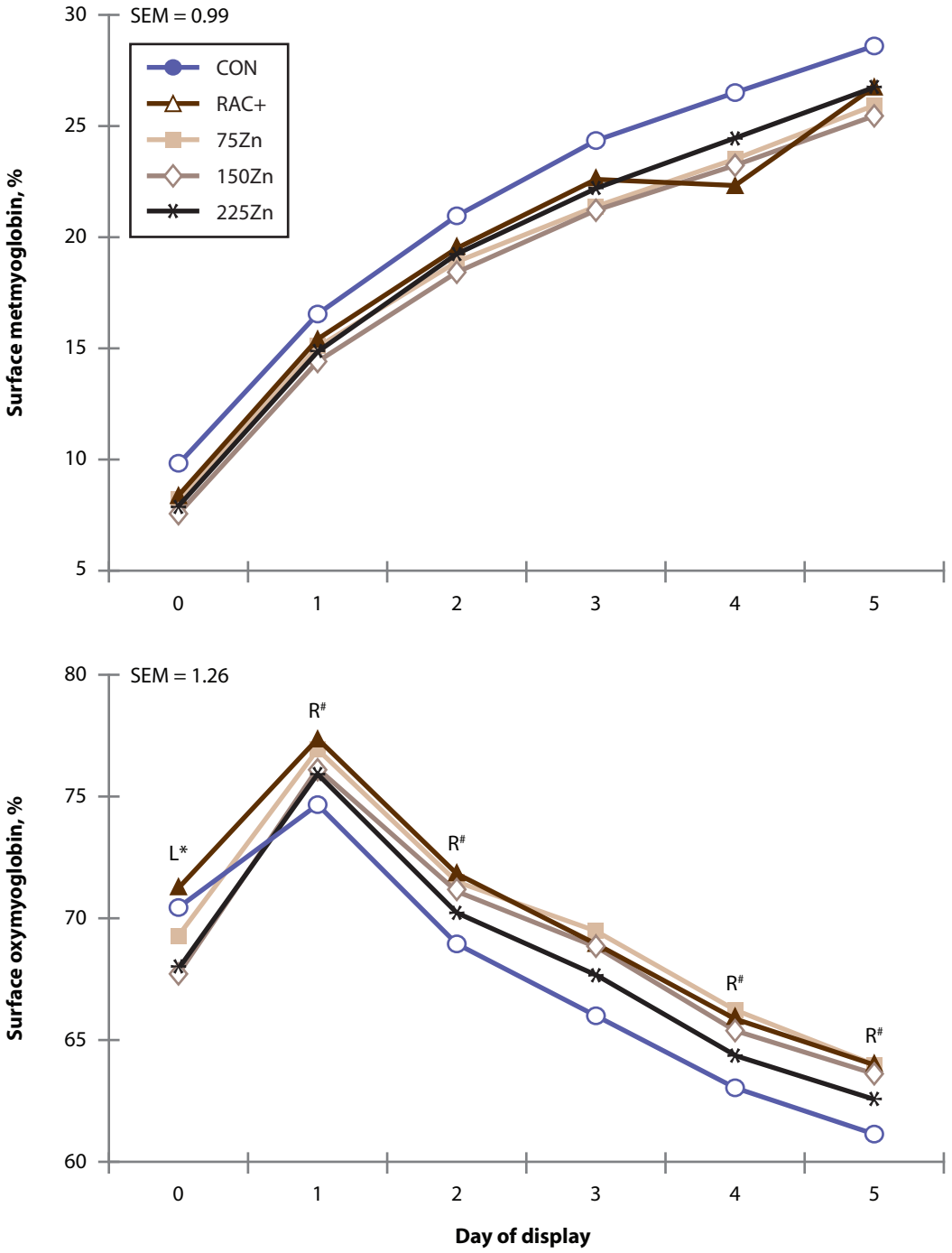

Figure 3. Surface oxymyoglobin and metmyoglobin percentages of loin chops from pigs fed a basal diet containing 0 ppm ractopamine HCl (CON), pigs supplemented 10 ppm ractopamine HCl (RAC+), and pigs supplemented 10 ppm ractopamine HCL and 75 ppm (75Zn), 150 ppm (150Zn), or 225 ppm (225Zn) of zinc. R designates a ractopamine HCl effect and L designates a linear zinc effect. The superscript * indicates a significant effect ($P \leq 0.05$), and the superscript # indicates marginal significance ($P \leq 0.10$).

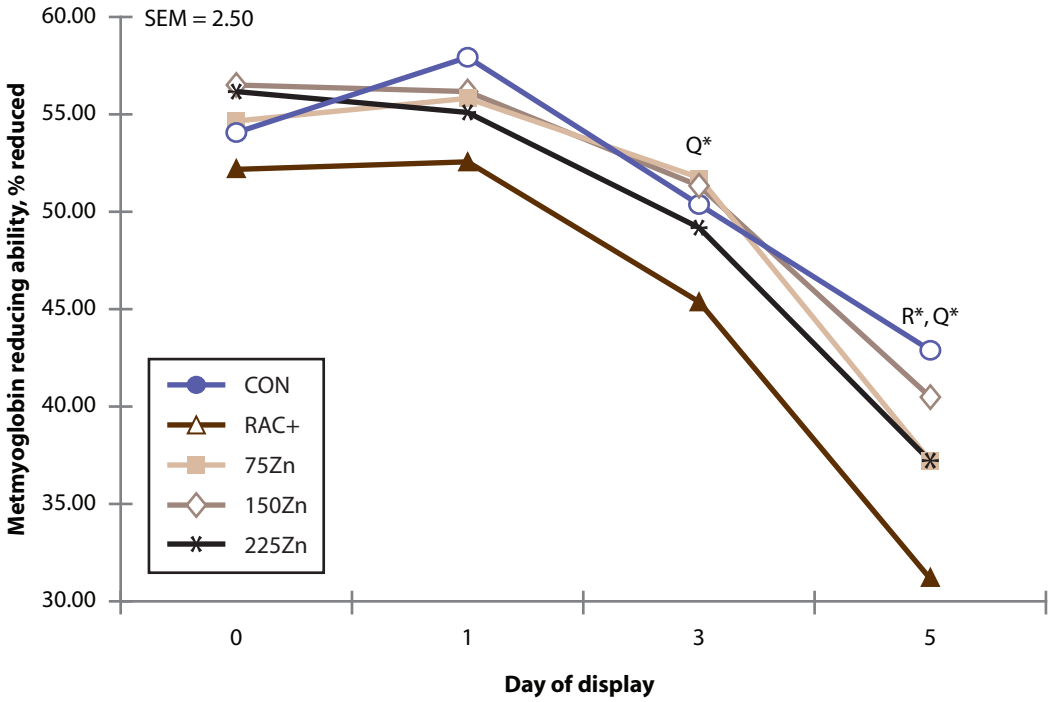

Figure 4. Metmyoglobin reducing ability of loin chops from pigs fed a basal diet containing 0 ppm ractopamine HCl (CON), pigs supplemented 10 ppm ractopamine HCl (RAC+), and pigs supplemented 10 ppm ractopamine HCl and 75 ppm (75Zn), 150 ppm (150Zn), or 225 ppm (225Zn) of zinc. R designates a ractopamine HCl effect, and Q designates a quadratic zinc effect. The superscript * indicates a significant effect ($P \leq 0.05$).

Effects of Added Zinc and Copper on Growth Performance and Carcass Characteristics of Finishing Pigs fed Ractopamine HCl[1]

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Summary

A total of 253 finishing pigs (PIC 327 × 1050; initial BW 204 lb) were used in a 28-d study to determine the effects of added Zn (Availa-Zn; Zinpro Corp., Eden Prairie, MN), Cu (Availa-Cu; Zinpro Corp.), or both to diets containing ractopamine HCl (RAC; Paylean; Elanco Animal Health, Greenfield, IN) on growth performance and carcass characteristics. Pens of pigs were randomly assigned to 1 of 5 treatments and balanced on average pig weight with 7 to 8 pigs per pen. Treatments included a control diet without RAC (negative control) and 4 diets containing 9 g/ton RAC with or without added Zn (50 ppm) or Cu (125 ppm) in a 2 × 2 factorial.

Overall, pigs fed RAC had increased ($P < 0.01$) ADG and improved F/G, which resulted in approximately a 15.5-lb heavier ($P < 0.01$) pig compared with those fed the negative control diet. Pigs fed added Zn had decreased ($P < 0.05$) ADG and tended to have decreased ($P < 0.09$) ADFI. Pigs fed added Cu also tended ($P < 0.10$) to have decreased ADG. No differences were observed in F/G when Zn or Cu was added to the diet.

Hot carcass weight, carcass yield, loin depth, and percentage lean increased ($P < 0.01$) in pigs fed the positive control diet containing RAC compared with those fed the negative control diet, whereas backfat was unaffected. Carcass characteristics were not affected by added Zn or Cu.

Feed cost and revenue increased ($P < 0.01$) for pigs fed the positive control diet containing RAC by approximately $9.63 and $10.08, respectively, compared with pigs fed the negative control diet; however, no difference was observed in feed cost per lb of gain. Income over feed cost (IOFC) did not differ in pigs fed the negative or positive control diet. Adding Zn decreased ($P < 0.05$) revenue per pig, and adding Cu tended to increase ($P < 0.06$) feed cost per lb of gain and reduce ($P < 0.10$) revenue per pig. There were no differences in IOFC between diets containing added Zn and no added Zn. Added Cu reduced ($P < 0.05$) IOFC.

In summary, growth and carcass characteristics improved in pigs fed dietary RAC as expected, but adding Zn, Cu, or both to diets containing RAC did not improve growth performance, carcass characteristics, or IOFC. Adding copper actually reduced IOFC due to the added expense.

[1] The authors would like to express thanks to Triumph Foods, Inc., St. Joseph, MO, for their help and cooperation in carcass data collection.

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Key words: finishing pigs, zinc, copper, ractopamine HCl

Introduction

Ractopamine HCl (RAC; Paylean; Elanco Animal Health, Greenfield, IN) is commonly added to finishing diets just before marketing to improve growth performance and carcass leanness. Research associated with RAC has predominately focused on amino acids and the higher protein accretion generally observed in pigs fed RAC; however, limited data exists evaluating the effects of mineral supplementation in conjunction with feeding RAC.

Previous research (Akey, 2011[3]; Patience, 2011[4]) has observed improvements in growth performance when adding Zn to diets containing RAC. Paulk et al. (2012[5]) also observed a tendency for increased ADG when adding 50 ppm Zn to diets containing RAC. This approach resulted in a $0.47 increase in IOFC per pig. Copper is another important trace mineral that is commonly added to nursery pig diets, but recent data evaluating the growth performance of pigs fed added Cu during the finishing period are limited, specifically during the last phase where diets may contain RAC. Therefore, the objective of this study was to evaluate the effects of added Zn, Cu, or both in diets containing RAC on growth performance, carcass characteristics, and economics.

Procedures

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

The barn was mechanically ventilated with completely slatted flooring over a deep pit. Each pen (10 ft × 10 ft) was equipped with a 2-hole stainless steel feeder and cup waterer for ad libitum access to feed and water. Feed deliveries were made and recorded by a robotic feeding system (FeedPro; Feedlogic Corp., Wilmar, MN) for each individual pen.

A total of 253 mixed sex pigs (PIC 327 × 1050, initially 204 lb) were used in a 28-day study. Pens of pigs were randomly allotted to 1 of 5 dietary treatments in a completely randomized design with 7 or 8 pigs per pen and 7 replications per treatment. Pigs were fed a negative control diet that did not contain RAC (negative control; 0.72% standardized ileal digestible [SID] lysine) or diets containing 9 g/ton RAC (positive control; 0.92% SID Lys; Table 1). Additional treatments included the positive control with or without added Zn (50 ppm from Availa-Zn; Zinpro Corp., Eden Prairie, MN) or Cu (125 ppm from Availa-Cu; Zinpro Corp., Eden Prairie, MN) arranged in a 2 × 2 factorial. All diets contained 55 ppm Zn and 8 ppm Cu from the trace mineral premix. Zinc and Cu were added at the expense of corn. All diets were analyzed for Zn and Cu and were found to be similar to calculated values (Table 2).

[3] Akey. 2011. Effects of Zinc Source and Level in Paylean Diets on Pig Performance and Carcass Characteristics. Akey Swine Newsletter.
[4] Patience, J.P. 2011. Impact of Zinc Source and Timing of Implementation on Grow-finish Performance, Carcass Composition, and Locomotion Score. Iowa St. Univ. Anim. Ind. Rep.
[5] Paulk, C.B. et al., Swine Day. 2012, Report of Progress 1074, pp. 356–364.

Pens of pigs and feeders were weighed on d 0, 14, and 28 of the experiment to determine ADG, ADFI, and F/G. Prior to d 28, pigs were individually tattooed for plant identification. On day 28, the pigs were individually weighed and transported to a commercial packing plant (Triumph Foods Inc., St. Joseph, MO) for processing and data collection. Carcass measurements included HCW, loin depth, and backfat depth. These measurements were used to determine the percentage carcass yield and percentage lean for each pig.

At the conclusion of the study, total feed cost per pig was determined by multiplying ADFI by the respective diet cost and the number of days on feed. Cost per lb of gain was calculated by dividing the total feed cost by the total weight gained during the 28-d period. Revenue was determined by multiplying ADG by 28 and a live price of $65.00 per cwt. Income over feed cost was calculated by subtracting total feed cost from revenue. Ingredient prices used were: corn = $7.84 per bushel; soybean meal = $478 per ton; L-lysine = $1.16 per lb; ractopamine HCl = $36.31 per lb; Availa-Zn = $1.50 per lb, and Availa-Cu = $2.15 per lb.

The experimental data were analyzed as a 2 × 2 + 1 factorial with main effects of added Zn or Cu, plus a contrast comparing pigs fed the negative control diet with those fed the diet containing RAC. The MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) was used with pen as the experimental unit. Hot carcass weight served as a covariate for the analysis of loin depth, backfat, and percentage lean. Data presented as least square means and results were considered significant at $P \leq 0.05$ and considered a tendency between $P > 0.05$ and $P \leq 0.10$.

Results and Discussion

No Zn × Cu interactions ($P > 0.10$) were observed for any of the response criteria throughout the study. From d 0 to 14, pigs fed the positive control diet containing RAC had increased ($P < 0.01$) ADG, BW, and improved F/G compared with those fed the negative control diet (Table 3). There were no differences in ADFI. Adding either Zn or Cu to the positive control during this period did not influence growth performance (Table 4).

From d 14 to 28, pigs fed the positive control diet again had increased ($P < 0.01$) ADG, BW, and improved F/G compared with those fed the negative control diet. Adding Zn, Cu, or both decreased ($P < 0.02$) ADG compared with the negative control; however, the reduction in ADG combined with no change in ADFI during this period resulted in pigs fed added Cu having poorer ($P < 0.04$) F/G compared with those not fed added Cu.

Overall, pigs fed the positive control diet had increased ($P < 0.01$) ADG and improved F/G compared with pigs fed the negative control diet. These pigs were approximately 15.5 lb lighter ($P < 0.01$) than pigs fed the positive control diet containing RAC. Pigs fed added Zn had decreased ($P < 0.05$) ADG and a tendency ($P < 0.09$) for decreased ADFI. Pigs fed added Cu had a tendency ($P < 0.10$) for decreased ADG. There were no differences in F/G when Zn or Cu was added to the positive control diet.

Pigs fed the positive control diet had increased ($P < 0.01$) HCW, loin depth, percentage lean, and carcass yield compared with pigs fed the negative control, but there were no differences in backfat. Added Zn or Cu to diets containing RAC had no effect on any of the carcass characteristics.

Feed cost and revenue increased ($P < 0.01$) for pigs fed the positive control diet containing RAC by approximately $9.63 and $10.08, respectively, compared with the negative control, but feed cost per lb of gain did not differ. Therefore, IOFC did not differ in pigs fed the negative and positive control diets. Added Zn decreased ($P < 0.05$) revenue per pig, and added Cu tended to increase ($P < 0.06$) feed cost per lb of gain and reduce ($P < 0.10$) revenue per pig, due in part to the expense of the adding both Zn and Cu to the diet. There were no differences in IOFC among pigs fed diets containing added Zn vs. no added Zn, but adding Cu reduced ($P < 0.05$) IOFC, again due in part to the expense of adding both Zn and Cu to the diet.

In conclusion, adding Zn or Cu to diets containing RAC did not improve growth, carcass characteristics, or IOFC.

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

Item	Negative control	Positive control
Ingredient, %		
Corn	82.77	74.03
Soybean meal, 46.5% CP	15.24	23.99
Limestone	1.00	0.95
Monocalcium P, 21%	0.25	0.20
Salt	0.35	0.35
Vitamin premix	0.075	0.075
Trace mineral premix[2]	0.075	0.075
L-lysine HCl	0.150	0.150
DL-methionine	---	0.025
L-threonine	0.010	0.035
Phytase[3]	0.075	0.075
Ractopamine HCl[4]	---	0.05
Availa-Zn[5]	---	---
Availa-Cu[6]	---	---
Total	100	100
Calculated analysis		
Standardized ileal digestible (SID) amino acids, %		
Lysine	0.70	0.92
Isoleucine:lysine	71	70
Leucine:lysine	179	158
Methionine:lysine	31	31
Met & Cys:lysine	65	61
Threonine:lysine	65	65
Tryptophan:lysine	18.7	19.3
Valine:lysine	84	79
Total lysine, %	0.79	1.03
ME, kcal/lb	1,521	1,520
SID lysine:ME, g/Mcal	2.09	2.75
CP, %	14.3	17.6
Ca, %	0.50	0.50
P, %	0.39	0.41
Available P, %	0.21	0.21

[1] Treatment diets fed for 28 d.
[2] Trace mineral premix provided 55 ppm Zn from $ZnSO_4$ and 8 ppm Cu from $CuSO_4$ in the complete diet.
[3] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 204.3 phytase units (FTU)/lb, with a release of 0.10% available P.
[4] Provided 9 g/ton of ractopamine HCl (Elanco Animal Health, Inc., Greenfield, IN).
[5] Zinpro Corp. (Eden Prairie, MN); added 50 ppm Zn at the expense of corn to the positive control diet.
[6] Zinpro Corp, (Eden Prairie, MN); added 125 ppm Cu at the expense of corn to the positive control diet.

Table 2. Analyzed zinc and copper concentrations of complete diets[1,2]

Concentration, ppm	Negative control	Positive control	50 ppm Zn	125 ppm Cu	50 ppm Zn + 125 ppm Cu
Zinc	98.7	106.3	143.8	95.2	134.7
Copper	12.3	14.6	15.2	114.8	108.2

[1] Values represent means from one composite sample, analyzed in triplicate.
[2] Trace mineral premix provided 55 ppm Zn from $ZnSO_4$ and 8 ppm Cu from $CuSO_4$ in the complete diet.

Table 3. The effects of added zinc and copper on finishing pig growth performance, carcass characteristics, and economics[1]

Item	Negative control	Positive control	50 ppm Zn	125 ppm Cu	50 ppm Zn + 125 ppm Cu	SEM[2]	Probability, $P <$ Neg. control vs. pos. control	Zn	Cu
BW, lb									
d 0	204.5	204.5	202.3	204.3	204.6	2.48	1.00	0.76	0.73
d 14	228.6	238.7	237.1	239.1	239.1	2.33	0.01	0.73	0.63
d 28	259.5	275.0	272.1	273.7	270.6	2.37	0.01	0.23	0.57
d 0 to d 14									
ADG, lb	1.72	2.44	2.43	2.48	2.46	0.086	0.01	0.83	0.69
ADFI, lb	6.20	6.33	6.18	6.52	6.29	0.130	0.49	0.17	0.26
F/G	3.61	2.62	2.56	2.63	2.58	0.082	0.01	0.51	0.86
d 14 to d 28									
ADG, lb	2.21	2.59	2.50	2.47	2.26	0.058	0.01	0.02	0.01
ADFI, lb	7.46	7.56	7.34	7.37	7.21	0.137	0.60	0.19	0.25
F/G	3.38	2.92	2.94	2.99	3.21	0.080	0.01	0.15	0.04
d 0 to d 28									
ADG, lb	1.96	2.52	2.47	2.48	2.36	0.042	0.01	0.05	0.10
ADFI, lb	6.83	6.94	6.76	6.94	6.75	0.106	0.44	0.09	0.96
F/G	3.48	2.76	2.74	2.80	2.86	0.048	0.01	0.67	0.11
Carcass characteristics									
HCW, lb	194.5	208.3	205.9	208.2	206.1	2.55	0.01	0.36	0.99
Yield, %	72.21	73.33	73.16	73.52	73.54	0.201	0.01	0.68	0.13
Backfat, in.[3]	0.85	0.80	0.77	0.76	0.76	0.025	0.09	0.59	0.31
Loin depth, in.[3]	2.39	2.56	2.50	2.55	2.56	0.041	0.01	0.57	0.49
Lean, %[3]	51.97	53.37	53.31	53.66	53.72	0.313	0.01	0.99	0.24
Economics									
Feed cost, $/pig	33.30	42.93	41.90	43.90	42.03	0.593	0.01	0.12	0.83
Feed cost, $/lb gain	0.606	0.610	0.608	0.621	0.637	0.009	0.78	0.53	0.06
Revenue, $ / pig[4]	35.75	45.83	44.87	45.10	42.93	0.759	0.01	0.05	0.10
IOFC, $/pig[5]	2.45	2.90	2.96	2.01	0.89	0.725	0.66	0.48	0.05

[1] A total of 253 (PIC 327 × 1050) were used in a 28-d finishing trial with 7 to 8 pigs per pen and 7 replications per treatment.
[2] No Zn × Cu interactions ($P > 0.10$).
[3] HCW was used as a covariate.
[4] Revenue based on $65.00/cwt live price.
[5] Income over feed cost = total revenue/pig – feed cost/pig.

Table 4. Main effects of added zinc and copper on finishing pig growth performance, carcass characteristics, and economics[1]

	Zn		Cu			Probability, $P <$	
Item	-	+	-	+	SEM	Zn	Cu
BW, lb							
d 0	204.4	203.6	203.6	204.5	1.82	0.76	0.73
d 14	238.9	238.1	237.9	239.1	1.72	0.73	0.63
d 28	274.4	271.36	273.6	272.16	1.74	0.23	0.57
d 0 to d 14							
ADG, lb	2.46	2.44	2.44	2.47	0.635	0.83	0.69
ADFI, lb	6.42	6.23	6.25	6.40	0.095	0.17	0.26
F/G	2.62	2.66	2.59	2.60	0.604	0.51	0.86
d 14 to d 28							
ADG, lb	2.53	2.38	2.55	2.36	0.043	0.02	0.01
ADFI, lb	7.46	7.28	7.45	7.29	0.101	0.19	0.25
F/G	2.96	3.08	2.93	3.10	0.059	0.15	0.04
d 0 to d 28							
ADG, lb	2.50	2.41	2.49	2.42	0.031	0.05	0.10
ADFI, lb	6.94	6.75	6.85	6.85	0.078	0.09	0.96
F/G	2.78	2.80	2.75	2.83	0.035	0.67	0.11
Carcass characteristics							
HCW, lb	208.2	206.0	207.1	207.1	1.75	0.36	0.99
Yield, %	73.43	73.34	73.24	73.53	0.137	0.68	0.13
Backfat, in.[2]	0.78	0.77	0.79	0.76	0.163	0.59	0.31
Loin depth, in.[2]	2.55	2.53	2.53	2.56	0.031	0.57	0.49
Lean, %[2]	53.51	53.51	53.34	53.69	0.215	0.99	0.24
Economics							
Feed cost, $/pig	43.01	41.97	42.42	42.56	0.474	0.12	0.83
Feed cost, $/lb gain	0.616	0.622	0.609	0.629	0.008	0.53	0.06
Revenue, $/pig[3]	45.47	43.90	45.35	44.02	0.559	0.05	0.10
IOFC, $/pig[4]	2.46	1.93	2.93	1.45	0.533	0.48	0.05

[1] A total of 253 (PIC 327 × 1050) were used in a 28-day finishing trial with 7 to 8 pigs per pen and 7 replications per treatment.
[2] HCW was used as a covariate.
[3] Revenue based on $65.00/cwt live price.
[4] Income over feed cost = total revenue/pig – feed cost/pig.

Effects of Copper Source (Intellibond C or Copper Sulfate) on Growth Performance, Carcass Characteristics, Pen Cleanliness, and Economics in Finishing Pigs[1,2]

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Summary

A total of 1,143 pigs (PIC 337 × 1050, initially 55.3 lb) were used to determine the effects of tribasic copper chloride (TBCC; Intellibond C; Micronutrients Inc., Indianapolis, IN) or copper sulfate ($CuSO_4$) on growth performance, carcass characteristics, pen cleanliness, and economics in a 111-d study. Pens of pigs were randomly allotted to 1 of 6 dietary treatments and balanced based on average pen weight in a completely randomized design with 25 to 28 pigs per pen and 8 pens per treatment. Treatment diets included a corn-soybean meal positive control, a high by-product diet with 30% dried distillers grains with solubles (DDGS) and 15% bakery meal (negative control), or the negative control diet with 75 or 150 ppm copper from $CuSO_4$ or TBCC. All diets were formulated on a standardized ileal digestible (SID) amino acid basis and were 0.05% below the pig's estimated lysine requirement throughout the trial. Pigs fed the corn-soybean meal positive control diet had improved ($P < 0.01$) F/G and tended to have increased ADFI ($P < 0.08$) compared with those fed the negative control, high by-product diet. Pigs fed increasing copper had improved (linear, $P < 0.01$) ADG and ADFI but tended to have slightly poorer (quadratic, $P < 0.06$) F/G. Although no interactions were observed between copper source and level, pigs fed increasing $CuSO_4$ had increased (linear, $P < 0.02$) ADFI, whereas pigs fed increasing TBCC had increased ADG, ADFI, and final BW (linear, $P < 0.01$).

Increasing added copper improved (linear, $P < 0.02$) HCW and loin depth, with the greatest response in HCW for pigs fed TBCC (linear, $P < 0.01$). For pen characteristics, pigs fed the high by-product diet had greater ($P < 0.01$) manure buildup and longer wash time than those fed the corn-soybean meal control diet. Addition of copper to diets did not influence pen wash time and had no impact on manure buildup. Economics were calculated on both a constant days on feed and constant market weight basis. Pigs fed either source of copper to a constant days on feed had an increase in feed cost per pig (linear, $P < 0.01$) as well as a higher ($P < 0.10$) revenue per pig. When economics were calculated on feeding pigs to a constant BW, facility costs decreased (linear, $P < 0.05$) with feeding copper. Although no significant differences were detected in income over feed and facility cost for added copper, the greatest numerical

[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 Micronutrients, Inc. (Indianapolis, IN) for funding of this experiment.
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advantage to individual copper sources occurred at 75 PPM for $CuSO_4$ ($0.26) and at 150 ppm for TBCC ($1.35 per pig).
In summary, feeding increased levels of copper sulfate or TBCC in diets formulated slightly below the estimated SID lysine requirement increased growth rate and feed intake, resulting in increased final BW and HCW. Pigs fed TBCC at 150 ppm had the highest final BW (+12.8 lb) and HCW (+7.7 lb). In addition, the use of added copper in the diets did not increase time required to wash pens. More research is needed to determine whether the amino acid concentration influences the response to copper source and level in diets for growing and finishing pigs.

Key words: finishing pig, copper sulfate, tribasic copper chloride, wash time

Introduction

Adding 250 ppm of copper from copper sulfate ($CuSO_4$) has been routine in nursery pig diets for many years. Due to the antimicrobial-like responses in growth performance in nursery pigs[4], copper is believed to serve as an antimicrobial-like agent in the gut. Although added copper in nursery diets is common, use of copper in the finishing stage has been relatively limited. Hastad et al. (2001[5]) reported that added $CuSO_4$ or copper chloride from approximately 74 to 135 lb improved ADG and F/G. However, these advantages were not maintained until market although copper was supplemented continuously, suggesting that supplementing copper in late finishing did not provide growth advantages.

Data on a relatively new source of supplemental copper, tribasic copper chloride (TBCC), are limited. Tribasic copper chloride may also offer improvements in finishing pig growth performance. Lastly, feeding diets high in by-product ingredients, as well as supplemental copper, are believed to increase manure buildup and therefore wash time, but few data are available to verify this speculation. Therefore, the objectives of this study were to evaluate the effects of TBCC and $CuSO_4$ 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 5-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 1,143 mixed-sex pigs (PIC 1050 × 337, initially 55.3 lb) were used in a 111-d study. Prior to initiating the trial, pigs were fed on a common diet containing 186 ppm TBCC (Intellibond C; Micronutrients, Inc., Indianapolis, IN). Pens of pigs were allotted to 1 of 6 dietary treatments in a completely randomized design, with 25 to 28 pigs per pen and 8 replications per treatment. Treatments included a positive control, corn-

[4] Cromwell, G.L. 2001. Antimicrobial and promicrobial agents. In: A.J. Lewis and L.L. Southern, eds., Swine Nutrition, Second Edition. CRC Press LLC, Boca Raton, FL. pp. 401–426.
[5] Hastad, C.W et al., Swine Day 2001. Report of Progress 880, pp. 111–117.

soybean meal diet and a negative control diet containing 30% dried distillers grains with solubles (DDGS) and 15% bakery meal. The negative control diet also served as the base for the remaining 4 copper treatments. Those diets consisted of the negative control with 75 or 150 ppm added TBCC or $CuSO_4$. All diets contained 20 ppm Cu from copper sulfate in the premix and were formulated on a standardized ileal digestible (SID) lysine basis at 0.05% below the estimated requirement during each phase. Treatment diets were fed in 5 phases (Tables 1 and 2). 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 copper (Table 3).

Pens of pigs were weighed and feed disappearance was recorded at d 27, 49, 71, 92, and 111 to determine ADG, ADFI, and F/G. On day 92, 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. Also, percentage carcass yield was calculated by dividing the average pen HCW by average final live weight at the farm.

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

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 copper in two separate 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. This adjustment was calculated by plotting the final BW against overall F/G using data from all pens in the experiment. A linear regression equation was developed, and the slope (0.0034 per lb of final weight) was used as the adjustment factor for the F/G. The actual ADG and adjusted F/G were then used to determine the difference in total number of days and 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 lb 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 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. Revenue per pig was calculated by multiplying the ADG times the total days in the trial times an assumed live price of $58.00 per cwt. To calculate

IOFC, total feed cost was subtracted from pig revenue. The income over feed and facility cost (IOFFC) was calculated for the constant market weight evaluation because pigs with a faster growth rate would reach 275 lb sooner, decreasing the cost of housing the pigs. Facility cost was calculated by multiplying the number of overall days the pigs needed to reach 275 lb based on their respective growth rate times $0.10 per day.

The experimental data were analyzed using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) using pen was as the experimental unit. The main effect of copper source and linear and quadratic effects of copper level were 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 $P \leq 0.10$.

Results

All diets, during each phase, had analyzed copper concentrations similar to calculated values (Table 3). The vitamin trace mineral premix, included at a rate of 2 lb/ton, provided 20 ppm Cu from $CuSO_4$ to each complete diet. The analyzed values for the positive corn-soybean meal control and the negative high-by-product control were from 21 to 42 ppm, which were within acceptable analytical levels. For the 75-ppm treatment group, $CuSO_4$ had copper concentrations between 116 and 137 ppm, whereas the TBCC had analyzed concentrations between 77 and 134 ppm for the duration of the trial. In the 150-ppm treatment group, the $CuSO_4$ had analyzed copper concentrations between 192 and 267 ppm, whereas the TBCC had analyzed concentrations between 157 and 189 ppm throughout the trial.

Pigs fed the positive control, corn-soybean meal or negative control, high-by-product diet, had similar ADG from d 0 to 71, 71 to 111, and for the overall trial (Table 4). Feeding the high- by-product diet tended to increase ADFI from d 0 to 71 ($P < 0.06$) and for the overall trial ($P < 0.08$) and resulted in poorer F/G from d 71 to 111 ($P < 0.04$) and for the overall trial ($P < 0.01$) compared with pigs fed the positive control diet. For carcass traits, pigs fed the corn-soybean meal diet tended ($P < 0.08$) to have greater loin depth than pigs fed the high by-product diet. As expected, pens that held pigs fed the corn-soybean meal diet had less ($P < 0.01$) manure buildup and required less ($P < 0.01$) wash time than pens that held pigs fed the high by-product diet. With the ingredient and pig prices from the time of the experiment, there were no differences in economic response between the positive and negative control diets (Table 5).

No copper level × source interactions were observed for any response criteria. From d 0 to 71 and for the overall trial, pigs fed increasing copper had increased ADG (linear, $P < 0.04$), ADFI (linear $P < 0.01$), and final weight ($P < 0.03$; Table 6). Adding copper to the diets worsened (quadratic, $P < 0.01$) F/G from d 0 to 71 and for the overall trial (quadratic, $P < 0.06$); however, when adjusted for increased final weight, F/G was not affected (Table 7).

Within copper source, increasing TBCC increased or tended to increase ADG from d 0 to 71 (quadratic, $P < 0.04$), d 71 to 111 (linear, $P < 0.06$), and for the overall trial (linear, $P < 0.01$). The increase in ADG resulted from increases in ADFI from during

both periods (linear, $P < 0.03$) and the overall trial (quadratic, $P < 0.05$). Increasing $CuSO_4$ also increased (quadratic, $P < 0.03$) ADG from d 0 to 71 and tended to increase (linear, $P < 0.08$) ADG for the overall trial due to increases (linear, $P < 0.02$) in ADFI for those periods. Final weight was increased by feeding TBCC (linear, $P < 0.01$) and $CuSO_4$ (linear, $P < 0.05$). Although no interaction was detected among copper sources, pigs fed 150 ppm TBCC were 12.8 lb heavier than pigs fed the negative control diet, and those fed 150 ppm $CuSO_4$ were 7.1 lb heavier.

For carcass characteristics, the increased final weight combined with no differences in carcass yield ($P > 0.10$) led to an increase (linear, $P < 0.02$) in HCW for pigs fed increasing levels of copper. Within copper source, pigs fed TBCC had greater (linear, $P < 0.01$) HCW than pigs fed the control, with no significant improvement in pigs fed $CuSO_4$. Pigs fed $CuSO_4$ tended trend (quadratic, $P < 0.07$) to have decreased backfat. Added copper increased loin depth (linear, $P < 0.02$), and percentage lean tended to increase with increasing $CuSO_4$ (quadratic, $P < 0.07$) and TBCC (quadratic, $P < 0.09$).

For pen characteristics, there were no differences ($P > 0.10$) in manure texture among dietary treatments, which suggests that the consistency of manure was not affected when copper was added to the diet. Manure buildup responded in a quadratic manner ($P < 0.01$) as TBCC increased in the diet, with the lowest score for pigs fed the diet containing 75 ppm of TBCC. Adding copper to the diet did not influence wash time.

When economics were calculated on a constant number of days basis, no differences were found in total feed cost, revenue, or IOFC between sources of copper; yet, as added copper increased, feed cost and revenue increased (linear, $P < 0.01$) as well as cost per lb of gain (quadratic, $P < 0.03$; Table 6). Due to these increases in cost and revenue, however, no differences occurred in IOFC between 75 and 150 ppm copper. Nevertheless, the greatest numerical response in IOFC for the individual copper sources was $1.51 per pig for pigs fed 150 ppm TBCC and $0.82 per pig for pigs fed 75 ppm $CuSO_4$.

When the economics were calculated on a constant weight basis, feed cost per pig and cost per lb of gain tended to increase (quadratic, $P < 0.08$), whereas there was a tendency for IOFC to decrease (quadratic, $P < 0.08$) as copper level increased. Increasing copper decreased facility cost ($P < 0.01$). More specifically, facility savings (linear, $P < 0.01$) were generated from feeding 150 ppm TBCC because of the numerically greater ADG. Although no differences were observed in IOFFC, the greatest numerical advantage for each copper source occurred at 150 ppm for TBCC ($1.35 per pig) and at 75 ppm for $CuSO_4$ ($0.26 per pig) due to the decrease in feed and facility costs.

Discussion

Historically, growth promotional levels of added copper have been used in nursery diets, typically with 12% improvements in ADG and 8.4% increase in ADFI, which are thought to be a result of the antimicrobial-like properties of copper (Cromwell, 1997[6]). With finishing pigs, Hastad et al. (2001) reported that growth performance was primarily improved during the first few weeks of the early finishing period with the

[6] Cromwell, G.L. 1997. Copper as a nutrient for animals. In: H.W. Richardson, ed., Handbook of copper compounds and applications. Marcel Dekker, Inc., New York, New York. pp. 177–201.

addition of copper, similar to nursery pigs. Although similar responses were observed in initial growth performance in the present study, feed intake continued to increase past the early periods of the finishing trial and beyond 200 lb BW; specifically, TBCC continued to increase ADFI, resulting in an increase in ADG in the late finisher phase. The response to copper sulfate was not as consistent, with no response in the late finisher phase. The increase in growth observed in the pigs fed TBCC ultimately led to increased final BW and HCW. This response is similar to the reported increase in final BW reported by Hastad et al. (2001), but the response was much greater in the present experiment. The combination of decreasing the SID lysine and copper source may have caused the increased response; however, full explanation for the magnitude of response cannot be determined from this study.

Although increased feed intake was the driver of improved growth, few studies have been completed to fully explain the mechanisms responsible. Li et al. (2006[7]) reported an increase in neuropeptide Y (NPY) and mRNA expression for NPY in the hypothalamus of pigs fed copper. A more recent study suggest that pigs fed copper have increased mRNA expression levels for growth hormone-releasing hormone, which provides positive feedback to the hypothalamus to increase appetite (Yang et al., 2010[8]). Expression of mRNA of somatostatin, which provides negative feedback that decreases appetite, was also shown to decrease with the supplementation of copper. This information could offer an explanation for the effect of copper on intake. The magnitude of response to copper may be amplified in pigs fed diets deficient in lysine because the increased feed intake would increase lysine intake on a grams-per-day basis. Lysine levels may be decreased in diets containing growth promoter levels of copper because of the increased feed intake, but further study is needed to confirm this potential benefit.

In summary, adding supplemental copper in the form of either CuSO4 or TBCC improved growth in the grower and early finishing periods, but pigs fed TBCC continued to have an increased growth rate in late finishing, especially those fed 150 ppm added copper, whereas pigs fed $CuSO_4$ did not. This result ultimately led to an increase in final BW and HCW for pigs fed copper, with the greatest advantage in pigs fed TBCC.

[7] Li, J., L. Yan, X. Zheng, G. Liu, N. Zhang, and Z. Wang. 2008. Effect of high dietary copper on weight gain and neuropeptide Y level in the hypothalamus of pigs. J. Trace Elem. Med. Biol. 22:33–38.
[8] Yang, W., J. Wang, L. Liu, X. Zhu, X. Wang, Z. Liu, Z. Wang, L. Yang, and G. Liu. 2011. Effect of high dietary copper on somatostatin and growth hormone-releasing hormone levels in the hypothalamic of growing pigs. Biol. Trace Elem. Res. 143:893–900.

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

	Phase 1		Phase 2		Phase 3	
Item	Positive control	Negative control	Positive control	Negative control	Positive control	Negative control
Ingredient, %						
Corn	73.07	36.05	77.96	41.07	81.76	44.69
Soybean meal, 46.5 CP	23.98	16.51	19.47	11.80	15.80	8.24
DDGS[2]	-	30.00	-	30.00	-	30.00
Bakery meal	-	15.00	-	15.00	-	15.00
Limestone	1.18	1.25	1.11	1.17	1.08	1.15
Monocalcium P, 21 %	0.75	0.18	0.55	-	0.52	-
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin-trace mineral premix[3]	0.10	0.10	0.10	0.10	0.10	0.10
Biolys[4]	0.460	0.565	0.400	0.515	0.360	0.470
L-threonine	0.060	-	0.040	-	0.030	-
MHA, dry[5]	0.055	-	0.015	-	-	-
Phytase[6]	0.005	0.005	0.005	0.005	0.005	0.005
Copper source[7]	-	-	-	-	-	-
Total	100	100	100	100	100	100
Calculated analysis						
Standardized ileal digestible (SID) amino acids, %						
Lysine	1.00	1.00	0.86	0.86	0.75	0.75
Isoleucine:lysine	63	71	64	74	65	77
Leucine:lysine	138	177	148	193	158	210
Methinone:lysine	30	32	29	35	29	38
Met & Cys:lysine	55	59	56	64	58	69
Threonine:lysine	60	60	60	62	61	64
Tryptophan:lysine	18.0	18.0	18.0	18.0	18.0	18.0
Valine:lysine	70	82	72	87	75	92
Total lysine, %	1.13	1.20	0.97	1.04	0.85	0.93
ME, kcal, lb	1,494	1,537	1,500	1,543	1,502	1,545
SID lysine:ME, g/Mcal	3.04	2.95	2.60	2.53	2.26	2.20
CP, %	17.9	21.3	16.1	19.5	14.6	18.0
Ca, %	0.65	0.58	0.57	0.51	0.54	0.49
P, %	0.52	0.47	0.46	0.41	0.44	0.39
Available P, %	0.28	0.28	0.24	0.24	0.22	0.23

[1] Phase 1 diets fed from d 0 to 27, Phase 2 diets fed from d 27 to 49, and Phase 3 diets fed from d 49 to 71.
[2] Dried distillers grains with solubles (Valero, Aurora, SD).
[3] Vitamin and trace mineral premix provided all diets with 20 ppm copper from copper sulfate.
[4] Lysine source (Evonik, Inc., Kennesaw, GA).
[5] Methionine source (Novus International, Inc., St. Charles, MO).
[6] Optiphose 2000 (Enzyva LLC, Sheridan, IN) provided 1,816,000 phytase units (FTU)/lb, with a release of 0.10% available P.
[7] Supplemental copper provided in the form of $CuSO_4$ and TBCC (Intellibond C; Micronutrients, Inc., Indianapolis, IN) at either 75 or 150 ppm at the expense of corn to the negative control diet.

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

	Phase 4		Phase 5	
Item	Positive control	Negative control	Positive control	Negative control
Ingredient, %				
Corn	84.42	47.295	76.66	39.65
Soybean meal, 46.5 CP	13.25	5.690	20.79	13.13
DDGS[2]	-	30.000	-	30.00
Bakery meal	-	15.000	-	15.00
Limestone	1.05	1.125	1.08	1.18
Monocalcium P, 21 %	0.48	0.000	0.44	-
Salt	0.35	0.350	0.35	0.35
Vitamin-trace mineral premix[3]	0.10	0.100	0.10	0.10
Biolys[4]	0.325	0.435	0.415	0.530
L-Thr	0.025	-	0.090	0.035
MHA, dry[5]	-	-	0.050	-
Paylean, 9g/ton[6]	-	-	0.025	0.025
Phytase[7]	0.005	0.005	0.005	0.005
Copper source[8]	-	-	-	-
Total	100	100	100	100

continued

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

Item	Phase 4		Phase 5	
	Positive control	Negative control	Positive control	Negative control
Calculated analysis				
Standardized ileal digestible (SID) amino acids, %				
Lysine	0.67	0.67	0.90	0.90
Isoleucine:lysine	67	79	64	73
Leucine:lysine	169	226	145	188
Methinone:lysine	31	40	31	34
Met & Cys:lysine	61	74	58	63
Threonine:lysine	62	67	65	65
Tryptophan:lysine	18.0	18.0	18.0	18.0
Valine:lysine	78	97	72	85
Total lysine, %	0.77	0.84	1.02	1.09
ME, kcal, lb	1,505	1,546	1,502	1,542
SID lysine:ME, g/Mcal	2.02	1.97	2.72	2.65
CP, %	13.5	17.0	16.6	20.0
Ca, %	0.52	0.48	0.55	0.52
P, %	0.42	0.38	0.44	0.41
Available P, %	0.21	0.23	0.21	0.24

[1] Phase 4 diets fed from d 71 to 92, and Phase 5 diets fed from d 92 to 111.
[2] Dried distillers grains with solubles (Valero, Aurora, SD).
[3] Provided all diets with 20 ppm copper from copper sulfate.
[4] Lysine source (Evonik, Inc., Kennesaw, GA).
[5] Methionine source (Novus International, Inc., St. Charles, MO).
[6] Ractopamine HCl (Elanco Animal Health, Inc., Greenfield, IN).
[7] Optiphose 2000 (Enzyva LLC, Sheridan, IN) provided 1,816,000 phytase units (FTU)/lb, with a release of 0.10% available P.
[8] Supplemental copper provided in the form of $CuSO_4$ and TBCC (Intellibond C; Micronutrients, Inc., Indianapolis, IN) at either 75 or 150 ppm at the expense of corn to the negative control diet.

Table 3. Copper analysis of complete diets[1]

Phase	Positive control	Negative control	$CuSO_4$, ppm		TBCC, ppm[2]	
			75	150	75	150
1	27	21	137	208	83	180
2	24	38	129	192	77	157
3	28	38	116	200	134	172
4	27	37	136	267	104	187
5	42	32	135	257	129	189

[1] Values represent means from one composite sample, analyzed in duplicate.
[2] Intellibond C; Micronutrients, Inc., Indianapolis, IN.

Table 4. The effects of copper sulfate ($CuSO_4$) and tri-basic copper chloride (TBCC) on finishing pig growth performance, pen cleanup, and carcass characteristics[1]

								Probability, $P <$[3]				
			$CuSO_4$, ppm		TBCC, ppm[2]							
Item	Positive control	Negative control	75	150	75	150	SEM	Pos. vs. neg. control	$CuSO_4$ linear	$CuSO_4$ quadratic	TBCC linear	TBCC quadratic
BW, lb												
d 0	55.3	55.3	55.3	55.4	55.3	55.3	2.04	0.97	0.96	0.92	0.97	0.97
d 71	186.6	190.2	196.9	194.6	199.8	196.3	3.90	0.19	0.12	0.07	0.03	0.01
d 111	274.5	273.9	281.4	281.0	283.1	286.7	4.50	0.87	0.05	0.20	0.01	0.37
d 0 to 71												
ADG, lb	1.84	1.89	1.99	1.95	2.02	1.97	0.033	0.16	0.11	0.03	0.04	0.01
ADFI, lb	4.30	4.48	4.71	4.73	4.81	4.69	0.101	0.06	0.01	0.20	0.03	0.01
F/G	2.33	2.36	2.36	2.42	2.38	2.38	0.022	0.17	0.01	0.13	0.43	0.70
d 71 to 111												
ADG, lb	2.28	2.21	2.21	2.25	2.19	2.33	0.044	0.29	0.51	0.77	0.06	0.14
ADFI, lb	6.40	6.49	6.66	6.62	6.60	6.77	0.113	0.45	0.33	0.34	0.03	0.77
F/G	2.81	2.94	3.01	2.94	3.02	2.91	0.050	0.04	0.96	0.22	0.59	0.08
d 0 to 111												
ADG, lb	1.99	2.00	2.07	2.05	2.08	2.09	0.025	0.76	0.08	0.11	0.01	0.20
ADFI, lb	5.01	5.16	5.38	5.37	5.43	5.40	0.094	0.08	0.02	0.13	0.01	0.05
F/G	2.52	2.58	2.60	2.62	2.61	2.58	0.024	0.01	0.10	0.89	0.98	0.11
Carcass												
HCW, lb	203.8	202.5	205.6	205.2	206.4	210.2	2.61	0.59	0.29	0.42	0.01	0.99
Yield, %	73.3	72.8	72.4	72.5	72.5	72.9	0.40	0.35	0.60	0.68	0.84	0.48
Backfat, in.[4]	0.69	0.67	0.62	0.66	0.66	0.66	0.017	0.46	0.62	0.07	0.74	0.69
Loin depth, in.[4]	2.53	2.47	2.50	2.56	2.60	2.53	0.028	0.08	0.01	0.70	0.10	0.01
Lean, %[4]	55.9	56.0	56.8	56.5	56.7	56.3	2.90	0.78	0.13	0.07	0.38	0.09
Pen cleanup												
Texture[5]	2.00	2.09	1.86	1.81	1.80	2.19	0.214	0.77	0.35	0.71	0.73	0.19
Buildup[6]	-1.00	0.62	0.90	0.62	-0.05	1.00	0.206	0.01	1.00	0.23	0.16	0.01
Wash time, sec	268	417	413	383	373		21.5	0.01	0.27	0.63	0.36	0.26

[1] A total of 1,143 (PIC 337 × 1050) were used in a 111-day finishing trial with 27 pigs per pen and 7 reps per treatment.
[2] Intellibond C; Micronutrients, Inc., Indianapolis, IN.
[3] No copper level × source interactions ($P > 0.10$).
[4] HCW was used as a covariate.
[5] Categorized as firm, medium, or loose with scores of 1, 2, and 3, respectively.
[6] Based on a value of 1 for visual manure buildup and -1 for no visual manure buildup.

Table 5. The effects of copper sulfate ($CuSO_4$) and tri-basic copper chloride (TBCC) on growth economics to a constant market date or market weight[1]

Item	Positive control	Negative control	$CuSO_4$, ppm		TBCC, ppm[2]		SEM	Probability, $P<$[3]				
			75	150	75	150		Pos. vs. neg. control	$CuSO_4$ linear	$CuSO_4$ quadratic	TBCC linear	TBCC quadratic
Constant days												
Feed cost												
$/pig	79.82	80.29	83.81	84.10	84.47	84.69	1.413	0.71	0.01	0.15	0.01	0.08
$/lb gain	0.361	0.361	0.365	0.369	0.366	0.365	0.003	0.93	0.01	0.96	0.25	0.23
Revenue,[4] $/pig	128.21	128.79	133.13	132.22	133.87	134.71	1.605	0.76	0.08	0.11	0.01	0.20
IOFC, [5]$/pig	48.39	48.50	49.32	48.12	49.40	50.01	0.749	0.91	0.71	0.26	0.15	0.88
Constant BW[6]												
Adjusted F/G[7]	2.52	2.58	2.58	2.60	2.58	2.54	0.019	0.02	0.64	0.63	0.09	0.36
Feed cost, $/pig	78.66	78.82	78.91	79.65	79.02	78.06	0.572	0.85	0.30	0.64	0.34	0.40
Feed cost, $/lb gain	0.358	0.359	0.359	0.363	0.360	0.355	0.003	0.85	0.30	0.64	0.34	0.40
Revenue, $/pig[4]	127.43	127.43	127.43	127.43	127.43	127.43						
IOFC, $/pig[5]	48.76	48.61	48.52	47.77	48.40	49.37	0.572	0.85	0.30	0.64	0.34	0.40
Facility cost, $/pig[8]	11.13	11.16	10.81	10.84	10.73	10.57	0.207	0.82	0.05	0.17	0.01	0.31
IOFFC, $/pig[9]	37.64	37.45	37.71	36.93	37.68	38.80	0.616	0.83	0.56	0.50	0.13	0.56

[1] A total of 1,143 (PIC 337 × 1050) were used in a 111-d finishing trial with 27 pigs per pen and 7 reps per treatment.
[2] Intellibond C; Micronutrients, Inc., Indianapolis, IN.
[3] No copper level × source interactions ($P > 0.10$).
[4] Revenue based on $58.00/cwt live price.
[5] Income over feed cost.
[6] Adjusted to constant final weight of 275 lb.
[7] Adjusted using the slope of the overall F/G vs. final market weight.
[8] Facility cost at $0.10/hd/day.
[9] Income over feed and facility cost.

Table 6. Main effects of copper sulfate ($CuSO_4$) and tri-basic copper chloride (TBCC) on finishing pig growth performance, pen cleanup, and carcass characteristics[1]

	Copper source		Copper level, ppm				Probability, *P*<		
								Level	
Item	$CuSO_4$	TBCC[2]	0	75	150	SEM	Source	Linear	Quadratic
BW, lb									
d 0	55.3	55.3	55.3	55.3	55.3	2.00	0.99	0.99	0.93
d 71	195.8	198.1	190.2	198.4	195.5	3.65	0.25	0.03	0.56
d 111	281.2	284.9	273.9	282.2	283.8	4.14	0.14	0.01	0.82
d 0 to 71									
ADG, lb	1.97	2.00	1.89	2.01	1.96	0.028	0.33	0.04	0.55
ADFI, lb	4.72	4.75	4.48	4.76	4.71	0.090	0.64	0.01	0.08
F/G	2.39	2.38	2.36	2.37	2.40	0.019	0.40	0.05	0.01
d 71 to 111									
ADG, lb	2.23	2.26	2.21	2.20	2.29	0.032	0.53	0.14	0.72
ADFI, lb	6.64	6.69	6.49	6.63	6.69	0.095	0.56	0.07	0.87
F/G	2.98	2.97	2.94	3.02	2.93	0.039	0.85	0.74	0.80
d 0 to 111									
ADG, lb	2.06	2.09	2.00	2.07	2.07	2.061	0.23	0.01	0.77
ADFI, lb	5.38	5.41	5.16	5.40	5.39	5.377	0.57	0.01	0.20
F/G	2.61	2.59	2.58	2.61	2.60	2.608	0.37	0.34	0.06
Carcass									
HCW, lb	205.4	208.3	202.5	206.0	207.7	2.29	0.11	0.02	0.59
Yield, %	72.0	73.0	72.8	72.0	73.0	0.01	0.56	0.86	0.47
Backfat, in.[3]	0.64	0.66	0.67	0.64	0.66	0.012	0.31	0.63	0.70
Loin depth, in.[3]	2.53	2.56	2.46	2.55	2.55	0.020	0.23	0.02	0.06
Lean, %[3]	56.7	56.5	56.0	56.7	56.4	0.18	0.44	0.17	0.21
Pen cleanup									
Texture[4]	1.84	1.99	2.09	1.83	2.00	0.159	0.44	0.73	0.21
Buildup[5]	0.76	0.48	0.62	0.43	0.81	0.156	0.14	0.42	0.42
Wash time, sec	398	380	417	393	386	15.2	0.43	0.24	0.45

[1] A total of 1,143 (PIC 337 × 1050) were used in a 111-day finishing trial with 27 pigs per pen and 7 reps per treatment.
[2] Intellibond C; Micronutrients, Inc., Indianapolis, IN.
[3] HCW used as a covariate.
[4] Categorized as firm, medium, or loose with scores of 1, 2, and 3, respectively.
[5] Based on a value of 1 for visual manure buildup and -1 for no visual manure buildup.

Table 7. Main effects of copper sulfate ($CuSO_4$) and tri-basic copper chloride (TBCC) on growth economics to a constant market date or market weight[1]

	Copper source		Copper level, ppm				Probability, $P <$		
								Level	
Item	$CuSO_4$	TBCC[2]	0	75	150	SEM	Source	Linear	Quadratic
Constant days									
Feed cost									
$/pig	83.95	84.58	80.29	84.14	84.39	1.267	0.48	0.01	0.15
$/lb gain	0.367	0.365	0.361	0.365	0.367	0.003	0.46	0.04	0.03
Revenue, $[3]	132.68	134.29	128.79	133.50	133.46	1.306	0.23	0.01	0.77
IOFC, $[4]	48.72	49.71	48.50	49.36	49.07	0.552	0.18	0.52	0.20
Constant BW[5]									
Adjusted F/G[6]	2.59	2.56	2.58	2.58	2.57	0.014	0.16	0.47	0.13
Feed cost									
$/pig	79.28	78.54	78.82	78.97	78.85	0.416	0.19	0.96	0.08
$/lb gain	0.361	0.357	0.359	0.359	0.359	0.002	0.19	0.96	0.08
Revenue, $[3]	127.43	127.43	127.43	127.43	127.43				
IOFC, $[4]	48.14	48.89	48.61	48.46	48.57	0.416	0.19	0.96	0.08
Facility cost, $[7]	10.83	10.65	11.16	10.77	10.71	0.191	0.13	0.01	0.85
IOFFC, $[8]	37.32	38.24	37.45	37.69	37.86	0.435	0.15	0.58	0.12

[1] A total of 1,143 (PIC 337 × 1050) were used in a 111-day finishing trial with 27 pigs per pen and 7 reps per treatment.
[2] Intellibond C; Micronutrients, Inc., Indianapolis, IN.
[3] Revenue based on $58.00/cwt live price.
[4] Income over feed cost.
[5] Constant weight of 275 lb.
[6] Adjusted using the slope of the overall F/G vs. final market weight.
[7] Facility cost at $0.10/hd/day.
[8] Income over feed and facility cost.

Influence of Copper Sulfate and Tribasic Copper Chloride on Feed Intake Preference in Finishing Pigs[1]

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Summary

A total of 150 pigs (PIC 327 × 1050; initially 191 lb BW) were used in a 15-d study to determine if pigs have a preference for diets that contain added Cu from either copper sulfate ($CuSO_4$) or tribasic copper chloride (TBCC). Pens of pigs were randomly allotted to 1 of 3 dietary preference comparisons with 10 replications per comparison. Treatment diets used were a corn-soybean meal control with no supplemental Cu, or the control diet with 150 ppm of added Cu from either $CuSO_4$ or TBCC. Pens contained two feeders, each with 1 of 2 treatment diets with feeders rotated once daily within each pen. The comparisons tested were: (1) control vs. $CuSO_4$, (2) control vs. TBCC, and (3) $CuSO_4$ vs. TBCC.

For comparison 1, pigs consumed more ($P < 0.01$) of the control diet than the added $CuSO_4$ diet (3.68 vs. 2.02 lb/d), which translated into pigs eating 66% of their daily intake from the control diet and 34% from the $CuSO_4$ diet. For comparison 2, pigs consumed more ($P < 0.03$) of the control diet than the TBCC diet (3.30 vs. 2.49 lb/d), which equated to 57% of their daily intake from the control diet and 43% from the TBCC diet. For comparison 3, pigs consumed more ($P < 0.01$) of the diet containing TBBC than that with the added $CuSO_4$ (3.50 vs. 1.96 lb/d), which was equivalent to 65% vs. 35% of daily intake, respectively.

In summary, when given a choice, pigs preferred to consume a diet without high levels of added Cu; however, when given the choice between diets containing either Cu source, pigs preferred diets containing TBCC.

Key words: finishing pig, copper, feed intake, preference

Introduction

Producers frequently utilize supplemental copper for growth promotion in the nursery and early finishing periods. Recent research, however, suggests that the ADFI and ADG response may continue longer through the finishing phase. Coble et al. demonstrated that when TBCC was included in finishing diets, a linear increase ($P < 0.01$) in overall ADG and ADFI was observed when pigs were fed diets with increased levels up to 150 ppm of Cu from TBCC (see "Effects of Copper Source (Intellibond C or Copper Sulfate) on Growth Performance, Carcass Characteristics, Pen Cleanliness,

[1] The authors would like to express appreciation to James Usry (Micronutrients, Inc.) for partial funding of this experiment.

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[3] Micronutrients, Inc., Indianapolis, IN.

and Economics in Finishing Pigs," page 168). Pigs fed Cu from copper sulfate ($CuSO_4$) had a tendency for increased (linear; $P < 0.08$) ADG with increased ($P < 0.02$) ADFI. Due to the added growth rate, pigs fed diets with the TBCC had an 8.3-lb heavier ($P < 0.01$) HCW than control pigs fed no supplemental Cu, which translated into an improvement in income over feed and facilities cost (IOFFC) of approximately $1.34 per head when data were adjusted to the same closeout weight of 275 lb. This difference in HCW was not demonstrated to this degree by pigs fed Cu from $CuSO_4$.

The exact mode of action through which TBCC affects feed intake is unknown, but it could be a reflection of either an up-regulation of the metabolic pathways influencing feed intake or that pigs simply prefer diets containing TBCC. Recent research completed by Yang et al. (2012[4]) observed that an increased dietary concentration of Cu offered to pigs was associated with increased Ghrelin mRNA expression in the fundic region of the stomach and increased serum growth hormone (GH) concentrations. Although increases in these hormones are known to be associated with increased feed intake, it is not known if pigs prefer to consume diets containing copper when given a choice. Therefore, the objective of this study was to determine if finishing pigs have a preference for diets containing no additional Cu or 150 ppm of added Cu from either TBCC or $CuSO_4$.

Procedures

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

A total of 150 pigs (PIC 327 × 1050; initially 191 lb BW) were used in a 15-d study. Pigs were housed in a mechanically ventilated, slatted-floor facility, with 2 nipple waters and 2 identical 2-hole stainless steel feeders in each pen (10 ft × 5 ft). Pigs were placed into pens by sex, with each sex accounting for 15 pens (30 pens total). On d 0, pens of pigs were individually weighed and pens were randomly allotted to 1 of 3 dietary comparisons, balancing on the average BW of the pen and sex across comparisons. Basal diets were corn-soybean meal–based, fed in meal form, and contained 8 ppm of Cu from $CuSO_4$ from the trace mineral premix. The 3 experimental diets consisted of a control diet with no additional Cu or diets with 150 ppm added Cu from either $CuSO_4$ or TBCC (Table 1).

The comparisons tested were: (1) control vs. $CuSO_4$, (2) control vs. TBCC, and (3) $CuSO_4$ vs. TBCC. The 3 dietary comparisons were assigned to pens with 10 replicate pens per comparison. Within each pen, each comparison diet was assigned to 1 of 2 separate feeders that were located on opposite sides of the pen. Daily, at approximately 8:00 a.m., feeders were moved from one side of the pen to the other to prevent location bias in feeding behaviors of the pigs. Feeders were weighed every 3 d at the same time feeders were moved to determine ADFI. At the end of the study, individual pigs were weighed to ensure performance was typical for pigs in this environment. Individual

[4] Yang, W., J. Wang, X. Zhu, Y. Gao, Z. Liu, L. Zhang, H. Chen, X. Shi, L. Yang, and G. Liu. 2012. High level of dietary copper promote ghrelin gene expression in the fundic gland of growing pigs. Biol. Trace Elem. Res. 150:154–157.

diets were sampled from multiple feeders during the trial, combined into a composite sample, then analyzed for Cu concentration in duplicate (Table 2).

Experimental data were analyzed using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). The LSMEANS procedure was used to determine the mean difference of ADFI as measured and as a percentage of the total consumed for the following contrasts: (1) control vs. $CuSO_4$, (2) control vs. TBCC, and (3) $CuSO_4$ vs. TBCC. Results from the experiment were considered significant at $P \leq 0.05$.

Results and Discussion

Analyzed dietary Cu concentrations were 18 ppm in the control diet, 196 ppm in the add $CuSO_4$ diet, and 243 ppm in the added TBCC diet. Although differences occurred between analyzed and calculated Cu concentrations, all final Cu concentrations were within the acceptable analytical variation for Cu analysis.

For comparison 1, pigs consumed more ($P < 0.01$) of the control diet compared with the added $CuSO_4$ diet (3.68 vs. 2.02 lb/d), which translated into pigs eating 66% of their daily intake from the control diet and only 34% from the $CuSO_4$ diet. For comparison 2, pigs consumed more ($P < 0.03$) of the control diet compared to the added TBCC diet (3.30 vs. 2.49 lb/d), which equated to 57% of their daily intake from the control diet whereas 43% came from the TBCC diet. For comparison 3, pigs consumed more ($P < 0.01$) of the diet containing TBCC than that with added $CuSO_4$ (3.50 vs. 1.96 lb/d), which was equivalent to 65% vs. 35% of total daily intake, respectively (Table 3).

In summary, when given a choice, pigs preferred to consume the control diet with no added Cu over diets that contained 150 ppm of Cu from added $CuSO_4$ or TBCC. However, when pigs were given the choice between diets containing added Cu, they preferred to consume diets with TBCC. These data do not explain the increase in feed intake in finishing pigs fed 150 ppm Cu from TBCC reported by Coble et al. (see page 168); in fact, supplemental copper appears to have a negative impact, suggesting that the increase in feed intake is not because of an increase in palatability. Therefore, further research efforts should be focused on determining the metabolic mechanisms behind the previously reported increased ADFI of pigs fed supplemental TBCC.

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

Item	Control
Ingredient, %	
Corn	81.09
Soybean meal , 46.5% CP	16.77
Monocalcium P, 21%	0.33
Limestone	1.05
Salt	0.35
L-lysine	0.15
L-threonine	0.02
Trace mineral premix[2]	0.08
Vitamin premix	0.08
Phytase[3]	0.10
Copper[4]	---
Total	100.00
Calculated analysis	
Standardized ileal digestible (SID) amino acids, %	
Lysine	0.71
Isoleucine:lysine	71
Leucine:lysine	171
Methionine:lysine	31
Met & Cys:lysine	62
Threonine:lysine	64
Tryptophan:lysine	20
Valine:lysine	81
SID lysine:ME, g/Mcal	2.14
ME, kcal/lb	1,503
Total lysine, %	0.82
CP, %	14.8
Ca, %	0.50
P, %	0.40
Available P, %	0.24
Copper added, ppm	8

[1]Treatment diets were fed for 15 d.
[2]Trace mineral premix provided 8 ppm Cu from $CuSO_4$.
[3]Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 204.3 phytase units (FTU)/lb, with a release of 0.10% available P.
[4]150 ppm added Cu from either $CuSO_4$ or TBCC was added to the control diet at the expense of corn.

Table 2. Analyzed copper concentrations of complete diets (as-fed basis)[1,2]

	Control	$CuSO_4$	TBCC
Copper, ppm	18	196	243

[1]Values represent means from one composite sample, analyzed in duplicate.
[2]All diets contained a trace mineral premix that provided 8 ppm Cu from $CuSO_4$.

Table 3. Effects of $CuSO_4$ and TBCC on feed intake preference of finishing pigs[1]

Item	ADFI, lb	ADFI, %
Comparison 1		
Control	3.68	65.7
$CuSO_4$	2.02	34.4
SE	0.341	5.69
Probability, *P* <	0.01	0.01
Comparison 2		
Control	3.30	57.0
TBCC	2.49	43.0
SE	0.247	3.71
Probability, *P* <	0.03	0.02
Comparison 3		
$CuSO_4$	1.96	35.0
TBCC	3.50	65.0
SE	0.286	5.257
Probability, *P* <	0.01	0.01

[1]A total of 150 pigs (PIC 327 × 1050; initially 190 lb) were used in a 15 d study with 10 replications per comparison.

Effects of Dietary Byproduct Feeding Withdrawal Prior to Market on Finishing Pig Growth Performance, Carcass Characteristics, Carcass Fat Quality, Intestinal Weights, and Economics[1,2]

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Summary

A total of 288 pigs (PIC 327 × 1050; initially 84.7 lb) were used in an 88-d study to determine the timing of high-fiber ingredient removal from the diet prior to marketing to optimize growth performance, carcass characteristics (primarily yield), carcass fatty acid composition, and economics. Two diet types, a corn-soybean meal control diet with low NDF (9.3%) and a high-fiber, high-NDF (19%) diet that contained 30% dried distillers grains with solubles (DDGS) and 19% wheat middlings (midds) were used throughout the study. Pens of pigs were randomly allotted to 1 of 6 dietary feeding strategies with 8 pigs per pen (4 barrows and 4 gilts) and 6 replications per treatment. The 6 feeding strategies consisted of the corn-soy control diet or high-fiber diet fed for the duration of the study, or the high-fiber diet fed until 20, 15, 10, or 5 d prior to slaughter after which the pigs were switched to the corn-soybean meal control diet.

Overall (d 0 to 88), ADG was not affected by diet type or withdrawal strategy. Pigs fed the high-fiber diet continuously tended ($P < 0.07$) to have increased ADFI compared with pigs fed the control diet. This led to an increase ($P < 0.01$) in F/G for pigs fed the high-fiber diet for the entire study compared to pigs fed the control diet. The caloric efficiency of live weight gain of pigs fed the high-fiber diet continuously was worse ($P < 0.03$) compared with pigs fed the control diet throughout. Withdrawing the high-fiber diet and switching to the control diet did not influence growth performance.

For carcass characteristics, percentage yield and backfat were reduced ($P < 0.01$), whereas loin depth and jowl iodine value (IV) increased ($P < 0.01$) in pigs fed the high-fiber diet continuously compared with those fed the corn-soybean meal control diet. As days of withdrawal from the high-fiber diet increased, percentage yield improved (linear; $P < 0.01$), whereas jowl IV decreased (linear; $P < 0.01$) and backfat increased (quadratic; $P < 0.04$). These data suggest that 15- to 20-d of removal from high-fiber diets prior to slaughter was optimal in terms of percentage carcass yield.

[1] Appreciation is expressed to The National Pork Board for partial financial support.
[2] Appreciation is expressed to New Horizon Farms for use of pigs and facilities, as well as Richard Brobjorg and Marty Heintz for their technical assistance.
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The full pluck from pigs fed the high-fiber diet continuously tended to weigh more ($P < 0.10$) than from those fed the control diet. In addition, pigs continuously fed the high-fiber diet had heavier ($P < 0.01$) whole intestines, specifically full large intestines, than pigs fed the control. For pigs fed the high-fiber diet then switched to the corn-soy control, whole intestine weight tended to decrease (linear; $P < 0.06$) and full large intestine weight decreased (linear; $P < 0.02$) as withdrawal time increased.

In summary, pigs fed the high-fiber diet had increased F/G, poorer caloric efficiency, and lower carcass yield compared with pigs fed the corn-soy control. Withdrawing pigs from the high-fiber diet and switching them to a corn-soy control diet did restore carcass yield when done for the last 15 to 20 d prior to harvest.

Key words: finishing pig, fiber, withdrawal, growth performance

Introduction

Including feed ingredient sources that are higher in fiber and lower in energy to partially replace a portion of the corn and soybean meal in diets has become a common practice. Reduced carcass yield is one negative effect of including high-fiber ingredients such as DDGS or wheat middlings. Research has reported (Asmus et al., 2011[5]) that changing pigs from a high-NDF diet (19% NDF; 30% DDGS and 19% wheat middlings) to a corn-soybean meal diet (9.3% NDF) approximately 20 d prior to marketing fully restored carcass yield; furthermore, switching from a high- to low-NDF diet prior to market could reduce gut fill and intestinal weights. Although packers do not pay producers on a yield basis, feeding high-fiber diets does influence HCW, thus affecting producer revenue. More data are needed to determine the optimum time to switch finishing pigs from the high- to low-NDF diet to fully recover carcass yield loss associated with higher fiber diets.

Therefore, the objective of this study was to determine the timing of high-fiber ingredient removals prior to marketing to optimize growth performance, carcass characteristics (primarily yield), carcass fat quality, intestinal weights, and economics.

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 was 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 288 pigs (PIC 327 × 1050; initially 84.7 lb) were used in an 88-d study. Pens of pigs were randomly allotted to 1 of 6 dietary feeding strategies with 8 pigs per pen (4 barrows and 4 gilts) and 6 replications per treatment. The 6 dietary strategies consisted of a corn-soy control diet (NDF = 9%) or high-fiber diet (NDF = 19%; 30% DDGS and 19% wheat middlings) fed for the duration of the study, or the high-fiber diet fed until 20, 15, 10, or 5 d prior to slaughter after which pigs were fed the corn-soy

[5] Asmus, M.D. et al., Swine Day 2012, Report of Progress 1074, pp. 204–207.

control diet. All diets were formulated on a standardized ileal digestible (SID) lysine basis and fed in 4 dietary phases (Tables 1 and 2). All diets were fed in meal form.

Composite samples of the DDGS and wheat middlings used in the diets were collected at the time of manufacturing and analyzed for DM, CP, fat, crude fiber, NDF, ADF, and ash (Table 3). Samples of the complete feed were obtained from each delivery for each diet type to measure bulk density (Table 4). In addition, samples of the DDGS, wheat middlings, and complete diets were analyzed for fatty acid concentrations (Table 5).

Pens of pigs and feeders were weighed approximately every 3 wk to calculate ADG, ADFI, and F/G. When the pigs reached approximately 227 lb, pigs fed the high-fiber diet were realloted to withdrawal strategy, balancing by the d 0 and d 68 average pen weights. This was done to ensure that any measured criteria were not influenced by prior performance when the pigs were all fed the same diet. During the last 20 d of the experiment, all pens of pigs and feeders were weighed each time a treatment group switched diets, which was 20, 15, 10, and 5 d prior to slaughter. Prior to harvest, pigs were individually tattooed for identification purposes in the plant. On the final day of the study, pens of pigs and feeders were weighed and each pig was weighed individually to allow carcass yield to be calculated. The second-heaviest gilt in each pen (1 pig per pen, 6 pigs per treatment) was identified and transported to the K-State Meat Laboratory, and all other pigs were transported to Triumph Foods LLC (St. Joseph, MO) for processing and data collection. Carcass measurements taken at the commercial plant included HCW, backfat, loin depth, and percentage lean. Jowl fat samples were collected and analyzed by near-infrared spectroscopy (NIR) at the plant for IV. Percentage yield was calculated by dividing HCW at the plant by live weight at the farm and multiplying by 100.

Gilts selected for harvest at K-State were blocked by treatment and randomly assigned to a slaughter order to equalize withdrawal time before slaughter. Immediately after evisceration, the entire pluck was weighed and individual organs (stomach, cecum, large intestine, small intestine, heart, liver, lungs, kidneys, spleen, and reproductive tract) were separated and weighed. The weights of the stomach, cecum, and large intestine were weighed full of intestinal contents, and weighed again after they were flushed with water and stripped of contents to determine an empty weight. During the harvest process, carcasses were split into two halves. At the end of the harvesting process, each pair of sides were moved onto a scale to record HCW and railed into a cooler for storage and further carcass measurements.

Carcass quality measurements were taken 24 h after slaughter on the right side of the carcass, which was ribbed at the 10th rib. Marbling and color scores were determined for the loin by using the Pork Quality Standards according to the American Meat Science Association (AMSA) and the National Pork Producers Council (NPPC). Ultimate pH of the loin was determined with a portable Hazard Analysis Critical Control Point (HACCP)–compliant pH meter designed for meat (model HI 99163; Hanna Instruments, Smithfield, RI). Fat samples from the jowl, belly, backfat, and ham collar were collected and analyzed for fatty acid. Jowl samples were taken from the lowest portion of the jowl when the carcass was hanging. Belly samples were taken from behind the 2nd teat on the teat line. Samples of the backfat were taken at the 10th rib

on the outer edge of the loin. Lastly, ham collar samples were collected from the middle portion of the ham collar. All 3 layers of fat were used in the analysis.

Measurements of belly quality were also collected from bellies cut from the left side of each carcass. The weight, length, width, and height were recorded for each belly. A belly flop test was also performed on each belly to determine firmness. To measure belly flop, bellies were centered upon a fulcrum point and allowed to hang for 1 min, at which point the distance between the two ends were measured. This was completed with both the skin side up and skin side down.

At the conclusion of the study, an economic analysis was completed to determine the impact of withdrawing pigs from a high-fiber diet to the control diet prior to harvest. 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 was calculated by multiplying the HCW by an assumed carcass value of $77.00/cwt and then subtracting initial pig cost, which was determined by multiplying the initial weight by 75% and the assumed carcass value of $77.00/cwt. To calculate income over feed cost (IOFC), total feed cost was subtracted from the value of the carcass gain.

Data were analyzed utilizing the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen serving as the experimental unit. Linear and quadratic contrasts were completed to determine the effects of withdrawing the high-fiber diet prior to slaughter, as well as a contrast between the corn-soy control and high-fiber diet fed throughout the entire study. Hot carcass weight served as a covariate for the analysis of loin depth, backfat, and percentage lean. Data are presented as least square means, and results were considered significant at $P \leq 0.05$ and tendencies between $P > 0.05$ and $P \leq 0.10$.

Results and Discussion

Chemical analysis of the DDGS and wheat middlings were similar to the nutrient values used for diet formulation (Table 3). As DDGS and wheat middlings were included in the diet, diet bulk density was reduced (Table 4). Fatty acid analysis of the wheat middlings, DDGS, and complete diets showed that the iodine value product (IVP) was lower in wheat middlings compared with DDGS (34.72 vs. 51.97). Also, because of the lower fat content, the corn-soy control diets had much lower IVP (15.7 to 21.3) than the high-fiber diet (20.6 to 43.9).

For growth performance from d 0 to 63, pigs fed the high-fiber diet for the entire study tended to have decreased ($P < 0.07$) ADG and worse ($P < 0.01$) F/G than pigs fed the corn-soybean meal control (Table 6).

From day d 63 to 88, pigs fed the high-fiber diet throughout tended to have greater ($P < 0.06$) ADG and ADFI ($P < 0.01$) compared with pigs fed the corn-soybean meal control diet. This resulted in no difference in F/G between the two treatments. For pigs withdrawn from the high-fiber diet and switched to the corn-soy control, there were no differences in ADG or F/G; however, ADFI increased then decreased (quadratic; $P < 0.05$) as days of fiber withdrawal prior to slaughter increased.

Overall (d 0 to 88), ADG was not affected by diet type or withdrawal strategy. Pigs fed the high-fiber diet continuously tended ($P < 0.07$) to have increased ADFI compared with pigs fed the control diet. This led to poorer ($P < 0.01$) F/G for pigs fed the high-fiber diet throughout compared with pigs fed the control diet. The caloric efficiency of pigs fed the high-fiber diet was worse ($P < 0.03$) compared with pigs fed the control diet, which suggests the energy content of the high-fiber diet was overestimated. Timing of the withdrawal of high-fiber ingredients prior to slaughter did not influence overall growth performance.

For carcass characteristics, percentage yield and backfat were reduced ($P < 0.01$), whereas percentage lean and jowl IV increased ($P < 0.01$) in pigs fed the high-fiber diet continuously compared with those fed the corn-soybean meal control diet (Table 7). As days withdrawn from the high-fiber diet increased, percentage yield improved (linear; $P < 0.01$; quadratic, $P < 0.03$), whereas jowl IV decreased (linear; $P < 0.01$) and backfat increased (quadratic; $P < 0.04$). These data suggest that 15 to 20 d of feeding a corn-soybean meal based diet prior to slaughter was optimal to recover percentage carcass yield when pigs were previously fed a high-fiber diet.

Pigs fed the high-fiber throughout tended ($P < 0.06$) to have increased belly width compared with those fed the control diet. In addition, belly firmness decreased ($P < 0.01$) when bellies were measured skin-up and skin-down for pigs fed the high-fiber diet continuously compared with pigs fed the control diet. Belly characteristics and firmness were not affected by withdrawal time.

Feed cost per pig, feed cost per pound of gain, and carcass gain value per pig all decreased ($P < 0.01$) in pigs fed the high-fiber diet throughout the study compared with those fed the control diet, but IOFC did not differ. Feed cost per pound of gain tended to respond in a quadratic ($P < 0.09$) manner as withdrawal time decreased, with the lowest feed cost per pound of gain for no withdrawal or 20 d of withdrawal. As a result of the improved carcass yield, IOFC tended to increase (linear; $P < 0.08$) as withdrawal time increased from 0 to 20 d. Pigs fed the high-fiber diet until 20 d prior to harvest had the highest IOFC at $27.76 per pig, or $1.64 over that of pigs fed the control.

Intestinal weights were analyzed on both a weight (Table 8) and percentage of BW (Table 9) basis. On a weight basis, the full pluck from pigs fed the high-fiber diet continuously tended to weigh more ($P < 0.10$) than plucks from pigs fed the control diet. Pigs fed the high-fiber diet continuously also had heavier ($P < 0.04$) whole intestines and full large intestines ($P < 0.01$) than pigs fed the control diet. This result suggests that more intestinal contents remained in the large intestine of the pigs fed the high-fiber diet than in the control-fed pigs. For pigs fed the high-fiber diet then switched to the control, whole-intestine weight tended to decrease (linear; $P < 0.06$) and full large intestine weight decreased (linear; $P < 0.02$) as withdrawal time increased. With the exception of the lungs, which unexpectedly tended to increase (linear; $P < 0.08$) as withdrawal time increased, the rinsed weights of the organs did not differ in the various diet types or withdrawal strategies.

When expressed as a percentage of BW, the whole intestine tended ($P < 0.06$) to be a greater percentage of BW in pigs fed the high-fiber diet continuously compared with

pigs fed the control diet. As the number of days pigs were withdrawn from the high-fiber diet increased, however, whole intestine as a percentage of BW decreased (linear; $P < 0.05$). The spleen occupied a lower ($P < 0.04$) percentage of BW in pigs fed the high-fiber throughout compared with the control. Similarly, the full large intestines of pigs fed the high-fiber diet also contributed a higher ($P < 0.01$) percentage of BW. The same effect existed for the full large intestine and spleen, because it contributed a lower (linear; $P < 0.05$) percentage of BW as days withdrawn from the high-fiber diet increased. The tendency for a quadratic response ($P < 0.06$) in full intestine weight when expressed as a percentage of BW indicates that much of the change in full intestine weight occurred in the first 5 d of withdrawal. Again, the lungs tended to increase (linear; $P < 0.09$) in weight as a percentage of BW as high-fiber diet withdrawal time increased.

Fatty acid analysis completed on the jowl, belly, backfat, and ham collar fat are reported in Tables 10, 11, 12, and 13, respectively. For pigs fed the high-fiber diet compared with the control diet, the concentration of PUFA was higher ($P < 0.01$) in jowl fat, partially because of the increase ($P < 0.01$) in linoleic (C18:2n-6) and α-linoleic (C18:3n-3) acid. Total *trans* fatty acids also increased ($P < 0.01$) in pigs fed the high-fiber diet throughout compared with pigs fed the corn-soy control. The PUFA:SFA ratio and IV also were higher ($P < 0.01$) in the jowl fat of pigs fed the high-fiber diet compared with the corn-soy control.

Fat from the belly of pigs fed the high-fiber diet had a lower ($P < 0.01$) percentage of MUFA and higher ($P < 0.01$) percentage of PUFA compared with those fed the corn-soy diet. This was mainly due to the shift from lower ($P < 0.01$) amounts of oleic acid (C18:1 *cis*-9) and higher amounts of linoleic and α-linoleic acid in the belly fat of pigs fed the control diet compared with the high-fiber diet. The PUFA:SFA ratio and IV also were higher ($P < 0.01$) in the belly fat of pigs fed the high-fiber diet for the entire study.

Similar differences existed in the backfat and ham collar fat of pigs fed the high-fiber diet compared with the corn-soy control. The total concentration of PUFA, concentration of total *trans* fatty acids, PUFA:SFA ratio, and IV increased ($P < 0.01$) when pigs were fed the high-fiber diet compared with the corn-soybean meal control. In addition to those differences, the concentrations of eicosatrienoic acid (C20:3n-3), dihomo-γ-linoleic acid (C20:3n-6), and arachidonic acid (C20:4n-6) were also higher ($P < 0.04$) in pigs fed the high-fiber compared with the corn-soy control. The concentration of total *trans* fatty acids, however, were higher ($P < 0.01$) only in backfat of pigs fed the high-fiber compared with the corn-soy control.

For pigs withdrawn from the high-fiber diet and switched to the corn-soy control, fewer differences were observed in fatty acid concentration. The concentration of palmitoleic acid increased (linear; $P < 0.03$) in jowl fat as the number of days withdrawn from the high-fiber diet increased. The concentration of eicosatrienoic acid decreased (linear; $P < 0.01$) in belly fat as the number of days withdrawn from the high-fiber diet increased. Most differences existed in the backfat, where total concentration of PUFA, PUFA:SFA ratio, and IV decreased (quadratic; $P < 0.03$) with the increase in withdrawal time. The difference in total concentration of PUFA was due in part to the change (quadratic; $P < 0.03$) in concentrations of α-linoleic, linoleic acid, and

arachidonic acid as withdrawal time increased. Dihomo-γ-linoleic acid concentration also decreased (quadratic; $P < 0.01$) as withdrawal time increased. Total concentration of PUFA in ham collar fat also increased (quadratic; $P < 0.05$) as withdrawal time increased, partially because of the increase in α-linoleic and arachidonic acid (quadratic; $P < 0.04$). The concentration of dihomo-γ-linoleic also increased (quadratic; $P < 0.02$) as withdrawal time increased from 0 to 20 d.

In summary, pigs fed the high-fiber diet had poorer F/G and caloric efficiency and lower carcass yield compared with pigs fed the corn-soybean meal control diet. Withdrawing pigs from the high-fiber diet and switching them to a corn-soy control diet restored carcass yield when done for the last 15 to 20 d prior to harvest. Withdrawal of high-fiber ingredients less than 20 d prior to slaughter, however, did not have a measurable impact on carcass fatty acid composition.

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

	Phase 1		Phase 2	
Item	Control	High-fiber	Control	High-fiber
Ingredient, %				
Corn	73.71	34.88	78.93	39.99
Soybean meal , 46.5% CP	23.80	13.74	18.84	8.71
DDGS[2]	---	30.00	---	30.00
Wheat middlings	---	19.00	---	19.00
Monocalcium P, 21%	0.45	---	0.35	---
Limestone	1.05	1.30	1.00	1.28
Salt	0.35	0.35	0.35	0.35
Vitamin premix	0.15	0.15	0.13	0.13
Trace mineral premix	0.15	0.15	0.13	0.13
L-lysine HCl	0.17	0.31	0.15	0.29
DL-methionine	0.02	---	---	---
L-threonine	0.03	---	0.01	---
Phytase[3]	0.13	0.13	0.13	0.13
Total	100.00	100.00	100.00	100.00
Calculated analysis				
Standardized ileal digestible (SID) amino acids, %				
Lysine	0.93	0.93	0.79	0.79
Isoleucine:lysine	69	72	70	74
Leucine:lysine	156	188	169	206
Methionine:lysine	30	34	30	37
Met & Cys:lysine	59	69	62	75
Threonine:lysine	63	66	63	69
Tryptophan:lysine	19	19	19	19
Valine:lysine	78	88	81	94
SID lysine:ME, g/Mcal	2.79	2.84	2.36	2.41
ME, kcal/lb	1,513	1,484	1,516	1,486
Total lysine, %	1.04	1.09	0.89	0.94
CP, %	17.5	20.8	15.6	18.9
Ca, %	0.59	0.58	0.53	0.56
P, %	0.47	0.58	0.42	0.56
Available P, %	0.28	0.39	0.26	0.39
Crude fiber, %	2.5	4.9	2.5	4.9
NDF, %	9.2	18.9	9.3	19.0
Diet cost, $/ton	319.56	290.51	306.67	278.94

[1] Phase 1 diets were fed from approximately 85 to 140 lb; Phase 2 diets were fed from 140 to 182 lb.
[2] Dried distillers grains with solubles.
[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. Phase 3 and 4 diet composition (as-fed basis)[1]

	Phase 3		Phase 4	
Item	Control	High-fiber	Control	High-fiber
Ingredient, %				
Corn	82.65	43.56	84.97	45.79
Soybean meal, 46.5% CP	15.32	5.20	13.15	3.04
DDGS[2]	---	30.00	---	30.00
Wheat middlings	---	19.00	---	19.00
Monocalcium P, 21%	0.25	---	0.20	---
Limestone	0.98	1.29	0.93	1.28
Salt	0.35	0.35	0.35	0.35
Vitamin premix	0.10	0.10	0.08	0.08
Trace mineral premix	0.10	0.10	0.08	0.08
L-lysine HCl	0.14	0.28	0.13	0.27
Phytase[3]	0.13	0.13	0.13	0.13
Total	100.00	100.00	100.00	100.00
Calculated analysis				
Standardized ileal digestible (SID) amino acids, %				
Lysine	0.69	0.69	0.63	0.63
Isoleucine:lysine	72	76	73	78
Leucine:lysine	181	224	191	238
Methionine:lysine	32	40	33	43
Met & Cys:lysine	66	81	69	86
Threonine:lysine	64	72	66	74
Tryptophan:lysine	19.0	19.0	19.0	19.0
Valine:lysine	85	99	87	103
SID lysine:ME, g/Mcal	2.06	2.10	1.88	1.92
ME, kcal/lb	1,520	1,487	1,522	1,488
Total lysine, %	0.78	0.83	0.72	0.77
CP, %	14.3	17.6	13.5	16.7
Ca, %	0.49	0.55	0.46	0.54
P, %	0.39	0.55	0.37	0.54
Available P, %	0.23	0.38	0.22	0.38
Crude fiber, %	2.5	4.9	2.5	4.9
NDF, %	9.3	19.0	9.3	19.0
Diet cost, $/ton	397.79	270.66	292.50	265.50

[1] Phase 2 diets were fed from approximately 182 to 228 lb; Phase 2 diets were fed from 228 to 277 lb.
[2] Dried distillers grains with solubles.
[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 3. Chemical analysis of dried distillers grains with solubles (DDGS) and wheat middlings (midds) (as-fed basis)

Nutrient, %	DDGS	Midds
DM	91.45	90.22
CP	27.5 (27.2)[1]	15.0 (15.9)
Ether extract	8.0	3.7
Crude fiber	7.3 (7.7)	7.8 (7.0)
ADF	12.4 (9.9)	12.2 (10.7)
NDF	28.9 (25.3)	34 (35.6)
Ash	4.64	5.55

[1]Values in parentheses indicate those used in diet formulation.

Table 4. Bulk density of experimental diets (as-fed basis)[1,2]

Bulk density, lb/bu	Control	High-fiber
Phase 1	48.01	37.43
Phase 2	46.51	37.18
Phase 3	48.24	37.43
Phase 4	47.11	36.09

[1] Diet samples were collected from the truck before unloading during each phase.
[2] Phase 1 was fed from d 0 to 22; Phase 2 from d 22 to 42; Phase 3 from d 42 to 63; Phase 4 from d 63 to 88.

Table 5. Fatty acid analysis of ingredients and treatment diets during each phase[1,2]

			Phase 1		Phase 2		Phase 3		Phase 4	
Item	DDGS[3]	Midds[4]	Control	High-fiber	Control	High-fiber	Control	High-fiber	Control	High-fiber
Myristic acid (C14:0), %	0.07	0.14	0.04	0.09	0.07	0.08	0.12	0.07	0.03	0.08
Palmitic acid (C16:0), %	15.80	16.17	14.93	16.03	15.22	15.29	14.47	14.80	15.14	15.49
Palmitoleic acid (C16:1), %	0.22	0.15	0.03	0.13	0.11	0.15	0.11	0.14	0.03	0.16
Stearic acid (C18:0), %	2.52	1.37	2.88	2.41	2.79	2.30	2.34	2.16	2.47	2.10
Oleic acid (C18:1 *cis*-9), %	26.02	19.21	23.03	24.14	25.53	25.21	26.33	25.94	25.08	24.31
Linoleic acid (C18:2n-6), %	52.25	57.11	55.09	53.96	52.45	53.28	53.44	53.88	53.77	54.58
α-linoleic acid (C18:3n-3), %	1.50	4.36	2.87	2.52	2.69	2.36	2.13	2.03	2.51	2.30
Arachidic acid (C20:0), %	0.40	0.24	0.39	0.36	0.27	0.39	0.42	0.40	0.14	0.35
Gadoleic acid (C20:1), %	0.27	0.73	0.10	0.26	0.12	0.37	0.28	0.35	0.06	0.29
Other fatty acids, %	0.94	0.52	0.63	0.10	0.72	0.56	0.38	0.23	0.77	0.34
Total SFA, %[5]	18.92	18.08	18.24	18.90	18.42	18.17	17.35	17.51	17.78	18.09
Total MUFA, %[6]	26.52	20.09	23.17	24.53	25.76	25.73	26.71	26.44	25.16	24.77
Total PUFA, %[7]	1.50	4.36	2.87	2.52	2.69	2.36	2.13	2.03	2.51	2.30
UFA:SFA ratio[8]	1.48	1.35	1.43	1.43	1.55	1.55	1.66	1.63	1.56	1.50
PUFA:SFA ratio[9]	0.08	0.24	0.16	0.13	0.15	0.13	0.12	0.12	0.14	0.13
Analyzed dietary lipids, %	4.43	2.72	1.73	2.59	1.47	3.37	1.79	3.62	1.29	1.69
Iodine value, g/100g[10]	117.2	127.6	122.8	121.1	120.0	120.6	121.1	121.4	121.4	121.8
Analyzed IVP[11]	51.9	34.7	21.3	31.4	17.5	40.6	21.7	43.9	15.7	20.6

[1] Values represent the mean of composite samples that were analyzed in duplicate. [2] All values are on a DM basis.
[3] Dried distillers grains with solubles.
[4] Wheat middlings.
[5] Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.
[6] Total MUFA = ([C14:1] + [C16:1] + [C18:1*cis*-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.
[7] Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:1] + [C20:4n-6]); brackets indicate concentration.
[8] UFA:SFA = (total MUFA+PUFA)/total SFA.
[9] PUFA:SFA = total PUFA/total SFA.
[10] 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.
[11] Iodine value product of dietary lipids calculated from analyzed fatty acid composition × % analyzed dietary lipids × 0.10.

Table 6. Effects of high-fiber withdrawal prior to market on growth performance of finishing pigs[1]

								Probability, $P <$		
		High-fiber ingredient withdrawal prior to market, d						Control vs.	Duration	
Item	Control	20	15	10	5	0	SEM	0 withdrawal	Linear	Quadratic
Weight, lb										
d 0	84.3	84.5	84.7	84.9	84.5	85.1	2.38	0.82	0.89	0.99
d 63	231.5	226.7	227.0	226.9	227.0	226.9	3.82	0.40	0.97	0.97
d 88	277.8	275.4	277.7	276.0	277.4	277.0	4.25	0.90	0.83	0.90
d 0 to 63										
ADG, lb	2.34	2.26	2.26	2.26	2.25	2.25	0.033	0.07	---	---
ADFI, lb	6.08	6.09	6.18	6.21	6.20	6.17	0.099	0.53	---	---
F/G	2.60	2.70	2.74	2.75	2.75	2.74	0.024	0.01	---	---
d 63 to 88										
ADG, lb	1.85	1.91	2.03	1.97	2.01	2.00	0.055	0.06	0.33	0.48
ADFI, lb	6.32	6.74	7.13	6.99	7.27	6.97	0.124	0.01	0.14	0.05
F/G	3.42	3.54	3.51	3.57	3.62	3.49	0.069	0.52	0.99	0.41
d 0 to 88										
ADG, lb	2.20	2.16	2.19	2.18	2.19	2.18	0.030	0.61	0.71	0.65
ADFI, lb	6.15	6.27	6.45	6.43	6.50	6.40	0.094	0.07	0.33	0.20
F/G	2.79	2.91	2.94	2.96	2.98	2.93	0.026	0.01	0.27	0.15
Caloric efficiency[2]										
ME	4,237	4,343	4,390	4,406	4,430	4,361	38.3	0.03	0.54	0.13

[1] A total of 280 pigs (PIC 327 × 1050, initial BW= 84.7 lb) were used in an 88-d study with 8 pigs per pen and 6 replications per treatment fed either a corn-soy control (9.3% NDF) or a high-fiber (19.0% NDF) diet.

[2] Caloric efficiency is expressed as kcal/lb of live weight gain.

Table 7. Effects of high-fiber withdrawal prior to market in finishing pigs on carcass characteristics and economics

		High-fiber ingredient withdrawal prior to market, d						Probability, $P <$		
								Control vs.	Duration	
Item	Control	20	15	10	5	0	SEM	0 withdrawal	Linear	Quadratic
Carcass characteristics										
HCW, lb	203.6	200.3	201.6	200.9	200.2	196.5	3.10	0.11	0.37	0.40
Yield, %[2]	72.69	72.50	72.51	72.24	72.03	71.15	0.204	0.01	0.01	0.03
Backfat, in.[3]	0.79	0.68	0.70	0.71	0.69	0.64	0.021	0.01	0.18	0.04
Loin depth, in.[3]	2.33	2.36	2.36	2.28	2.37	2.28	0.036	0.36	0.22	0.90
Lean, %[3]	52.62	53.66	53.31	53.03	53.67	53.66	0.268	0.01	0.68	0.12
Jowl iodine value[4]	66.8	72.6	73.3	73.2	73.8	74.5	0.350	0.01	0.01	0.65
Marbling[5]	1.50	1.33	1.30	1.25	1.08	1.25	0.153	0.26	0.44	0.63
Color[5]	2.25	2.17	2.00	2.42	1.67	2.17	0.202	0.77	0.61	0.83
Ultimate pH[5]	5.49	5.51	5.52	5.48	5.48	5.50	0.030	0.67	0.60	0.59
Belly characteristics[5]										
Weight, lb	10.90	11.13	11.45	10.91	11.43	11.68	0.474	0.26	0.48	0.62
Length, in	23.55	23.06	23.57	22.43	23.38	23.79	0.363	0.61	0.24	0.14
Width, in	8.93	9.29	9.20	9.24	9.16	9.57	0.253	0.06	0.48	0.32
Height, in	1.51	1.51	1.53	1.48	1.53	1.44	0.066	0.40	0.49	0.59
Belly Firmness[6]										
Skin-up, in.	5.16	2.78	2.98	3.50	3.23	3.01	0.627	0.01	0.70	0.46
Skin-down, in.	7.61	4.38	4.11	4.84	4.15	4.13	0.772	0.01	0.84	0.73
Economics, $/pig										
Feed cost	81.97	77.70	79.56	78.88	79.23	77.35	1.169	0.01	0.79	0.15
Feed cost/ lb gain	0.423	0.409	0.412	0.412	0.412	0.403	0.004	0.01	0.32	0.09
Carcass gain value[7]	108.10	105.46	106.31	105.64	105.36	102.14	1.479	0.01	0.12	0.17
IOFC[8]	26.12	27.76	26.76	26.77	26.13	24.79	1.129	0.41	0.08	0.76

[1] A total of 280 pigs (PIC 327 × 1050, initial BW= 84.7 lb) were used in an 88-d study with 8 pigs per pen and 6 replications per treatment fed either a corn-soy control (9.3% NDF) or a high-fiber (19.0% NDF) diet.

[2] Carcass characteristics were adjusted by using HCW as a covariate.

[3] Percentage yield was calculated by dividing HCW by live weight obtained at the farm before transport to the packing plant.

[4] Iodine value was measured on the jowl of the carcass at the plant.

[5] The second-heaviest gilt was selected to represent the pen.

[6] Values represent the distance from each end of the belly when centered upon a fulcrum point.

[7] Carcass gain value is calculated as $77.00/cwt of final carcass wt. minus (initial weight x 75% assumed yield x $77.00/cwt).

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

Table 8. Effects of high-fiber withdrawal prior to market on finishing pig intestinal and organ weights, lb[1]

								Probability, $P <$		
		High-fiber ingredient withdrawal prior to market, d						Control vs.	Duration	
Item, lb	Control	20	15	10	5	0	SEM	0 withdrawal	Linear	Quadratic
Full pluck	29.58	29.49	31.83	31.08	30.96	32.53	1.230	0.10	0.19	0.85
Whole intestine	19.45	18.93	21.17	20.21	20.41	22.25	0.935	0.04	0.06	0.92
Stomach										
Full	2.69	2.48	2.45	2.93	2.63	2.86	0.238	0.62	0.23	0.78
Rinsed	1.98	2.01	2.05	2.05	2.12	2.15	0.109	0.27	0.32	0.90
Cecum										
Full	1.62	1.58	1.97	1.88	1.89	2.03	0.178	0.11	0.16	0.58
Rinsed	0.68	0.62	0.72	0.63	0.71	0.68	0.036	1.00	0.30	0.57
Large intestine										
Full	6.39	6.52	7.51	6.38	7.04	9.03	0.569	0.01	0.02	0.09
Rinsed	3.94	3.85	4.42	3.94	4.09	4.21	0.191	0.33	0.53	0.70
Small intestine										
Rinsed	7.13	6.58	7.53	7.18	7.04	6.71	0.347	0.40	0.84	0.08
Heart	1.03	1.03	1.04	1.08	1.09	1.05	0.075	0.88	0.72	0.69
Lungs	2.38	2.58	2.47	2.59	2.18	2.36	0.129	0.89	0.08	0.92
Liver	4.10	4.36	4.48	4.53	4.43	4.20	0.199	0.73	0.56	0.27
Kidneys	0.84	0.94	0.99	0.99	0.88	0.97	0.061	0.16	0.77	0.86
Spleen	0.58	0.58	0.49	0.58	0.48	0.46	0.050	0.11	0.11	0.87
Reproductive tract	1.06	1.03	1.14	1.08	1.41	1.01	0.138	0.80	0.62	0.25

[1]The second-heaviest gilt was selected to represent the pen (6 pigs/treatment).

Table 9. Effects of high-fiber withdrawal prior to market on finishing pig intestinal and organ weights, % of live weight[1]

		High-fiber ingredient withdrawal prior to market, d						Probability, $P <$		
								Control vs.	Duration	
Item,[2] %	Control	20	15	10	5	0	SEM	0 withdrawal	Linear	Quadratic
Full pluck	10.95	10.76	11.44	11.46	11.14	11.75	0.378	0.15	0.18	0.74
Whole intestine	7.20	6.92	7.61	7.46	7.33	8.04	0.295	0.06	0.05	0.97
Stomach										
Full	0.99	0.90	0.89	1.09	0.94	1.03	0.086	0.74	0.25	0.68
Rinsed	0.73	0.73	0.74	0.76	0.76	0.78	0.035	0.38	0.31	0.94
Cecum										
Full	0.60	0.58	0.71	0.69	0.67	0.74	0.062	0.14	0.17	0.55
Rinsed	0.25	0.23	0.26	0.23	0.25	0.25	0.013	0.71	0.37	0.56
Large intestine										
Full	2.37	2.38	2.69	2.34	2.53	3.26	0.188	0.01	0.01	0.06
Rinsed	1.47	1.41	1.59	1.45	1.47	1.52	0.059	0.53	0.57	0.64
Small intestine										
Rinsed	2.64	2.41	2.71	2.66	2.54	2.42	0.136	0.27	0.75	0.09
Heart	0.38	0.38	0.37	0.40	0.40	0.38	0.030	0.94	0.72	0.62
Lungs	0.88	0.95	0.89	0.96	0.79	0.85	0.051	0.69	0.09	0.98
Liver	1.52	1.59	1.61	1.67	1.60	1.52	0.059	0.98	0.42	0.14
Kidneys	0.31	0.34	0.35	0.36	0.32	0.35	0.018	0.15	0.66	0.84
Spleen	0.21	0.21	0.18	0.21	0.17	0.17	0.015	0.04	0.05	0.87
Reproductive tract	0.39	0.38	0.41	0.39	0.52	0.37	0.053	0.74	0.62	0.25

[1] The second-heaviest gilt was selected to represent the pen (6 pigs/treatment).
[2] All values are expressed as a percent of final live weight (ex. (full pluck/final live weight) × 100).

Table 10. Effects of high-fiber withdrawal prior to market on jowl fatty acid analysis[1,2]

Item	Control	High-fiber ingredient withdrawal prior to market, d					SEM	Probability, $P <$		
		20	15	10	5	0		Control vs. 0 withdrawal	Duration	
									Linear	Quadratic
Myristic acid (C14:0). %	1.30	1.41	1.38	1.34	1.33	1.28	0.071	0.84	0.15	0.98
Myristoleic acid (C14:1), %	0.02	0.03	0.02	0.02	0.02	0.02	0.003	0.73	0.12	0.15
Palmitic acid (C16:0), %	23.30	22.23	24.99	22.25	22.33	21.98	1.203	0.40	0.37	0.42
Palmitoleic acid (C16:1), %	3.29	3.67	3.41	3.12	3.32	2.94	0.234	0.26	0.03	0.75
Stearic acid (C18:0), %	10.26	8.67	11.00	9.55	9.18	9.57	0.735	0.47	0.99	0.27
Oleic acid (C18:1 *cis*-9), %	48.56	44.95	37.91	44.55	44.58	43.72	2.979	0.22	0.63	0.58
Linoleic acid (C18:2n-6), %	9.95	15.33	16.91	15.25	15.50	16.45	0.998	0.01	0.78	0.85
α-linoleic acid (C18:3n-3), %	0.44	0.60	0.63	0.57	0.59	0.61	0.041	0.01	0.87	0.68
γ-linoleic acid (C18:3n-6), %	0.15	0.13	0.14	0.13	0.14	0.15	0.017	0.89	0.37	0.89
Conjugated Linoleic acid (*c*9, *t*11), %	0.09	0.11	0.12	0.11	0.12	0.11	0.011	0.20	0.98	0.94
Arachidic acid (C20:0), %	0.20	0.18	0.19	0.19	0.19	0.18	0.012	0.22	0.95	0.35
Gadoleic acid (C20:1), %	0.88	0.78	0.99	0.93	0.84	0.90	0.069	0.83	0.71	0.18
Eicosadienoic acid (C20:2), %	0.06	0.14	0.24	0.06	0.05	0.06	0.077	1.00	0.14	0.96
Eicosatrienoic acid (C20:3n-3), %	0.07	0.08	0.09	0.09	0.08	0.09	0.010	0.08	0.50	0.83
Dihomo-γ-linoleic acid (C20:3n-6), %	0.08	0.11	0.11	0.11	0.10	0.11	0.010	0.03	0.96	0.49
Arachidonic acid (C20:4n-6), %	0.21	0.27	0.31	0.25	0.25	0.27	0.022	0.06	0.37	0.81
Other fatty acids, %	0.69	0.68	0.82	0.72	0.69	0.79	0.063	0.22	0.63	0.99
Total SFA, %[3]	35.06	32.49	37.56	33.34	33.03	33.01	1.916	0.41	0.54	0.35
Total MUFA, %[4]	52.75	49.42	42.32	48.62	48.75	47.58	2.871	0.17	0.75	0.57
Total PUFA, %[5]	10.81	16.47	18.22	16.26	16.54	17.53	1.049	0.01	0.88	0.84
Total *trans* fatty acids, %[6]	0.59	0.73	0.76	0.70	0.73	0.76	0.049	0.01	0.87	0.70
UFA:SFA ratio[7]	1.82	2.04	1.74	1.96	1.98	1.97	0.117	0.31	0.76	0.35
PUFA:SFA ratio[8]	0.31	0.51	0.49	0.49	0.50	0.53	0.022	0.01	0.34	0.13
Iodine value, g/100g[9]	65.0	72.1	68.9	71.1	71.7	72.4	1.143	0.01	0.30	0.12

[1] The second-heaviest gilt in each pen was selected to represent the pen (6 pigs/treatment).
[2] All values are on a DM basis.
[3] Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.
[4] Total MUFA = ([C14:1] + [C16:1] + [C18:1*cis*-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.
[5] Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:1] + [C20:4n-6]); brackets indicate concentration.
[6] Total *trans* fatty acids = ([C18:1trans] + [C18:2trans] + [C18:3trans]); 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.

Table 11. Effects of high-fiber withdrawal prior to market on belly fatty acid analysis[1,2]

Item	Control	High-fiber ingredient withdrawal prior to market, d					SEM	Probability, $P <$		
		20	15	10	5	0		Control vs. 0 withdrawal	Duration	
									Linear	Quadratic
Myristic acid (C14:0). %	1.30	1.41	1.23	1.39	1.38	1.33	0.043	0.65	0.83	0.53
Myristoleic acid (C14:1), %	0.02	0.02	0.02	0.02	0.03	0.02	0.004	0.66	0.41	0.53
Palmitic acid (C16:0), %	24.70	24.74	23.69	23.78	24.03	23.48	0.471	0.05	0.12	0.48
Palmitoleic acid (C16:1), %	3.41	3.33	3.07	2.95	3.28	3.10	0.164	0.15	0.60	0.29
Stearic acid (C18:0), %	11.46	11.14	11.06	11.01	10.56	10.33	0.544	0.12	0.19	0.71
Oleic acid (C18:1 *cis*-9), %	49.03	43.92	46.47	42.95	43.87	43.91	1.302	0.01	0.49	0.90
Linoleic acid (C18:2n-6), %	7.16	12.42	11.32	14.41	13.53	14.27	1.345	0.01	0.14	0.95
α-linoleic acid (C18:3n-3), %	0.31	0.47	0.42	0.54	0.51	0.53	0.058	0.01	0.22	0.97
γ-linoleic acid (C18:3n-6), %	0.11	0.04	0.06	0.08	0.09	0.08	0.027	0.44	0.17	0.44
Conjugated Linoleic acid (*c*9, *t*11), %	0.085	0.089	0.070	0.084	0.093	0.078	0.014	0.72	0.99	0.95
Arachidic acid (C20:0), %	0.21	0.19	0.16	0.19	0.16	0.18	0.012	0.07	0.53	0.46
Gadoleic acid (C20:1), %	0.84	0.69	0.82	0.79	0.76	0.83	0.066	0.90	0.26	0.65
Eicosadienoic acid (C20:2), %	0.28	0.21	0.24	0.20	0.23	0.22	0.075	0.52	0.99	0.96
Eicosatrienoic acid (C20:3n-3), %	0.03	0.02	0.03	0.06	0.05	0.06	0.012	0.06	0.01	0.38
Dihomo-γ-linoleic acid (C20:3n-6), %	0.05	0.09	0.06	0.09	0.08	0.09	0.014	0.03	0.47	0.52
Arachidonic acid (C20:4n-6), %	0.20	0.25	0.26	0.26	0.26	0.28	0.016	0.01	0.37	0.93
Other fatty acids, %	0.52	0.56	0.55	0.65	0.60	0.65	0.064	0.14	0.23	0.88
Total SFA, %[3]	37.66	37.48	36.14	36.37	36.12	35.31	0.927	0.06	0.12	0.86
Total MUFA, %[4]	53.30	47.96	50.39	46.71	47.94	47.86	1.447	0.01	0.53	0.98
Total PUFA, %[5]	8.06	13.39	12.30	15.49	14.62	15.38	1.386	0.01	0.13	0.94
Total *trans* fatty acids, %[6]	0.42	0.51	0.49	0.61	0.60	0.61	0.075	0.06	0.15	0.76
UFA:SFA ratio[7]	1.64	1.64	1.75	1.72	1.73	1.80	0.068	0.08	0.15	0.87
PUFA:SFA ratio[8]	0.21	0.36	0.34	0.43	0.40	0.44	0.042	0.01	0.09	0.95
Iodine value, g/100g[9]	60.2	65.1	65.2	67.8	67.3	68.6	1.682	0.01	0.08	0.91

[1] The second-heaviest gilt in each pen was selected to represent the pen (6 pigs/treatment).
[2] All values are on a DM basis.
[3] Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.
[4] Total MUFA = ([C14:1] + [C16:1] + [C18:1*cis*-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.
[5] Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:1] + [C20:4n-6]); brackets indicate concentration.
[6] Total *trans* fatty acids = ([C18:1trans] + [C18:2trans] + [C18:3trans]); 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.

Table 12. Effects of high-fiber withdrawal prior to market on backfat fatty acid analysis[1,2]

		High-fiber ingredient withdrawal prior to market, d						Probability, $P <$		
								Control vs.	Duration	
Item	Control	20	15	10	5	0	SEM	0 withdrawal	Linear	Quadratic
Myristic acid (C14:0). %	1.23	1.40	1.18	1.30	1.27	1.23	0.061	0.99	0.22	0.34
Myristoleic acid (C14:1), %	0.01	0.02	0.01	0.01	0.01	0.01	0.002	0.51	0.54	0.84
Palmitic acid (C16:0), %	24.42	20.46	23.46	24.38	23.61	22.70	1.61	0.42	0.33	0.10
Palmitoleic acid (C16:1), %	2.75	2.66	2.30	2.36	2.50	2.35	0.139	0.04	0.31	0.30
Stearic acid (C18:0), %	13.64	13.40	13.44	10.81	12.27	11.88	0.998	0.18	0.16	0.36
Oleic acid (C18:1 *cis*-9), %	44.07	41.35	41.41	41.19	39.40	39.03	1.171	0.01	0.06	0.55
Linoleic acid (C18:2n-6), %	10.76	17.17	14.75	16.26	17.36	18.95	0.796	0.01	0.01	0.01
α-linoleic acid (C18:3n-3), %	0.43	0.64	0.53	0.57	0.63	0.66	0.035	0.01	0.16	0.02
γ-linoleic acid (C18:3n-6), %	0.13	0.12	0.13	0.13	0.12	0.11	0.013	0.41	0.48	0.45
Conjugated Linoleic acid (*c*9, *t*11), %	0.07	0.08	0.09	0.09	0.09	0.10	0.007	0.02	0.11	0.82
Arachidic acid (C20:0), %	0.25	0.25	0.24	0.24	0.24	0.22	0.019	0.16	0.28	0.84
Gadoleic acid (C20:1), %	0.77	0.72	0.81	0.87	0.75	0.78	0.054	0.86	0.64	0.11
Eicosadienoic acid (C20:2), %	0.05	0.04	0.04	0.04	0.04	0.04	0.008	0.50	0.98	0.72
Eicosatrienoic acid (C20:3n-3), %	0.05	0.07	0.06	0.08	0.08	0.08	0.006	0.01	0.03	0.44
Dihomo-γ-linoleic acid (C20:3n-6), %	0.08	0.10	0.08	0.10	0.10	0.11	0.004	0.01	0.08	0.01
Arachidonic acid (C20:4n-6), %	0.19	0.25	0.22	0.22	0.21	0.26	0.018	0.01	0.93	0.03
Other fatty acids, %	0.65	0.67	0.64	0.65	0.67	0.73	0.060	0.34	0.43	0.40
Total SFA, %[3]	39.55	35.51	38.32	36.74	37.39	36.03	1.447	0.07	0.98	0.23
Total MUFA, %[4]	47.60	44.75	44.53	44.43	42.67	42.18	1.290	0.01	0.07	0.62
Total PUFA, %[5]	11.56	18.22	15.67	17.22	18.35	20.02	0.843	0.01	0.02	0.01
Total *trans* fatty acids, %[6]	0.56	0.76	0.65	0.70	0.75	0.78	0.040	0.01	0.31	0.06
UFA:SFA ratio[7]	1.50	1.88	1.58	1.70	1.64	1.73	0.145	0.23	0.59	0.23
PUFA:SFA ratio[8]	0.29	0.54	0.41	0.47	0.49	0.56	0.045	0.01	0.40	0.03
Iodine value, g/100g[9]	61.8	71.2	66.4	69.0	69.5	72.1	1.716	0.01	0.33	0.04

[1] The second-heaviest gilt in each pen was selected to represent the pen (6 pigs/treatment).
[2] All values are on a DM basis.
[3] Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.
[4] Total MUFA = ([C14:1] + [C16:1] + [C18:1*cis*-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.
[5] Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:1] + [C20:4n-6]); brackets indicate concentration.
[6] Total *trans* fatty acids = ([C18:1trans] + [C18:2trans] + [C18:3trans]); 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.

Table 13. Effects of high-fiber withdrawal prior to market on ham collar fatty acid analysis[1,2]

		High-fiber ingredient withdrawal prior to market, d						Probability, $P <$		
								Control vs.	Duration	
Item	Control	20	15	10	5	0	SEM	0 withdrawal	Linear	Quadratic
Myristic acid (C14:0). %	1.36	1.44	1.26	1.38	1.39	1.35	0.096	0.94	0.86	0.63
Myristoleic acid (C14:1), %	0.01	0.01	0.01	0.02	0.01	0.01	0.003	0.96	0.48	0.36
Palmitic acid (C16:0), %	23.87	25.56	22.19	22.99	22.80	22.69	1.173	0.44	0.14	0.18
Palmitoleic acid (C16:1), %	3.41	3.47	2.95	3.05	3.28	2.79	0.191	0.02	0.07	0.79
Stearic acid (C18:0), %	11.13	11.57	10.31	10.30	9.81	10.60	0.767	0.59	0.28	0.18
Oleic acid (C18:1 *cis*-9), %	46.38	35.89	43.22	42.69	42.25	40.50	2.882	0.13	0.33	0.08
Linoleic acid (C18:2n-6), %	10.45	18.12	16.26	15.69	16.61	17.71	1.081	0.01	0.89	0.06
α-linoleic acid (C18:3n-3), %	0.48	0.73	0.64	0.60	0.67	0.69	0.047	0.01	0.73	0.04
γ-linoleic acid (C18:3n-6), %	0.15	0.11	0.13	0.13	0.13	0.13	0.016	0.29	0.46	0.52
Conjugated Linoleic acid (*c*9, *t*11), %	0.09	0.10	0.11	0.09	0.11	0.09	0.012	0.91	0.46	0.80
Arachidic acid (C20:0), %	0.22	0.21	0.18	0.19	0.20	0.19	0.013	0.10	0.51	0.59
Gadoleic acid (C20:1), %	0.81	0.76	0.79	0.89	0.81	1.03	0.110	0.13	0.09	0.57
Eicosadienoic acid (C20:2), %	0.10	0.08	0.06	0.14	0.06	0.17	0.045	0.29	0.17	0.57
Eicosatrienoic acid (C20:3n-3), %	0.07	0.10	0.08	0.09	0.08	0.09	0.008	0.04	0.78	0.13
Dihomo-γ-linoleic acid (C20:3n-6), %	0.09	0.12	0.11	0.10	0.11	0.12	0.007	0.01	0.90	0.02
Arachidonic acid (C20:4n-6), %	0.24	0.33	0.30	0.26	0.28	0.31	0.020	0.01	0.33	0.02
Other fatty acids, %	0.71	0.76	0.75	0.71	0.72	0.81	0.074	0.32	0.77	0.35
Total SFA, %[3]	36.58	38.78	33.95	34.87	34.20	34.83	1.939	0.49	0.19	0.17
Total MUFA, %[4]	50.61	40.13	46.97	46.64	46.35	44.34	2.816	0.09	0.35	0.08
Total PUFA, %[5]	11.43	19.37	17.38	16.82	17.75	19.01	1.138	0.01	0.92	0.05
Total *trans* fatty acids, %[6]	0.63	0.84	0.76	0.73	0.79	0.82	0.052	0.01	0.94	0.09
UFA:SFA ratio[7]	1.70	1.65	1.90	1.83	1.88	1.82	0.105	0.36	0.28	0.18
PUFA:SFA ratio[8]	0.31	0.51	0.51	0.48	0.52	0.55	0.028	0.01	0.30	0.23
Iodine value, g/100g[9]	64.3	69.4	71.7	70.2	71.8	72.1	1.349	0.01	0.17	0.84

[1] The second-heaviest gilt in each pen was selected to represent the pen (6 pigs/treatment).
[2] All values are on a DM basis.
[3] Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.
[4] Total MUFA = ([C14:1] + [C16:1] + [C18:1*cis*-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.
[5] Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:1] + [C20:4n-6]); brackets indicate concentration.
[6] Total *trans* fatty acids = ([C18:1trans] + [C18:2trans] + [C18:3trans]); 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.

Effects of Withdrawing High-Fiber Ingredients Prior to Market on Growth Performance, Carcass Characteristics, and Economics in Commercial Finishing Pigs[1,2]

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Summary

A total of 1,089 mixed-sex pigs (PIC 337 × 1050; initial BW 98.2 lb) were used in a 96-d study. The two diet types fed during the study were a corn-soybean meal control diet with low NDF (9.3%) and a high-fiber diet with high NDF (19%) that contained 30% dried distillers grains with solubles (DDGS) and 19% wheat middlings (midds). Pens of pigs were randomly allotted to 1 of 6 dietary feeding strategies with 25 to 27 pigs per pen and 7 replications per treatment. The six dietary strategies consisted of the corn-soybean meal control diet or high-fiber diet fed for the duration of the study, or the high-fiber diet fed until 24, 19, 14, or 9 d prior to harvest, at which time the pigs were switched to the corn-soybean meal control diet for the remainder of the study. Overall (d 0 to 96), pigs fed the high-fiber diet through the entire study compared with the corn-soy control diet had lower ($P < 0.01$) ADG and poorer F/G. This reduction in growth performance led to a trend for poorer ($P < 0.10$) caloric efficiency and lower ($P < 0.01$) final BW in pigs fed the high-fiber diet throughout compared to the control. For pigs fed the high-fiber diet then switched to the corn-soy control, ADG and ADFI were not different between withdrawal days, but F/G tended (linear; $P < 0.07$) to improve as withdrawal days increased from 0 to 24 d.

Pigs fed the high-fiber diet throughout had a 9.5-lb lighter ($P < 0.01$) HCW compared to those fed the corn-soy control. Neither percentage yield using the farm live weight or plant live weight were significantly influenced by withdrawal days from the high-fiber diet; however, HCW increased linearly ($P < 0.05$) as withdrawal days increased. Backfat and loin depth both decreased ($P < 0.02$) in pigs fed the high-fiber diet throughout compared with those fed the corn–soybean meal diet. Loin depth increased, then decreased (quadratic; $P < 0.04$) as high-fiber diet withdrawal time increased.

Total feed cost per pig and feed cost per lb of gain was lower ($P < 0.01$) for pigs fed the high-fiber diet until harvest, but carcass gain value per pig also decreased ($P < 0.01$) by $7.34. Total feed cost tended ($P < 0.10$) to increase and carcass gain value increased ($P < 0.05$) as high-fiber diet withdrawal time increased. Although no significant differences were observed in income over feed cost (IOFC) between treatments, switching pigs from the high-fiber diet to the corn-soybean meal diet at 14 to 19 d before market numerically increased IOFC by $1.42 to $2.30/pig over pigs fed the high-fiber diet

[1] Appreciation is expressed to the National Pork Board for partial financial support.
[2] Appreciation is expressed to New Horizon Farms for use of pigs and facilities, as well as Richard Brobjorg and Marty Heintz for their technical assistance.
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continuously and $2.04 to 2.92/pig over pigs fed the corn-soybean meal diet throughout. These data indicate that much of the benefit in lower feed cost from feeding high-fiber diets can be captured while minimizing the reduction in revenue by switching pigs to a low-fiber, high-energy diet for 14 to 19 d prior to market.

Key words: finishing pig, fiber withdrawal, growth performance

Introduction

Using feed ingredients that are lower in energy and higher in fiber compared with corn is a common practice as producers and nutritionists attempt to decrease diet cost. This topic has been an active area of research; however, the effects that these ingredients have on carcass yield and ultimately carcass revenue are not fully understood. Previous research (Asmus et al., 2011[4]) reported that switching pigs from a diet high in NDF (19% NDF, 30% DDGS, and 19% wheat middlings) to a corn-soy diet (9.3% NDF) approximately 20 d prior to market restored carcass yield to levels similar to pigs fed the control diets. This result occurred partly because of the decrease in gut fill that is common with high-fiber diets; specifically, the weight of the large intestine was reduced. These data are intriguing, but the question of how much time is needed to withdraw these high-fiber ingredients prior to slaughter to minimize the negative impacts on carcass yield and maximize economic return remains.

Therefore, the objective of this study was to determine in a commercial setting the optimal time that high-fiber ingredients should be removed prior to market so growth, carcass performance and economic return can be maximized.

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 1,089 mixed-sex pigs (PIC 337 × 1050; initial BW 98.2 lb) were used in a 96-d study. Two diet types were fed consisting of a corn-soybean meal control diet with low NDF (9.3%) and a high-fiber diet with high NDF (19%) that contained 30% DDGS and 19% wheat midds. Diets were formulated on a standardized ileal digestible (SID) lysine basis and fed in meal form in 4 phases (Tables 1 and 2). Pens of pigs were randomly allotted to 1 of 6 dietary feeding strategies with 25 to 27 pigs per pen and 7 replications per treatment. The six dietary strategies consisted of the corn-soybean meal control diet or high-fiber diet fed for the duration of the study, or the high-fiber diet fed until 24, 19, 14, or 9 d prior to slaughter, at which time the pigs were switched to the corn-soybean meal control diet for the remainder of the study. The original design was to change pigs at d 20, 15, 10, and 5 prior to harvest; however, inclement weather led to a power outage at the processing plant and increased the original withdrawal schedule by 4 d.

[4] Asmus, M.D. et al., Swine Day 2012. Report of Progress 1074, pp. 204–207.

Samples of the DDGS and midds used in the diets were collected at the time of manufacturing and a composite sample was analyzed. Analyses included DM, CP, ether extract (fat), CF, ADF, NDF, and ash. Samples of the complete feed were taken from the feeder at the beginning and end of each phase, and composite samples for each phase and diet type were made to determine bulk density.

Pens of pigs were weighed and feeder measurements were recorded on d 0, 14, 27, 64, 72, 77, 82, 87, and 96 to calculate ADG, ADFI, F/G, and ME caloric efficiency. On d 64, the 3 heaviest pigs in each pen were weighed and sold according to standard farm procedures. After removing those pigs, pens on the high-fiber diets were realloted to withdrawal time, balancing on d 0 and 64 average BW across treatments to ensure that prior performance did not bias the performance during the last phase when pigs were withdrawn from the high-fiber diet. During the high-fiber diet withdrawal period, all pens of pigs were weighed and feeder measurements were recorded each time a treatment group switched diets. 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 96, 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. Also, percentage carcass yield was calculated by dividing the average pen HCW by average final live weight both at the farm and plant.

At the conclusion of the study, an economic analysis was completed to determine the financial impact of withdrawing pigs from a high-fiber diet to the control diet prior to harvest. 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 was calculated by multiplying the HCW by an assumed carcass value of $77.00/cwt, then subtracting an initial pig cost, which was determined by multiplying the initial weight by 75% and the assumed carcass value of $77.00/cwt. To calculate IOFC, total feed cost was subtracted from the value of the carcass gain.

Experimental 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 and initial BW as a blocking factor. Linear and quadratic contrast were completed to determine the effects of withdrawing the high-fiber diet prior to slaughter, as well as contrast between the continuous feeding of the corn-soy control and high-fiber diet. 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 completed on the DDGS and midds demonstrated that the nutrient values used for diet formulation were similar to the analyzed values (Table 3). As expected, diet bulk density showed that as DDGS and midds were included in the diet, bulk density was reduced (Table 4).

From day d 0 to 64, pigs fed the high-fiber diet throughout the entire study had decreased ($P < 0.02$) ADG and ADFI, as well as poorer ($P < 0.02$) F/G compared with pigs fed the corn-soy control; consequently, the high-fiber pigs weighed approximately 8 lb less than those fed the corn-soy control diet on d 64 (Table 5).

From d 64 to 96, there was no difference in ADG or ADFI between pigs fed the high-fiber or corn-soy diets throughout the study; however, F/G was worse ($P < 0.03$), and final BW was lower ($P < 0.01$) for pigs fed the high-fiber diet throughout compared with the corn-soy diet. There were no differences in ADG, ADFI, F/G, or final BW for pigs fed the high-fiber diet with different withdrawal days. The lack of significant differences may have been influenced by the daily weighing of pens the last 4 d of the experiment as we anticipated shipment each of those days, but the inclement weather prevented us from doing so. All treatments would have been influenced similarly during this time, but repeated weighing seems to have increased variation.

Overall (d 0 to 96), pigs continuously fed the high-fiber diet compared with the corn-soy control diet had lower ($P < 0.01$) ADG and poorer F/G, but ADFI was not affected. This reduction in growth performance led to decreased ($P < 0.01$) final BW and a tendency for poorer ($P < 0.10$) caloric efficiency for pigs fed the high-fiber diet throughout compared with the control. For pigs initially fed the high-fiber diet then switched to the corn-soybean meal control, ADG and ADFI were not different between withdrawal days; however, F/G tended (linear; $P < 0.07$) to improve as withdrawal days increased from 0 to 24 d, with the pigs withdrawn 19 and 24 days prior to harvest being the most efficient. Final BW and caloric efficiency were unaffected by withdrawal days.

For carcass characteristics, pigs fed the high-fiber diet throughout had a 9.5-lb lighter ($P < 0.01$) HCW compared with pigs fed the corn-soy control (Table 6). Percentage yield was unaffected by dietary treatment, but daily weighing of pigs the last 4 d of the study may have reduced the potential to find a difference. Nevertheless, pigs withdrawn from the high-fiber diet had heavier HCW (linear; $P < 0.05$) as withdrawal days increased. Backfat and loin depth were both reduced ($P < 0.02$) in pigs continuously fed the high-fiber diet. Loin depth increased (quadratic; $P < 0.04$) as withdrawal time increased.

Total feed cost per pig and feed cost per lb of gain were lower ($P < 0.01$) for pigs fed the high-fiber diet until harvest. The value of the carcass gain was reduced ($P < 0.01$) by $7.34 in pigs fed the high-fiber diets throughout the entire study. Total feed cost tended ($P < 0.10$) to increase and carcass gain value increased ($P < 0.05$) as withdrawal time increased. Although we observed no significant differences in IOFC between treatments, switching pigs from the high-fiber diet to the corn-soybean meal diet at 15 to 19 d before market numerically increased IOFC by $1.42 to $2.30/pig over pigs continuously fed the high-fiber diet and $2.04 to 2.92/pig over pigs fed the corn-soybean meal diet throughout.

In summary, feeding diets higher in fiber has been and will continue to be a viable option to producers and nutritionist to decrease feed cost and reduce cost of gain. However, this practice is also associated with the consequences of reduced yield and HCW. These data indicate that much of the benefit in lower feed cost from feeding

high-fiber diets can be captured while minimizing the loss of carcass value by switching pigs to a lower fiber, higher energy diet for 14 to 19 d prior to market.

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

	Phase 1		Phase 2	
Item	Control	High-fiber	Control	High-fiber
Ingredient, %				
Corn	73.15	34.18	76.85	37.83
Soybean meal , 46.5% CP	24.55	14.68	20.97	11.10
DDGS[2]	---	30.00	---	30.00
Wheat middlings	---	19.00	---	19.00
Monocalcium P, 21%	0.60	---	0.55	---
Limestone	0.95	1.25	0.93	1.20
Salt	0.35	0.35	0.35	0.35
Vitamin and trace mineral premix[3]	0.10	0.10	0.10	0.10
L-lysine sulfate[4]	0.27	0.44	0.25	0.42
L-threonine	0.02	---	0.01	---
MHA[5]	0.01	---	---	---
Phytase[6]	0.01	0.01	0.01	0.01
Total	100.00	100.00	100.00	100.00
Calculated analysis				
Standardized ileal digestible (SID) amino acids, %				
Lysine	0.95	0.95	0.85	0.85
Isoleucine:lysine	69	74	70	75
Leucine:lysine	155	189	163	202
Methionine:lysine	28	35	29	37
Met & Cys:lysine	58	66	60	70
Threonine:lysine	62	65	62	67
Tryptophan:lysine	19.0	19.0	19.0	19.0
Valine:lysine	78	90	80	93
SID lysine:ME, g/Mcal	2.84	2.90	2.54	2.59
ME, kcal/lb	1,517	1,486	1,518	1,488
Total lysine, %	1.07	1.13	0.96	1.02
CP, %	17.8	21.3	16.5	19.9
Ca, %	0.58	0.58	0.55	0.55
P, %	0.50	0.55	0.48	0.54
Available P, %	0.26	0.31	0.25	0.31
Crude fiber, %	2.6	5.3	3.3	5.1
NDF, %	9.2	20.5	9.2	20.5
Diet cost, $/ton	280.23	262.08	271.16	253.93

[1] Phase 1 diets were fed from approximately 98 to 127 lb; Phase 2 diets were fed from 127 to 175 lb.
[2] Dried distillers grains with solubles.
[3] Provided 2,043 IU/lb vitamin A, 318 IU/lb vitamin D, 11 IU/lb vitamin E, 1.4 ppm vitamin K, 3 ppm vitamin B_2, 18 ppm niacin, 12 ppm pantothenic acid, 40 ppm Mn, 100 ppm Zn, 90 ppm Fe, 10 ppm Cu, 0.3 ppm Se, and 0.5 ppm I to the complete diet.
[4] L-lysine sulfate provided by Biolys (Evonik Corporation, Kennesaw, GA).
[5] Methionine source (Novus International, St. Charles, MO).
[6] Optiphos 2000 (Enzyvia LLC, Sheridan, IN) provided 227 phytase units (FTU)/lb, with a release of 0.07% available P.

Table 2. Phase 3 and 4 diet composition (as-fed basis)[1]

	Phase 3		Phase 4	
Item	Control	High-fiber	Control	High-fiber
Ingredient, %				
Corn	80.16	41.17	83.10	43.99
Soybean meal, 46.5% CP	17.78	7.82	14.90	5.04
DDGS[2]	---	30.00	---	30.00
Wheat middlings	---	19.00	---	19.00
Monocalcium P, 21%	0.45	---	0.40	---
Limestone	0.95	1.18	0.95	1.15
Salt	0.35	0.35	0.35	0.35
Vitamin and trace mineral premix[3]	0.08	0.08	0.08	0.08
L-lysine sulfate[4]	0.23	0.40	0.21	0.38
L-threonine	---	---	0.01	---
Phytase[5]	0.01	0.01	0.01	0.01
Total	100.00	100.00	100.00	100.00
Calculated analysis				
Standardized ileal digestible (SID) amino acids, %				
Lysine	0.76	0.76	0.68	0.68
Isoleucine:lysine	71	77	72	79
Leucine:lysine	172	216	183	231
Methionine:lysine	30	39	32	42
Met & Cys:lysine	63	75	66	80
Threonine:lysine	63	69	65	71
Tryptophan:lysine	19.0	19.0	19.0	19.0
Valine:lysine	83	97	85	102
SID lysine:ME, g/Mcal	2.27	2.32	2.03	2.07
ME, kcal/lb	1,520	1,489	1,522	1,490
Total lysine, %	0.86	0.92	0.77	0.84
CP, %	15.3	18.7	14.2	17.6
Ca, %	0.53	0.53	0.51	0.51
P, %	0.44	0.53	0.42	0.52
Available P, %	0.22	0.31	0.21	0.30
Crude fiber, %	2.5	5.2	2.4	5.2
NDF, %	9.3	20.6	9.3	20.6
Diet cost, $/ton	262.88	246.12	256.16	239.17

[1] Phase 3 diets were fed from approximately 175 to 225 lb; Phase 4 diets were fed from 225 to 286 lb.
[2] Dried distillers grains with solubles.
[3] Provided 2,043 IU/lb vitamin A, 318 IU/lb vitamin D, 11 IU/lb vitamin E, 1.4 ppm vitamin K, 3 ppm vitamin B_2, 18 ppm niacin, 12 ppm pantothenic acid, 40 ppm Mn, 100 ppm Zn, 90 ppm Fe, 10 ppm Cu, 0.3 ppm Se, and 0.5 ppm I to the complete diet.
[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.

Table 3. Chemical analysis of dried distillers grains with solubles (DDGS) and wheat middlings (midds); (as-fed basis)

Nutrient, %	DDGS	Midds
DM	90.35	90.72
CP	29.4 (27.3)[1]	15.5 (15.9)
Ether extract (fat)	11.2	4.4
Crude fiber	7.4 (8.9)	8.4 (7.0)
ADF	9.1 (12.0)	11.9 (10.7)
NDF	22.4 (30.4)	34.6 (35.6)
Ash	3.89	4.97

[1] Values in parentheses indicate those used in diet formulation.

Table 4. Bulk density of experimental diets (as-fed basis)[1,2]

Bulk density, lb/bu	Control	High-fiber
Phase 1	45.6	38.2
Phase 2	45.4	40.0
Phase 3	44.3	35.6
Phase 4	44.8	35.1

[1] Diet samples were collected at the beginning and end of each phase from the feeder.
[2] Phase 1 was fed from d 0 to 14 ; Phase 2 from d 14 to 37; Phase 3 from d 37 to 64; Phase 4 from d 64 to 96.

Table 5. Effects of high-fiber withdrawal prior to market on growth performance of finishing pigs[1]

		High-fiber withdrawal prior to market, d						Probability, $P <$		
								Control vs.	Duration	
Item	Control	24	19	14	9	0	SEM	0 withdrawal	Linear	Quadratic
Weight, lb										
d 0	98.2	98.0	98.1	98.2	98.2	98.2	2.07	1.00	0.88	0.92
d 64	232.1	224.3	223.8	224.2	224.0	224.5	3.24	0.01	0.85	0.73
d 96	292.0	285.1	285.5	284.7	283.0	282.7	3.48	0.01	0.23	0.80
d 0 to 64										
ADG, lb	2.09	1.97	1.96	1.97	1.97	1.97	0.028	0.01	--	--
ADFI, lb	5.63	5.38	5.38	5.40	5.41	5.48	0.069	0.02	--	--
F/G	2.69	2.73	2.74	2.75	2.75	2.79	0.028	0.02	--	--
d 64 to 96										
ADG, lb	1.88	1.91	1.90	1.91	1.82	1.86	0.041	0.72	0.20	0.98
ADFI, lb	6.24	6.54	6.44	6.55	6.43	6.46	0.122	0.19	0.61	0.95
F/G	3.31	3.43	3.40	3.43	3.53	3.48	0.059	0.03	0.17	0.85
d 0 to 96										
ADG, lb	2.03	1.95	1.94	1.95	1.92	1.94	0.021	0.01	0.28	0.79
ADFI, lb	5.82	5.74	5.71	5.76	5.73	5.79	0.077	0.68	0.53	0.66
F/G	2.87	2.94	2.94	2.95	2.98	2.99	0.024	0.01	0.07	0.79
Caloric efficiency[2]										
ME	4,364	4,401	4,400	4,411	4,452	4,448	35.12	0.10	0.19	0.86

[1] A total of 1,089 pigs (PIC 337 × 1050, initial BW= 98.2 lb) were used in a 96-d study with 7 replications per treatment. [2] Caloric efficiency is expressed as ME kcal/lb gain.

Table 6. Effects of high-fiber withdrawal prior to market of finishing pigs on carcass characteristics and economics

		High-fiber withdrawal prior to market, d						Probability, $P <$		
								Control vs.	Duration	
Item	Control	24	19	14	9	0	SEM	0 withdrawal	Linear	Quadratic
Carcass characteristics										
HCW, lb	218.5	211.2	212.9	212.2	210.6	209.0	2.00	0.01	0.05	0.08
Yield, %[2]										
Farm	74.85	74.10	74.62	74.54	74.43	73.93	0.496	0.19	0.73	0.27
Plant	75.35	74.28	74.59	75.14	74.95	74.52	0.705	0.39	0.69	0.37
Backfat, in.[3]	0.704	0.659	0.673	0.654	0.641	0.645	0.016	0.02	0.21	0.79
Loin depth, in.[3]	2.619	2.556	2.582	2.580	2.595	2.515	0.030	0.02	0.39	0.04
Lean, %[3]	55.90	56.45	56.32	56.57	56.87	56.55	0.296	0.14	0.39	0.75
Economics, $/pig										
Feed cost	85.58	79.30	78.36	78.65	77.69	77.62	1.061	0.01	0.10	0.86
Feed cost/lb gain	0.440	0.423	0.420	0.420	0.422	0.418	0.003	0.01	0.34	0.95
Carcass gain value[4]	111.54	105.95	107.25	106.65	105.44	104.20	1.543	0.01	0.05	0.08
IOFC[5]	25.96	26.64	28.88	28.00	27.75	26.58	1.261	0.71	0.73	0.17

[1] A total of 1,089 pigs (PIC 337 × 1050, initial BW= 98.2 lb) were used in a 96-d study with 7 replications per treatment.
[2] Percentage yield was calculated by dividing HCW by pen live weight obtained at the farm before transport to the packing plant as well as the pen live weight obtained at the plant.
[3] Carcass characteristics were adjusted by using HCW as a covariate.
[4] Carcass gain value is calculated as $77.00/cwt of final carcass wt. minus (initial weight x 75% assumed yield x $77.00/cwt).
[5] Income over feed cost = carcass gain value – feed cost.

Effects of Low-, Medium-, and High-Oil Dried Distillers Grains with Solubles on Growth Performance, Nutrient Digestibility, and Fat Quality in Finishing Pigs[1]

A.B. Graham, R.D. Goodband, M.D. Tokach, S.S. Dritz[2], J.M. DeRouchey, S. Nitikanchana[2], and J.J. Updike

Summary

A total of 1,480 pigs were used in 3 experiments to determine the effects of dried distillers grains with solubles (DDGS) varying in oil content on growth performance, carcass characteristics, carcass fat quality, and nutrient digestibility in growing-finishing pigs. In Exp. 1, 1,198 pigs (PIC 337 × 1050, initially 101.6 lb) were used to evaluate the effects of corn DDGS with 5.4 or 9.6% oil (as-fed). Pigs were allotted to a corn-soybean meal–based control diet or diets with 20 or 40% of the two DDGS sources. From d 0 to 82, ADG was unaffected by DDGS source or level. Increasing 5.4% oil DDGS made F/G poorer (linear, $P < 0.01$), whereas F/G did not change for pigs fed 9.6% oil DDGS. Regardless of DDGS source, carcass yield and HCW decreased (linear, $P < 0.04$) with increasing DDGS. Increasing DDGS increased jowl iodine value (IV), but the magnitude was greater in pigs fed the 9.6% oil DDGS compared with those fed 5.4% oil DDGS (DDGS source × level interaction; $P < 0.01$). In Exp. 2, a total of 270 pigs (PIC 327 × 1050, initially 102.5 lb) were allotted a corn-soybean meal–based control diet with 20 or 40% of a 9.4% oil or 12.1% oil DDGS. From d 0 to 75, ADG increased for pigs fed increasing 9.4% oil DDGS but not for pigs fed 12.1% oil DDGS (quadratic interaction, $P < 0.02$). Increasing DDGS increased (linear, $P < 0.01$) jowl IV and tended (linear, $P < 0.07$) to improve F/G. Regardless of source, HCW and carcass yield decreased (linear, $P < 0.05$) as DDGS increased. In Exp. 3, nutrient digestibility of the 4 DDGS sources was determined using pigs fed either a corn-based basal diet or a DDGS diet with 50% basal diet and 50% DDGS. On an as-fed basis, corn contained 1,756 and 1,594 kcal/lb GE and DE, respectively. The 5.4, 9.6, 9.4, and 12.1% oil DDGS contained 1,972, 2,108, 2,142, and 2,224 kcal/lb (as-fed) GE and 1,550, 1,674, 1,741, and 1,694 kcal/lb DE, respectively (as-fed). Stepwise regression indicated that the oil (ether extract) content was the only significant variable in explaining differences in energy content, and that a 1% change in oil content will change the DE by 28 kcal/lb (Adjusted $R^2 = 0.41$) and NE by 52 kcal/lb (Adjusted $R^2 = 0.86$; as-fed).

Key words: corn, DDGS, digestibility, growth performance, finishing pigs, iodine value

Introduction

Dried distillers grains with solubles are a by-product of the ethanol industry and are commonly used to replace portions of corn and soybean meal in swine diets. Tradi-

[1] This project was supported by National Research Initiative Competitive Grant no. 2011-68004-30336 from the USDA National Institute of Food and Agriculture.

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tional DDGS with approximately 10% oil have a relatively similar feeding value to that of corn. In a review of over 20 papers, Stein and Shurson (2009[3]) concluded that growth performance will remain unchanged when feeding DDGS up to 30% of the diet; however, carcass characteristics such as carcass yield and jowl IV are adversely affected by feeding DDGS because of its high unsaturated fatty acid content.

As the value of corn oil has risen, ethanol plants have begun implementing oil extraction procedures to remove a greater portion of the corn oil, resulting in DDGS that vary in oil content from approximately 4 to 12%. Because the feeding value of DDGS is largely based on its energy content, changing the oil content of DDGS may affect growth performance. As a result, NRC (2012[4]) values for DDGS are based on oil content and are categorized as low (>4% oil), medium (between 6 and 9% oil), or high-oil (>10%).

Research suggests that variables such as GE, ash, oil (ether extract), ADF, and total dietary fiber are significant in estimating energy values of corn co-products (Pederson et al., 2007[5]; Anderson et al., 2011[6]); however, relatively few studies are available comparing the feeding value of DDGS containing less than 8% ether extract. Therefore, the objectives of this study were to evaluate the effects of DDGS with varied oil contents on finishing pig growth performance, carcass characteristics, and carcass fat quality and to determine the DE content and nutrient digestibility relationships between DDGS sources.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in these experiments.

Experiment 1 was conducted in 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 5-hole stainless steel dry self-feeder (Thorp Equipment, Thorp, WI) and a cup waterer for ad libitum access to feed and water.

Experiment 2 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 × 10 ft). The pens had adjustable gates facing the alleyway, allowing for 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. Facilities in both Exp. 1 and 2 were equipped with a computerized feeding system (FeedPro; Feedlogic Corp., Willmar, MN) that delivered

[3] Stein, H.H., and G.C. Shurson. 2009. Board-Invited Review: The use and application of distillers dried grains with solubles (DDGS) in swine diets. J. Anim. Sci. 87:1292–1303.
[4] NRC. 2012. Nutrient Requirements of Swine. 11th rev. ed. Natl. Acad. Press, Washington, DC.
[5] Pederson, C., M.G. Boersma, and H.H. Stein. 2007. Digestibility of energy and phosphorus in ten samples of distillers dried grains with solubles fed to growing pigs. J. Anim. Sci. 85:1168–1176.
[6] Anderson, P.V., B.J. Kerr, T.E. Weber, C.J. Ziemer, and G.C. Shurson. 2012. Determination and prediction of digestible and metabolizable energy from chemical analysis of corn coproducts fed to finishing pigs. J. Anim. Sci. 90:1242–1254.

and recorded daily feed additions and diets as specified. The equipment provided pigs with ad libitum access to food and water.

In Exp. 3, pigs were housed in a totally enclosed, environmentally controlled, mechanically ventilated facility containing 12 stainless steel metabolism cages (5 × 2 ft). Each cage was equipped with a feeder as well as a nipple waterer to allow ad libitum access to water and had metal mesh flooring that allowed for total collection of feces.

Animals and diets

Samples of DDGS from Exp. 1 were taken upon delivery of every new batch, whereas DDGS from Exp. 2 were from a single batch of either 9.4 or 12.1% oil DDGS. Corn samples were obtained at the time of diet manufacture for Exp. 3. These DDGS and corn samples were combined and homogenized, and subsamples were taken and analyzed for DM, CP, crude fiber, NDF, ADF, and ether extract at a commercial laboratory (Ward Laboratories, Inc., Kearney, NE; Table 1). Amino acid profile was analyzed at the University of Missouri-Columbia Agricultural Experiment Station Chemical Laboratory (Columbia, MO; AOAC, 2006; Table 1). Fatty acid analysis (Sukhija and Palmquist, 1988) was conducted at the K-State Analytical Lab (Manhattan, KS; Table 2). Samples of ingredients were taken from every DDGS delivery, and a composite sample was used to measure bulk density (Table 3). Bulk density of a material represents the mass per unit of volume (lb/bu). Lastly, particle size was measured on all DDGS sources used.

Experiment 1

A total of 1,198 pigs (PIC 337 × 1050, Hendersonville, TN; initially 101.6 lb BW) were used in an 82-d growth study to determine the effects of 5.4 or 9.6% oil corn DDGS in finishing diets on growth performance, carcass characteristics, and carcass fat quality. Pens with 26 or 27 pigs per pen were randomly allotted to 1 of 5 treatment groups, with average pig BW balanced across treatments to provide 9 replications per treatment. All diets were fed in meal form, with treatments delivered over 3 phases (101 to 157, 157 to 231, and 231 to 284 lb; Tables 4, 5, and 6). Pigs were allotted to a corn-soybean meal–based control diet with 20 or 40% of the 5.4% oil DDGS or 9.6% oil DDGS. Diets were balanced across treatments by phase for standardized ileal digestible (SID) lysine and available P but not for energy. At the time of diet formulation, the 2012 NRC publication was not available; therefore, total amino acid and SID coefficients in DDGS from Stein (2007[7]) were used in diet formulation.

On d 61, the 3 heaviest pigs from each pen (determined visually) were weighed and sold in accordance with the farm's normal marketing procedure. Near the conclusion of the trial, all remaining pigs were tattooed according to pen number and dietary treatment to allow for carcass data collection and data retrieval by pen. On d 82, 2 medium-weight barrows were selected from each pen and transported approximately 1.5 h to a commercial packing plant (Sioux-Preme Packing Co., Sioux Center, IA), where they were harvested, and jowl, backfat, and belly fat samples were collected and analyzed for their fatty acid content. Jowl samples were collected from the distal end of the carcass, and belly fat samples were taken along the midline, parallel to the diaphragm.

[7] Stein, H.H. 2007. Feeding distillers dried grains with solubles (DDGS) to swine. Swine Focus #001. University of Illinois Extension, Urbana-Champaign, IL.

Backfat samples were taken midline at the 10th rib, with care taken to sample all 3 layers. Fatty acid analysis was conducted in the University of Nebraska Department of Nutrition and Health Sciences Analytical Lab. On d 82, the remaining pigs were transported approximately 1 h to a different commercial packing plant (JBS Swift and Company, Worthington, MN) for data collection. Standard carcass criteria of percentage carcass yield, HCW, backfat depth, loin depth, and percentage lean were calculated. Hot carcass weight was measured immediately after evisceration, and carcass yield was calculated as HCW divided by live weight at the plant. Fat depth and loin depth were measured with an optical probe inserted between the third- and fourth-last rib (counting from the ham end of the carcass) at a distance approximately 3 in. from the dorsal midline. Fat-free lean index (FFLI) was calculated according to National Pork Producers Council (1991[8]) procedures.

Experiment 2

A total of 270 pigs (PIC 327 × 1050, Hendersonville, TN; initially 102.5 lb BW) were used in a 75-d growth study to determine the effects of 9.4 or 12.1% oil corn DDGS in finishing diets on pig growth performance and carcass characteristics. There were 8 pigs per pen and 7 replications per treatment. All diets were fed in meal form, and treatments were fed over 3 phases (103 to 161, 161 to 220, and 220 to 269 lb; Tables 4, 5, and 6). Pigs were allotted to a corn-soybean meal–based control diet or diets with 20 or 40% of 9.4%-oil DDGS or 12.1%-oil DDGS. In this study, NRC (2012) nutrient values for DDGS with greater than 10% oil were used to formulate both DDGS sources. Diets were formulated above the pigs' estimated requirements for amino acids to avoid limiting growth performance. All pigs and feeders were weighed on d 0, 14, 26, 38, 54, and 75 to determine ADG, ADFI, and F/G.

On d 75, all pigs were weighed and transported approximately 2.5 h to a commercial packing plant (Triumph Foods LLC, St. Joseph, MO) for harvest under USDA inspection. Before slaughter, pigs were individually tattooed according to pen number to allow for carcass data collection at the packing plant and data retrieval by pen. Hot carcass weight was measured immediately after evisceration, and each carcass was evaluated for carcass yield, backfat depth, loin depth, percentage lean, and jowl IV. Carcass yield was calculated by dividing HCW at the plant by live weight at the farm before transport to the plant. Fat depth and loin depth were measured with an optical probe inserted between the third- and fourth-last rib. Jowl fat samples were collected and analyzed by near-infrared spectroscopy (Bruker MPA, Breman, Germany) at the plant for IV using the equation of Cocciardi et al. (2009[9]).

Experiment 3

A total of 12 barrows (PIC 327 × 1050, Hendersonville, TN; initially 56.4 lb BW) were used in a 6-wk study to determine nutrient digestibility of corn and the 4 DDGS sources used in Experiments 1 and 2 as well as a fifth source of medium-oil DDGS used

[8] NPPC. 1991. Procedures to evaluate market hogs. 3rd ed. National Pork Producers Council, Des Moines, IA.

[9] Cocciardi, R.A., J.M. Benz, H. Li, S.S. Dritz, J.M. DeRouchey, M.D. Tokach, J.L. Nelssen, R.D. Goodband, and A.W. Duttlinger. 2009. Analysis of iodine value in pork fat by Fourier transform near infrared spectroscopy for pork fat quality assessment. J. Anim. Sci. 87(Suppl. 2):579. (Abstr.).

in a different growth study outlined by Graham (2013[10]). The fifth source contained 7.6% oil, 30.1% CP, 19.53% ADF, and 36.47% NDF (as-fed). The 5 DDGS sources plus the control corn-basal diets were evaluated using a replicated Latin square design with 6 pigs assigned to each square to achieve 12 replications per diet. The pigs within each replicate square were randomly allotted to treatment within each period using the PLAN procedure of SAS (SAS Inst. Inc., Cary, NC). The sources of DDGS used in the digestibility study were from the same batches as the corresponding growth trials. Nutrient digestibility of the DDGS source was determined by feeding either a 96.6% corn-based basal diet (96.6% corn, 3.4% vitamins and minerals) or 50% basal diet and 50% DDGS (Table 6); thus, vitamins and minerals in the test diet were fed at half of the levels fed in the corn-basal diet.

Pigs were fed the same amount of each diet for the duration of each 7-d period. Feeding level was 2.5 times maintenance requirements and was determined based on pig BW on d 1 of each period. Daily rations were equally divided between two meals fed at 0600 and 1800 h. Each period consisted of 5 d of diet adjustment (10 meals) followed by 2 consecutive days of total fecal collection. On the morning of day 6 (meal 11), pigs were allowed approximately 5 min to stand, drink, and defecate before eating. After that time, feces were removed and the morning meal was fed. This meal on the morning of d 6 marked the beginning of the timed fecal collection period. On d 8 of period 1, (d 1 of period 2 or meal 15), the same amount of time was given to pigs, allowing them to stand up, drink, and defecate. Before feeding, all feces were collected, marking the end of the timed collection period. On the same morning that collection ended, pigs were weighed and fed a new treatment diet in a random order. Feces were stored in a freezer until further processing and analysis. At the conclusion of a collection period, all feces for each pig were combined, homogenized, and dried in a forced-air oven. Samples were finely ground, then subsampled for further analysis following the procedures of Jacela et al. (2010[11]). Gross energy concentrations of the ingredients, diets, and fecal samples were measured via adiabatic bomb calorimetry. Calculations outlined by Adeola (2001[12]) were used to determine energy values. Ingredients, diets, and feces were also analyzed for DM, CP, crude fiber, NDF, ADF, and ether extract at a commercial laboratory (Ward Laboratories, Inc., Kearney, NE).

Statistical analysis

Data for the growth trials were analyzed as a completely randomized design with pen as the experimental unit and treatment as a fixed effect; IV analysis in Exp. 1, however, was analyzed using a completely randomized design with the fixed effect of treatment and the random effect of pen. Analysis of variance was used with the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). Because HCW differed, it was used as a covariate for backfat, loin depth, and percentage lean. For Exp. 1 and 2, contrasts were used to make comparisons between (1) the linear and quadratic interactions of DDGS

[10] Graham, A.B. 2013. The effects of low-, medium-, and high-oil dried distillers grains with solubles (DDGS) on growth performance, nutrient digestibility, and fat quality in finishing pigs. MS Thesis. Kansas State Univ., Manhattan.

[11] Jacela, J.Y., J.M. Benz, S.S. Dritz, M.D. Tokach, J.M. DeRouchey, R.D. Goodband, J.L. Nelssen, and K.J. Prusa. 2010. Effect of dried distillers grains with solubles (DDGS) withdrawal regimens on finishing pig performance and carcass traits. J. Anim. Sci. 88 (Suppl. 3):53 (Abstr.).

[12] Adeola, O. 2001. Digestion and balance techniques in pigs. In: A.J. Lewis and L.L. Southern, Editors, Swine Nutrition. 2nd ed. CRC Press, New York, NY. p. 903–916.

source × level; (2) corn-soy and 20% and 40% DDGS-containing diets; and (3) linear and quadratic effects of increasing DDGS. In Exp. 3, period, pig, and Latin square were random effects and treatment was a fixed effect. Single degree of freedom contrasts were used to separate means of pigs fed either the corn- or DDGS-based diet in the nutrient balance study. Differences were considered significant at $P \leq 0.05$ and a trend at $P > 0.05$ and $P \leq 0.10$. Stepwise regression was used to determine the effect of the feedstuff composition on DE and NE. Variables were retained in the model with *P*-values ≤ 0.15. The adjusted R^2, the SE of the estimate, the SE, and the Mallows statistic [C(p)] were used to define the best-fit equation. If the intercept was determined insignificant in the final prediction model, it was excluded from the model and an adjusted R^2 value was calculated using the NOINT option of SAS.

Results

Chemical analysis

Analyzed samples of DDGS were similar in CP concentrations but considerably varied in fiber content (Table 1). Crude fiber ranged from 7.9 to 12% on an as-fed basis, with crude fiber increasing as oil content increased. The same overall trend was observed in ADF and NDF concentrations.

According to NRC (2012), the lysine concentrations in low, medium-, and high-oil DDGS are 0.68, 0.90, and 0.77%, respectively. The analysis of AA on the 5.4, 9.6, 9.4, and 12.1%-oil DDGS showed that lysine concentrations were 1.03, 1.12, 1.00, and 0.90%, respectively (Table 1). The analyzed values of lysine from the DDGS sources were greater than those used in diet formulation, so diets containing DDGS contained slightly more lysine and other amino acids than calculated; therefore, lysine should not have limited pig performance. The remaining analyzed amino acids were similar in concentration to values listed in the NRC (2012). Fatty acid analyses was similar among the DDGS samples (Table 2).

Bulk density tests on the ingredients used in this study further demonstrated the variability in DDGS from different ethanol plants (Table 3). Research has established that as DDGS are added to corn-soybean meal–based diets, diet bulk density decreases (Asmus, 2012[13]). Ethanol plants have begun to implement extra centrifugation processes to capture more corn oil during ethanol production (CEPA, 2011[14]). Although we would expect oil removal to reduce bulk density, bulk density did not appear to be greatly influenced by oil content. Particle size varied from 371 to 744 microns in the DDGS used in these experiments.

Experiment 1

Overall (d 0 to 82), ADG was unaffected by DDGS source or level, although a DDGS source × level interaction ($P < 0.02$) was observed for ADFI and F/G. Increasing 5.4%-oil DDGS increased ADFI and worsened F/G, but no significant change occurred in

[13] Asmus, M.D. 2012. Effects of dietary fiber on the growth performance, carcass characteristics, and carcass fat quality in growing-finishing pigs. MS. Thesis. Kansas State Univ., Manhattan.
[14] California Environmental Protection Agency. 2011. California-Modified GREET Pathway for the Production of Biodiesel from Corn Oil at Dry Mill Ethanol Plants. Stationary Source Division, Release Date: November, 3, 2011, Version 2.0. 40 pp.

ADFI or F/G when pigs were fed increasing amounts of 9.6%-oil DDGS (Table 7). No significant differences in final BW were observed.

Regardless of DDGS source, carcass yield and HCW decreased (linear, $P < 0.04$) with increasing DDGS (Table 8). As DDGS increased, loin depth tended to increase (quadratic, $P = 0.05$), especially in pigs fed the 9.6%-oil DDGS source. DDGS source × level interactions (linear, $P < 0.02$) were observed for jowl, belly, and backfat IV. Increasing DDGS increased jowl, belly, and backfat IV, but the magnitude of increase was greater in pigs fed the 9.6%-oil DDGS than in those fed the 5.4%-oil DDGS.

Experiment 2

Overall (d 0 to 75), ADG increased in pigs fed 20% of the 9.4%-oil DDGS but decreased slightly in those fed 40% DDGS compared with control-fed pigs (quadratic interaction, $P < 0.02$; Table 9). Average daily gain did not differ among pigs fed 12.1%-oil DDGS. Increasing DDGS, regardless of source, tended (linear, $P < 0.06$) to improve F/G. As DDGS increased, ADFI decreased (linear, $P < 0.04$), regardless of source. Final BW followed the same trend as ADG (quadratic interaction, $P < 0.10$), with the pigs fed 40% DDGS (which contained 9.4% oil) having the lowest final BW among all treatments.

Regardless of source, increasing DDGS decreased (linear, $P < 0.04$) carcass yield and HCW (Table 10). No significant differences were observed in backfat depth, loin depth, or percentage lean. Increasing DDGS increased (linear, $P < 0.01$) jowl IV, but to a greater extent in pigs fed 12.1%-oil DDGS than those fed 9.4%-oil DDGS (DDGS source × level interaction, linear, $P < 0.001$) for jowl IV.

Experiment 3

Gross energy values observed for the corn, 5.4, 9.6, 9.4, and 12.1%-oil DDGS used in the growth portion of this study were 1,756, 1,972, 2,108, 2,142, and 2,224 kcal/lb, respectively (as-fed; Table 11). Based on the corresponding GE digestibility coefficients calculated for each DDGS source (Table 12), DE values for the corn, 5.4, 9.6, 9.4, and 12.1% oil DDGS were 1,594, 1,550, 1,674, 1,741, and 1,694 kcal/lb, respectively (as-fed). Dry matter digestibility was relatively similar among the 4 DDGS sources. Crude protein digestibility was highest in the 9.4 and 9.6%-oil DDGS. Digestibility of the ether extract in DDGS was considerably more variable, ranging from approximately 62 to 76%. In general, the digestibility of ether extract increases as the oil content of DDGS increased, with the exception of the 9.6%-oil DDGS used in this study. Acid detergent fiber digestibility of the DDGS sources increased as the oil content increased, with the exception of the 9.4%-oil DDGS source, which was intermediate. Neutral detergent fiber and CF digestibility did not follow this pattern and varied among sources.

Discussion

Research has shown that corn DDGS can be fed at up to 30% of the diet without adversely affecting growth performance because >10%-oil DDGS has an energy value similar to that of corn (Stein, 2007). As new oil extraction capabilities are implemented in ethanol plants to harvest more corn oil, reduced-oil DDGS are becoming more abundant in the marketplace. One concern is that the new, reduced-oil DDGS might

negatively affect pig growth performance, as was the case in recent research by Graham (2013), where feeding pigs increasing medium-oil DDGS (7.6% oil) linearly decreased ADG and worsened F/G.

The hypothesis in the current study was that oil content would be highly significant in predicting energy values of DDGS sources varying considerably in oil content. Stepwise regression was used to determine DE and NE equations based on the 4 DDGS sources used in the growth portion of this study and one other source of DDGS outlined by Graham (2013). The DDGS source used in Graham (2013) contained 7.6% oil (as-fed basis) and had DE of 1,522 kcal/lb. The DE content of the corn and the 5 DDGS were determined using the digestibility data collected from the 12 pigs housed in metabolism crates. The GE and DE values observed for the corn used in this study, 1,756 and 1,594 kcal/lb (as-fed), respectively, were similar to published values (1,811 and 1,565 kcal/lb, respectively; NRC, 2012). The GE values observed for the 5.4, 9.6, 9.4, and 12.1%-oil DDGS used in the growth portion of this study were 1,972, 2,108, 2,142, and 2,224 kcal/lb, respectively (as-fed; Table 11). These compare to values listed in the NRC (2012) for low-, medium-, and high-oil DDGS of 2,312, 2,136, and 2,199 kcal/lb (as-fed), respectively. In contrast to GE values from NRC (2012), those observed in the current study increased as oil content in DDGS increased.

Gross energy digestibility coefficients determined in the current study for 5.4, 9.6, 9.4, and 12.1% oil DDGS were 78.6, 79.4, 81.3, and 76.1%, respectively. The calculated GE digestibility coefficients from low-, medium-, and high-oil DDGS in NRC (2012) are 64.6, 76.1, and 74.7%, respectively.

Based on the corresponding GE digestibility coefficients calculated for each DDGS source (Table 12), DE values for the 5.4, 9.6, 9.4, and 12.1%-oil DDGS were 1,550, 1,674, 1,741, and 1,694 kcal/lb, respectively (as-fed). These DE values compare to values listed in the NRC (2012) for low-, medium-, and high-oil DDGS of 1,493, 1,625, and 1,642 kcal/lb (as-fed), respectively. In the current study, similar to NRC (2012) values, DE increases as the oil content of DDGS sources increases, with the exception of the 12.1%-oil DDGS source, which is intermediate. The NE of the DDGS sources was calculated based on the actual growth performance from Exp. 1 and 2 and data from the 7.6% oil DDGS from Graham (2013). Net energy efficiency (NEE) was determined by calculating the calories of NE intake in kcal/per lb of gain on a phase basis (studies utilized either 2- or 3-phase feeding strategies), using solving functions to set the NEE of pigs fed each DDGS source equal to that of those fed the corn-soybean meal control diet. This was done with the assumption that the NE contents of corn and soybean meal were 1,212 and 947 kcal/lb, respectively (as-fed; NRC, 2012).

Based on results from the growth portion of the current study, as well as those of Graham (2013), energy content of DDGS sources should be considered in determining a price relative to corn because of reduced feeding values from the extraction of larger quantities of corn oil from DDGS. This conclusion agrees with previous research that determined the NE value of 7.8% oil DDGS is less than the stated value for DDGS with 6–9% oil in the NRC (2012), indicating a wide range of energy values that are dependent on the oil content of DDGS. The equations generated to predict DE and NE as a function of oil content on an as-fed basis were: DE (kcal/lb) = 28.28 × ether extract (%) + 1387 (n=5, Adjusted R^2 = 0.41); NE (kcal/lb) = 52.17 × ether extract

(%) + 681 (n=5, Adjusted R^2 = 0.86; Figure 1). These equations indicate that changing the oil content 1% in DDGS will change the DE by 28 kcal/lb and NE by 52 kcal/lb on an as-fed basis.

Table 1. Analyzed nutrient composition of ingredients (as-fed basis)[1]

		Exp. 1		Exp. 2	
Item, %	Corn	5.4% oil DDGS[2]	9.6% oil DDGS	9.4% oil DDGS	12.1% oil DDGS
DM	88.03	92.38	91.97	93.17	93.20
CP	8.80	29.53	29.63	29.40	28.53
Crude fiber	3.85	7.93	11.02	11.25	12.07
ADF	5.83	8.90	15.25	19.57	17.57
NDF	16.22	21.75	28.58	34.50	31.38
Ash	1.49	4.90	3.94	4.65	4.61
Amino acids					
Arginine	---	1.31	1.30	1.38	1.27
Cysteine	---	0.57	0.54	0.54	0.46
Histidine	---	0.79	0.77	0.78	0.69
Isoleucine	---	1.09	1.13	1.16	1.02
Leucine	---	3.27	3.39	3.42	3.06
Lysine	---	1.03	1.12	1.00	0.90
Methionine	---	0.58	0.58	0.54	0.49
Threonine	---	1.10	1.09	1.10	1.02
Tryptophan	---	0.19	0.22	0.22	0.21
Valine	---	1.40	1.46	1.50	1.34

[1] Values represent the mean of 1 sample analyzed 6 times.
[2] Dried distillers grains with solubles.

Table 2. Fatty acid analysis of low- and high-oil dried distillers grains with solubles (DDGS)

	Exp 1		Exp 2	
Fatty acid, % of total fat	5.4% oil DDGS	9.6% oil DDGS	9.4% oil DDGS	12.1% oil DDGS
Myristic (14:0)	0.08	0.08	0.07	0.06
Palmitic (16:0)	14.87	14.65	14.11	13.88
Palmitoleic (16:1)	0.14	0.13	0.13	0.13
Stearic (18:0)	2.33	2.15	2.01	1.98
Elaidic (18:1*t9*)	0.08	0.07	0.07	0.07
Oleic (18:1*n9*)	26.14	26.57	26.01	25.46
Linoleic (18:2)	52.43	52.47	53.85	54.96
Linolenic (ω18:3)	1.54	1.62	1.50	1.44
Arachidic (20:0)	0.41	0.44	0.41	0.38
Gadoleic acid (C20:1n9)	0.42	0.44	0.41	0.36
Docosanoic (22:0)	0.23	0.24	0.22	0.22
Lignoceric (24:0)	0.37	0.32	0.33	0.30
Other fatty acids	0.96	0.82	0.88	0.76
Total SFA, %[1]	18.29	17.88	17.15	16.82
Total MUFA, %[2]	26.78	27.21	26.62	26.02
Total PUFA, %[3]	53.97	54.09	55.35	56.40
UFA:SFA ratio[4]	4.41	4.55	4.78	4.90
PUFA:SFA ratio[5]	2.95	3.02	3.22	3.35
Iodine value, %[6]	131.8	132.2	133.3	134.3

[1] Total SFA = ([C14:0] + [C16:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.
[2] Total MUFA = ([C16:1] + [C18:1 *t*-9] + [C18:1n-9] + [C20:1]); brackets indicate concentration.
[3] Total PUFA = ([C18:2] + [C18:3]); brackets indicate concentration.
[4] UFA:SFA = (total MUFA + total PUFA)/total SFA.
[5] PUFA:SFA = total PUFA/total SFA.
[6] Calculated as iodine value = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785); brackets indicate concentration.

Table 2. Bulk densities and particle size of dried distillers grains with solubles (DDGS) sources (as-fed basis)[1]

	Source and DDGS, %			
	Exp. 1		Exp. 2	
Item	5.4% oil DDGS	9.6% oil DDGS	9.4% oil DDGS	12.1% oil DDGS
Bulk density, lb/bu[2]	45.7	42.7	43.8	40.2
Particle size, μ	371	562	744	687

[1] Ingredient samples were taken from every delivery (Exp. 1) and were combined so that a composite sample could be evaluated. In Exp. 2, all diets were made from single batches of both DDGS sources; therefore, a representative sample was analyzed.

[2] Bulk densities represent the mass per unit volume. Diet samples were taken from the tops of feeders during each phase.

Table 3. Phase 1 diet compositions (as-fed basis)[1]

	Exp. 1			Exp. 2		
	Control	DDGS source,[2] % inclusion		Control	DDGS source,[3] % inclusion	
Item	0	20	40	0	20	40
Ingredient, %						
Corn	76.2	59.4	41.9	74.2	58.1	41.8
Soybean meal (46.5% CP)	21.5	18.5	15.8	22.9	19.25	15.7
5.4 or 9.6% oil DDGS	-	20.0	40.0	-	-	-
9.4 or 12.1% oil DDGS	-	-	-	-	20.0	40.0
Monocalcium P (21% P)	0.43	0.03	-	0.90	0.45	-
Limestone	0.90	1.10	1.38	0.95	1.2	1.45
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin and trace mineral premix[4]	0.10	0.10	0.10	0.30	0.30	0.30
L-lysine HCl	0.48	0.53	0.58	0.23	0.27	0.31
DL-methionine	0.04	-	-	0.02	-	-
L-threonine	0.07	0.01	-	0.03	-	-
Phytase	0.02	0.01	0.01	0.13	0.13	0.13
Total	100	100	100	100	100	100
Calculated analysis						
Standardized ileal digestible (SID) amino acids, %						
Lysine	0.95	0.95	0.95	0.95	0.95	0.95
Isoleucine:lysine	62	68	75	65	70	74
Leucine:lysine	139	179	219	150	177	205
Methionine:lysine	29	30	34	29	32	37
Met & Cys:lysine	55	59	66	57	61	66
Threonine:lysine	60	60	65	61	63	69
Tryptophan:lysine	18	18	18	18	18	18
Valine:lysine	69	79	89	75	82	90
Total lysine, %	1.07	1.10	1.13	1.06	1.10	1.14
ME, kcal/lb	1,505	1,483	1,453	1,508	1,511	1,515
SID lysine: ME, g/Mkcal	2.86	2.91	2.96	2.86	2.85	2.84
CP, %	17.0	19.7	22.5	17.2	19.6	22.0
Ca, %	0.48	0.48	0.57	0.63	0.63	0.63
P, %	0.44	0.44	0.53	0.55	0.53	0.51
Available P, %	0.27	0.27	0.37	0.38	0.38	0.38

[1] Phase 1 diets were fed in meal form from d 0 to 27 (Exp. 1) and d 0 to 26 (Exp. 2).
[2] Diets included both 5.4 and 9.6%-oil dried distillers grains with solubles (DDGS) sources fed at 20 and 40% of the diet.
[3] Diets included both 9.4 and 12.1%-oil DDGS sources fed at 20 and 40% of the diet.
[4] Provided per pound of premix in Exp.1: 2,000,000 IU vitamin A; 250,000 IU vitamin D_3; 8,000 IU vitamin E; 800 mg vitamin K; 1,500 mg riboflavin; 5,000 mg pantothenic acid; 9,000 mg niacin; 7 mg vitamin B_{12}; 12 g Mn from manganese oxide; 50 g Fe from iron sulfate; 50 g Zn from zinc sulfate; 5 g Cu from copper sulfate; 90 mg I from calcium iodate; and 90 mg Se from sodium selenite. Normal K-State vitamin and trace mineral premixes were used in Exp. 2.

Table 4. Phase 2 diet compositions (as-fed basis)[1]

	Exp. 1			Exp. 2		
	Control	DDGS source,[2] % inclusion		Control	DDGS source,[3] % inclusion	
Item	0	20	40	0	20	40
Ingredient, %						
Corn	79.8	62.8	45.4	79.6	63.3	47.1
Soybean meal (46.5% CP)	18.2	15.3	12.4	17.7	14.2	10.5
5.4 or 9.6% oil DDGS	-	20.0	40.0	-	-	-
9.4 or 12.1% oil DDGS	-	-	-	-	20.0	40.0
Monocalcium P (21% P)	0.40	-	-	0.80	0.35	-
Limestone	0.90	1.10	1.35	0.98	1.25	1.43
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin and trace mineral premix[4]	0.10	0.10	0.10	0.25	0.25	0.25
L-lysine HCl	0.35	0.38	0.44	0.20	0.24	0.29
DL-methionine	0.01	-	-	0.01	-	-
L-threonine	0.03	-	-	0.02	-	-
Phytase	0.02	0.01	0.01	0.13	0.13	0.13
Total	100	100	100	100	100	100
Calculated analysis						
Standardized ileal digestible (SID) amino acids, %						
Lysine	0.80	0.80	0.80	0.80	0.80	0.80
Isoleucine:lysine	66	74	82	67	72	77
Leucine:lysine	156	203	250	163	196	228
Methionine:lysine	29	33	38	29	35	41
Met & Cys:lysine	58	66	75	60	66	73
Threonine:lysine	61	65	71	62	66	73
Tryptophan:lysine	18	18	18	18	18	18
Valine:lysine	75	87	98	78	87	96
Total lysine, %	0.91	0.94	0.98	0.90	0.94	0.98
ME, kcal/lb	1,506	1,484	1,455	1,510	1,514	1,517
SID lysine: ME, g/Mkcal	2.41	2.45	2.49	2.40	2.40	2.39
CP, %	15.5	18.3	21.1	15.2	17.6	20.0
Ca, %	0.47	0.47	0.55	0.60	0.61	0.60
P, %	0.42	0.42	0.51	0.51	0.49	0.49
Available P, %	0.26	0.26	0.36	0.35	0.35	0.38

[1] Phase 2 diets were fed in meal form from d 27 to 61 (Exp. 1) and d 26 to 54 (Exp. 2).
[2] Diets included both 5.4 and 9.6%-oil dried distillers grains with solubles (DDGS) sources fed at 20 and 40% of the diet.
[3] Diets included both 9.4 and 12.1%-oil DDGS sources fed at 20 and 40% of the diet.
[4] Provided per pound of premix in Exp.1: 2,000,000 IU vitamin A; 250,000 IU vitamin D3; 8,000 IU vitamin E; 800 mg vitamin K; 1,500 mg riboflavin; 5,000 mg pantothenic acid; 9,000 mg niacin; 7 mg vitamin B12; 12 g Mn from manganese oxide; 50 g Fe from iron sulfate; 50 g Zn from zinc sulfate; 5 g Cu from copper sulfate; 90 mg I from calcium iodate; and 90 mg Se from sodium selenite. Normal K-State vitamin and trace mineral premixes were used in Exp. 2.

Table 5. Phase 3 diet compositions (as-fed basis)[1]

	Exp. 1			Exp. 2		
	Control	DDGS source,[2] % inclusion		Control	DDGS source,[3] % inclusion	
Item	0	20	40	0	20	40
Ingredient, %						
Corn	76.6	59.4	42.0	83.1	66.9	50.6
Soybean meal (46.5% CP)	21.4	18.6	15.7	14.4	10.8	7.2
5.4 or 9.6% oil DDGS	-	20.0	40.0	-	-	-
9.4 or 12.1% oil DDGS	-	-	-	-	20.0	40.0
Monocalcium P (21% P)	0.15	-	-	0.80	0.30	-
Limestone	0.85	1.10	1.38	0.88	1.15	1.30
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamine and trace mineral premix[4]	0.10	0.10	0.10	0.20	0.20	0.20
L-lysine HCl	0.38	0.43	0.48	0.18	0.22	0.27
DL-methionine	0.05	-	-	-	-	-
L-threonine	0.08	0.04	-	0.03	-	-
Phytase	0.02	0.01	0.01	0.13	0.13	0.13
Ractopamine HCl, 10 ppm[5]	0.03	0.03	0.03	-	-	-
Total	100	100	100	100	100	100
Standardized ileal digestible (SID) amino acids, %						
Lysine	0.90	0.90	0.90	0.70	0.70	0.70
Isoleucine:lysine	65	72	79	68	75	81
Leucine:lysine	148	190	231	175	213	250
Methionine:lysine	32	31	36	31	38	44
Met & Cys:lysine	59	62	70	63	71	79
Threonine:lysine	65	67	69	65	69	76
Tryptophan:lysine	18	18	18	18	18	18
Valine:lysine	73	83	94	81	92	102
Total lysine, %	1.02	1.05	1.08	0.79	0.83	0.87
ME, kcal/lb	1,509	1,482	1,453	1,513	1,517	1,520
SID lysine: ME, g/Mkcal	2.70	2.75	2.80	2.10	2.09	2.09
CP, %	16.9	19.7	22.4	13.9	16.3	18.8
Ca, %	0.42	0.48	0.57	0.55	0.56	0.55
P, %	0.38	0.44	0.53	0.50	0.47	0.48
Available P, %	0.21	0.26	0.37	0.35	0.34	0.37

[1] Phase 3 diets were fed in meal form from d 61 to 82 (Exp. 1) and d 54 to 75 (Exp. 2).
[2] Diets included both 5.4 and 9.6%-oil dried distillers grains with solubles (DDGS) sources fed at 20 and 40% of the diet.
[3] Diets included both 9.4 and 12.1%-oil DDGS sources fed at 20 and 40% of the diet.
[4] Provided per pound of premix in Exp.1: 2,000,000 IU vitamin A; 250,000 IU vitamin D3; 8,000 IU vitamin E; 800 mg vitamin K; 1,500 mg riboflavin; 5,000 mg pantothenic acid; 9,000 mg niacin; 7 mg vitamin B12; 12 g Mn from manganese oxide; 50 g Fe from iron sulfate; 50 g Zn from zinc sulfate; 5 g Cu from copper sulfate; 90 mg I from calcium iodate; and 90 mg Se from sodium selenite. Normal K-State vitamin and trace mineral premixes were used in Exp. 2.
[5] Paylean; Elanco Animal Health (Greenfield, IN).

Table 6. Diet composition, Exp. 3, as-fed basis[1]

Ingredient, %	Corn-basal diet
Corn	96.90
Limestone	2.30
Salt	0.40
Vitamin premix	0.25
Trace mineral premix	0.15

[1]A total of 12 pigs (PIC 327 × 1050; initially 11,6 lb BW) were used in a 6-wk study to provide 12 observations per treatment. The basal diet was blended 50/50 with the 4 dried distillers grains with solubles sources to provide the other experimental diets.

Table 7. Effects of low- vs. high-oil dried distillers grains with solubles (DDGS) on growth performance of finishing pigs (Exp.1)[1]

	Control	5.4% oil DDGS		9.6% oil DDGS			5.4% oil DDGS		9.6% oil DDGS		5.4 vs.	DDGS level		Source × level	
	0	20	40	20	40	SEM	Linear	Quad.	Linear	Quad.	9.6% Oil	Linear	Quad.	Linear	Quad.
d 0 to 82															
ADG, lb	2.28	2.29	2.24	2.27	2.27	0.02	0.29	0.33	0.73	0.84	0.96	0.42	0.62	0.47	0.36
ADFI, lb	5.73	5.93	6.07	5.69	5.82	0.07	0.002	0.69	0.40	0.36	0.002	0.02	0.73	0.02	0.30
Feed/gain	2.52	2.59	2.71	2.51	2.57	0.03	0.001	0.62	0.21	0.37	0.0003	0.001	0.36	0.001	0.76
BW, lb															
d 0	101.7	101.6	101.6	101.7	101.7	1.38	0.96	0.99	0.98	0.98	0.97	0.97	0.99	0.99	0.98
Final BW, lb	285.5	286.0	283.1	285.0	286.0	2.40	0.50	0.57	0.87	0.80	0.69	0.77	0.83	0.40	0.52

[1] A total of 1,198 pigs (PIC 337 × 1050, initially 20.9 lb) were used in this 82-d study with 26 to 27 pigs per pen and 9 pens per treatment.

Table 8. Effects of low- vs. high-oil dried distillers grains with solubles (DDGS) on carcass characteristics of finishing pigs (Exp.1)[1]

	CS[2]	5.4% oil DDGS		9.6% oil DDGS			5.4% oil DDGS		9.6% oil DDGS		5.4 vs.	DDGS level		Source × level	
	0	20	40	20	40	SEM	Linear	Quad.	Linear	Quad.	9.6% Oil	Linear	Quad.	Linear	Quad.
HCW, lb	210.2	207.1	204.7	205.4	206.7	1.78	0.03	0.88	0.16	0.18	0.93	0.04	0.32	0.43	0.35
Carcass yield, %[3]	76.23	75.99	74.92	75.43	75.21	0.46	0.05	0.47	0.13	0.62	0.78	0.05	0.89	0.66	0.34
Backfat depth, in.[4]	0.61	0.62	0.61	0.60	0.62	0.01	0.89	0.81	0.86	0.50	0.82	0.99	0.77	0.75	0.48
Loin depth, in.[4]	2.82	2.76	2.79	2.76	2.80	0.03	0.36	0.18	0.59	0.09	0.84	0.40	0.05	0.67	0.75
Lean, %[4]	57.92	57.74	57.91	57.92	57.84	0.22	0.97	0.49	0.80	0.89	0.78	0.87	0.72	0.83	0.53
Fat-free lean index[4]	51.26	51.21	51.29	51.38	51.22	0.17	0.88	0.74	0.89	0.49	0.75	0.99	0.81	0.77	0.43
Jowl iodine value (IV)[5]	67.36	70.92	76.68	72.02	78.73	0.96	<0.001	0.32	<0.001	0.27	0.06	<0.001	0.17	0.06	0.96
Belly IV[5]	62.10	67.84	73.52	70.88	76.18	0.96	<0.001	0.98	<0.001	0.11	0.002	<0.001	0.29	0.03	0.24
Backfat IV[5]	66.48	70.30	75.79	71.74	78.83	0.74	<0.001	0.34	<0.001	0.25	0.001	<0.001	0.94	0.001	0.94

[1] A total of 1,198 pigs (PIC 337 × 1050, initially 20.9 lb) were used in this 82-d study. There were 26 or 27 pigs per pen and 9 pens per treatment.
[2] Refers to the control, corn-soybean meal diet.
[3] Percentage yield was calculated by dividing HCW by live weight obtained at the packing plant.
[4] Adjusted by using HCW as a covariate.
[5] Calculated as IV = [C16:1] × 0.9502 + [C18:1] × 0.8598 + [C18:2] × 1.7315 + [C18:3] × 2.6152 + [C20:1] × 0.7852 + [C20:4] × 3.2008; brackets indicate concentration.

Table 9. Effects of low- vs. high-oil dried distillers grains with solubles (DDGS) on growth performance of finishing pigs (Exp.2)[1]

	DDGS source and % of diet														
	Control	9.4% oil DDGS		12.1% oil DDGS			9.4% oil DDGS		12.1% oil DDGS		9.4 vs. 12.1%	DDGS level		Source × level	
Item	0	20	40	20	40	SEM	Linear	Quad.	Linear	Quad.	Oil	Linear	Quad.	Linear	Quad.
d 0 to 90															
ADG, lb	2.22	2.20	2.21	2.31	2.16	0.04	0.23	0.01	0.79	0.70	0.34	0.40	0.11	0.34	0.02
ADFI, lb	6.27	6.07	6.01	6.18	5.90	0.12	0.04	0.51	0.14	0.63	0.96	0.04	0.90	0.54	0.38
Feed/gain	2.82	2.76	2.72	2.67	2.73	0.04	0.12	0.03	0.08	0.82	0.31	0.06	0.11	0.85	0.13
BW, lb															
d 0	102.3	102.0	101.9	102.0	102.2	2.9	0.99	0.95	0.93	0.97	0.96	0.95	0.95	0.95	0.99
Final BW, lb	268.8	267.8	268.6	275.5	264.2	3.7	0.38	0.06	0.96	0.85	0.66	0.59	0.25	0.41	0.10

[1]A total of 270 pigs (PIC 327 × 1050, initially 20.9 lb BW) were used in this 75-d study with 8 pigs per pen and 7 pens per treatment.

Table 10. Effects of low- vs. high-oil dried distillers grains with solubles (DDGS) on carcass characteristics of finishing pigs (Exp. 2)[1]

	DDGS source and % of diet														
	CS[2]	9.4% oil DDGS		12.1% oil DDGS			9.4% oil DDGS		12.1% oil DDGS		9.4% vs. 12.1% Oil	DDGS level		Source × level	
	0	20	40	20	40	SEM	Linear	Quad.	Linear	Quad.		Linear	Quad.	Linear	Quad.
HCW, lb	195.2	193.0	191.1	196.5	186.5	2.44	0.02	0.06	0.24	0.97	0.81	0.04	0.23	0.18	0.14
Carcass yield, %[3]	72.59	71.94	71.02	72.30	71.16	0.18	0.001	0.54	0.001	0.06	0.17	0.001	0.10	0.59	0.31
Backfat depth, in.[4]	18.6	19.1	18.1	18.3	18.25	0.49	0.62	0.79	0.46	0.23	0.52	0.47	0.53	0.81	0.25
Loin depth, in.[4]	61.3	60.2	60.4	60.0	59.90	0.87	0.26	0.60	0.46	0.54	0.73	0.28	0.45	0.70	0.93
Lean, %	53.72	53.55	53.51	53.29	53.65	0.30	0.63	0.86	0.88	0.29	0.84	0.72	0.41	0.74	0.49
Jowl fat iodine value[5]	66.80	73.08	77.47	73.38	80.01	0.42	0.001	0.07	0.001	0.96	0.002	0.001	0.25	0.0001	0.15

[1] A total of 270 pigs (PIC 327 × 1050, initially 21.1 lb BW) were used in this 75-d study. There were 8 pigs per pen and 7 pens per treatment.
[2] Refers to the control, corn-soybean meal treatment.
[3] Percentage yield was calculated by dividing HCW by live weight obtained at the farm before transport to the packing plant.
[4] Adjusted by using HCW as a covariate.
[5] Analyzed by near-infrared spectroscopy (Bruker MPA, Breman, Germany) at the plant for IV using the equation of Cocciardi et al. (2009).

Table 11. Energy values of corn and dried distillers grains with solubles (DDGS) sources and 7.6%-oil DDGS (Graham, 2013; as fed basis)

		Exp. 1		Exp. 2		Graham (2013)
Item, kcal/lb	Corn	5.4% oil DDGS	9.6% oil DDGS	9.4% oil DDGS	12.1% oil DDGS	7.6% oil DDGS
GE	1,756	1,972	2,108	2,142	2,224	2,080
DE	1,594	1,550	1,674	1,741	1,694	1,522
ME[1]	1,567	1,459	1,582	1,650	1,606	1,430

[1] Eqation 1-6 from NRC (2012) with values converted from kcal/kg to kcal/lb.

Table 12. Comparison of corn and DDGS source digestibilities[1]

		Exp. 1		Exp. 2	
Item, %	Corn	5.4% oil DDGS	9.6% oil DDGS	9.4% oil DDGS	12.1% oil DDGS
DM	93.3^{a}	70.0^{b}	73.6^{b}	73.3^{b}	71.9^{b}
GE	91.1^{a}	78.6^{bc}	79.4^{bc}	81.3^{b}	76.1^{c}
CP	85.5^{a}	78.6^{b}	86.3^{a}	88.4^{a}	76.0^{b}
Ether extract	21.8^{c}	67.0^{ab}	61.8^{b}	71.2^{ab}	75.6^{a}
ADF	59.4^{c}	62.8^{c}	79.3^{ab}	74.9^{b}	82.2^{a}
NDF	59.9^{b}	54.8^{bc}	72.0^{a}	61.5^{b}	51.4^{c}
CF	47.4^{d}	45.3^{d}	53.5^{c}	72.1^{a}	63.4^{b}

[a,b,c] Within a row, means without a common superscript differ ($P < 0.05$).

[1] A total of 12 pigs were used to achieve 12 replications per treatment.

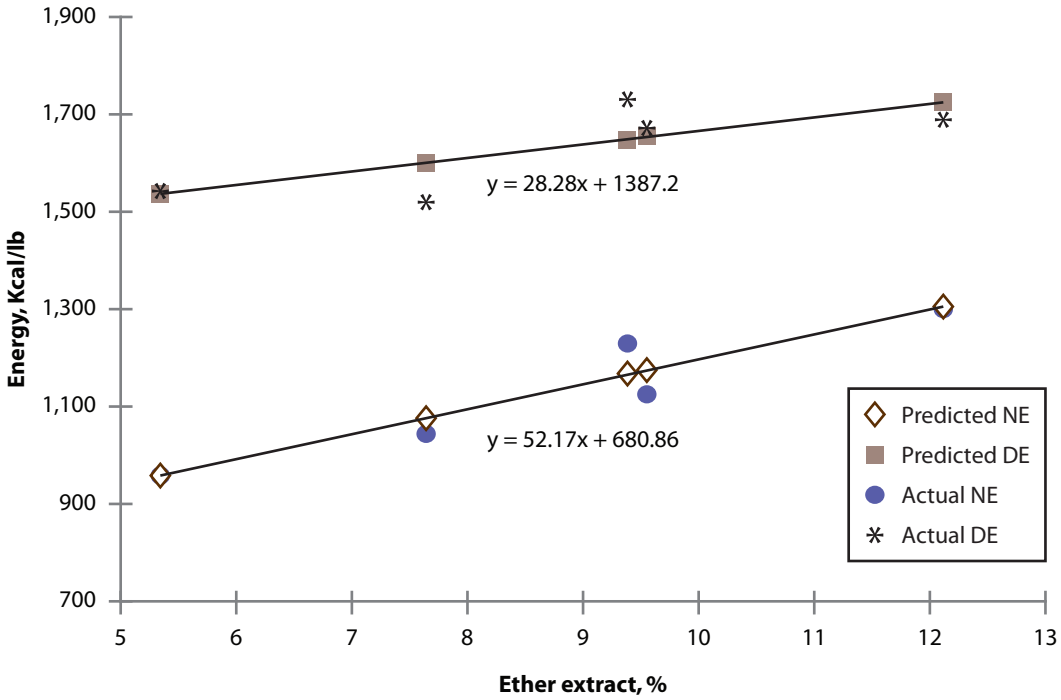

Figure 1. Predicted and actual DE and NE values of dried distillers grains with solubles sources varying in oil content (as-fed basis).

Regression Analysis to Predict Growth Performance from Dietary Net Energy in Growing-Finishing Pigs

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Summary

Energy concentration in livestock feed is often altered to optimize pig growth performance and feed cost; therefore, an accurate prediction of growth performance as affected by feeding different energy levels is crucial. Data from 41 trials from 17 journal articles, 10 technical memos, and a thesis were used to develop a regression equation to predict ADG or gain to feed (G:F) as influenced by BW and NE content. Linear and quadratic terms of NE, average BW, CP, standardized ileal digestible [SID] lysine, crude fiber, NDF, ADF, fat, and ash, including their interaction terms, were the variables in the regression analysis. Our regression analysis showed that improvements in growth rate and feed efficiency could be obtained by increasing dietary NE across a wide variety of trials with different dietary ingredients and under different environmental conditions, but the magnitude of improvement in growth performances by dietary NE can be minimized if the amino acids are limiting. Regression equations from this paper can be used to predict the influence of dietary NE on ADG and G:F; however, these equations still need validation from growth studies not included in their development.

Key words: growth performance, finishing pig, net energy, regression

Introduction

Dietary energy components represent the greatest portion of the feed cost and over half the total cost in swine production. Increased energy levels in diets have been shown to improve growth performance but simultaneously increase feed costs. Given the increased price of traditional dietary energy sources, the swine industry has shifted to using more high-fiber, low-energy diets to reduce feed costs, but feeding lower energy diets decreases growth performance. Therefore, the prediction of growth performance is essential to quantify the effect of dietary energy.

Digestible (DE) and metabolizable energy (ME) are the most commonly used energy systems in swine industry, but these energy values do not account for the varying metabolic utilization and production of heat increments between nutrients. The energy value of feed with a high content of fiber or protein is overestimated, whereas the energy of fat or starch is underestimated (Noblet, 2007[2]). For this reason, NE should be the most accurate system to evaluate the effect of dietary energy on growth performance, but NE is difficult to measure, and few estimates of NE are available for many by-product ingredients. Therefore, the purpose of this study was to obtain a regression equation

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

[2] Noblet, J. 2007. Recent developments in net energy research for swine. Advances in Pork Production 18:149.

to predict growth rate and feed efficiency of growing-finishing pigs based on dietary NE content using meta-analysis.

Procedures

A literature search was conducted via Kansas State University Libraries using the internet and the CABI search engine including data from theses, technical memos, and university publications using the key words "energy and growth and pig" or "fiber and growth and pig." The search was restricted to dates from 1991 through November 2012. All publications were initially screened by determining that the research was conducted on growing-finishing pigs (>20 kg BW) and provided growth performance responses. Screening left 36 publications providing 50 trials.

Selection for inclusion and exclusion criteria

For inclusion, treatment diets in the trials had to vary in dietary DE, ME, or NE. Other criteria included: pigs used in the trial had to have ad libitum access to feed and water, treatments had to be replicated (>4 replications /treatment), and the experimental design had to include randomization (completely randomized design, CRD, or randomized complete block design, RCBD). The number of pigs per pen was also investigated, and the trial that used only 1 pig per pen was excluded. The ingredients and inclusion rates used in each dietary treatment had to be clearly stated such that diets could be re-created. All diets were then reformulated using the NRC ingredient library (chapter 17, NRC 2012[3]) as a reference for nutrients. The trial had to have ingredients that were listed in NRC (2012) ingredient library. Trials using ractopamine HCl were not considered. After excluding trials using these criteria, 41 trials were extracted from 17 journal articles, 10 technical memos, and a thesis.

Data from each trial were then recorded in a template; the template included the mean ADG and G:F for each treatment in each feeding period. If the report did not provide responses in each period, the overall mean was recorded. Average BW of each treatment was also extracted by averaging the initial and final BW of each period. Days on feed of each period were included in the template and used to calculate final BW of pigs fed each treatment from ADG and initial BW when the report omitted the periodic BW range. Other information included during the data extraction process was number of pigs per pen, replications, gender, genetic background, type of study (CRD or RCBD), dietary treatment, basic diet information (corn, soybean meal, wheat, barley, oats, wheat middlings, wheat bran), and type of report (journal article, technical memo, thesis).

Diet composition calculations

Dietary treatment of each trial was reformulated using a spreadsheet-based software program (Kansas State University Diet Formulation Program V.7.1) to obtain dietary nutrient content. Dietary nutrient content was derived from accumulating the nutrient of each ingredient according to its proportion in the diet. The NRC ingredient library (chapter 17, NRC, 2012) was used as a reference for nutrient ingredients in diet reformulation. The dietary NE (kcal/kg), CP (%), SID lysine (%), crude fiber (CF, %), NDF (%), ADF (%), fat (%), and ash (%) on an as-fed basis were obtained and recorded in the template for each dietary treatment.

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

Preparation of database

All of the selected trials reported overall growth performance, and some also reported growth performance by period. For trials that reported growth performance by period, growth performance and nutrient profile by period were recorded in the database as different experiments. In trials that reported overall performance but listed the feed formulation by period, the average dietary NE and nutrient content across periods was used to correspond with the overall growth performance.

To avoid the effects of factors other than energy, trials that had a factorial design were divided into experiments by factors that were crossed with the energy factor. Factors divided into separate experiments were CP, fat source, lysine:calorie ratio, with or without wheat middlings, and yellow dent vs. NutriDense corn. For the trials (n = 3) with a lysine:calorie ratio treatment factor, only data from the optimal lysine:calorie ratio as indicated in the literature was used in the analysis.

Overall, data from 100 experiments in 41 trials were used as a database for the statistical analysis (Table 1). The database included diets with a range of 1,980 to 2,815 kcal/kg NE, 8.9 to 22.9 % CP, 0.51 to 1.15% SID lysine, 1.9 to 12.5% CF, 6.7 to 29.5% NDF, 2.5 to 14.9% ADF, 3.1 to 6.7% ash, and 1.8 to 10% fat. Pigs used in the database could be described as modern genetic lines with BW from 21 to 138 kg BW, with the trial average BW ranging from 33.2 to 127.8 kg. Most of the trials (20) applied treatments to barrows and gilts in a single-sex pen; however, due to the lack of interaction with gender, these trials reported the main effect averaged across gender. Some trials were conducted using mixed-sex pens (5), and some used only barrows (4) or gilts (12); thus, data used in the analysis were derived from both single-sex and mixed-sex pens. No trials that used intact males were in the database.

The MIXED procedure of SAS (SAS institute, Inc., Cary, NC) was used to develop a regression equation to predict ADG or G:F depending on BW and NE content. The dietary NE applied within each experiment (285 observations) was the experimental unit for the modeling of the equation, and experiment within trial was included as a random effect. Linear and quadratic terms of NE, average BW, CP, CF, NDF, ADF, fat, and ash, including their interaction term, were the variables in the regression analysis. 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 Akaike Information Criteria (AIC), where models that minimized AIC were preferred candidate models. Minimizing AIC has been shown to result in regression models that have better precision (Littell et al., 2002[4]). The adequacies of candidate models were also examined using residual analysis. Briefly, this consisted of evaluating a histogram of residuals for evidence of normality and plotting studentized residuals against the corresponding fitted values.

Results and Discussion

Prediction equations for ADG

The equation predicting ADG using dietary NE as a single predictor (AIC = 3018.7) was improved when including the average BW in the model (AIC = 3,017.6). Because

[4] Littell, R.C., W.W. Stroup, and R.J. Freund. 2002. SAS for Linear Models, 4th edition. SAS Institute Inc., Cary, NC.

of the improvement in the precision of the model and because growing-finishing swine feed is generally formulated according to BW range, average BW was included in the model. The regression analysis showed that the model with dietary NE, average BW, CP, and the interaction between dietary NE and CP (NE × CP) demonstrated the smallest AIC (AIC = 3,002.0) compared with other significant models. Because diets were formulated to achieve a certain dietary lysine level by adjusting the amount of intact protein and crystalline lysine, the lysine level and CP in diet were highly correlated; therefore, CP in the equation was replaced with SID lysine to investigate whether the model could be improved. Having SID lysine with dietary NE and average BW improved the AIC value (3004.5). Having the interaction between NE and SID lysine (NE × SID lysine) in the model with dietary NE, average BW, and SID lysine also resulted in a better AIC (3002.5), but adding SID lysine as another variable in the model with NE, average BW, CP, and NE × CP presented the best AIC (3,000.8; Table 2). The interaction between NE and CP or lysine indicated that the magnitude of improvement in ADG by dietary NE was maximized when CP or lysine level increased (Figure 1). Generally, feed intake is adjusted according to energy density in the diet to achieve a suitable amount of energy intake on a daily basis; thus, feeding a high-energy diet results in a reduction in feed intake, which in turn can compromise the amount of amino acids consumed per day. On the contrary, when formulating a diet at low energy density, feed intake increases and amino acids can be consumed to meet the requirement. Therefore, when feeding a high-energy diets, the increase in amino acid content in the diet would improve the growth rate to a greater extent than feeding at low energy density, where proper amino acids intake can be achieved with higher feed consumption. The interaction between dietary NE and CP or lysine seems to suggest that amino acid levels were limiting growth rate across many of the trials included in the analysis; therefore, the equations adapted from Main et al. (2008[5]) that determine lysine:calorie requirements for barrows and gilts were used to calculate the lysine requirement at different dietary energy levels [Gilts SID Lys:NE ratio : -0.000000153*((Initial BW + Final BW)/2)^3 + 0.000104928*((Initial BW + Final BW)/2)^2 - 0.030414451*((Initial BW + Final BW)/2) + 6.043540689; Barrow SID Lys:NE ratio : 0.0000454*((Initial BW + Final BW)/2)^2 - 0.0249885*((Initial BW + Final BW)/2) + 5.8980083]. The trials that fed SID lysine below the requirement were then removed from the database, resulting in 104 observations from 17 trials for re-analysis. Neither SID lysine nor CP was a significant predictor in the re-analysis. Instead, the model with dietary NE, average BW, and the quadratic term of average BW demonstrated the smallest AIC (1071.2) compared with other significant models (Table 3). The model indicated that increasing dietary NE resulted in a linear improvement in ADG across all BW. Also, ADG increases with heavier average BW, but decreases when average BW is above 87 kg (Figure 2).

Prediction equations for G:F

The AIC values of all significant equations to predict G:F were negative, and the same principal can be applied to compare the precision of equations (Burnham and Anderson, 1998[6]). Thus, the equation that minimized the AIC value was preferred, which in

[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.

[6] Burnham, K.P., and D.R. Anderson. 1998. Model selection and inference: a practical information–theoric approach. Springer–Verlag, New York.

this case was the equation with the most negative AIC value. The equation to predict G:F using dietary NE as a single predictor presented the AIC value of -1,320.3. When including average BW, CP, and the interaction between dietary NE and CP in the model, the AIC value was largely improved to -1,449.7, which is the smallest of the AIC value compared with other significant models.

The CP term in the equation was then replaced with SID lysine. Having SID lysine with dietary NE and average BW improved the AIC value (-1,466.6), but having NE × SID lysine in the model with dietary NE, average BW, and SID lysine presented the best AIC (-1,470.1). Therefore, the equation to predict G:F from dietary NE obtained from this regression method was a function of dietary NE, average BW, SID lysine, and NE × SID lysine (Table 2). The equation showed that feed efficiency improved with the increase in dietary NE. Similar to the ADG model, however, the magnitude of improvement in feed efficiency by dietary NE was maximized when lysine level increased which suggested that lysine levels were limiting growth across many of the trials in database.

When the trials that fed SID lysine below the requirement were removed from the database, the equation that presented the best AIC (-600.8) was a function of dietary NE, average BW, and fat, which showed that G:F improved with increasing dietary NE, fat, and lower BW (Table 3). The improvement of G:F with fat in the model may suggest that the NE value of fat is underestimated.

Application of prediction equations

Discrepancies in health status, genetics, and environment among farms could make a difference between the predicted value and the actual growth rate or feed efficiency. The predicting equations can be adjusted accordingly to accommodate differences. One method is to adjust the intercept of the equation. With this method, a set of data on NE, CP, and SID lysine of diet that was fed to a certain BW on the farm can be used to calculate the ADG and G:F from the predicting equation. The difference between predicted and actual value of growth performance is then used to adjust the intercept of the equation; for instance, the 90- to 110-kg pigs in farm A demonstrated a growth rate and feed efficiency of 898.9 g/d and 0.317 when feeding a corn-soybean meal diet that contained 2,511 kcal/kg NE, 15.7% CP, and 0.67 % SID lysine. Based on these feed characteristics and BW range, the predicting equation would calculate the growth rate of 885.7 g/d (ADG = (0.1809×2511) + (1.6119×100) + (34.2735×15.7) + (0.01476×2511×15.7) + (129.63×0.67) + 1047.92) and G:F of 0.303 (G:F = (0.000004365×2511) - (0.00162×100) - (0.08023×0.67) + (0.000094*2511*0.67)+0.3496). As a result, the actual ADG was 13.2 g/d greater than the predicted value; thus, the intercept of the ADG prediction equation can be adjusted to 1,061.12 (1,047.92+13.2). Likewise, the 0.014 G:F difference between predicted and actual value was used to adjust the intercept of G:F prediction equation to 0.3636 (0.3496 + 0.014).

The NRC (2012) ingredient library was the source of ingredient nutrients and the nutrients of the diets that were used in the regression analysis to obtain these equations. Therefore, it is important that the nutrient values of every ingredient be obtained from NRC (2012) when using these predicting equations. These equations also should be used to predict growth performance within the range of nutrients in the database

(1,980 to 2,815 kcal/kg NE, 8.9 to 22.9 % CP, 0.51 to 1.15% SID lysine, 1.8 to 10% fat).

In conclusion, dietary NE is an important predictor of the growth performance of growing-finishing pigs. Our regression analysis showed that improvements in growth rate and feed efficiency could be obtained by increasing dietary NE across a wide variety of trials with different dietary ingredients and under different environmental conditions. However, the magnitude of improvement in growth performances by dietary NE can be minimized if the amino acids are limiting. These prediction equations still need to be validated with the growth studies that feed amino acids above the requirement.

Table 1. Summary of papers used in the regression analysis to predict growth performance from dietary net energy in growing-finishing pigs

First author, year	Source type: J = journal T = thesis M = technical memo	Trials	Gender[1]	Range of dietary NE, (kcal/kg)	Range of CP, (%)	Initial BW, (kg)	Final BW, (kg)	Diet
Friesen et al., 1991[2]	J	1	both	2,560–2,784	16.8–17.2	57.9	89.9	Sorghum–soybean meal (SBM)
Myer and Comb, 1991	J	1	both	2,204–2,619	14.3–14.9	27.0	102.0	Corn–SBM–oat
Lopez-Bote et al., 1997	J	1	both	2,257–2,409	17.5–17.7	30.4–30.5	89.1–90.1	Barley–SBM–sunflower meal
Smith et al., 1997	M	1	gilt	2,515–2,626	10.7–17.6	47.7	106.9–115.5	Corn–SBM
Knowles et al., 1998	J	3	gilt, barrow	2,499–2,733	8.9–15.6	63.0–83.0	101.0–119.2	Corn–SBM–wheat middlings–rice bran
Smith et al., 1999[3]	J	2	gilt	2,402–2,726	16.4–21.9	29.2–44.5	104.3–107	Corn–SBM
De la Llata et al., 2001[4]	J	1	both	2,396–2,786	13.9–22.9	36.0	118.0–121.6	Corn–SBM
Engel et al., 2001	J	1	gilt	2,523–2,775	13.7–14.4	59.2–61.0	109.8–111.7	Corn–SBM
Baudon et al., 2003	M	1	both	2,469–2,809	14.0–17.3	57.7	127.3	Corn–SBM
Kerr et al., 2003[5]	J	1	gilt	2,393–2,534	11.3–21.4	25.3	109.7	Corn–SBM–wheat middlings
Shriver et al., 2003[5]	J	1	both	2,529–2,688	12.2–15.7	28.4–28.8	114–117.5	Corn–SBM–soybean hull
Young et al., 2003	M	1	both	2,500–2,746	16.3–17.2	71.8	105.5	Corn–SBM
Hastad et al., 2005[5]	J	1	gilt	2,434–2,815	14.9–20.9	50.1	113.9–117.0	Corn–SBM
Hastad et al., 2005	M	2	gilt	2,442–2,735	16.9–20.7	30.6–35.3	117.5–120.0	Corn–SBM
Beaulieu et al., 2007	J	2	both	2,187–2,572	14.7–20.4	31.06–37.4	115.0–119.0	Wheat–barley–SBM–canola meal
Benz et al., 2007	M	1	both	2,500–2,785	15.5–17.0	54.5	133.9	Corn–sorghum–SBM
De la Llata et al., 2007[3]	J	2	gilt, barrow	2,405–2,749	15.1–22.6	24.0–34.0	120.0	Corn–SBM
Duttlinger et al., 2008	M	1	both	2,534–2,788	14.2–14.7	77.9	102.6	Corn–SBM
Apple et al., 2009	J	1	mixed	2,484–2,797	11.5–17.0	28.1	113.6	Corn–SBM
Ball et al., 2010	J	1	both	2,215–2,304	20.9–21.3	39.7–39.8	90.9–93.4	Wheat–Barley–SBM

continued

Table 1. Summary of papers used in the regression analysis to predict growth performance from dietary net energy in growing-finishing pigs

First author, year	Source type: J = journal T = thesis M = technical memo	Trials	Gender[1]	Range of dietary NE, (kcal/kg)	Range of CP, (%)	Initial BW, (kg)	Final BW, (kg)	Diet
Asmus et al., 2011[6]	M	1	both	2,343–2,546	13.4–20.9	40.9–41.0	120.5–122.6	Corn–SBM–DDGS–wheat middlings
Barns et al., 2011	T	1	both	2,408–2,491	16.8–17.3	46.6	129.8–134.9	Corn–SBM–DDGS–wheat middlings
Barns et al., 2011	T	1	both	2,423–2,710	16.0–17.0	42.3	128.2–136.9	Corn–SBM–DDGS
Wheat middlings								
Barns et al., 2011[7]	T	1	both	2,409–2,619	15.1–18.6	48.1	121.0–124.8	Corn–SBM–DDGS
Wheat middlings								
Benz et al., 2011	J	1	both	2,495–2,732	15.5–16.1	44.1	123.0	Corn–SBM
Chen et al., 2011	J	2	barrow	2,329–2,701	12.2–16.5	62.0–69.0	95.0–98.0	Corn–SBM–wheat bran
Chu et al., 2012	J	3	mixed	2,260–2,650	13.6–20.9	20.8–78.6	55.9–105.8	Corn–SBM–wheat bran
Graham et al., 2012[8]	M	1	mixed	2,359–2,537	13.9–20.0	53.0	121.9	Corn–SBM–DDGS–Wheat middlings
Jungst et al., 2012	M	3	both	2,368–2,709	15.4–20.3	28.6–30.4	135.2–138.2	Corn–SBM–DDGS–Wheat middlings
Jungst et al., 2012	M	1	gilt	1,980–2,480	12.3–19.5	33.9–34.3	118.9–121.2	Corn–SBM–soyhulls–Wheat middlings

[1] "Both" in gender category refers to applying treatments to barrows and gilts in a single–sex pen; "mixed" refers to trials that applied treatments in mixed-sex pen.
[2] Only data for diets supplemented with 0.2% lysine were used in the analysis.
[3] Only data for diets with lysine:calorie ratio at the requirement as indicated in the literature were used in the analysis.
[4] Two experiments were reported in the literature, but only data from experiment 1 were used in the analysis.
[5] Two experiments were reported in the literature, but only data from experiment 2 were used in the analysis.
[6] Data from treatments that fed low-NDF and high-NDF diets throughout the experiment without withdrawal periods were used in the analysis.
[7] Only data from feeding diets without xylanase were used.
[8] Data of treatments that fed corn–SBM without ractopamine and diets with 30% DDGS and 19% midds without ractopamine throughout the experiment without withdrawal periods were used in the analysis.

Table 2. Regression equations to predict ADG and G:F from dietary NE using ingredient NE values from NRC (2012)[1]

Growth performance	Model	AIC[2]
ADG (g/day)	= –0.1809*NE (kcal/kg) + 1.6119*Average BW (kg) – 34.2735*CP (%) + 0.01476*NE (kcal/kg)*CP (%) + 129.63*SID lysine (%) + 1047.92	3,000.8
G:F	= 0.000004365*NE (kcal/kg) – 0.00162*Average BW (kg) – 0.08023*SID lysine (%) + 0.000094* NE (kcal/kg)*SID lysine (%) + 0.3496	–1,470.1

[1] Data from 41 trials divided into 100 experiments were used as a database for the statistical analysis.
[2]Akaike Information Criteria (AIC) were used to compare the precision of the model where the model with smaller AIC value was preferred. The AIC values of all significant equations to predict G:F were negative; however, the same principal can be applied to compare the precision of equations. Thus, the equation that minimized AIC value was preferred; in this case, it was the equation with the most negative AIC value.

Table 3. Regression equation to predict ADG and G:F from dietary NE using ingredient NE values from NRC (2012)[1]

Growth performance	Model	AIC[2]
ADG (g/day)	= 0.1135*NE (kcal/kg) + 8.8142*Average BW (kg) – 0.05068* Average BW (kg) *Average BW (kg) + 275.99	1,071.2
G:F	= 0.000096*NE (kcal/kg) – 0.0025*Average BW(kg) + 0.003071*Fat(%) + 0.3257	–600.8

[1] Trials that fed standardized ileal digestible (SID) lysine below the requirement were removed from the database, resulting in 104 observations from 17 trials for regression analysis.
[2]Akaike Information Criteria (AIC) were used to compare the precision of the model where the model with smaller AIC value was preferred. The AIC values of all significant equations to predict G:F were negative; however, the same principal can be applied to compare the precision of equations. Thus, the equation that minimized AIC value; in this case, the equation with the most negative AIC value was preferred.

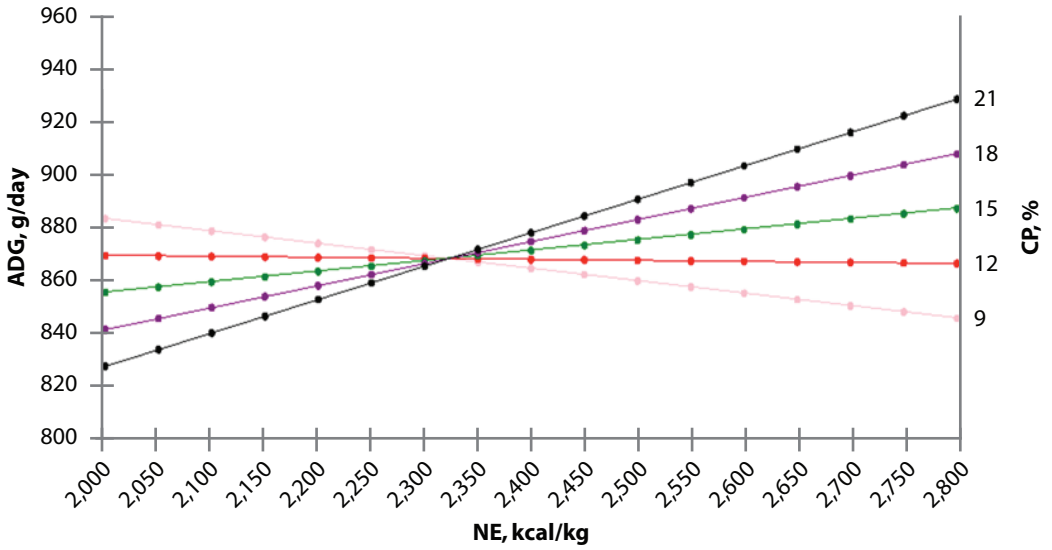

Figure 1. Predicted ADG of 100-kg pig fed increasing dietary NE (kcal/kg) at varying levels of CP (%) from regression analysis using the model [ADG (g/d) = –0.1809*NE (kcal/kg) + 1.6119*average BW (kg) – 34.2735*CP(%) + 0.01476*NE(kcal/kg)*CP(%) + 129.63*SID lysine(%) + 1047.92] (SID = standardized ileal digestible). Increasing dietary NE resulted in a linear improvement in ADG; however, the rate of improvement (slope) was different due to the level of CP. The magnitude of improvement in ADG by dietary NE was maximized when CP level increased.

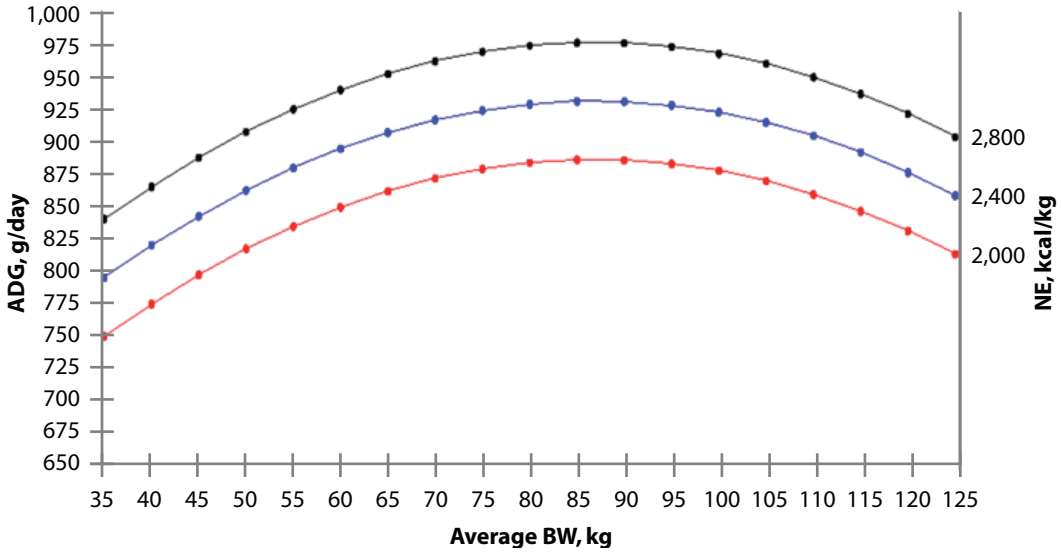

Figure 2. Predicted ADG of pigs fed varying levels of dietary NE at heavier average BW from regression analysis using the model [ADG (g/d) = 0.1135*NE (kcal/kg) + 8.8142*average BW (kg) – 0.05068*average BW (kg)*average BW (kg) + 275.99]. Growth rate increases with heavier average BW, but decreases when average BW is above 87 kg.

Amino Acid Digestibility and Energy Concentration of Fermented Soybean Meal and Camelina Meal for Swine[1]

A.B. Graham, J.M. DeRouchey, R.D. Goodband, M.D. Tokach, S.S. Dritz[2], and R.C. Thaler[3]

Summary

Two experiments were conducted to determine the amino acid and GE digestibility of fermented soybean meal and camelina meal. For Exp. 1, to determine standardized ileal amino acid digestibility, five growing gilts (BW= 60.4 lb) were surgically fitted with T-cannulas at the terminal ileum and randomly allotted to 1 of 3 dietary treatments in a crossover design with 3 periods. The basal diets were corn starch–based with adequate vitamins and minerals to meet the pigs' requirements. The experimental treatments consisted of the basal diet with 30% fermented soybean meal or 39.25% camelina meal as the sole protein sources. A third nitrogen-free diet was also fed to determine basal endogenous amino acid losses.

For Exp. 2, to determine energy concentrations, 6 growing barrows (BW = 64.8 lb) were randomly allotted to 1 of 3 dietary treatments in a crossover design with 3 periods. The corn-based treatment diets had 25% fermented soybean meal or 30% camelina meal. A third corn basal diet was also offered to allow for energy calculations by the difference method. All diets contained 0.25% titanium oxide as an indigestible marker. Digesta samples were collected and analyzed for amino acid concentrations, and fecal samples were collected and analyzed for energy concentrations. After chemical analysis, standardized and apparent ileal digestible (SID and AID, respectively) amino acids were determined, and DE, ME, and NE were calculated for each ingredient. On a DM basis, GE, DE, ME, and NE were 1,973, 1,377, 1,232, and 880 kcal/lb, respectively, for fermented soybean meal and 2,075, 1,150, 1,041, and 715 kcal/lb, respectively, for camelina meal. In fermented soybean meal, the AID for lysine, methionine, threonine, and tryptophan were 63.5 ± 7.5, 84.6 ± 1.0, 74.0 ± 3.5, and 81.8 ± 1.4%, respectively, and SID values were 71.1 ± 6.2, 89.2 ± 2.1, 88.0 ± 3.1, and 93.7 ± 2.0%, respectively. For camelina meal, the AID for lysine, methionine, threonine, and tryptophan were 47.3 ± 7.7, 74.6 ± 3.3, 39.7 ± 6.8, and 67.3 ± 8.3%, respectively, and SID values were 53.9 ± 6.4, 77.7 ± 3.5, 51.6 ± 6.7, and 79.7 ± 6.8%, respectively. The SID availability for amino acids in fermented soybean meal were relatively high and similar to published values for soybean meal, with the exception of lysine. Standardized ileal digestible amino acid availability values for camelina meal were low, indicating that it may have contained the high glucosinolate concentrations generally observed in camelina meal.

Key words: camelina meal, fermented soybean meal, digestibility, finishing pig

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[1] Appreciation is expressed to Heartland Assays, DSM Nutritional Products, and Iowa State University College of Veterinary Medicine for providing funding and/or laboratory analysis for this project.
[2] Diagnostic Medicine and Pathobiology, College of Veterinary Medicine, Kansas State University.
[3] South Dakota State University, Brookings.

Introduction

Soybean meal is traditionally included in most swine diets because it provides a good balance of indispensable amino acids; however, the presence of certain antinutritional factors, such as trypsin inhibitors, pectins, and lectins, has been shown to reduce the growth performance of weanling pigs because their gastrointestinal tracts are not fully developed. Thus, highly digestible animal proteins, such as spray-dried animal plasma, poultry by-product meal, and fish meal, are often included in diets for young pigs. Recent research also has concluded that fermented soybean meal may be used to replace conventional soybean meal in diets fed to young pigs without reducing growth performance because most antinutritional factors are eliminated or reduced during the fermentation process. Feeding fermented soybean meal in lieu of conventional soybean meal may decrease nursery diet costs because it may be possible to reduce levels of specialty animal products and increase levels of fermented soybean meal.

Similar to canola, camelina is traditionally produced for oil production because of its relatively high concentration of omega-3 fatty acids. It is distantly related to rapeseed and is classified in the mustard family. Its major limitation in animal diets is high glucosinolate concentration. Although camelina meal is not widely used in current swine diet formulations, its availability may increase because camelina is a potential source of oil for biofuel production. Camelina meal is left after the cold extraction of oil from the camelina seed; the meal retains a high level of oil (10 to 15%) as well as at least 30% protein. The Food and Drug Administration has granted approval for camelina meal to be fed in swine diets at up to 2% of the diet, but companies must obtain a commercial feed license before manufacturing feed with camelina meal as an ingredient. Only limited research has been done to determine the amino acid digestibility and energy content of camelina meal to determine its feeding value in swine diets; therefore, the objective of these experiments was to determine the amino acid digestibility and energy values of fermented soybean meal and camelina meal for swine.

Procedures

Experimental procedures and animal care were approved by the Kansas State Institutional Animal Care and Use Committee. This experiment was conducted at the Kansas State University Swine Teaching and Research Facility in Manhattan, KS.

Experiment 1

Five growing gilts (initially 60.4 lb; PIC, Hendersonville, TN) were surgically fitted with a T-cannula on their right flanks, approximately 6 in. anterior to their ileocecal valves. The pigs were allowed to recover from surgery then placed in individual stainless-steel metabolism cages in an environmentally controlled building. Each cage was equipped with a feeder and a nipple waterer to allow for ad libitum access to water. During the first 9 d after surgery (recovery period), the pigs were fed a common diet ad libitum. On d 10 after surgery, the pigs were randomly allotted to 1 of 3 dietary treatments in a single Latin square design. The basal diets were corn starch–based with adequate vitamins and minerals to meet the pigs' requirements. Experimental treatments consisted of the basal diet with 30% fermented soybean meal (Fermentation Experts, Denmark) or 39.25% camelina meal (Dakota Lakes Research Farm, Pierre, SD) as the sole protein sources. A third nitrogen-free diet was also fed to determine basal endogenous amino acid losses (Table 1). Titanium oxide was added in all diets

at 0.35% as an indigestible marker. There were 3 periods in the experiment, and each period consisted of 7 d. The first 5 d of each period were used to allow pigs to adapt to the dietary treatment. On d 6 and 7, ileal digesta were collected over a 10-h period (between 7:00 a.m. and 5:00 p.m. each day). Pig BW was determined at the start of each period before new diets were fed to allow for determination of the daily feed allocation, which was calculated to be 3 times the estimated daily maintenance requirements for energy. The daily feed allocation was equally divided between two equal amounts and given twice daily at 0600 and 1800 h.

On collection days, the cannula of each pig was opened to allow the digesta to flow out of the ileum and into a latex balloon. Balloons were checked and removed every 30 min or as they became full. Contents of the balloons were then transferred into 500-mL plastic containers and stored in a freezer (-4°F) until further chemical analyses were conducted. After the collection phase of the experiment, digesta samples from each period from each animal were thawed and homogenized. A subsample from each homogenized ileal digesta collection was then transferred to a new 500-mL plastic container, freeze-dried, and ground for amino acid analysis.

Amino acid analysis for the diets, fermented soybean meal, camelina meal, and ileal digesta samples were conducted at the University of Missouri-Columbia Agricultural Experiment Station Chemical Laboratories. The test diets, fermented soybean meal, and camelina meal were analyzed for DM, CP, crude fat, crude fiber, ash, Ca, P, ADF, and NDF in a commercial laboratory (Ward Laboratories, Inc., Kearney, NE).

Titanium oxide was an indigestible marker used to calculate amino acid digestibility values. The apparent ileal digestibility for amino acids in the experimental protein sources were calculated using the following equation:

$$AID = \{100 - [(AAd/AAf) \times (Tif/Tid)]\} \times 100$$

where AID is the apparent ileal digestibility of an amino acid (%), AAd is the amino acid concentration in the ileal digesta DM, AAf is the amino acid concentration in the feed DM, Tif is the titanium concentration in the feed DM, and Tid is the titanium concentration in the ileal digesta DM.

The basal endogenous amino acid loss (EAAL) to the ileum of each amino acid was determined based on the digesta obtained after feeding the nitrogen-free diet using the following equation:

$$EAAL = [AAd \times (Tif/Tid)]$$

where EAAL is the basal endogenous amino acid loss (g/kg of DMI), AAd is the amino acid concentration in the ileal digesta DM, Tif is the titanium concentration in the feed DM, and Tid is the titanium concentration in the ileal digesta DM.

Standardized ileal digestibilities of each amino acid were then calculated by correcting the AID for the EAAL for each amino acid using the following equation:

$$SID = [AID + (EAAL/AAf) \times 100]$$

where SID is the standardized ileal digestibility of an amino acid (%).

Experiment 2

Six growing barrows (initially 64.8 lb; PIC, Hendersonville, TN) were housed in individual stainless-steel metabolism cages in an environmentally controlled building. Each cage was equipped with a feeder and a nipple waterer for ad libitum access to water. Pigs were randomly allotted to 1 of 3 dietary treatments in a single Latin square design in which pigs were fed all 3 diets in a random order. The corn-based treatments contained 25% fermented soybean meal or 30% camelina meal. A third corn basal diet was fed to allow for calculation of energy concentration by the difference method (Table 2). Titanium oxide was added in all diets at 0.35% as an indigestible marker. There were 3 periods in the experiment, and each period consisted of 8 d. The first 5 d of each period were used to allow pigs to adapt to the dietary treatment followed by 3 d of total fecal collection. On the morning of d 5, a marker (ferric oxide) was added to the first 100 g of the feed allocation, and after the 100 g was consumed, the remainder of the allocation was given. Fecal collection began when the marker first appeared in the feces. On the morning of day 9, a marker was added to the feed again when the pig began its next diet. Collection continued until the marker appeared again in the feces.

On collection days, feces were collected twice daily at the time of feeding. Feces were stored in a freezer (-4°F) until further chemical analyses were conducted. After the collection period for the experiment, feces were thawed and homogenized within each pig and diet. Homogenized collections were dried in a forced-air oven at 140°F and then were weighed, ground, and subsampled for chemical analysis.

Adiabatic bomb calorimetry (Parr Instruments, Moline, IL) was used to determine the GE energy content in the diets, fermented soybean meal, camelina meal, and fecal samples. The concentration of titanium oxide in the diets and fecal samples was determined and used to calculate digestibility.

The DE values of both the fermented soybean meal and camelina meal diets were calculated using the same equation for AID to determine the total tract digestibility (ATTD) of energy. This value was then multiplied by the analyzed concentration of GE in the diets to obtain the total amount of DE in the diet. The ME and NE were determined using the following equations:

$$ME = 1 \times DE - 0.68 \times CP \ (R^2 = 0.99; \text{Noblet and Perez, 1993}[4])$$

$$NE = (0.87 \times ME) - 442 \ (R^2 = 0.94; \text{Noblet et al., 1994}[5])$$

Results and Discussion

Nutrient analysis

The nutrient compositions of experimental diets containing fermented soybean meal and camelina meal for Exp. 1 are reported in Table 3, and the analyzed nutrient composition of the fermented soybean meal and camelina meal is reported in Table 4. The CP content of fermented soybean meal was 47.5%, which was considerably lower than the

[4] Noblet, J., and J.M. Perez. 1993. Prediction of digestibility of nutrients and energy values of pig diets from chemical analysis. J. Anim. Sci. 71:3389–3398.

[5] Noblet, J., H. Fortune, X.S. Shi, and S. Dubois. 1994. Prediction of net energy value of feeds for growing pigs. J. Anim. Sci. 72:344–354

NRC (2012[6]) published value of 58.2% CP when converted on a DM basis. As a result, the amounts of most amino acids in fermented soybean meal were lower than those reported for other fermented soybean meal sources, especially for lysine. The crude fat content of fermented soybean meal was 1.8%, which is less than the value reported in NRC (2012) of 2.5% crude fat when converted to a DM basis. This result suggests variation in the fermentation process among plants manufacturing fermented soybean meal.

The CP content of camelina meal in the present study was 35.3% (DM basis), which is similar to the as-fed value of 35.15% reported by NRC (2012); unfortunately, no DM content was listed for camelina meal in this publication. The amino acid profile provided in the NRC (2012) for camelina meal was similar to the values in the current study.

Experiment 1

For fermented soybean meal, the AID for lysine, methionine, threonine, and tryptophan were 63.5, 84.6, 74.0, and 81.8%, respectively (Table 5). After AID values were corrected for basal ileal endogenous losses, SID values for lysine, methionine, threonine, and tryptophan were calculated to be 71.1, 89.2, 88.0, and 89.9%, respectively. The fermented soybean meal source used in this study had lower SID for lysine, similar SID for methionine, and higher SID for threonine and tryptophan than reported by the NRC (2012).

For camelina meal, the AID for lysine, methionine, threonine, and tryptophan were 47.3, 74.6, 39.7, and 67.3%, respectively (Table 5). To the best of our knowledge, no other published research determines the digestibility of amino acids in camelina meal for swine.

Experiment 2

The GE and calculated DE, ME, and NE for fermented soybean meal were 1,973, 1,377, 1,232, and 880 kcal/lb of DM, respectively (Table 6). The NRC (2012) values reported for fermented soybean meal are 2,214, 1,941, and 1,762 kcal/lb for GE, DE, and ME, respectively, when converted to a DM basis. The reason for the difference in energy content is not fully known but could be partially explained by the lower crude fat in the products we tested compared with those represented by the NRC.

The GE and calculated DE, ME, and NE for camelina meal were 2,075, 1,150, 1,041, and 715 kcal/lb of DM, respectively; GE reported in the NRC (2012) was 2,237 kcal/lb on an as-fed basis. Again, DM was not reported in the NRC (2012) for camelina meal; however, the GE observed in the current study converted to an as-fed basis was 1,895 kcal/lb, which is considerably lower than that reported by the NRC (2012). The oil content of the source listed in the NRC (2012) was 18.5%, however, whereas the source in the current study was only 11.9% (as-fed). This difference is likely responsible for the large difference in energy content between the two sources.

In conclusion, fermented soybean meal is a plant protein source with a nutrient profile and associated digestibility coefficients that allow it to be considered a meaningful

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

ingredient for inclusion in nursery pigs diets. Camelina meal, however, had poorer SID amino acid availability and lower nutrient concentrations, making it a less attractive ingredient for swine diets. Comparing the results we obtained with those published in the NRC (2012) for similar products shows considerable variation that could originate from differences in processing conditions, specific variety of the source grain, weather, growing conditions, etc. The ultimate value of these plant-derived protein ingredients will depend on their impact on growth performance of pigs and the resulting impacts on economic indicators such as income over feed cost.

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

Ingredient, %	Fermented soybean meal	Camelina meal	N-free
Corn starch	53.77	44.79	68.89
Fermented soybean meal	30.00	-	-
Camelina meal	-	39.25	-
Soybean oil	3.00	3.00	3.00
Monocalcium phosphate, 21% P	1.20	1.00	1.50
Limestone	0.63	0.79	0.86
Salt	0.40	0.40	0.40
Vitamin premix	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15
Sow add pack	0.25	0.25	0.25
Potassium chloride	-	-	0.50
Magnesium oxide	-	-	0.10
Titanium oxide	0.35	0.35	0.35
Powdered cellulose[2]	-	-	4.00
Sucrose	10.00	10.00	20.00

[1]A total of 5 pigs (PIC 327 × 1050; initially 60.4 lb BW) were used in a crossover design with 3 periods to provide 5 observations per treatment.
[2] Solka-Floc; International Fiber Corp. (North Tonawanda, NY).

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

Ingredient, %	Fermented soybean meal	Camelina meal	Corn
Corn	71.40	66.40	96.00
Fermented soybean meal	25.00	-	-
Camelina meal	-	30.00	-
Monocalcium phosphate, 21% P	1.60	1.60	1.80
Limestone	0.85	0.85	1.05
Salt	0.40	0.40	0.40
Vitamin premix	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15
Titanium oxide	0.35	0.35	0.35

[1]A total of 6 pigs (PIC 327 × 1050; initially 64.8 lb BW) were used in a crossover design with 3 periods to provide 6 observations per treatment.

Table 3. Analyzed nutrient composition of experimental diets, Exp. 1 (% as-fed basis)

Item	Fermented soybean meal	Camelina meal	N-free
DM	90.29	90.75	91.70
CP	11.31	13.36	0.33
Indispensable amino acids			
Arginine	0.70	1.08	0.01
Histidine	0.26	0.28	0.00
Isoleucine	0.49	0.49	0.02
Leucine	0.82	0.83	0.03
Lysine	0.52	0.61	0.01
Methionine	0.14	0.22	0.00
Phenylalanine	0.55	0.55	0.02
Threonine	0.41	0.51	0.01
Tryptophan	0.13	0.12	<0.04
Valine	0.56	0.70	0.02
Dispensable amino acids			
Alanine	0.49	0.62	0.02
Aspartic acid	1.17	1.04	0.02
Cysteine	0.14	0.28	0.00
Glutamic acid	1.84	2.13	0.03
Serine	0.46	0.53	0.01
Tyrosine	0.36	0.36	0.00

Table 4. Analyzed DM content and nutrient composition of fermented soybean meal and camelina meal (%, DM basis)[1]

Item	Fermented soybean meal	Camelina meal
CP	47.5	35.3
Crude fat	1.8	13.0
ADF	6.5	26.6
NDF	13.6	48.8
Ca	0.50	0.57
P	0.93	0.95
Ash	7.13	6.33
Indispensable amino acid		
Arginine	2.89	2.78
Histidine	1.07	0.72
Isoleucine	1.98	1.16
Leucine	3.30	2.07
Lysine	2.20	1.55
Methionine	0.59	0.63
Phenylalanine	2.21	1.35
Threonine	1.63	1.31
Tryptophan	0.56	0.32
Valine	2.14	1.70
Dispensable amino acid		
Alanine	1.91	1.54
Aspartic acid	4.71	2.62
Cysteine	0.57	0.72
Glutamic acid	7.06	5.13
Serine	1.76	1.36
Tyrosine	1.56	0.92

[1] The as-received DM of the fermented soybean meal was 89.43%, and the camelina meal was 91.34%.

Table 5. Apparent (AID) and standardized ileal digestibility (SID) coefficients (%) of fermented soybean meal and camelina meal, Exp. 1[1]

	AID, %		SID, %[2]	
Amino acid, %	Fermented soybean meal	Camelina meal	Fermented soybean meal	Camelina meal
Indispensable				
Arginine	81.6(7.6)	77.4 (5.8)	93.4 (4.6)	84.5 (3.4)
Histidine	80.3(1.6)	67.2 (4.8)	88.2 (2.7)	74.7 (3.2)
Isoleucine	82.4(1.3)	60.8 (4.1)	89.1 (2.1)	67.5 (3.5)
Leucine	83.0(0.8)	65.6 (4.4)	89.9 (1.5)	72.7 (3.8)
Lysine	63.5(7.5)	47.3 (7.7)	71.1 (6.2)	53.9 (6.4)
Methionine	84.6(1.0)	74.6 (3.3)	89.2 (2.1)	77.7 (3.5)
Phenylalanine	84.3(0.3)	64.6 (4.2)	90.4 (2.0)	70.9 (3.5)
Threonine	74.0(3.5)	39.7 (6.8)	88.0 (3.1)	51.6 (6.7)
Tryptophan	81.8(1.4)	67.3 (8.3)	93.7 (2.0)	79.7 (6.8)
Valine	82.1(2.0)	63.3 (4.1)	89.9 (2.2)	69.6 (4.4)
Dispensable				
Alanine	73.8(4.7)	52.2 (6.4)	86.8 (4.0)	62.2 (3.7)
Aspartic acid	77.4(3.4)	56.9 (4.6)	84.4 (3.6)	64.9 (4.1)
Cysteine	67.7(3.9)	51.3 (5.3)	80.6 (3.4)	58.0 (4.8)
Glutamic acid	82.6(1.4)	73.3 (3.5)	87.8 (1.6)	77.8 (3.0)
Serine	77.4(3.2)	44.7 (7.0)	89.2 (2.8)	55.1 (6.1)
Tyrosine	79.7(2.5)	52.2 (4.6)	86.6 (1.1)	59.1 (3.7)

[1]Values are the mean of 5 observations per treatment. Standard deviation for each digestibility value is shown in parentheses.

[2] The SID represents the corrected AID for basal endogenous loss of an amino acid. Calculated basal endogenous losses after feeding the N-free diet were (g/kg of DMI) arginine, 0.08; histidine, 0.02; isoleucine, 0.04; leucine, 0.06; lysine, 0.04; methionine, 0.01; phenylalanine, 0.04; threonine, 0.07; tryptophan, 0.02; valine, 0.05; alanine, 0.07; aspartic acid, 0.09, cysteine, 0.02; glutamic acid, 0.11; serine, 0.06; tyrosine, 0.03.

Table 6. Energy values (DM basis) of fermented soybean meal and camelina meal[1]

Ingredient, kcal/lb	Fermented soybean meal	Camelina meal
GE	1,973	2,075
DE[2]	1,377 (90)	1,150 (181)
ME[3]	1,232 (90)	1,041 (181)
NE[4]	880 (78)	715 (158)

[1] A total of 6 pigs (PIC 327 × 1050; initially 27.4 kg BW) were used in a crossover design with 3 periods to provide 6 observations per treatment.
[2] The DE values were determined using the difference procedure (Adeola, 2001).
[3] ME was calculated using the equation: ME = 1 × DE – 0.68 × CP (R^2 = 0.99; Noblet and Perez, 1993).
[4] NE was calculated by using the equation: NE = (0.87 × ME) - 442 (R^2 = 0.94; Noblet et al., 1994).

Ammonia and Hydrogen Sulfide Emissions from Swine Production Facilities in North America: a Meta-Analysis[1]

Z. Liu[2] and W.J. Powers[3]

Summary

Ammonia (NH_3) and hydrogen sulfide (H_2S) emissions from swine production facilities receive considerable attention due to human health and environmental implications. Accurate quantification of farm emissions is essential to ensure compliance with regulatory requirements. The objectives of this study were to provide a review of the literature on NH_3 and H_2S emissions from swine production facilities in North America with a meta-analysis that integrates results of independent studies, including measured emissions data from both swine houses and manure storage facilities as well as concentration data in the vicinity of swine production facilities. Results from more than 80 studies were identified through a thorough literature search, and the data were compiled together with results from the 11 swine sites in the National Air Emissions Monitoring Study (NAEMS). Data across studies were analyzed statistically using the MIXED procedures of SAS.

Median emissions rates from swine houses were 2.78 and 0.09 kg/year per pig for NH_3 and H_2S, respectively. Median emissions rates from swine storage facilities were 2.08 and 0.20 kg/year per pig for NH_3 and H_2S, respectively. The Emergency Planning and Community Right-to-Know Act (EPCRA) require reporting of NH_3 and H_2S emissions that exceed 100 lb/d. The size that may trigger the need for a farm to report NH_3 emissions is 3,410 pigs based on median NH_3 emissions rates in the literature, but the threshold can be as low as 992 pigs based on 90th-percentile emissions rates. Swine hoop houses had significantly higher NH_3 emission rates than other manure-handling systems ($P < 0.01$), whereas deep pit houses had the highest H_2S emission rates ($P = 0.03$). Farrowing houses had the highest H_2S emission rates, followed by gestation houses, and finishing houses had lowest H_2S emission rates ($P < 0.01$). Regression models for NH_3 and H_2S emission rates were developed for finishing houses with deep pits, recharge pits, and lagoons. The NH_3 emission rates increased with increasing air temperature, but effects of air temperature on H_2S emission rates were not significant. The recharge interval of manure pits significantly affected H_2S but not NH_3 emission rates. The H_2S emission rates were also influenced by the size of the operation. Although NH_3 and H_2S concentrations at the edge of swine houses or lagoons were often higher than corresponding acute or intermediate minimum risk levels (MRLs), they decreased quickly to be less than corresponding chronic or intermediate MRLs as distances from emission sources increase. At distances 30 to 1,185 m from emission sources, the average ambient concentrations for NH_3 and H_2S were 66 ± 66 ppb and 3.1 ± 6.2 ppb, respectively.

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Key words: air quality, ammonia, hydrogen sulfide, swine

Introduction

Air emissions from swine production facilities receive considerable attention due to human health and environmental implications. Major farm emissions of interest include ammonia (NH_3) and hydrogen sulfide (H_2S). The H_2S is of interest mainly at the local level because of health concerns, whereas NH_3 has regional-scale impacts on ecosystems. Air emissions from industries are subject to permit requirements under the Clean Air Act (CAA) as well as reporting requirements under the Emergency Planning and Community Right-to-Know Act (EPCRA) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) if emissions reach specified thresholds; for example, operations that exceed 100 lb/d NH_3 or H_2S emissions are required to report under EPCRA. Accurate quantification of farm emissions is essential to ensure compliance with the regulatory requirements, but direct measurements of farm emissions are expensive and difficult. Fortunately, a large volume of published studies on NH_3 and H_2S emissions from swine production facilities are available for a meta-analysis. Meta-analysis is a quantitative statistical analysis of a collection of results from individual previous studies for the purpose of integrating the findings. Results from meta-analyses are usually more robust and have less bias than individual studies because of improved statistical power.

The objectives of this study were to provide a review of the literature on NH_3 and H_2S emissions from swine production facilities in North America, with a meta-analysis that integrates results of independent studies, including measured emissions data from both swine houses and manure storage facilities as well as concentration data in the vicinity of swine production facilities.

Procedures

Literature search and data extraction

Multiple strategies were undertaken to identify potentially eligible studies to be included in the meta-analysis. The inclusion criteria were that studies must have been conducted in North America and must have reported measured NH_3 or H_2S emissions data from swine production facilities, including manure storage systems, or concentration data in the vicinity of swine facilities. Data from reports of the 11 swine sites in the National Air Emissions Monitoring Study (NAEMS) were included in the database. Two individuals independently conducted the search processes and screened the studies by reading the title and abstract to select studies for full review according to the inclusion criteria.

The included studies were distributed to a group of reviewers for data extraction. Standard data extraction sheets were developed for consistency. Some studies provided emissions data from different sites or settings; in these cases, more than one data point was extracted from one study. Each study was reviewed in duplicate by two independent reviewers for quality control. After the data review and extraction processes, a meta-analysis database was created. Emissions data for NH_3 and H_2S were compiled into the two emission sources (swine houses and manure storage facilities). Concentration data were compiled separately and included sampling locations and distances from emission sources.

Data analysis

Various units of emissions data have been used in the literature. To perform statistical analysis and compare emissions data between different studies, the units of measured emissions data were converted to kg/year per pig and kg/year per AU (AU is an animal unit corresponding to 500 kg of body mass) for emissions from swine houses and to kg/year per pig and kg/year per m^2 for emissions from manure storage facilities. When unit conversion was not possible due to lack of key information, the original emissions data were excluded from statistical analysis. A full list of included studies and completed data extraction spreadsheets are available to allow for independent scrutiny of the process.

Data across studies were analyzed statistically using the MIXED procedures of SAS (SAS for Windows, Version 9.3, SAS Institute, Inc., Cary, NC). Study (or each publication) was treated as a random variable because some studies contain multiple data points. The ratios of emissions rate over SD were used as a weighting variable such that data points with relatively small SDs were given more weight in the analysis. Effects of production stage and manure handling/storage system on emissions rates were examined using Tukey's test. Significant effects were declared at $P < 0.05$. Multi-linear regression models were developed for certain emission sources to reflect the effects of indoor or ambient air temperature, average pig weight, size of operation (number of pigs), area of manure storage, recharging interval of manure pits, etc. A backward-elimination process was used to remove the confounded terms and to reduce non-significant terms one by one. When a regression model failed to pass normality tests, a natural log transformation was applied to the response variable (emission rate).

Results and Discussion

Statistics of NH_3 and H_2S emissions from swine houses and manure storage facilities

The ranges, means, and medians of NH_3 and H_2S emission rates for swine houses and manure storage facilities are presented in Table 1. Large variations in emission rates were observed. Histograms of NH_3 and H_2S emission rates for swine houses and manure storage facilities all showed a positively skewed distribution. The median emission rates were believed more robust, and the means were all larger than the medians due to a few large values. For swine houses, the median NH_3 emission rate was 2.78 kg/year per pig, whereas the highest emission rate was 11 times higher; the median H_2S emission rate was only 0.09 kg/year per pig, but the highest emission rate was 35 times higher. For swine manure storage facilities, the median NH_3 emission rate was 2.08 kg/year per pig, whereas the highest emission rate was 11 times higher; the median H_2S emission rate was only 0.20 kg/year per pig, but the highest emission rate was 7 times higher.

Emission rates from swine houses: Effects of production stage and manure-handling system

Means and least squares means of NH_3 and H_2S emission rates from swine houses for various production stages and manure-handling systems are presented in Table 2. Swine hoop houses had significantly higher NH_3 emission rates than other manure handling systems ($P < 0.01$ for NH_3 emission rates in both kg/year per pig and kg/year per AU). Effects of production stages (gestation, farrowing, nursery, or finishing) were not significant for NH_3 emission rates from swine houses ($P = 0.23$ and 0.15 for NH_3 emission

rates in kg/year per pig and kg/year per AU, respectively). Deep-pit houses had higher H_2S emission rates than other manure-handling systems ($P = 0.03$ and <0.01 for H_2S emission rates in kg/year per pig and kg/year per AU, respectively). Farrowing houses had the highest H_2S emission rates, followed by gestation houses, and finishing houses had lowest H_2S emission rates, regardless of whether emission rates were expressed in kg/year per pig or kg/year per AU ($P < 0.01$ in both cases).

Emission rates from manure storage facilities: Effects of production stage and storage type

Means and least squares means of NH_3 and H_2S emission rates from manure storage facilities for various production stages and storage types are presented in Table 3. No storage type or production stage effects were observed for NH_3 emission rates (in kg/year per pig, $P = 0.45$ and 0.24, respectively; or in kg/year per m^2, $P = 0.75$ and 0.30, respectively), or H_2S emission rates (in kg/year per pig, $P = 0.47$ and 0.13, respectively; or in kg/year per m^2, $P = 0.06$ and 0.60, respectively).

Regression models for NH_3 and H_2S emission rates

Regression models for NH_3 and H_2S emission rates were developed for deep-pit finishing houses, finishing houses with recharge pits, and lagoons for finishing operations (Table 4) to reflect the effects of indoor or ambient air temperature, average pig weight, size of operation (number of pigs), area of manure storage, recharging interval of manure pits, etc. The indoor air temperatures ranged from 8 to 28°C; average pig weights ranged from 21 to 249 kg; number of pigs ranged from 6 to 13,680; recharge interval of manure pits ranged from 1 to 42 d; ambient air temperatures ranged from 2 to 32°C; and areas of lagoons ranged from 1,131 to 97,600 m^2.

For finishing houses with deep pits or recharge pits, NH_3 emission rates were positively related to indoor air temperature. Finishing operation lagoons had NH_3 emission rates that were positively related to ambient air temperature ($P < 0.01$). Effects of temperature on H_2S emission rates were not significant. The recharge interval of manure pits in finishing houses significantly affected H_2S but not NH_3 emission rates. Swine houses with pits that had longer recharge intervals emitted more H_2S ($P < 0.01$). The NH_3 and H_2S emission rates from swine houses in kg/year per pig increased with increasing pig weights. When expressed in kg/year per AU, NH_3 emission rates were no longer influenced by pig weight, but for finishing houses with recharge pits, H_2S emission rates in kg/year per AU remained positively related with pig weight ($P = 0.01$). The H_2S emission rates were also influenced by size of operation. Deep-pit finishing houses with larger pig numbers tend to have higher H_2S emission rates in kg/year per AU ($P = 0.02$).

Swine farm sizes that may trigger the need to report NH_3 or H_2S emissions

The EPCRA and CERCLA require reporting of NH_3 and H_2S emissions that exceed 100 lb/d. Swine farm sizes that may trigger the need to report NH_3 and H_2S emissions under EPCRA and CERCLA were calculated and are presented in Table 5.

NH_3 concentrations in the vicinity of swine facilities

The average NH_3 concentration at the edge of the emission sources (swine houses or lagoons) was 5.5 ± 5.2 ppm (ranging from 0.3 to16 ppm), which is higher than the acute minimum risk levels (MRL) for NH_3 (1700 ppb[4]). The ambient NH_3 concentrations in the vicinity of swine facilities decreased quickly to be less than the chronic MRL (100 ppb) as distances from emission source increased (Figure 1). At distances of 30 to 1,185 m from emissions sources, the average ambient NH_3 concentration was 66 ± 66 ppb (ranging from 10 to 280 ppb). In comparison, the average background ambient NH_3 concentration outside swine production areas was 7.7 ± 3.5 ppb, whereas Godbout et al. (2009[5]) and Donham et al. (2006[6]) reported the average ambient NH_3 concentration within swine production areas was 11.8 ± 5.5 ppb. The average ambient NH_3 concentration in the vicinity of swine facilities (66 ± 66 ppb at distances from 30 to 1,185 m) was about 8 times higher than the average background ambient NH_3 concentration in areas not influenced by swine production facilities (7.7 ± 3.5 ppb).

H_2S concentrations in the vicinity of swine facilities

The average H_2S concentration at the edge of the emission sources (swine houses or lagoons) was 40 ± 48 ppb (ranging from 0.9 to146 ppb), which is less than the acute MRL (100 ppb) but higher than the intermediate MRL (20 ppb) for H_2S[7]. The ambient H_2S concentrations in the vicinity of swine facilities decrease quickly to be less than 20 ppb as distances from emission sources increase (Figure 2). The average ambient H_2S concentration was 3.1 ± 6.2 ppb at the distances of 30 to 1,185 m from emission sources. In comparison, Godbout et al. (2009[8]) and Donham et al. (2006[9]) reported average ambient H_2S concentrations of 1.9 ± 1.1 ppb in areas not influenced by swine production facilities.

[4] The Agency for Toxic Substances and Disease Registry (ATSDR) has suggested minimum risk levels (MRLs) for NH_3 and H_2S designed to protect sensitive populations (ATSDR, 2008). The MRLs for NH_3 are 1700 ppb and 100 ppb for an acute (1–14 d continuous) and chronic (>365 d continuous) exposure, respectively.

[5] Godbout, S., S.P. Lemay, C. Duchaine, F. Pelletier, J.P. Larouch, M. Belzile, and J.J.R. Feddes. 2009. Swine Production Impact on Residential Ambient Air Quality, J. Agromed. 14:3, 291–98.

[6] Donham, K.J., J.A. Lee, K. Thu, and S.J. Reynolds. 2006. Assessment of air quality at neighbor residences in the vicinity of swine production facilities. J. Agromed. 11(3/4):15–24.

[7] The Agency for Toxic Substances and Disease Registry (ATSDR) has suggested minimum risk levels (MRLs) for NH_3 and H_2S designed to protect sensitive populations (ATSDR, 2008). The MRLs for H_2S are 70 ppb and 20 ppb for an acute and intermediate (15–365 d continuous) exposure, respectively.

[8] Godbout, S., S.P. Lemay, C. Duchaine, F. Pelletier, J.P. Larouch, M. Belzile, and J.J.R. Feddes. 2009. Swine Production Impact on Residential Ambient Air Quality, J. Agromed. 14:3, 291–298.

[9] Donham, K.J., J.A. Lee, K. Thu, and S.J. Reynolds. 2006. Assessment of air quality at neighbor residences in the vicinity of swine production facilities. J. Agromed. 11(3/4):15–24.

Table 1. Statistics of NH_3 and H_2S emissions from swine houses and manure storage facilities

	NH_3			H_2S		
	Range	Mean	Median	Range	Mean	Median
Swine houses						
Emissions rates in kg/year per pig	0.33 to 31.6 (97)[1]	3.95 ± 4.51	2.78	0.00 to 3.12 (65)	0.26 ± 0.56	0.09
Emissions rates in kg/year per AU[2]	0.79 to 124.2 (101)	20.64 ± 18.09	16.43	0.00 to 11.09 (70)	1.08 ± 1.07	0.55
Manure storage facilities						
Emissions rates in kg/year per pig	0.00 to 23.23 (74)	3.83 ± 4.43	2.08	0.00 to 1.33 (27)	0.33 ± 0.37	0.20
Emissions rates in kg/year per m^2	0.00 to 7.28 (72)	1.68 ± 1.66	1.08	0.00 to 0.70 (30)	0.18 ± 0.21	0.07

[1] Number of data points in each category were presented in parentheses.
[2] AU = animal unit corresponding to 500 kg body mass.

Table 2. Means and least squares means of NH_3 and H_2S emission rates from swine houses by various production stages and manure handling systems

	Gestation	Farrowing	Finishing	Nursery	Least squares mean
NH_3 emission rates (in kg/year per pig)					
Hoop	(0)[1]	(0)	12.93 ± 0.89 (2)	(0)	14.80 ± 1.97[b] (2)
Dry	(0)	(0)	4.19 ± 4.77 (7)	(0)	3.26 ± 1.22[a] (7)
Deep pit	5.85 ± 5.13 (3)	7.030 (1)	3.57 ± 2.00 (36)	0.66 (1)	4.30 ± 0.90[a] (41)
Recharge pit	14.61 ± 14.39 (4)	7.80 ± 10.97 (3)	2.38 ± 1.48 (32)	0.860 (1)	2.90 ± 0.80[a] (40)
Drain pit	3.44 ± 0.09 (2)	2.18 ± 2.09 (2)	1.32 ± 0.40 (3)	(0)	3.13 ± 0.84[a] (7)
Least squares mean	6.69 ± 1.06 (9)	5.46 ± 1.74 (6)	4.89 ± 0.49 (80)	(2)	
NH_3 emission rates (in kg/year per AU[2])					
Hoop	(0)	(0)	69.18 ± 8.22 (2)	(0)	73.62 ± 13.69[b] (2)
Dry	8.67 ± 1.94 (2)	(0)	32.38 ± 40.70 (7)	(0)	8.05 ± 9.13[a] (9)
Deep pit	10.59 ± 6.54 (7)	17.18 (1)	24.67 ± 13.52 (34)	16.04 (1)	16.03 ± 5.60[a] (43)
Recharge pit	7.39 ± 1.23 (2)	4.08 ± 4.66 (2)	17.95 ± 13.26 (32)	(0)	8.77 ± 4.99[a] (36)
Drain pit	8.61 ± 0.23 (2)	2.51 ± 2.63 (6)	7.81 ± 2.02 (3)	(0)	10.83 ± 4.96[a] (11)
Least squares mean	20.53 ± 6.88 (13)	16.90 ± 9.13 (9)	32.95 ± 3.83 (78)	(1)	
H_2S emission rates (in kg/year per pig)					
Hoop	(0)	(0)	0.015 ± 0.004 (2)	(0)	1.457 ± 0.378[a,b] (2)
Dry	(0)	(0)	0.017 ± 0.007 (6)	(0)	1.224 ± 0.309[a,b] (6)
Deep pit	1.709 ± 1.503 (3)	1.065 (1)	0.136 ± 0.127 (25)	0.455(1)	1.545 ± 0.205[b] (30)
Recharge pit	0.110 ± 0.014 (2)	2.790 (1)	0.071 ± 0.057 (17)	(0)	0.970 ± 0.183[a,b] (20)
Drain pit	0.275 ± 0.007 (2)	1.375 ± 0.007 (2)	0.023 ± 0.006 (3)	(0)	0.778 ± 0.190[a] (7)
Least squares mean	1.098 ± 0.245[b] (7)	2.499 ± 0.309[c] (4)	-0.012 ± 0.121[a] (53)	(1)	
H_2S emission rates (in kg/year per AU)					
Hoop	(0)	(0)	0.078 ± 0.004 (2)	(0)	3.690 ± 1.173[a,b] (2)
Dry	0.730 (1)	(0)	0.121 ± 0.048(6)	(0)	2.132 ± 1.186[a,b] (6)
Deep pit	2.309 ± 2.063 (7)	2.604 (1)	1.019 ± 0.912 (24)	11.089 (1)	4.068 ± 0.686[b] (33)
Recharge pit	0.304 ± 0.039 (2)	7.707 (1)	0.525 ± 0.391 (17)	(0)	1.450 ± 0.620[a] (20)
Drain pit	0.688 ± 0.675 (2)	1.703 ± 1.737 (4)	0.137 ± 0.038 (3)	(0)	0.754 ± 0.601[a] (9)
Least squares mean	1.791 ± 0.822[a] (12)	5.056 ± 0.960[b] (6)	0.410 ± 0.460[a] (52)	(1)	

[a,b,c] Values within the same effect section differ significantly if without common letter ($P < 0.05$).

[1] Number of data points in each category is in parentheses.

[2] AU = animal unit corresponding to 500 kg body mass.

Table 3. Means and least squares means of NH_3 and H_2S emission rates from swine manure storage facilities by various production stages and storage systems

	Gestation	Farrowing	Finishing	Nursery	Least squares mean
NH_3 emission rates (in kg/year per pig)					
Lagoon	(0)[1]	8.92 ± 6.68 (10)	3.70 ± 3.74 (47)	0.020 (1)	5.35 ± 1.53 (58)
Slurry tank	(0)	(0)	1.85 ± 2.28 (12)	0.45 ± 0.38 (4)	3.01 ± 2.96 (16)
Least squares mean	(0)	6.00 ± 3.79 (10)	4.36 ± 1.51 (59)	2.19 ± 1.89 (5)	
NH_3 emission rates (in kg/year per m^2)					
Lagoon	(0)	2.26 ± 1.69 (11)	1.59 ± 1.81 (45)	0.030 (1)	3.02 ± 0.68 (57)
Slurry tank	(0)	(0)	1.67 ± 1.15 (11)	1.35 ± 1.30 (4)	3.50 ± 1.49 (15)
Least squares mean	(0)	4.27 ± 1.71 (11)	2.47 ± 0.76 (56)	3.04 ± 0.88 (5)	
H_2S emission rates (in kg/year per pig)					
Lagoon	(0)	0.387 ± 0.321 (8)	0.256 ± 0.344 (13)	(0)	0.388 ± 0.155 (21)
Slurry tank	(0)	(0)	0.438 ± 0.554 (5)	0.204 (1)	0.554 ± 0.181 (6)
Least squares mean	(0)	0.516 ± 0.278 (8)	0.774 ± 0.109 (18)	0.121 ± 0.271 (1)	
H_2S emission rates (in kg/year per m^2)					
Lagoon	(0)	0.128 ± 0.117 (10)	0.121 ± 0.160 (14)	(0)	0.360 ± 0.063 (24)
Slurry tank	(0)	(0)	0.378 ± 0.300 (5)	0.656 (1)	0.660 ± 0.071 (6)
Least squares mean	(0)	0.374 ± 0.115 (10)	0.450 ± 0.042 (19)	0.556 ± 0.114 (1)	

[1] Number of data points in each category is in parentheses.

Table 4. Regression models for NH_3 and H_2S emission rates from various emission sources

Emission sources	Regression model
Finishing houses with deep pits	NH_3 emission rates in kg/year per pig = EXP (-0.6284+0.01854W+0.02495T_i)
	NH_3 emission rates in kg/year per AU = EXP (2.6859+0.02569T_i)
	H_2S emission rates in kg/year per pig = EXP (-3.4502+0.002431W+0.000382N)
	H_2S emission rates in kg/year per AU = EXP (-1.0983+0.000061N)
Finishing houses with recharge pits	NH_3 emission rates in kg/year per pig = EXP (-1.4247+0.01333W+0.05562T_i)
	NH_3 emission rates in kg/year per AU = EXP (1.5524+0.05484T_i)
	H_2S emission rates in kg/year per pig = EXP (-5.9333+0.03780W+0.04709R)
	H_2S emission rates in kg/year per AU = EXP (-2.8309+0.02183W+0.04877R)
Lagoons for finishing operations	NH_3 emission rates in kg/year per pig = EXP (-0.3782+0.07017T_a)
	NH_3 emission rates in kg/year per m^2 = EXP (-1.3843+0.07373T_a)

Note: AU = animal unit corresponding to 500 kg body mass; T_i = indoor air temperature in swine houses, °C; T_a = ambient air temperature, °C; W = average weight of pigs, kg; N = number of pigs in the farm; R = recharge interval of manure pits, in days.

Table 5. Sizes of swine farm that may trigger the need to report NH_3 or H_2S emissions

		Emission rates (kg/year per pig)			Sizes that may reach the 100-lb NH_3 or H_2S/d threshold
Scenarios		Swine houses	Manure storage	Total	
Based on the median emission rates in literature	NH_3	2.78	2.08	4.86	3,410 pigs
	H_2S	0.09	0.20	0.29	57,141 pigs
Based on the 75th-percentile emission rates in literature	NH_3	4.49	6.27	10.76	1,540 pigs
	H_2S	0.20	0.63	0.83	19,965 pigs
Based on the 90th-percentile emission rates in literature	NH_3	7.17	9.54	16.71	992 pigs
	H_2S	0.47	0.83	1.30	12,747 pigs

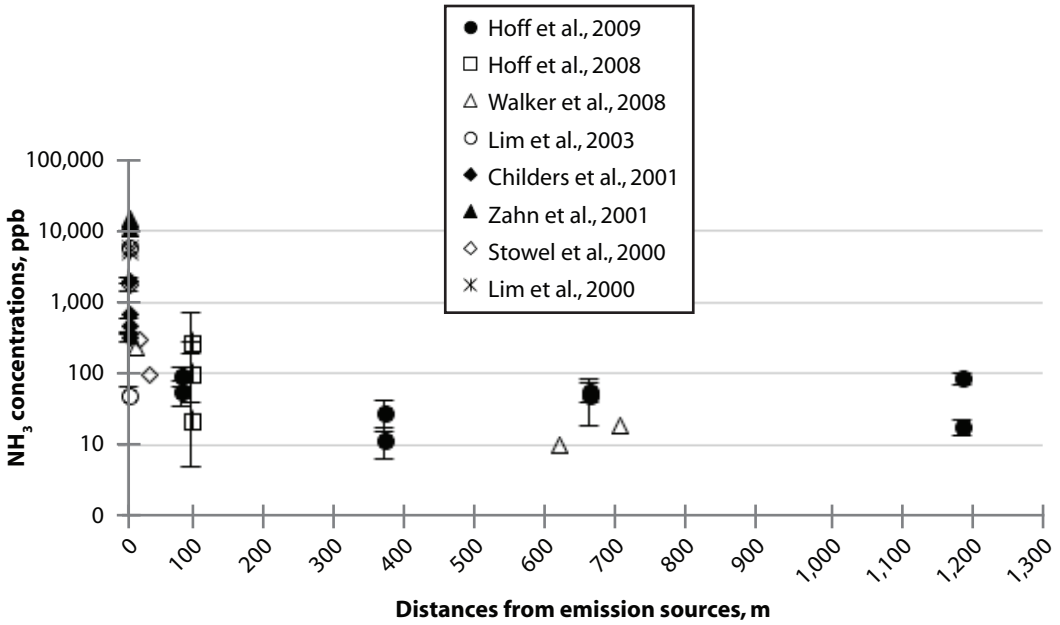

Figure 1. Measured NH_3 concentrations at various distances from swine facilities[10]

[10] References in Figure 1: Hoff, S.J., J.D. Harmon, D.S. Bundy, and B.C. Zelle. 2009. Source and receptor ammonia and hydrogen sulfide concentrations in communities with and without swine emission sources: follow-up study. Appl. Eng. Agric. 25(6):975–986.

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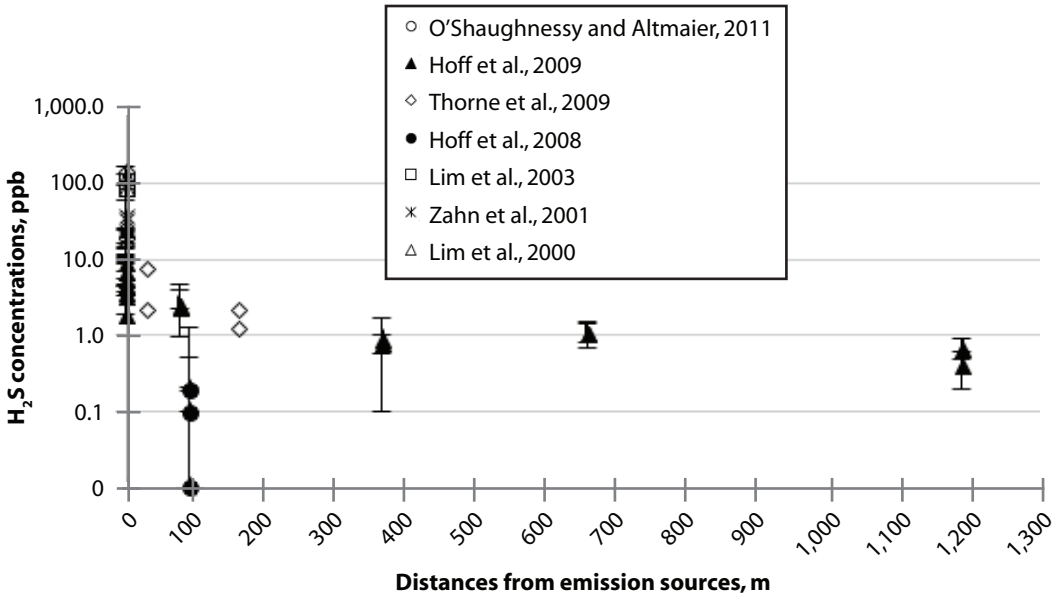

Figure 2. Measured H_2S concentrations at various distances from swine facilities[11]

[11] References in Figure 2: O'Shaughnessy, P.T. and R. Altmaier. 2011. Use of AERMOD to determine a hydrogen sulfide emission factor for swine operations by inverse modeling. Atmos. Environ. 45:4617–4625.

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