SWINE DAY 2009

Report of Progress 1020

K-STATE Kansas State University

Kansas State University
Agricultural Experiment
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Extension Service

KANSAS STATE UNIVERSITY
SWINE INDUSTRY DAY
2009

New finishing barn at the Kansas State University Swine Teaching and Research Center.

SWINE DAY 2009

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Foreword

It is with great pleasure that we present the 2009 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.

2009 Swine Day Report of Progress Editors

Bob Goodband Mike Tokach Steve Dritz Joel DeRouchey

Standard Abbreviations

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

K-State Vitamin and Trace Mineral Premixes

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

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

Note

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

Biological Variability and Chances of Error

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

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

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

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

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

Effects of Piglet Birth Weight and Litter Size on the Preweaning Growth Performance of Pigs on a Commercial Farm[1]

J. R. Bergstrom, M. L. Potter[2], M. D. Tokach, S. C. Henry[3], S. S. Dritz[2], J. L. Nelssen, R. D. Goodband, and J. M. DeRouchey

Summary

A total of 2,204 pigs (PIC 327 sired) were used to evaluate the effects of piglet birth weight and litter size on preweaning piglet performance. At a commercial sow farm, all pigs born alive for 22 consecutive days were identified individually at birth with a numbered ear tag. Each sow was assigned a body condition score (BCS; 1 = very thin to 5 = very fat), and the number of total born, live born, and born dead as well as the individual gender, birth weight, and identification of piglets were recorded within 18 h of parturition and before the movement of pigs to equalize litter size. During lactation, all pigs fostered, removed, or found dead were weighed, and the event was recorded. No litters were provided creep feed or supplements during lactation. Pigs were individually weighed and assigned a BCS (1 = emaciated, 2 = thin, or 3 = full-bodied) at weaning over 6 weaning days during a 19-d period, which resulted in a mean weaning age of 25 d. For data analysis, individual birth weight was used to assign pigs to 4 birth weight categories (≤ 2.3 lb, 2.4 to 3.3 lb, 3.4 to 4.3 lb, and ≥ 4.4 lb), and the number of total born in each pig's litter of origin was used to assign pigs to 3 total born categories (≤ 11, 12 to 14, and ≥ 15). As expected, birth weight was greater ($P < 0.0001$) for pigs of heavier birth weight categories. Pigs of heavier birth weight categories were associated ($P < 0.02$) with a decreased number of total and live born. Also, preweaning ADG, weaning weight, weaning BCS, and preweaning mortality were improved ($P < 0.0001$) for pigs of heavier birth weight categories. Birth weight decreased ($P < 0.04$) for pigs of greater total born categories, and an increased sow BCS was associated ($P < 0.0001$) with total born category ≥ 15. As expected, the litter total born, as well as live born and number born dead, increased ($P < 0.0001$) with greater total born categories. Preweaning ADG (0.51, 0.50, and 0.50 lb/d, respectively) and weaning weight (16.3, 15.9, and 15.8 lb, respectively) were modestly improved ($P < 0.04$) for pigs from the smallest total born category compared with the 2 larger categories. These data indicate that low-birth-weight pigs had poorer preweaning growth performance and survivability. Although larger litters resulted in a greater number of low-birth-weight pigs, the number of heavier pigs also increased. In addition to increasing litter size, maximizing reproductive and economic efficiency of swine requires identifying methods to improve birth weight and performance of the lightest pigs born.

Key words: birth weight, litter size

[1] Appreciation is expressed to Keesecker Agri-business, Washington, KS, for providing pigs and facilities involved with this study.

[2] Food Animal Health and Management Center, College of Veterinary Medicine, Kansas State University.
[3] Abilene Animal Hospital, PA, Abilene, KS.

Introduction

Research by Main et al. (2002[4]) demonstrated that weaning weight and postweaning performance improved linearly with increased weaning age. When these data were modeled to quantify the changes in performance associated with increasing weaning age, Main et al. (2002) found it useful to express these benefits on a change per pound of weaning weight basis. As a result, the importance of weaning age and weaning weight for subsequent performance is well understood. Since that time, many swine production systems have increased their weaning age to improve weaning weight, postweaning growth, efficiency of growth, welfare, and economic return. However, litter size has also increased during this time because of improvements in genetics, sow nutrition and feeding practices, and health management. The increased lactation period may also be contributing to the improved reproductive performance.

Unfortunately, improved ovulation rates and embryonic survival have occurred without any measurable change in the uterine capacity of sows (Foxcroft, 2007[5]). This has resulted in concern that birth weights will be reduced. Although the relationship of birth weight and subsequent growth is fairly well understood, the existing studies have used a relatively small number of pigs. These studies have characterized the effects of birth weight on growth using only 2 or 3 birth weight categories. Also, other economically important traits (such as mortality) that may be influenced by birth weight have not been adequately described. Few studies have evaluated the effects of both litter size and birth weight on the subsequent performance of pigs.

Therefore, our objective was to evaluate the relationship of piglet birth weight and the size of the piglet's litter of origin with subsequent preweaning performance using a large population of pigs on a commercial farm.

Procedures

Procedures used in this experiment were approved by the Kansas State University Institutional Animal Care and Use Committee. The experiment was conducted at a commercial farm in Kansas and used 1,181 pigs (PIC 327 sired) born of first, second, and a few third parity females (Triumph TR24) and 1,023 pigs (PIC 327 sired) born of third parity and older sows (PIC 1050). Throughout the experiment, all litters were penned in individual farrowing crates located over totally slatted floors in environmentally controlled buildings.

All pigs born alive for 22 consecutive days were identified individually at birth with a numbered ear tag. Each sow was assigned a body condition score (BCS; 1 = very thin to 5 = very fat), and the number of total born, live born, and born dead was recorded. Also, the individual gender, birth weight, and identification of piglets were recorded within 18 h of parturition and before the movement of pigs to equalize litters. Afterward, litters born within the same day were equalized and processed following the farm's normal procedures to optimize sow and piglet health and welfare. During lactation, all pigs fostered, removed, or found dead were weighed, and the event was recorded. No litters were provided creep feed or supplements during lactation. The

[4] Main et al., Swine Day 2002, Report of Progress 897, pp. 1-19.

[5] Foxcroft, G. R. 2007. Pre-natal programming of variation in postnatal performance – How and when? Adv. Pork Prod. 18:167-189.

pigs were individually weighed and assigned a BCS (1 = emaciated, 2 = thin, or 3 = full-bodied) at weaning over 6 occasions during a 19-d period, which resulted in a mean weaning age of 25 d.

For data analysis, individual birth weight was used to assign pigs to 4 birth weight categories (≤ 2.3 lb, 2.4 to 3.3 lb, 3.4 to 4.3 lb, and ≥ 4.4 lb), and the number of total born in each pig's litter of origin was used to assign pigs to 3 total born categories (≤ 11, 12 to 14, and ≥ 15). Because of a change in maternal genetics delivered to the farm, the parity and genetic background (PIC 1050 and Triumph TR24) of sows were confounded. Therefore, the effects of sow parity and genetic background on piglet performance were not evaluated. Parity was used as a random effect in the data analysis. Data were analyzed as a 4 × 3 factorial design using the PROC MIXED procedure of SAS (SAS Institute Inc., Cary, NC). Weaning age was used as a covariate for the analysis of preweaning growth. Individual pig was the experimental unit for the analysis of response criteria.

Results

Meaningful interactions were not observed during the study. As expected, birth weight was greater ($P < 0.001$) for pigs of heavier birth weight categories (Table 1). As birth weight category increased, the number of total born and live born decreased ($P < 0.02$). Preweaning ADG (0.38 lb/d for ≤ 2.3 lb birth weight to 0.59 lb/d for ≥ 4.4 lb birth weight), weaning weight (11.6 lb to 19.5 lb), weaning BCS (2.69 to 2.93), and preweaning mortality (24.2% to 4.6%) were improved ($P < 0.0001$) for pigs of heavier birth weight categories.

The birth weight of pigs from the smallest total born category (≤ 11) was greater ($P < 0.04$) than that of pigs from the largest total born category (≥ 15; Table 2). Sows of the largest total born category had an increased ($P < 0.0001$) BCS after parturition compared with the other two categories. As expected, the litter total born, as well as live born and number born dead, increased ($P < 0.0001$) with greater total born categories. Also, preweaning ADG and weaning weight were greatest ($P < 0.04$) for pigs from the smallest total born category (≤ 11) compared with the 2 larger categories. Preweaning mortality tended ($P < 0.07$) to be greatest for pigs from the 12 to 14 total born category.

Discussion

Several studies have reported an improved growth rate of heavier birth weight pigs (Powell and Aberle, 1980[6]; Wolter et al., 2002[7]; Bee, 2004[8]; Bérard et al., 2008[9]). However, these studies have generally compared 2 or 3 birth weight categories using a relatively small population, and none have adequately described the effect of birth

[6] Powell, S. E., and E. D. Aberle. 1980. Effects of birth weight on growth and carcass composition of swine. J. Anim. Sci. 50:860-868.
[7] Wolter, B. F., M. Ellis, B. P. Corrigan, and J. M. DeDecker. 2002. The effect of birth weight and feeding supplemental milk replacer to piglets during lactation on preweaning and postweaning growth performance and carcass characteristics. J. Anim. Sci. 80:301-308.
[8] Bee, G. 2004. Effect of early gestation feeding, birth weight, and gender of progeny on muscle fiber characteristics of pigs at slaughter. J. Anim. Sci. 82:826-836.
[9] Bérard, J., M. Kreuzer, and G. Bee. 2008. Effect of litter size and birth weight on growth, carcass and pork quality, and their relationship to postmortem proteolysis. J. Anim. Sci. 86:2357-2368.

weight on preweaning performance. Bérard et al. (2008) did not observe any differences in the preweaning growth of low-birth-weight, average-birth-weight, and heavy-birth-weight pigs. However, there were only 20 pigs in each of their birth weight categories. Wolter et al. (2002) did not observe any differences in preweaning growth of light- and heavy-birth-weight pigs, but preweaning mortality tended ($P = 0.10$) to be lower for heavy-birth-weight pigs. They started with 192 piglets in each of 2 weight categories, but categorizing pigs into a heavy half and light half is not adequate for understanding the relative differences in performance between the extremes. Bee (2004) observed differences in the preweaning growth performance of light- and heavy-birth-weight pigs but reported the performance of the lightest barrow and gilt (not less than 2.2 lb) and the heaviest barrow and gilt from 16 litters. This excluded any bias from categorizing pigs with birth weights similar to the mean. However, Bee (2004) did not have enough pigs to evaluate mortality differences.

Recent increases in litter size have raised concern over the impact that the increase may have on piglet birth weight and performance. However, there is little data available that adequately describes these relationships and their effects on subsequent performance. Only Bérard et al. (2008) has reported on the effect of both birth weight and litter size on piglet growth performance. Similar to the present experiment, they reported that the birth weight of pigs from large litters (≥ 14) was less than that of pigs from small litters (≤ 10). Although Bérard et al. (2008) did not observe significant differences in preweaning ADG among the low-, average-, and heavy-birth-weight pigs, the low-birth-weight pigs had numerically lower ADG and maintained a significantly lighter BW than heavy-birth-weight pigs at weaning (35 d of age). Average-birth-weight pigs had an intermediate BW at weaning. Unlike the current experiment, Bérard et al. (2008) did not observe any differences in preweaning ADG and weaning weight for pigs originating from small and large litters. Their estimates were based on the means of 3 pigs from each of 20 litters: the lightest pig, a single average-weight pig, and the heaviest pig. Therefore, their estimates for the 2 litter size categories did not include all pigs in the litter. In the present study, the greater number of low-birth-weight pigs from larger litters was responsible for the reduced performance, but these litters also produced more pigs that were heavier than 2.3 lb and 3.3 lb (Figures 1 and 2). Therefore, growth differences among the litter size categories were relatively small.

In conclusion, these data indicate that low-birth-weight pigs, especially those weighing 2.3 lb or less at birth, had poorer growth performance and higher mortality preweaning. Although larger litters had a greater number of low-birth-weight pigs, these litters also produced a greater number of live pigs with a birth weight greater than 2.3 lb. Litters with 15 or more total born produced the greatest number of live pigs that were heavier than 3.3 lb at birth. In addition to increasing litter size, maximizing the reproductive and economic efficiency of swine requires identifying methods to improve birth weight and performance of the lightest pigs born.

Table 1. Effect of piglet birth weight on preweaning growth performance[1]

	Birth weight category, lb[2]					
Item	≤ 2.3	2.4 to 3.3	3.4 to 4.3	≥ 4.4	SEM	Probability, $P <$
Pigs, no.	243	796	857	308		
Live born, %	11.0	36.1	38.9	14.0		
Birth weight, lb	1.92[a]	2.92[b]	3.78[c]	4.72[d]	0.02	0.0001
Sow BCS post-farrowing[3]	3.0	3.0	3.0	3.1	0.1	---[4]
Litter total born	13.3[a]	13.1[ab]	13.0[b]	12.6[c]	0.1	0.0001
Litter live born	12.1[a]	11.9[a]	11.9[a]	11.6[b]	0.1	0.02
Litter born dead	1.1	1.2	1.1	1.0	0.1	---
Preweaning ADG, lb	0.38[a]	0.49[b]	0.55[c]	0.59[d]	0.01	0.0001
Weaning wt, lb	11.6[a]	15.3[b]	17.5[c]	19.5[d]	0.2	0.0001
Pig BCS at weaning[5]	2.69[a]	2.87[b]	2.89[bc]	2.93[c]	0.02	0.0001
Preweaning mortality, %	24.2[a]	9.7[b]	5.0[c]	4.6[c]	1.6	0.0001

[1] A total of 2,204 pigs were used to evaluate the effect of piglet birth weight on preweaning performance. Pigs were weaned at approximately 25 d of age, and weaning age was used as a covariate in data analysis.
[2] Results are reported as least squares means.
[3] Sow body condition score (1 = very thin to 5 = very fat, with 3 being ideal).
[4] Probability, $P > 0.10$.
[5] Pig body condition score (1 = emaciated, 2 = thin, and 3 = full-bodied).
[abcd] Within a row, means without a common superscript differ ($P < 0.05$).

Table 2. Effect of litter size on piglet growth performance preweaning[1]

	Total born category[2]							
Item	≤ 11		12 to 14		≥ 15		SEM	Probability, $P <$
Litters, no.	73		77		45			
Pigs, no.	644		903		657			
Birth weight, lb	3.36[a]		3.34[ab]		3.31[b]		0.02	0.04
Sow BCS post-farrowing[3]	2.96[a]		3.01[a]		3.10[b]		0.05	0.0001
Litter total born	9.4[a]		13.0[b]		16.6[c]		0.1	0.0001
Litter live born	8.8[a]		12.0[b]		14.8[c]		0.1	0.0001
By birth weight category	% of litter	no./litter	% of litter	no./litter	% of litter	no./litter		
≤ 2.3 lb	8	0.7	11	1.3	13	1.9		
2.4 to 3.3 lb	26	2.3	41	4.9	40	6.0		
3.4 to 4.3 lb	39	3.4	37	4.4	41	6.1		
≥ 4.4 lb	27	2.4	11	1.3	6	0.9		
Litter born dead	0.6[a]		1.0[b]		1.8[c]		0.1	0.0001
Preweaning ADG, lb	0.51[a]		0.50[b]		0.50[b]		0.01	0.04
Weaning wt, lb	16.3[a]		15.9[b]		15.8[b]		0.2	0.03
Pig BCS at weaning[4]	2.86		2.84		2.85		0.02	---[5]
Preweaning mortality, %	8.6[a]		12.6[b]		11.5[ab]		1.6	0.07

[1] A total of 2,204 pigs were used to evaluate the effect of the size of the litter of origin on preweaning performance of pigs. Pigs were weaned at approximately 25 d of age, and weaning age was used as a covariate in data analysis.

[2] Results are reported as least squares means.

[3] Sow body condition score (1 = very thin to 5 = very fat, with 3 being ideal).

[4] Pig body condition score (1 = emaciated, 2 = thin, and 3 = full-bodied).

[5] Probability, $P > 0.10$.

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

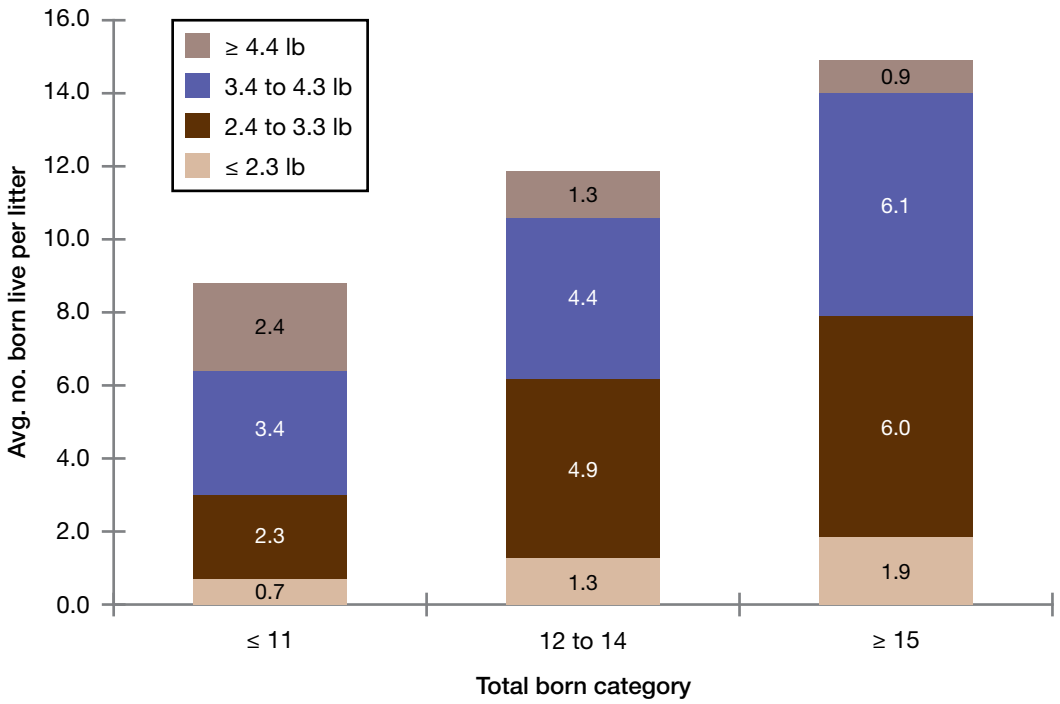

Figure 1. Relationship between total born and number of live pigs born within each birth weight category.

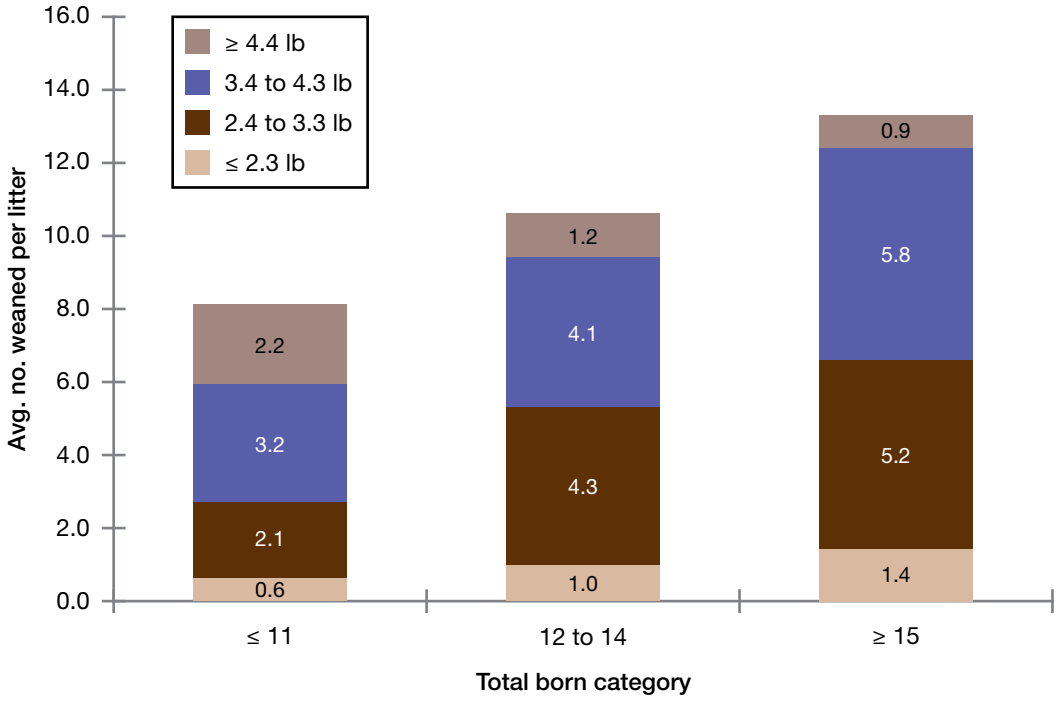

Figure 2. Relationship between total born and number of pigs weaned from each birth weight category.

Effects of Porcine Circovirus Type 2 and *Mycoplasma hyopneumoniae* Vaccination Strategy, Birth Weight, and Gender on Postweaning Performance of Growing-Finishing Pigs Reared in a Commercial Environment

J. R. Bergstrom, M. L. Potter[1], M. D. Tokach, S. C. Henry[2], S. S. Dritz[1], J. L. Nelssen, R. D. Goodband, and J. M. DeRouchey

Summary

A total of 1,995 pigs were used to evaluate the effects of two porcine circovirus type 2 (PCV2) and *Mycoplasma hyopneumoniae* (*Mhyo*) vaccination strategies and birth weight on pig performance and carcass characteristics. The first vaccination strategy (BI) was a single full dose of CircoFLEX-MycoFLEX (Boehringer Ingelheim, St. Joseph, MO) at weaning. The second strategy (Intervet) was a full dose of Circumvent and MYCOSILENCER (Intervet/Schering-Plough Animal Health, Millsboro, DE) at weaning and again 22 d later. At a commercial sow farm, all pigs born alive for 22 consecutive days were identified individually at birth with a numbered ear tag. The dam, gender, and birth weight were recorded and used to randomly allot pigs at weaning (d 0) to the PCV2/*Mhyo* vaccination treatments. The pigs were weaned into 4 consecutive nursery rooms of approximately 500 pigs each on 6 occasions during a 19-d period. Pigs from each vaccination treatment were comingled in pens within rooms throughout the study. Pigs were moved to a finishing barn on d 74. Pigs were individually weighed on d 0, 22, 44, 74, and 156 to measure growth rate. Carcass data were obtained from a subsample of 420 pigs harvested on a single day (d 167). For data analysis, individual birth weight was used to assign pigs to 7 birth weight categories, each containing a similar number of observations. Therefore, data were analyzed as a 2 × 2 × 7 factorial arrangement in a completely randomized design with main effects of vaccine strategy, gender, and weight category. As birth weight category increased, ADG increased ($P < 0.01$) during each weight period and overall. Percentage of culls and light weight pigs at market also were reduced ($P < 0.01$) as weight category increased. Overall, ADG, final BW, HCW, and backfat depth of barrows were increased ($P < 0.0001$) compared with gilts, whereas the percentage of culls and pigs < 215 lb and fat-free lean were reduced ($P < 0.0001$) compared with gilts.

From d 0 to 22 and d 44 to 74, vaccine strategy did not influence ADG. However, ADG and BW were greater ($P < 0.05$) from d 22 to 44 for pigs vaccinated once with BI rather than twice with Intervet. From d 74 to 156, pigs vaccinated twice with Intervet had greater ($P < 0.05$) ADG than those vaccinated once with BI. Thus, there were no differences between the 2 vaccination strategies for overall growth performance, carcass measurements, or mortality. These results are similar to those of previous experiments that demonstrated that vaccination with Intervet reduced performance in the nursery stage but improved performance in the finisher stage. In summary, vaccination strategy,

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piglet birth weight, and gender all influence the growth of pigs during the nursery stage, finishing stage, and overall and should be considered to enhance overall performance.

Key words: birth weight, gender, growth, PCV2, vaccination

Introduction

Porcine circoviral disease (PCVD) clinical signs include one or more of the following in growing pigs: wasting, labored breathing, diarrhea, porcine dermatitis and nephropathy syndrome, secondary bacterial infections, and high mortality. Porcine circoviral disease is caused by infection with porcine circovirus type 2 (PCV2). Recent studies (Jacela et al., 2007[3]; Horlen et al., 2008[4]) have demonstrated that the subclinical manifestation of this organism in unvaccinated pigs is also associated with significant reductions in performance of growing-finishing pigs. For this reason, many swine producers are currently vaccinating growing pigs for PCV2 with one of the commercially available vaccines.

Although improvements in the health and performance of growing-finishing pigs have been observed with the implementation of PCV2 vaccination in the field, some producers have experienced increased difficulty in getting pigs started on feed after weaning. In most of these cases, pigs have been vaccinated for PCV2 and *Mycoplasma hyopneumoniae* (*Mhyo*) at weaning. Recent work at Kansas State University (K-State; Kane et al., 2008[5]) suggests that vaccination of pigs for PCV2 and *Mhyo* at the recommended ages may be followed by a transient reduction in nursery performance.

Little work has been done to determine whether this transient reduction is characteristic of all commercially available PCV2 and *Mhyo* vaccines or vaccination strategies. Jacela et al. (2007) reported that pigs vaccinated with 2 doses (d 0 and 21) of one PCV2 vaccine were heavier than unvaccinated pigs at d 113, with pigs vaccinated with 1 dose (d 7) of a second PCV2 vaccine being intermediate. They reported that the benefits to growth from PCV2 vaccination occurred primarily during the first 113 d and did not observe any transient reductions in performance after vaccination. However, the post-vaccination weighing events occurred at lengthy intervals.

Other factors are known to influence the growth performance of pigs immediately postweaning, including management, genetics, health, nutrition, environment, gender, weaning age, and weaning weight. Many farms have demonstrated acceptable levels of nursery performance prior to the implementation of PCV2 vaccination. However, since the implementation of PCV2 vaccinations, some of these farms have reported an unacceptable number of pigs that appeared normal at weaning but began a progressive decline in body condition within the first 5 d postweaning. These "failure-to-thrive" pigs appeared to remain hydrated and alert with normal vital signs but did not respond to individualized environmental, nutritional, and antimicrobial interventions. They continued to progressively catabolize fat and muscle tissue to the point that euthanasia was the only remaining humane resolution. In these populations of pigs, it has

[3] Jacela et al., Swine Day 2007, Report of Progress 985, pp. 5-16.
[4] Horlen, K. P., S. S. Dritz, J. C. Nietfeld, S. C. Henry, R. A. Hesse, R. Oberst, M. Hays, J. Anderson, and R. R. R. Rowland. 2008. A field evaluation of pig mortality, performance and infection following commercial vaccination against porcine circovirus type 2. J. Am. Vet. Med. Assoc. 232:906-912.
[5] Kane et al., Swine Day 2008, Report of Progress 1001, pp. 14-20.

been difficult to identify the individual characteristics that may be associated with an increased risk for becoming a "failure-to-thrive" pig.

Therefore, our objective was to compare the effects of 2 vaccination strategies for mitigating the effects of PCV2 and *Mhyo* on postweaning performance. A second objective was to evaluate the combined effects of PCV2 vaccination strategy, birth weight, and gender on individual pig performance postweaning.

Procedures

Procedures used in this experiment were approved by the K-State Institutional Animal Care and Use Committee. The experiment was conducted at a commercial farm in Kansas with a segregated, 3-site production system (breeding/gestation/farrowing, nursery, and finisher). This experiment used 908 pigs (PIC 327 sired) born of first, second, and a few third parity females (Triumph TR24) and 1,047 pigs (PIC 327 sired) born of third parity and older sows (PIC 1050). All pigs were housed in environmentally controlled buildings with pens over totally slatted floors throughout the experiment.

During lactation, sows and their litters were housed in farrowing crates and given ad libitum access to food and water. For 22 consecutive days, all pigs born alive were identified with a small numbered button ear tag, and their weight and gender were recorded within 18 h after parturition. Afterward, litters were equalized and processed following normal farm procedures to optimize sow and piglet health and welfare. Every attempt was made to keep subsequent pig movement at a minimum; however, all necessary pig movement, fostering, removals, and mortalities were recorded. None of the pigs were given access to creep feed or additional supplements during lactation.

A total of 1,995 pigs were weaned (16.4 lb and 25 d of age) in 6 groups of approximately 330 to 340 pigs to fill four 500-head rooms over a 19-d period. Prior to each weaning event, pigs scheduled to be weaned were allotted to one of 2 vaccination strategies stratified by dam, gender, and birth weight. One vaccination strategy consisted of a single full dose of CircoFLEX-MycoFLEX (BI; Boehringer Ingelheim, St. Joseph, MO) administered intramuscularly at weaning. The other vaccination strategy consisted of 2 full doses of Circumvent and MYCOSILENCER (Intervet; Intervet/Schering-Plough Animal Health, Millsboro, DE) administered intramuscularly at weaning and again 22 d later. Both vaccination strategies were administered according to their product label. The BI vaccination consisted of a combination vaccine that provided an immunization for PCV2 and *Mhyo* with a single 2-mL injection. The Intervet vaccination required 2 separate injections each time of 2 mL of Circumvent and 1 mL of MYCOSILENCER to provide immunization for PCV2 and *Mhyo*, respectively. Prior to implementation of PCV2 vaccination for all growing pigs at weaning, pigs in this production system had exhibited severe clinical signs indicative of PCVD that had been confirmed by the histopathologic evaluation of tissues, and the presence of PCV2 was confirmed by immunohistochemistry. Subsequent to implementation, these clinical signs had abated and were not apparent in the growing pig population at the time this trial was performed.

At weaning (d 0), all pigs were randomly placed in nursery pens in groups of 25 pigs. Immediately afterward, the pigs were individually weighed, assigned a body condition

score (BCS; 1 = emaciated, 2 = thin, or 3 = full-bodied), and vaccinated with their designated vaccine. This resulted in the comingling of pigs from each vaccination treatment in all pens and in all rooms throughout the study. On d 22, all pigs were weighed and again assigned a BCS. Also, pigs assigned to the Intervet vaccination strategy were administered their second dose of PCV2 and *Mhyo* vaccines. During vaccination, pigs that exhibited a "fainting" reaction immediately after administration were monitored and recorded. A "fainting" reaction was defined as any pig that was briefly unable to stand, was immobile, or exhibited involuntary muscle contractions accompanied by interrupted or irregular respiration. Pigs were weighed and assigned a BCS again on d 44 and were moved to a finishing barn at approximately 74 d postweaning, where they were weighed again. Afterward, all remaining pigs were weighed once more on d 156. Throughout the study, each pen was equipped with a dry self-feeder and cup waterer, providing ad libitum access to feed and water. Pig removals and deaths, as well as the suspected reasons, were recorded throughout the study. Carcass data were obtained from a subsample of 420 pigs from one finisher room that were harvested on a single day (d 167).

For data analysis, individual birth weight was used to assign pigs to 7 birth weight categories, such that each category contained a roughly similar number of observations. The genetic background and parity of sows were confounded, so the effects of these variables on the performance of their offspring were not evaluated in this experiment. The dam (litter of origin), nursery room, and finisher room were used as random effects in the analysis. Therefore, vaccination strategy, gender, and birth weight category were used to analyze the data as a 2 × 2 × 7 factorial arrangement in a completely randomized design using the PROC MIXED procedure of SAS (SAS Institute Inc., Cary, NC). Weaning age was used as a covariate for data analysis. Individual pig was the experimental unit for the analysis of response criteria.

Results

There were no vaccination strategy × gender × birth weight category interactions observed during the study. Therefore, the effects of vaccination strategy, gender × weight category interactions, gender, and weight category are reported.

Effects of Vaccination Strategy on Subsequent Growth

From d 0 to 22, there were no differences in growth performance between the 2 vaccination strategies (Table 1). However, pigs vaccinated with Intervet had a greater ($P < 0.0001$) risk of demonstrating a "fainting" reaction to vaccination immediately following injection. The "fainting" reactions observed were not associated with any mortality.

Following the second dose of Intervet on d 22, ADG of pigs vaccinated with BI was greater ($P < 0.0001$) from d 22 to 44 than that of pigs vaccinated with Intervet. This resulted in improved ($P < 0.0001$) ADG from d 0 to 44 and d 44 BW for pigs vaccinated with BI. There were no differences in performance from d 44 to 74, but pigs vaccinated with BI had greater ($P < 0.001$) ADG from d 0 to 74 and d 74 BW.

During the finishing period (d 74 to 156), pigs vaccinated with Intervet had greater ($P < 0.05$) ADG than those vaccinated with BI. This change in the growth response

between the 2 vaccination strategies resulted in similar overall (d 0 to 156) growth performance. There were no differences in carcass characteristics, percentage of pigs less than 215 lb, or mortality between the 2 vaccination strategies.

Birth Weight Category and Gender Interactions

During the experiment, gender × weight category interactions were observed ($P < 0.03$) for ADG from d 44 to 74, percentage of culls, and percentage of pigs weighing less than 215 lb on d 156. The ADG of barrows from d 44 to 74 was 1.43, 1.53, 1.60, 1.69, 1.72, 1.76, and 1.68 for weight categories ≤ 2.5 lb, 2.6 to 3.0 lb, 3.1 to 3.3 lb, 3.4 to 3.6 lb, 3.7 to 3.9 lb, 4.0 to 4.4 lb, and ≥ 4.5 lb, respectively. The ADG of gilts from d 44 to 74 was 1.33, 1.47, 1.51, 1.51, 1.53, 1.54, and 1.60, respectively. The interaction occurred because the rate of increase in ADG as weight category increased was not consistent for both genders. Despite the interaction, ADG was greater ($P < 0.01$) for barrows than gilts and for heavier weight categories compared with lighter categories.

The percentage of culls and pigs weighing less than 215 lb for barrows was 7.62%, 7.97%, 4.70%, 3.61%, 4.40%, 1.65%, and 3.25% for weight categories ≤ 2.5 lb, 2.6 to 3.0 lb, 3.1 to 3.3 lb, 3.4 to 3.6 lb, 3.7 to 3.9 lb, 4.0 to 4.4 lb, and ≥ 4.5 lb, respectively. Percentage of culls and pigs weighing less than 215 lb for gilts was 27.50%, 13.62%, 4.52%, 10.97%, 2.05%, 3.21%, and 0.96%, respectively. The interaction occurred because the percentage of culls and pigs less than 215 lb was significantly greater in lighter weight categories for gilts, but the percentage of culls and pigs less than 215 lb was similar for barrows and gilts in heavier weight categories. In spite of the interaction, the percentage of culls and pigs weighing less than 215 lb was less ($P < 0.001$) for barrows and pigs of heavier weight categories.

The Effects of Birth Weight Category on Subsequent Growth

As expected, birth weight increased ($P < 0.0001$) as weight category increased. Also, preweaning ADG, weaning weight, and BCS at weaning were improved ($P < 0.0001$) for pigs as weight category increased (Table 2).

After weaning, pigs in increasing weight categories had improved ($P < 0.0001$) ADG and final BW for all periods (d 0 to 22, d 22 to 44, d 0 to 44, d 44 to 74, d 0 to 74, d 74 to 156, and d 0 to 156). Postweaning mortality was not affected by weight category. Pigs of heavier weight categories also had greater ($P < 0.0001$) HCW compared with lighter weight category pigs. However, there were no differences in the backfat depth, loin depth, and fat-free lean of pigs subsampled from the different weight categories in this experiment.

The Effects of Gender on Subsequent Growth

From d 0 to 22, ADG, d 22 BW, and d 22 BCS were greater ($P < 0.01$) for gilts than for barrows (Table 3). Although there were no differences in ADG from d 22 to 44 or d 44 BW, there was a tendency for ($P < 0.06$) gilts to have greater ADG from d 0 to 44.

However, for d 44 to 74 and the entire nursery period (d 0 to 74), ADG and d 74 BW were improved ($P < 0.001$) for barrows. The ADG of barrows was also greater ($P < 0.0001$) during the finishing period (d 74 to 156) than that of gilts.

Overall (d 0 to 156), ADG, final BW, HCW, and backfat depth of barrows were increased ($P < 0.0001$), whereas the percentage fat-free lean was reduced ($P < 0.0001$) compared with gilts. Postweaning mortality of barrows and gilts was not significantly different.

Discussion

Although there was not an unvaccinated control group in the current experiment, the differences observed between the 2 vaccination strategies are similar to previous nursery experiments (Kane et al., 2008; Potter et al., 2009[6]; Shelton et al., 2009[7]). Pigs vaccinated in the current experiment with Intervet on d 0 and 22 experienced a transient reduction in growth after administration of the second dose. Kane et al. (2008) reported a transient reduction in growth after a single dose of Circumvent, but the pigs in their experiment were primarily maternal-line (PIC 1050) barrows, considerably lighter at weaning, and vaccinated with Respisure 1 (Pfizer Animal Health, New York, NY) at the same time. Potter et al. (2009) observed similar differences in the growth of pigs vaccinated with 2 doses of Circumvent and 1 dose of CircoFLEX as in the current experiment. It is unclear whether the growth of pigs vaccinated with BI in the current experiment was affected by vaccination, but Potter et al. (2009) did not observe any differences in nursery growth between pigs vaccinated with CircoFLEX and the controls.

In spite of the negative effect of the Intervet vaccination strategy on nursery performance, the growth of these pigs in the finisher was better than that of pigs vaccinated using the BI strategy. As a result, overall performance was not different between the 2 vaccination strategies. Although clinical PCVD was not noted in any of the growing pig groups, this suggests that the Intervet strategy may have provided more effective immunity during the finisher phase, which led to better growth performance. The end result was the same, but the similar efficacy of the two vaccination strategies is worthy of further investigation.

These data demonstrate the importance of increasing birth weight for improving the lifetime growth performance of pigs (Figures 1 and 2). Although identifying differences in preweaning mortality between birth weight categories was not undertaken for this report, it is apparent that management strategies to increase the birth weight and growth performance of the lightest 30% of pigs born may be beneficial.

The overall differences in growth and carcass characteristics between barrows and gilts were typical and not unexpected. These data reinforce the potential need for differing management strategies to optimize the performance of barrows and gilts within a population (e.g., split-sex feeding, different pig flows, different feeders, etc.). Although there were no differences in postweaning mortality, the slower overall growth rate of gilts resulted in twice as many gilts being culled for weight than barrows. This was particularly problematic for the gilts in this study that had a birth weight ≤ 2.5 lb. These gilts were nearly 4 times more likely to be culled because of poor growth rate than barrows of similar birth weight.

[6] Potter et al., Swine Day 2009, Report of Progress 1020, pp. 21-27.
[7] Shelton et al., Swine Day 2009, Report of Progress 1020, pp. 28-XX.

In conclusion, vaccinating pigs for PCV2 and *Mhyo* with different vaccination strategies resulted in differences in growth rate in the nursery and finishing phases but equal performance overall. These data also illustrate the biological differences in growth among pigs of differing birth weights and between barrows and gilts. A greater understanding of these differences, and the implementation of management strategies to mitigate their effects, may result in significant improvements in overall performance.

Table 1. Effect of PCV2 and *Mhyo* vaccine strategy on growth and carcass characteristics of pigs[1]

	PCV2 and *Mhyo* vaccination strategy[2]			
Growth performance	BI	Intervet	SEM	Probability, $P <$
Pigs, no.	1,006	989		
Preweaning ADG, lb[3]	0.52	0.52	0.01	---[4]
Initial birth wt, lb	3.51	3.50	0.01	---
Weaning age, d	25.10	25.05	0.44	---
ADG, lb				
d 0 to d 22	0.74	0.74	0.03	---
d 22 to 44	1.43	1.36	0.07	0.0001
d 0 to d 44	1.09	1.05	0.02	0.0001
d 44 to 74	1.58	1.56	0.04	---
d 0 to d 74	1.28	1.25	0.02	0.001
d 74 to 156	1.89	1.92	0.03	0.05
d 0 to 156	1.61	1.61	0.02	---
Pig weight, lb				
Weaning (d 0)	16.54	16.49	0.15	---
d 22	32.69	32.54	2.68	---
d 44	63.71	61.97	3.55	0.0001
d 74	111.06	108.73	3.33	0.001
d 156	268.21	267.88	5.79	---
Body condition score[5]				
d 0	2.86	2.86	0.02	---
d 22	2.98	2.99	0.01	---
d 44	3.00	3.00	0.01	---
"Fainting" reaction, %	0.00	1.58	0.29	0.0001
Cull and < 215 lb BW, %	6.80	6.80	1.50	---
Postweaning mortality, %	1.67	1.46	0.41	---
Carcass characteristics[6]				
Pigs, no.	213	205		
Final BW (181 d of age), lb	267.7	270.3	2.88	---
HCW (192 d of age), lb	206.8	208.9	1.97	---
Backfat depth, mm	17.46	18.13	0.38	---
Loin depth, mm	56.78	57.66	0.53	---
Fat-free lean, %	52.22	51.91	0.24	---

[1] A total of 1,995 pigs were used to evaluate the effects of PCV2 and *Mhyo* vaccine strategy on pig performance and carcass characteristics.
[2] PCV2 and *Mhyo* vaccine strategies tested were: BI, a single full dose of CircoFLEX-MycoFLEX at d 0, and Intervet, a full dose of Circumvent and MYCOSILENCER at d 0 and 22.
[3] Results are reported as least squares means.
[4] Probability, $P > 0.10$.
[5] 1 = emaciated, 2 = thin, or 3 = full-bodied.
[6] Carcass data were obtained from a subsample of 420 pigs harvested in a single day (d 167 postweaning).

Table 2. Effect of pig birth weight on subsequent growth and carcass characteristics[1]

	Birth weight category, lb							
Growth performance	≤ 2.5	2.6 - 3.0	3.1 - 3.3	3.4 - 3.6	3.7 - 3.9	4.0 - 4.4	≥ 4.5	SEM
Pigs, no.	283	325	287	314	270	275	239	
Preweaning ADG, lb[2]	0.40[a]	0.49[b]	0.50[b]	0.52[c]	0.54[c]	0.58[d]	0.60[d]	0.01
Initial birth wt, lb	2.18[a]	2.82[b]	3.21[c]	3.50[d]	3.80[e]	4.18[f]	4.83[g]	0.01
ADG, lb								
d 0 to d 22	0.59[a]	0.67[b]	0.73[bc]	0.75[cd]	0.78[d]	0.82[e]	0.86[f]	0.03
d 22 to 44	1.17[a]	1.30[b]	1.37[c]	1.41[d]	1.47[e]	1.48[e]	1.56[f]	0.07
d 0 to d 44	0.88[a]	0.98[b]	1.05[c]	1.08[d]	1.12[e]	1.15[e]	1.21[f]	0.02
d 44 to 74	1.39[a]	1.51[b]	1.56[bc]	1.60[cd]	1.62[d]	1.65[d]	1.64[d]	0.04
d 0 to d 74	1.09[a]	1.19[b]	1.25[c]	1.29[d]	1.32[e]	1.35[ef]	1.38[f]	0.02
d 74 to 156	1.76[a]	1.87[b]	1.91[bc]	1.90[bc]	1.95[cd]	1.98[d]	1.98[d]	0.03
d 0 to 156	1.45[a]	1.55[b]	1.60[c]	1.61[c]	1.66[d]	1.69[de]	1.71[e]	0.02
Pig weight, lb								
Weaning (d 0)	12.26[a]	15.05[b]	15.78[c]	16.70[d]	17.33[e]	18.68[f]	19.81[g]	0.23
d 22	24.93[a]	29.51[b]	31.56[c]	33.00[d]	34.25[e]	36.56[f]	38.51[g]	2.70
d 44	50.39[a]	57.75[b]	61.18[c]	63.51[d]	66.14[e]	68.72[f]	72.20[g]	3.60
d 74	92.23[a]	103.10[b]	107.94[c]	111.61[d]	114.95[e]	118.10[f]	121.33[g]	3.45
d 156	239.22[a]	258.09[b]	264.99[c]	268.80[c]	276.35[d]	282.77[e]	286.09[e]	6.08
Body condition score[3]								
d 0	2.73[a]	2.85[b]	2.88[bc]	2.88[bc]	2.85[b]	2.93[d]	2.92[cd]	0.03
d 22	2.98	2.97	2.99	2.98	2.99	2.98	2.99	0.01
d 44	3.00	3.00	3.00	3.00	3.00	3.00	3.00	0.01
Cull and < 215 lb BW, %	17.38[a]	10.48[b]	4.95[c]	7.35[bc]	3.09[cd]	2.35[cd]	1.77[d]	2.15
Postweaning mortality, %	1.15	1.21	1.02	2.71	1.16	1.96	1.73	0.84

continued

Table 2. Effect of pig birth weight on subsequent growth and carcass characteristics[1]

	Birth weight category, lb							
Growth performance	≤ 2.5	2.6 - 3.0	3.1 - 3.3	3.4 - 3.6	3.7 - 3.9	4.0 - 4.4	≥ 4.5	SEM
Carcass characteristics[4]								
Pigs, no.	58	69	62	60	56	59	56	
Final BW (181 d of age), lb	258.73^{a}	264.37^{b}	269.74^{b}	269.33^{bc}	270.15^{bc}	274.96^{cd}	277.70^{d}	3.60
HCW (192 d of age), lb	195.75^{a}	204.43^{b}	209.66^{bc}	209.47^{bc}	210.98^{bc}	210.81^{bc}	214.96^{c}	2.93
Backfat depth, mm	17.83	18.17	18.55	17.98	17.66	17.45	17.09	0.62
Loin depth, mm	55.11	56.62	57.29	57.66	58.51	57.12	58.27	0.97
Fat-free lean, %	51.99	51.89	51.55	51.99	52.23	52.20	52.51	3.94

[1] A total of 1,995 pigs were used to evaluate the effects of birth weight (7 categories) on pig performance and carcass characteristics.
[2] Results are reported as least squares means.
[3] 1 = emaciated, 2 = thin, or 3 = full-bodied.
[4] Carcass data were obtained from a subsample of 420 pigs harvested in a single day (d 167 postweaning).
[abcdefg] Within a row, means without a common superscript differ ($P < 0.05$).

Table 3. Effect of gender on growth and carcass characteristics of pigs[1]

	Gender			
Growth performance	Barrows	Gilts	SEM	Probability, $P <$
Pigs, no.	980	1,015		
Preweaning ADG, lb[2]	0.52	0.52	0.01	---[3]
Initial birth wt, lb	3.51	3.50	0.01	---
Weaning age, d	25.09	25.06	0.44	---
ADG, lb				
d 0 to d 22	0.73	0.76	0.03	0.0001
d 22 to 44	1.40	1.39	0.07	---
d 0 to d 44	1.06	1.08	0.02	0.06
d 44 to 74	1.63	1.50	0.04	0.0001
d 0 to d 74	1.29	1.25	0.02	0.0001
d 74 to 156	2.02	1.80	0.03	0.0001
d 0 to 156	1.68	1.54	0.02	0.0001
Pig weight, lb				
Weaning (d 0)	16.49	16.54	0.15	---
d 22	32.24	32.99	2.68	0.01
d 44	62.49	63.19	3.55	---
d 74	111.44	108.35	3.33	0.0001
d 156	278.87	257.22	5.79	0.0001
Body condition score[4]				
d 0	2.87	2.86	0.02	---
d 22	2.98	2.99	0.01	0.01
d 44	3.00	3.00	0.01	---
Cull and < 215 lb BW, %	4.60	8.90	1.50	0.001
Postweaning mortality, %	1.73	1.40	0.41	---
Carcass characteristics[5]				
Pigs, no.	203	217		
Final BW (181 d of age), lb	279.33	258.65	2.87	0.0001
HCW (192 d of age), lb	215.04	200.65	1.95	0.0001
Backfat depth, mm	19.66	15.93	0.38	0.0001
Loin depth, mm	57.04	57.41	0.53	---
Fat-free lean, %	50.90	53.23	0.24	0.0001

[1] A total of 1,995 pigs were used to evaluate the effects of gender on pig performance and carcass characteristics.
[2] Results are reported as least squares means.
[3] Probability, $P > 0.10$.
[4] 1 = emaciated, 2 = thin, or 3 = full-bodied.
[5] Carcass data were obtained from a subsample of 420 pigs harvested in a single day (d 167 postweaning).

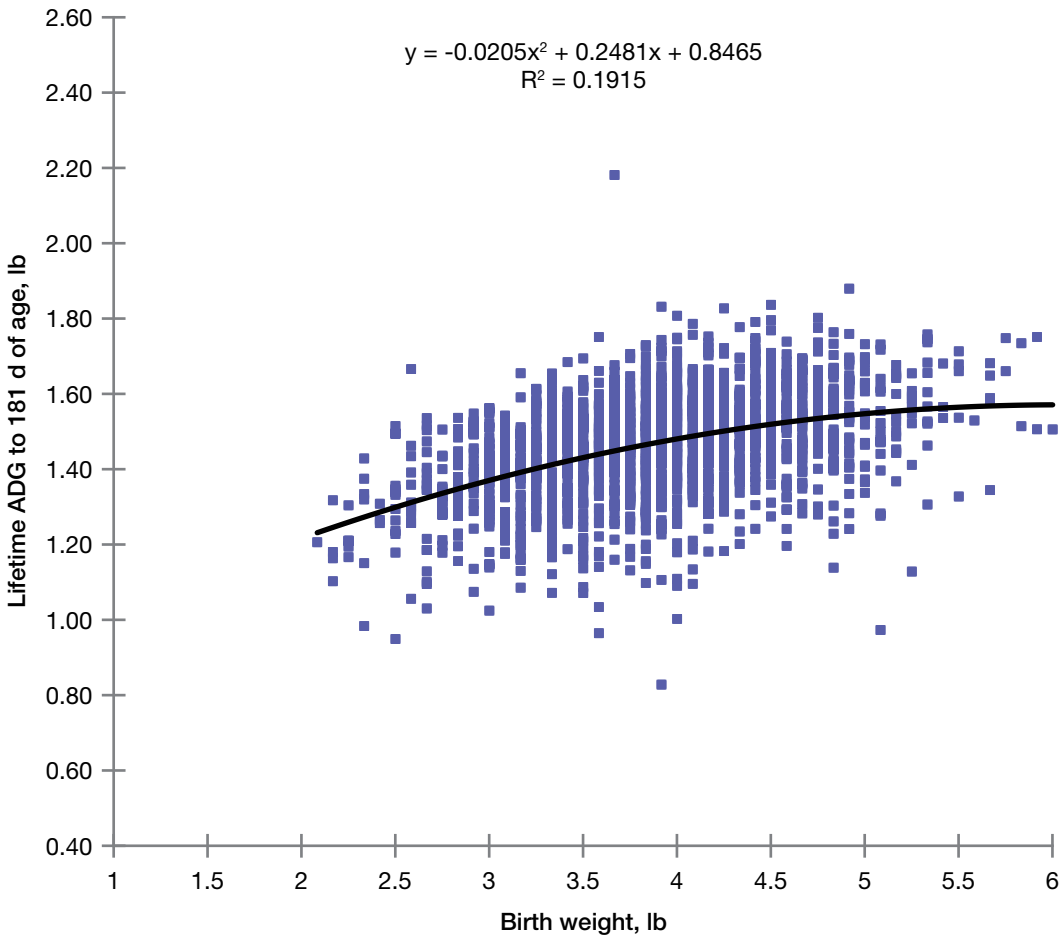

Figure 1. Relationship of birth weight and lifetime ADG.

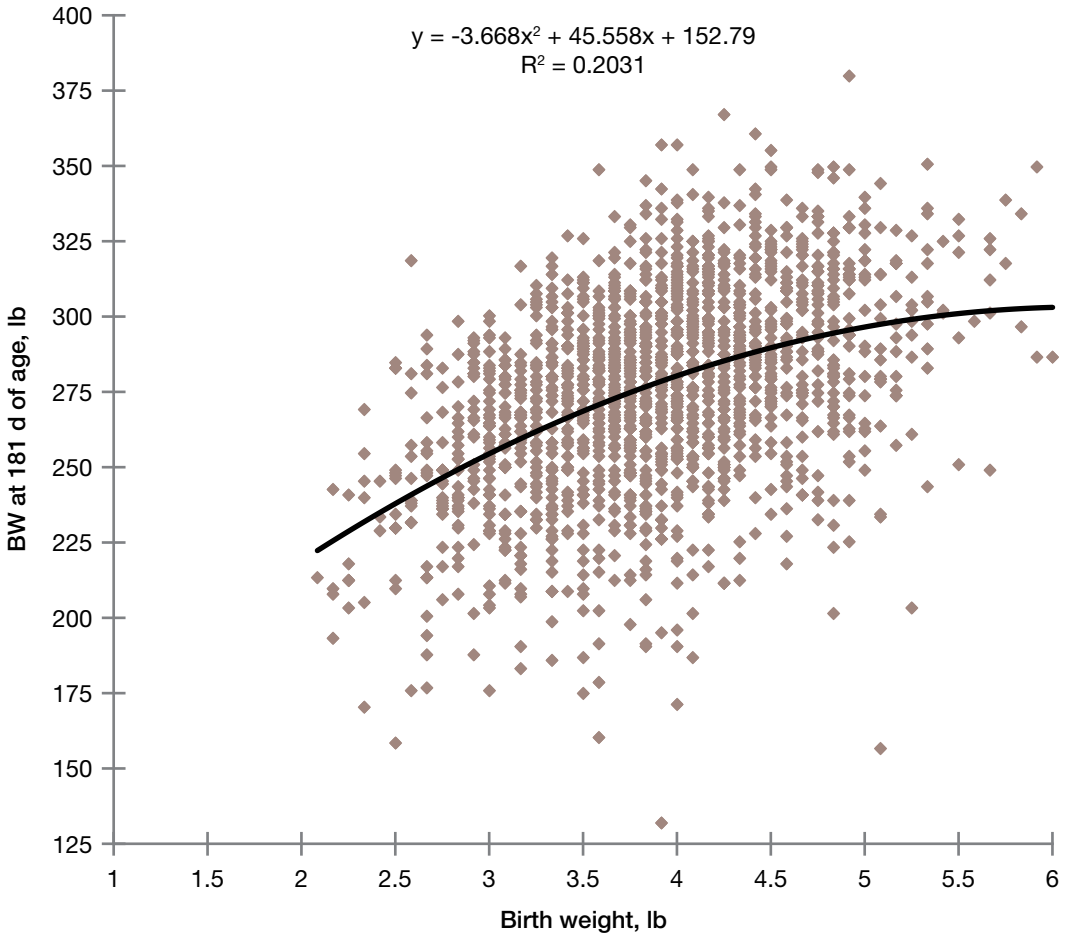

Figure 2. Relationship of birth weight and BW at 181 d of age.

Effects of Porcine Circovirus Type 2 and *Mycoplasma hyopneumoniae* Vaccines on Nursery Pig Performance

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Summary

A total of 360 weanling barrows (PIC 1050, 21 d of age and 13.0 lb) were used in a 35-d study to evaluate the effects of porcine circovirus type 2 (PCV2) and *Mycoplasma hyopneumoniae* (*M. hyo)* vaccines on nursery pig growth performance. Two commercial PCV2 vaccines were evaluated in this study: (1) a 2-dose product, Circumvent PCV (Circumvent; Intervet/Schering-Plough Animal Health, Millsboro, DE) and (2) a 1-dose product, Ingelvac CircoFLEX (CircoFLEX; Boehringer Ingelheim Vetmedica, Inc, St. Joseph, MO). For the *M. hyo* vaccine, RespiSure (Pfizer Animal Health, New York, NY), a single 2-dose product, was used. At weaning (d 0), pens of pigs were blocked by average pig weight and randomly allotted to 1 of 6 treatments in a 3 × 2 factorial arrangement composed of a combination of PCV2 vaccine (Circumvent, CircoFLEX, or non-PCV2-vaccinated control) and *M. hyo* vaccine (RespiSure or non-*M. hyo*-vaccinated control). There were 5 pigs per pen and 12 pens per PCV2 × *M. hyo* vaccine treatment. All vaccines were administered according to label directions—CircoFLEX at weaning and Circumvent and RespiSure at weaning and 21 d later. Common diets were fed by phase to all pigs.

There were no PCV2 × *M. hyo* vaccine interactions for any response criteria. Overall, pigs vaccinated with Circumvent had decreased ADG ($P < 0.02$) and ADFI ($P \leq 0.01$) compared with CircoFLEX-vaccinated and control pigs, respectively. On d 35, Circumvent-vaccinated pigs weighed less (42.9 lb, $P < 0.01$) than pigs vaccinated with CircoFLEX (44.4 lb) or control pigs (44.4 lb). Pigs vaccinated with RespiSure had decreased ADG compared with control pigs ($P \leq 0.05$) from d 14 to 21 and d 21 to 25. On d 35, RespiSure-vaccinated pigs tended to weigh less (43.5 lb, $P = 0.06$) and have lower ADFI ($P = 0.06$) than controls (wt = 44.3 lb). These data indicate that PCV2 and *M. hyo* vaccination can independently reduce feed intake and performance of nursery pigs and that the PCV2 vaccine effect is product dependent. Although PCV2 and *M. hyo* vaccines are known to improve finishing performance, their negative impact on nursery performance must be considered when implementing vaccine strategies.

Key words: growth, *Mycoplasma*, PCV2, vaccination

Introduction

Porcine circovirus type 2 (PCV2) and *Mycoplasma hyopneumoniae* (*M. hyo)* vaccines are routinely administered to pigs during the nursery phase to lessen the severity of disease during the finishing period. Although vaccines for both of these pathogens have been shown to reduce severity of disease in the finishing phase, the impact on the

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nursery pig has not been well characterized. In addition, as use of PCV2 vaccines has increased, field reports have emerged indicating that producers are having increased difficulty starting or maintaining weaned pigs on feed. Speculation that nursery pig vaccines may contribute to this problem prompted an initial study at Kansas State University (K-State) to investigate the role of PCV2 and *M. hyo* vaccines in combination on growth performance (Kane et al., 2008[2]). Results from that study demonstrated that feed intake and subsequent gain was decreased after initial vaccination with a 2-dose PCV2 vaccine product administered concurrently with a 1-dose *M. hyo* vaccine product. However, there is limited research on the effects of different vaccine products on feed intake. Therefore, the objective of this study was to determine effects of 2 commercial PCV2 vaccines and a *M. hyo* vaccine on nursery pig growth performance.

Procedures

Procedures used in this study were approved by the K-State Institutional Animal Care and Use Committee. A total of 360 weanling barrows (PIC 1050, 21 d of age and 13.0 lb) were used in a 35-d growth trial at the K-State Segregated Early Wean Facility. Pens were equipped with a single cup waterer and a 4-hole self-feeder that provided pigs with ad libitum access to water and feed. At weaning (d 0), pens of pigs were blocked by average pig weight and randomly allotted to 1 of 6 treatments in a 3 × 2 factorial arrangement of PCV2 vaccine and *M. hyo* vaccine. The PCV2 vaccine treatments were: a 2-dose product, Circumvent PCV (Circumvent; Intervet/Schering-Plough Animal Health, Millsboro, DE); a 1-dose product, Ingelvac CircoFLEX (CircoFLEX; Boehringer Ingelheim Vetmedica, Inc., St. Joseph, MO); and a non-PCV2-vaccinated control. The *M. hyo* vaccine treatments were: a 2-dose product, RespiSure (Pfizer Animal Health, New York, NY) and a non-*M. hyo*-vaccinated control. There were initially 5 pigs per pen and 12 pens per PCV2 vaccine × *M. hyo* vaccine treatment. All 3 commercially available vaccines were administered according to label directions. Pigs in the CircoFLEX group were administered 1 mL as an intramuscular injection on d 0. Pigs in the Circumvent treatment group received intramuscular injections of 2 mL on d 0 and 21. A single *M. hyo* vaccine product was tested; therefore, pigs in the RespiSure treatment group received intramuscular injections of 2 mL on d 0 and 21. All pigs were fed common diets throughout the trial. Initially, 1 lb/pig SEW diet was budgeted, followed by ad libitum access to a transition diet until d 8. Phase 2 diets were fed from d 8 to d 21, and Phase 3 diets were fed from d 21 to the end of the trial. Feeders were emptied on d 8 and 21 prior to feeding the Phase 2 and 3 diets, respectively. Pigs were weighed and feed disappearance was determined on d 0, 4, 8, 14, 21, 25, 29, and 35 to calculate ADG, ADFI, and F/G.

Data were analyzed as a randomized complete block design using the GLIMMIX procedure of SAS (SAS Institute Inc., Cary, NC). Fixed effects included PCV2 vaccine, *M. hyo* vaccine, and their interaction. Weaning weight, the blocking factor, was a random effect. Pen was considered the experimental unit for this analysis. Differences between treatments were determined by using least squares means ($P < 0.05$).

Results and Discussion

There were no PCV2 × *M. hyo* vaccine interactions for the response criteria evaluated in this study. Evaluation of the main effects of PCV2 vaccine (Table 1) revealed

[2] Kane et al., Swine Day 2008, Report of Progress 1001, pp. 14-20.

that growth rate was unaffected ($P \geq 0.01$) by PCV2 treatment during the first 21 d of the trial. Following the initial vaccination (d 0 to 8), Circumvent-vaccinated pigs had decreased ($P = 0.01$) ADFI compared with CircoFLEX-vaccinated pigs, and ADFI for control pigs was intermediate. During the d 8 to 14 period, ADFI was decreased ($P < 0.03$) for Circumvent-vaccinated pigs compared with control and CircoFLEX-vaccinated pigs. Gain was similar ($P = 0.81$) among PCV2 vaccine treatment groups for the d 14 to 21 period. However, F/G was improved ($P = 0.02$) for Circumvent-vaccinated pigs from d 14 to 21 compared with CircoFLEX-vaccinated pigs, and the control group had intermediate F/G.

From d 21 to 29, pigs vaccinated with Circumvent had decreased ($P < 0.01$) ADG and ADFI compared with both the control and CircoFLEX-vaccinated pigs. There was no difference ($P \geq 0.34$) in ADG or ADFI between the control pigs and pigs vaccinated with CircoFLEX. From d 29 to 35, PCV2 treatment did not affect ($P \geq 0.17$) ADG or F/G, although Circumvent-vaccinated pigs had numerically lower ADFI relative to control or CircoFLEX-vaccinated pigs.

Overall (d 0 to 35), growth was decreased ($P = 0.02$) in pigs vaccinated with Circumvent compared with non-PCV2-vaccinated control pigs, with the majority of the effect occurring following the second vaccination. Pigs vaccinated with CircoFLEX had a similar ($P = 0.85$) overall rate of gain compared with the control group and grew faster ($P < 0.01$) than pigs vaccinated with Circumvent. The decreased growth rate for Circumvent-vaccinated pigs is attributable to their reduced ($P \leq 0.01$) feed consumption compared with the control and CircoFLEX-vaccinated pigs. There was no difference ($P = 0.34$) in ADFI observed among the CircoFLEX-vaccinated pigs compared with control pigs. This performance disparity resulted in Circumvent-vaccinated pigs weighing less (42.9 lb, $P < 0.01$) on d 35 than CircoFLEX-vaccinated pigs (44.4 lb) or control pigs (44.4 lb).

In the 21 d following the first vaccination, performance of pigs vaccinated with RespiSure did not differ from that of control pigs (Table 2). After the second RespiSure vaccination, ADG and ADFI were lower ($P \leq 0.02$) for vaccinated pigs compared with controls, and F/G was unaffected ($P = 0.80$) by *M. hyo* treatment. The negative effects of RespiSure vaccination on intake and ADG following the second administration resulted in RespiSure-vaccinated pigs having a tendency ($P = 0.10$) to gain less and have decreased ($P = 0.06$) ADFI from d 0 to 35 compared with control pigs. The poorer growth performance of the RespiSure-vaccinated pigs resulted in a trend ($P = 0.06$) for these pigs to have lighter d-35 weights than control pigs.

Compared with performance of control pigs in the respective treatment groups, the pattern of negative effects was similar for both Circumvent and RespiSure vaccines, whereas CircoFLEX-vaccinated pigs did not appear to experience negative impacts from vaccination. For the Circumvent-vaccinated and RespiSure-vaccinated pigs, the biggest reduction in performance was observed after the second vaccination.

Although there was no PCV2 × *M. hyo* vaccine interaction, d-35 weights for the 6 different PCV2 × *M. hyo* treatments measured against non-vaccinated control pigs showed that approximately a 1.5-lb reduction in weight may be due to Circumvent

vaccine and an additional 0.8 lb reduction in weight may be due to RespiSure vaccination. Therefore, when Circumvent and RespiSure products were used in conjunction, these negative effects were additive and resulted in a 2.5 lb lighter d-35 weight (Figure 1).

These findings support previous research conducted at K-State (Kane et al., 2008) in which following an initial vaccination with both Circumvent PCV and RespiSure-One (Pfizer Animal Health, New York, NY), vaccinated pigs had lower ($P < 0.01$) ADG and ADFI (d 4 to 8 and d 0 to 8) and weighed less ($P < 0.01$) on d 8 than pigs not vaccinated until d 8. In the current study, this difference in feed intake for Circumvent-vaccinated pigs was noted within the first 21 d after initial vaccination, and the lower feed consumption continued and negatively affected growth rate following the second vaccination. The second Circumvent vaccination appears to be an additional stressor and has substantial negative effects on nursery performance that are not recovered from within 14 d after the second vaccination. It is likely that vaccines factor into how pigs start or are maintained on feed, although the severity of the response as well as its timing may be vaccine dependent. We believe the effects on feed intake noted in this study may be a factor in field reports that have indicated that producers are having increased difficulty starting or maintaining pigs on feed postweaning.

These data demonstrate that nursery pig performance differs because of the PCV2 vaccine product selected and *M. hyo* vaccination. However, this study was not designed to evaluate efficacy of these products. Therefore, no conclusions as to vaccine selection for best control of clinical disease from these infections should be drawn. However, these data indicate that PCV2 and *M. hyo* vaccination can independently reduce feed intake and performance of nursery pigs and that the PCV2 vaccine effect is product dependent. Although PCV2 and *M. hyo* vaccines are known to improve finishing performance, their negative effect on nursery performance must be considered when implementing vaccine strategies.

Table 1. Effect of PCV2 vaccines on nursery pig growth performance, feed intake, and feed efficiency[1]

	PCV2 treatment[2]			
Item	Control	Circumvent	CircoFLEX	SEM
d 0 to 8				
ADG, lb	0.28	0.26	0.29	0.02
ADFI, lb	0.28[ab]	0.26[a]	0.29[b]	0.01
F/G	1.02	1.03	1.04	0.03
d 8 to 14				
ADG, lb	0.73	0.68	0.70	0.03
ADFI, lb	0.96[a]	0.87[b]	0.95[a]	0.04
F/G	1.31	1.29	1.37	0.03
d 14 to 21				
ADG, lb	1.04	1.03	1.02	0.03
ADFI, lb	1.55	1.48	1.54	0.04
F/G	1.50[ab]	1.45[a]	1.52[b]	0.03
d 21 to 29				
ADG, lb	1.07[a]	0.96[b]	1.10[a]	0.03
ADFI, lb	1.70[a]	1.57[b]	1.72[a]	0.04
F/G	1.60	1.65	1.58	0.03
d 29 to 35				
ADG, lb	1.50	1.48	1.50	0.04
ADFI, lb	2.20	2.16	2.25	0.06
F/G	1.47	1.46	1.51	0.02
d 0 to 35				
ADG, lb	0.89[a]	0.85[b]	0.90[a]	0.02
ADFI, lb	1.29[a]	1.23[b]	1.32[a]	0.03
F/G	1.45	1.45	1.47	0.01
Weight, lb				
d 0	12.9	13.0	13.0	0.6
d 21	26.9	26.3	26.6	0.9
d 35	44.4[a]	42.9[b]	44.4[a]	1.2

[1] Results are reported as least squares means. A total of 360 barrows (PIC 1050) were used in a 35-d study. There were 5 pigs per pen and 24 pens per PCV2 treatment.

[2] PCV2 vaccine treatments were: 2 groups of vaccinates receiving either 2 mL Circumvent PCV administered intramuscularly on d 0 and 21 or 1 mL Ingelvac CircoFLEX administered intramuscularly on d 0 and a non-PCV2-vaccinated control group.

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

Table 2. Effect of *M. hyo* vaccines on nursery pig growth performance, feed intake, and feed efficiency[1]

	M. hyo treatment[2]			
Item	Control	RespiSure	SEM	Probability, *P* <
d 0 to 8				
ADG, lb	0.28	0.27	0.01	0.44
ADFI, lb	0.28	0.27	0.01	0.40
F/G	1.03	1.03	0.03	0.88
d 8 to 14				
ADG, lb	0.69	0.72	0.03	0.10
ADFI, lb	0.93	0.93	0.04	0.82
F/G	1.35	1.29	0.02	0.06
d 14 to 21				
ADG, lb	1.05	1.01	0.03	0.05
ADFI, lb	1.54	1.51	0.04	0.25
F/G	1.47	1.50	0.02	0.23
d 21 to 29				
ADG, lb	1.07	1.01	0.03	0.02
ADFI, lb	1.71	1.62	0.04	<0.01
F/G	1.61	1.60	0.02	0.80
d 29 to 35				
ADG, lb	1.51	1.48	0.04	0.31
ADFI, lb	2.24	2.16	0.06	0.03
F/G	1.49	1.47	0.02	0.26
d 0 to 35				
ADG, lb	0.89	0.87	0.02	0.10
ADFI, lb	1.30	1.26	0.03	0.06
F/G	1.46	1.45	0.01	0.57
Weight, lb				
d 0	12.9	13.0	0.6	0.22
d 21	26.7	26.5	0.9	0.50
d 35	44.3	43.5	1.2	0.06

[1] Results are reported as least squares means. A total of 360 barrows (PIC 1050) were used in a 35-d study. There were 5 pigs per pen and 36 pens per *M. hyo* treatment.

[2] *M. hyo* vaccine treatments were: Vaccinates receiving 2 mL RespiSure administered intramuscularly on d 0 and 21 and a non-*M. hyo*-vaccinated control group.

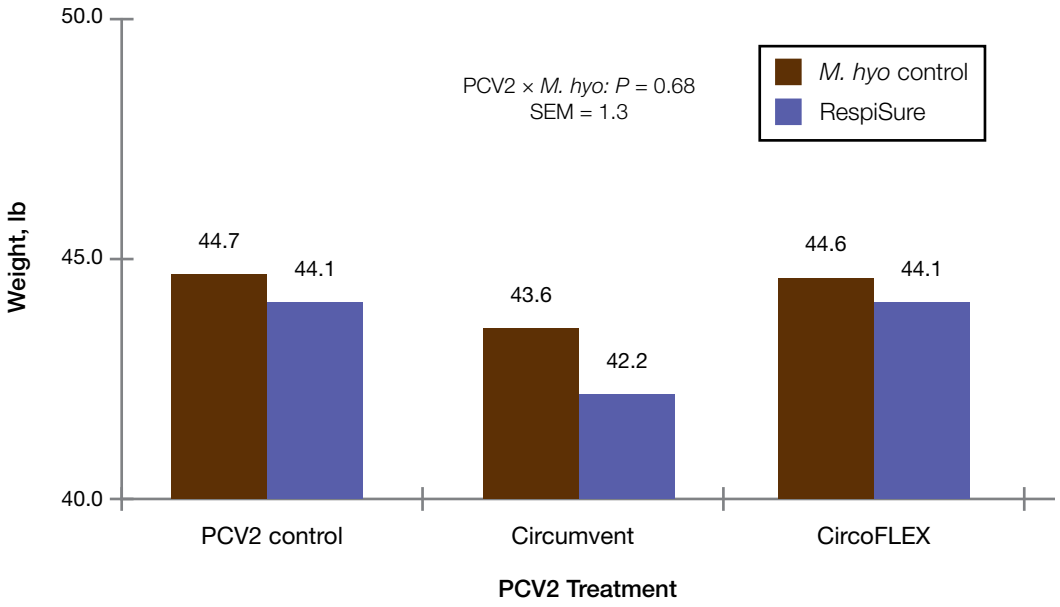

Figure 1. Effect of PCV2 and *M. hyo* vaccination on d-35 pig weight.
PCV2 vaccine treatments were: PCV2 controls (No PCV2 vaccine), Circumvent (pigs vaccinated with 2 mL Circumvent PCV administered intramuscularly on d 0 and 21), and CircoFLEX (pigs vaccinated with 1 mL Ingelvac CircoFLEX administered intramuscularly on d 0). *M. hyo* vaccine treatments were: *M. hyo* controls (No *M. hyo* vaccine) and RespiSure (pigs vaccinated with 2 mL RespiSure administered intramuscularly on d 0 and 21.)

Effects of Porcine Circovirus Type 2 Vaccination on Nursery and Finishing Pig Performance under a PRRS Challenge[1,2]

N. W. Shelton, M. D. Tokach, S. S. Dritz[3], R. D. Goodband, J. L. Nelssen, J. M. DeRouchey, and J. L. Usry[4]

Summary

A total of 2,571 barrows and gilts (PIC 337 × 1050) were used to determine the effects of porcine circovirus type 2 vaccine (PCV2) on nursery and finishing pigs that were challenged with porcine respiratory and reproductive syndrome (PRRS). Treatments were arranged in a 2 × 2 factorial design with main effects of gender (barrow or gilt) and vaccine (PCV2 vaccinates or non-vaccinates). Vaccinated pens received 2 doses of commercial PCV2 vaccine (Circumvent PCV, Intervet Inc., Millsboro, DE) according to label directions on d 1 and 22 in the nursery. All pigs were also inoculated on d 30 with serum containing PRRS virus as part of this production system's protocol. Barns were double stocked from d 0 to 51. On d 51, gilts were moved to an adjacent facility and barrows were split into 2 pens.

In the period after the initial PCV2 vaccination (d 0 to 15), no difference in ADG, ADFI, or F/G was observed ($P > 0.13$) between genders or between vaccinates and non-vaccinates. However, in the period after the second PCV2 vaccination (d 15 to 29), vaccinated pigs had decreased ($P < 0.02$) ADG compared with non-vaccinates as a result of decreased ($P < 0.04$) ADFI. Gilts also had increased ($P < 0.04$) ADG and ADFI compared with barrows. In the period after all pigs were inoculated with PRRS virus (d 29 to 50), PCV2 vaccinates had improved ($P < 0.001$) F/G over non-vaccinates and a trend ($P < 0.08$) for improved ADG. Gilts had poorer ($P < 0.01$) F/G compared with barrows from d 29 to 50. Over the entire 50-d nursery portion of the study, no differences were observed ($P > 0.61$) for ADG, ADFI, or final weight among gender or PCV2 vaccinates and non-vaccinates. However, F/G was improved ($P < 0.001$) with PCV2 vaccination.

Pig weights on d 71 and 99 were increased ($P < 0.001$) in vaccinates compared with non-vaccinates, and barrows had increased ($P < 0.001$) BW compared with gilts on d 99. At the conclusion of the study (d 132 for barrows and d 142 for gilts), the percentage of pigs remaining on test was decreased ($P < 0.001$) in non-vaccinated pens compared with vaccinated pens (70.2% vs. 94.7%, respectively). This study suggests that despite the decrease in performance related to the second vaccination of PCV2, the second vaccination improved final performance and decreased the number of removals due to the PRRS health challenge.

Key words: disease challenge, porcine circovirus type 2 (PCV2) vaccine

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[1] Appreciation is expressed to New Horizon Farms for the use of pigs and facilities and to Richard Brobjorg, Scott Heidebrink, and Marty Heintz for technical assistance.
[2] The authors thank Ajinimoto Heartland Inc. for partial funding of this project.
[3] Food Animal Health and Management Center, College of Veterinary Medicine, Kansas State University.
[4] Ajinimoto Heartland Inc., Chicago, IL.

Introduction

Porcine circovirus disease (PCVD) caused by porcine circovirus type 2 (PCV2) has recently become a major disease affecting growing pigs worldwide. Several commercial PCV2 vaccines are available to decrease the impact of PCVD. Recent research has shown increases in growth rates and finals weights of finishing pigs vaccinated with PCV2 vaccine (Jacela et al., 2007[5], 2008[6]; Potter et al., 2008[7]). However, Kane et al. (2008[8]) reported a decrease in nursery pig ADG due to decreases in feed intake after vaccination for PCV2 and *Mycoplasma hyopneumoniae.* This indicates that although there may be improvements in finishing pig performance with PCV2 vaccination, there may be some expense due to lost nursery performance. Additional health challenges could also affect the response to PCV2 vaccination. The objective of this study was to determine the effects of PCV2 vaccination in gilts and barrows challenged with porcine respiratory and reproductive syndrome (PRRS).

Procedures

Procedures in this experiment were approved by the Kansas State University Institutional Animal Care and Use Committee. The experiment was conducted at a commercial research finishing facility in southwestern Minnesota. The facility was double curtain sided with completely slatted flooring. Pens were 10 × 18 ft and were equipped with a 5-hole conventional dry feeder and a cup waterer.

A total of 2,571 barrows and gilts (PIC 337 × 1050, initially 12.6 lb) were weaned into a wean-to-finish facility. Pens were double stocked with 56 pigs per pen, and gilts and barrows were penned separately. A total of 46 pens were used; 24 pens contained barrows, and 22 pens contained gilts. All pigs were vaccinated for *M. hyopneumoniae* while in the farrowing facility. The PCV2 vaccination treatments were then allotted by pen at placement to both barrow and gilt pens in a completely randomized design. Vaccine treatments included either no PCV2 vaccine or vaccination with 2 doses of commercial PCV2 vaccine (Circumvent PCV, Intervet Inc., Millsboro, DE) given according to label directions on d 1 and d 22. All pigs were then inoculated with serum containing PRRS virus on d 30 as part of this production system's protocol. On d 51, gilts pens were moved to an adjacent barn of similar design. Pen integrity was maintained for gilt pens, and the original pen was split into 2. Once all gilt pens were moved, a gate cut of half of each barrow pen was moved to an empty pen in the wean-to-finish barn. Thus, similar to gilts, the pen integrity was maintained across the 2 pens.

Pig weights (by pen), feed disappearance, and pen head counts were measured throughout the nursery portion of the experiment to determine ADG, ADFI, and F/G for each pen. After the conclusion of the nursery portion and pigs were split between barns, pen counts were determined on d 71, 99, and at the conclusion of the study (d 132 and 142 for the barrow and gilt barns, respectively). Pen head counts from both the nursery and finishing phases were compared with the starting original pen count to determine the percentage of pigs remaining. Pig weights (by pen) were also determined on d 71 and 99; however, weights were not obtained on d 132 and 142 for the barrow and gilt barns,

[5] Jacela et al., Swine Day 2007, Report of Progress 985, pp. 5-9.
[6] Jacela et al., Swine Day 2007, Report of Progress 985, pp. 10-16.
[7] Potter et al., Swine Day 2008, Report of Progress 1001, pp. 5-13.
[8] Kane et al., Swine Day 2008, Report of Progress 1001, pp. 14-20.

respectively. These same pigs were used in 2 lysine trials during the finishing phase from d 71 to 99 with dietary treatments equally allotted across vaccine treatments in a balanced design. To limit the effect of pig space for the lysine trials, a portion of the PCV2-vaccinated pigs were removed from pens on d 132 and 142 for the barrow and gilt barns, respectively, which is the reason this trial ended on those particular days. Therefore, during the trial, pigs were removed only for poor health.

Data were then analyzed for each experiment as a 2 × 2 factorial design (with or without PCV2 vaccine and gender). The nursery and finishing growth and weight responses were analyzed using the PROC MIXED procedure in SAS (SAS Institute Inc., Cary, NC). The percentage of remaining pigs was analyzed using the PROC GENMOD procedure in SAS. The original pen was used as the experimental unit in all analyses.

Results and Discussion

From d 0 to 15, no difference in ADG, ADFI, or F/G was observed ($P > 0.13$) between genders or between vaccinates and non-vaccinates, indicating that the first injection of PCV2 vaccine did not affect performance (Table 1). However, in the period after the second injection (d 15 to 29), PCV2-vaccinated pigs had decreased ($P < 0.02$) ADG compared with non-vaccinates. This appears to be a result of decreased ($P < 0.04$) ADFI. Gilts had increased ($P < 0.04$) ADG and ADFI compared with barrows. A trend was also detected ($P < 0.07$) for a gender × vaccine interaction for F/G from d 15 to 29. This interaction was due to a slightly poorer F/G among vaccinated barrows and a slight improvement among vaccinated gilts. However, in the period after inoculation with PRRS virus (d 29 to 50), PCV2 vaccinates had improved ($P < 0.001$) F/G and a trend for increased ($P < 0.08$) ADG compared with non-vaccinates. Gilts had poorer ($P < 0.01$) F/G compared with barrows from d 29 to 50. Over the entire 50-d nursery portion of the study, no difference was detected ($P > 0.61$) for ADG, ADFI, or final weight between genders or between PCV2 vaccinates and non-vaccinates. However, F/G was improved ($P < 0.001$) with PCV2 vaccination and improved ($P < 0.001$) for barrows compared with gilts.

Although there was no difference in final weight after the nursery portion on d 50, pig weights on d 71 and 99 were greater ($P < 0.001$) in PCV2 vaccinates than in non-vaccinates. Barrows had increased ($P < 0.001$) BW comparison with gilts on d 99.

No differences were observed ($P > 0.37$) in the percentage of pigs remaining in pens throughout the nursery portion of the study (d 15, 29, or 50; Table 2). However, the percentage of pigs remaining on test was reduced ($P < 0.001$) in non-vaccinated pens compared with vaccinated pens on d 71, 99, and d 132 and 142 for the barrow and gilt barns, respectively. The majority of these removals were unthrifty appearing pigs. Only 5 of the non-vaccinated pigs showed clinical signs of PCVD. Also, gender × vaccine interactions were detected ($P < 0.07$) for pigs remaining on d 99 and on d 132 and 142 for the barrow and gilt barns, respectively. This interaction is a result of more unvaccinated gilts pigs remaining on test compared with barrows, which had a greater difference in removal rate of non-vaccinates compared with vaccinates. Despite the interaction, in barrows and gilts, pigs remaining decreased in non-vaccinates compared with vaccinates.

The data from this study suggest that when health challenges such as inoculation with PRRS virus are present, PCV2 vaccination can improve final performance and decrease the number of removals related to the particular health challenge. However, vaccination for PCV2, especially the second injection, decreased feed intake and affected performance in the nursery stage. Additional research is needed to understand the optimal vaccine timing for PCV2 vaccination in order to limit any negative effects vaccination may have on nursery pig performance.

Table 1. Effects of porcine circovirus type 2 (PCV2) vaccination and gender on growth performance[1]

	Barrow		Gilt			Probability, *P* <		
PCV2 vaccination:	No	Yes	No	Yes	SEM	Gender × Vaccine	Vaccine	Gender
Initial wt, lb	12.6	12.6	12.6	12.6	0.37	0.99	0.99	0.99
d 0 to 15[2]								
ADG, lb	0.59	0.58	0.60	0.59	0.03	0.95	0.93	0.75
ADFI, lb	0.87	0.82	0.87	0.86	0.04	0.62	0.46	0.55
F/G	1.50	1.41	1.49	1.47	0.04	0.33	0.14	0.57
d 15 to 29[3]								
ADG, lb	0.93	0.89	0.98	0.92	0.02	0.56	0.02	0.04
ADFI, lb	1.43	1.36	1.50	1.44	0.04	0.88	0.04	0.04
F/G	1.55	1.53	1.53	1.56	0.01	0.07	0.82	0.48
d 29 to 50[4]								
ADG, lb	0.90	0.96	0.84	0.92	0.04	0.85	0.08	0.22
ADFI, lb	1.61	1.60	1.56	1.60	0.07	0.66	0.81	0.69
F/G	1.80	1.66	1.85	1.74	0.02	0.54	0.001	0.01
d 0 to 50								
ADG, lb	0.81	0.83	0.81	0.82	0.03	0.99	0.62	0.86
ADFI, lb	1.34	1.30	1.34	1.33	0.05	0.69	0.63	0.71
F/G	1.65	1.57	1.66	1.62	0.02	0.10	0.001	0.05
d 50 wt, lb	53.9	54.1	53.4	54.0	1.76	0.94	0.82	0.88
Finisher weights[5]								
d 71 wt, lb	82.6	90.0	82.1	87.5	1.38	0.47	0.001	0.26
d 99 wt, lb	139.3	147.9	130.6	137.1	1.75	0.51	0.001	0.001

[1] A total of 2,571 barrows and gilts (PIC 337 × 1050) were double stocked into a wean-to-finish barn and observed for 50 d to determine the effects of PCV2 vaccine on growth performance.
[2] The first PCV2 vaccine was given on d 1 of this study to the selected pens of pigs.
[3] The second PCV2 vaccine was given on d 22 of the study to the selected pens of pigs.
[4] All pigs were injected with live PRRS virus on d 30.
[5] Pens were split and gilts were moved to another barn on d 51, and finisher weights were determined by using both split pens.

Table 2. Effects of porcine circovirus type 2 (PCV2) vaccination and gender on pig counts[1]

	Barrow		Gilt			Probability, $P <$		
PCV2 vaccination:	No	Yes	No	Yes	SEM	Gender × Vaccine	Vaccine	Gender
d 0 pen count, no.	55.8	55.8	56.0	56.0				
Pigs remaining, %								
d 15[2]	99.7	99.5	99.3	99.6	0.31	0.39	0.41	0.76
d 29[3]	98.8	99.3	99.3	99.1	0.39	0.38	0.74	0.66
d 50[4]	95.1	98.7	96.2	97.5	1.01	0.25	0.38	0.39
d 71[5]	79.3	97.3	81.0	96.2	1.82	0.44	0.001	0.68
d 99[5]	69.9	96.5	76.2	96.0	1.68	0.05	0.001	0.83
Trial conclusion[5,6]	65.6	95.3	74.8	94.0	1.91	0.07	0.001	0.62

[1] A total of 2,571 barrows and gilts were double stocked into a wean-to-finish barn and observed for 50 d to determine the effects of PCV2 vaccine on nursery growth performance.
[2] Time period after the first PCV2 vaccine (d 1).
[3] Time period after the second PCV2 vaccine (d 22).
[4] Time period after all pigs were injected with live PRRS virus (d 30).
[5] Pens were split and gilts were moved to another barn on d 51.
[6] Barrow barn on d 132 and gilt barn on d 142.

Effects of Sirrah-Bios PRRSV-RS Vaccine on Mortality Rate and Finisher Pig Performance[1]

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Summary

A total of 1,561 pigs (initially 4 d of age) were used to determine the effects of a porcine reproductive and respiratory syndrome virus (PRRSv) subunit vaccine, PRRSV-RS (Sirrah-Bios, Ames, IA), on mortality rate and finisher pig growth performance in a PRRSv-positive commercial herd. Pigs were randomly assigned by litter to either the subunit PRRSv vaccine or non-vaccinated control group. Pigs in the vaccinated group received an intramuscular injection of 1 mL PRRSV-RS vaccine at processing (approximately 4 d after birth) and again at weaning (approximately 24 d of age). Vaccinated and control pigs were comingled in a single nursery during the nursery phase. In the finishing phase, pigs were housed in a standard commercial curtain-sided finisher barn by treatment and gender by pen, with treatments randomly distributed across pens. Mortality was tracked from processing (4 d of age) to market (d 187 to 193). There was no difference between the control and vaccinated pigs for cumulative mortality (21.5% vs. 20.6%, $P = 0.67$) or for mortality during each production phase (processing to weaning: 9.5% vs. 7.1%, $P = 0.08$; nursery: 9.3% vs. 9.2%, $P = 0.95$; finishing: 4.4% vs. 5.9%, $P = 0.20$). Pigs were initially weighed by single-sex pens (control or vaccinated) 2 wk after placement into the finisher (d 0), and at that time, control and vaccinated mean pig weights were not different (58.4 vs. 58.7 lb, $P = 0.90$). Pens of pigs were subsequently weighed every 2 wk, and feed consumption was recorded to calculate ADG, ADFI, and F/G. Overall (d 0 to 112), control and vaccinated pig performance was similar (ADG: 1.96 vs. 1.93 lb, $P = 0.45$; ADFI: 5.35 vs. 5.36 lb, $P = 0.94$; F/G: 2.74 vs. 2.78, $P = 0.15$) throughout the finishing period. This resulted in no difference ($P = 0.79$) in off-test (d 112) weights between control (271.9 lb) and vaccinated (270.4 lb) pigs. These data indicate that this subunit PRRSv vaccine did not affect finisher pig performance or mortality in this commercial herd.

Key words: growth, mortality, PRRSv, vaccine

Introduction

Porcine reproductive and respiratory syndrome is caused by a virus in the family *Arteriviridae*. This virus has become endemic in many herds. Continual evolution of porcine reproductive and respiratory syndrome virus (PRRSv) strains has made development of an effective and reliable vaccine difficult. Modified-live and whole virus inactivated PRRSv vaccine products are available commercially. Inactivated products have not been demonstrated to be efficacious under field conditions. Use of the modified-live vaccines is considered to provide more effective immunity than inactivated products. However, the modified-live PRRSv vaccine is shed and will transmit to unvaccinated

[1] Appreciation is expressed to J-Six Enterprises, Seneca, KS, for their assistance and for providing the pigs and facilities used in this experiment.

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pigs. Also, there is concern that further transmission of the PRRSv vaccine strain virus will increase the potential for reversion to virulence.

Another class of PRRSv vaccines consists of subunit vaccines. Subunit vaccines are formed by using specific proteins of a virus to which an antibody response is stimulated. Thus, like a whole virus inactivated vaccine product, a subunit vaccine cannot propagate or revert to virulence. Commercially available subunit vaccines have been proven to provide effective immunization against other viruses, such as porcine circovirus type 2. Recently, a new subunit PRRSv vaccine, PRRSV-RS (Sirrah-Bios, Ames, IA), has been made available for use on sows or growing pigs. This vaccine contains an adjuvant and a heterodimer of the PRRSv glycoprotein 5 and matrix protein expressed with an AlphaVax replicon vector. It has been documented in a mouse model that a heterodimer of specific proteins is necessary to promote neutralizing antibodies against equine arteritis virus, also a member of the family *Arteriviridae*. For that reason, it has been suggested that the GP5-M heterodimer may induce cross-protective neutralizing antibodies against PRRSv infection in the pig and potentially allow for differentiating capabilities between vaccinated and infected pigs. However, there is limited data demonstrating subunit PRRSv vaccine efficacy under field conditions. Thus, the objective of this trial was to evaluate the effects of a subunit PRRSv vaccine (PRRSV-RS) vaccine on cumulative mortality rate, growth performance, and feed efficiency of commercial finisher pigs.

Procedures

Procedures used in this trial were approved by the Kansas State University Institutional Animal Care and Use Committee.

A total of 1,561 pigs from 140 litters within a single week of farrowings across 5 sow farms were assigned to either a non-vaccinated control or subunit PRRSv vaccine treatment group. Treatment groups were formed by randomly assigning the first litter processed at each sow farm to one of the treatments and then alternating vaccine treatment assignments on subsequently processed litters. This resulted in 70 litters represented within the 781 control pigs and 70 litters represented within the 780 vaccinated pigs. Pigs in the vaccinated group received 1 mL of PRRSV-RS vaccine intramuscularly at processing (4 d of age) and again at weaning (approximately 24 d of age). All pigs were weaned as a group into a single nursery.

Pigs were identified by ear tags, and mortality was tracked by collecting ear tags of pigs that died or were humanely euthanized. Mortality was tracked from processing to weaning, weaning to the end of the nursery period, and throughout the finishing period until the majority of the pigs were marketed. Cumulative mortality was determined by identifying the number of pigs in each treatment group that died or were euthanized from processing to marketing day divided by the initial number of pigs in each treatment.

Throughout the nursery period, control and vaccinated pigs were comingled within single-sex pens, and all test pigs were contained within a common room. All pigs were vaccinated with a 2-dose porcine circovirus type 2 vaccine and a *Mycoplasma hyopneumoniae* vaccine during the nursery period according to routine nursery procedures. Similar diets were fed to all pigs throughout the nursery period.

Pigs were moved to a single finisher barn and separated by vaccine treatment (vaccinated or control) and gender (barrow or gilt). There were 12 pens of each treatment × gender combination, with the exception of vaccinated barrows, for which there were 13 pens. Pens (10 × 18 ft) for each treatment were randomly distributed throughout the barn. Each pen was equipped with a double swinging waterer and a 3-hole dry self-feeder, allowing for ad libitum access to water and feed. An automated feeding system (FeedPro; Feedlogic Corp., Willmar, MN) was used in the barn to deliver and measure feed added to individual pen feeders. Pigs were weighed and feed intake was recorded beginning 2 wk after arrival in the finisher (d 0) and again on d 14, 28, 41, 56, 70, 90, and 112. From these data, ADG, ADFI, and F/G were calculated. On d 90, there were 0, 2, or 4 heavy pigs removed per pen in a balanced manner across treatment and gender, resulting in 84 "top" pigs marketed per vaccine treatment. At the end of the trial, pigs were marketed over 2 consecutive days in a balanced fashion, with the last pigs being weighed off test on d 112.

Finisher growth and feed performance data were analyzed as a completely randomized design using the GLIMMIX procedure of SAS (SAS Institute Inc., Cary, NC) and pen as the experimental unit. Vaccine treatment was managed as the main fixed effect of interest; however, gender was added in the model to control for expected differences in growth rate between barrows and gilts. Differences between treatments were determined by using least squares means ($P < 0.05$).

Mortality data were analyzed using the FREQ procedure in SAS. Mortality differences between treatments were determined using the chi-square test ($P < 0.05$). Analysis was performed on mortality data both within production phase (processing to weaning, nursery, and entry to finisher to off test) and cumulatively.

Results and Discussion

There were no gender × vaccine treatment interactions for the response criteria in the finishing trial. Although barrows were 1 lb lighter (58.0 vs. 59.0 lb, $P = 0.90$) than gilts initially, growth performance across genders was as expected. Barrows had greater overall ADG (2.01 vs. 1.87 lb, $P < 0.001$) and ADFI (5.65 vs. 5.07 lb, $P < 0.001$) and poorer F/G (2.81 vs. 2.70, $P < 0.001$) than gilts.

Non-vaccinated control pigs performed similarly to vaccinated pigs during the finishing period (Table 1). When pigs were first weighed, 2 wk after entry to the finisher, there was no difference ($P = 0.90$) in weight between controls (58.4 lb) and vaccinates (58.7 lb). From this point forward, there was no difference ($P > 0.06$) in ADG, ADFI, or F/G between the 2 treatment groups. This lack of difference in performance during the finishing period resulted in similar ($P = 0.79$) off-test (d 112) weights between controls (271.9 lb) and vaccinates (270.4 lb).

Mortality, either cumulative or within production phase, was not different ($P > 0.08$) between treatment groups (Table 2). Historically, during the nursery period, pigs in this production system undergo natural exposure to PRRSv and influenza. During the nursery period, pigs used in this trial exhibited clinical signs indicating similar exposure to PRRSv and influenza virus. The lack of difference in growth performance detected in this trial between controls and vaccinates indicates that the vaccine did not have a

negative or positive impact on growth or mortality. This is important because it appears that the majority of the cost associated with the vaccine would be due to administration materials, labor, and the vaccine product itself.

Although this subunit PRRSv vaccine is made from viral strains similar to historical strains, which are considered to provide some cross-protective immunity, it is unknown whether the vaccine-induced level of protection varies with viral strain challenge. In this herd, which has historical PRRSv-associated challenge, this subunit PRRSv vaccine failed to influence overall mortality or growth performance during the finishing phase.

Table 1. Effect of PRRSV-RS vaccine on growth performance of finisher pigs[1]

	Treatment[2]		
Item	Control	Vaccinated	Probability, $P <$
Initial wt, lb	58.4 ± 1.7	58.7 ± 1.7	0.90
d 0 to 112			
ADG, lb	1.96 ± 0.03	1.93 ± 0.03	0.45
ADFI, lb	5.35 ± 0.08	5.36 ± 0.08	0.94
F/G	2.74 ± 0.02	2.78 ± 0.02	0.15
Final wt, lb	271.9 ± 3.9	270.4 ± 3.8	0.79

[1] A total of 1,561 pigs (barrows or gilts) from 140 litters across 5 sow farms were assigned to 1 of 2 treatments at processing (4 d of age) by randomly assigning entire litters to either the vaccinated or non-vaccinated control groups. Control and vaccinated pigs were comingled in the nursery and then separated by vaccine treatment and gender in the finisher barn. Treatment pens were randomly distributed throughout the barn. There were 24 pens of control pigs and 25 pens of vaccinated pigs. All pens of pigs (1,292 pigs total) were initially weighed 2 wk after placement in the finisher (d 0) and then on d 14, 28, 41, 56, 70, 90, and 112.
[2] Treatments were: Control = no vaccine administered and Vaccinated = 1 mL PRRSV-RS administered intramuscularly at processing and weaning (approximately 24 d of age). Results are reported as least squares mean ± standard error of the mean.

Table 2. Effect of PRRSV-RS vaccine on within-period and cumulative mortality[1]

	Treatment[2]		
Item	Control	Vaccinate	Probability, $P <$
Inventory			
Processing[3]	781	780	---
Weaning[4]	707	725	---
Entry to finisher[5]	641	658	---
Off test[6,7]	529	535	---
Within-period mortality			
Processing to weaning, %	9.5	7.1	0.08
Nursery, %	9.3	9.2	0.95
Finisher, %	4.4	5.9	0.20
Cumulative mortality			
Processing to weaning, %	9.5	7.1	0.08
Processing to end of nursery, %	17.9	15.6	0.23
Processing to off test, %[6]	21.5	20.6	0.67

[1] A total of 1,561 pigs (barrows or gilts) from 140 litters across 5 sow farms were assigned to 1 of 2 treatments at processing (4 d of age) by randomly assigning entire litters to either the vaccinated or non-vaccinated control groups. Control and vaccinated pigs were comingled in the nursery and then separated by vaccine treatment and gender in the finisher barn. Mortality was tracked for controls and vaccinates from processing to the end of the finishing portion of the trial.

[2] Treatments were: Control = no vaccine administered and Vaccinated = 1 mL PRRSV-RS administered intramuscularly at processing and weaning.

[3] 4 d of age.

[4] Weaning age range was 20 to 26 d of age.

[5] Entry-to-finisher age range was 60 to 66 d of age.

[6] Off-test age range was 187 to 193 d of age.

[7] Inventory at off test (d 112) excludes pigs marketed (84 controls and 84 vaccinates) on d 90 of the trial.

Effects of Increasing Feeding Level During Late Gestation on Sow and Litter Performance[1]

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Summary

A total of 108 gilts and sows (PIC 1050) and their litters were used over 2 gestation and lactation periods to determine the effect of increasing late gestation feeding level on sow and litter performance. Treatments were structured as a 2 × 2 factorial design with main effects of feeding level (0 or 2 lb of extra feed from d 90 to farrowing) and parity group (gilts or sows). The trial was conducted for 2 successive parities, with gilts and sows remaining on the same treatment for both parities.

For the first gestation and lactation period, gilts had increased ($P < 0.001$) backfat thickness on d 35, 90, and 112 of gestation and at farrowing compared with sows but had increased ($P < 0.001$) lactation backfat loss. Increasing late gestation feed increased ($P < 0.001$) weight gain from d 90 to 112 in both gilts and sows.

There were late gestation feeding level × parity interactions observed ($P < 0.04$) for ADFI and total feed intake for the overall lactation period. This was due to gilts having decreased lactation ADFI when fed extra feed in late gestation, but when sows were fed extra feed, lactation ADFI increased. Increasing feeding level in late gestation also increased ($P < 0.04$) total feed cost.

A feeding level × parity interaction was observed ($P < 0.04$) for average weight of total born and live born pigs. Increasing feeding level in late gestation increased piglet birth weight in gilts but decreased piglet weight in sows. Gilts had increased ($P < 0.02$) number and total weight of the total born, live born, and number after fostering compared with older parity sows. Gilts weaned larger ($P < 0.002$) litters and had increased ($P < 0.03$) total litter weaning weight compared with older parity sows. At weaning, sows had a decreased ($P < 0.002$) weaning to breeding interval compared with gilts, and a late gestation feeding level × parity interaction was observed ($P < 0.03$) for conception rate. Gilts that received increased late gestation feed had a greater conception rate than those maintained on the same level, whereas a decrease in conception rate was observed when sows received increased late gestation feed.

During the subsequent lactation period, a feeding level × parity interaction was detected ($P < 0.005$) for lactation backfat loss. This interaction was reflective of an increase in backfat loss in parity 2 sows as the late gestation feeding level was increased and a decrease in backfat loss in parity 3 and older sows with increasing late gestation feeding level. A feeding level × parity interaction was detected ($P < 0.02$) for lactation weight loss; parity 2 sows lost a greater amount of weight when late gestation feeding level was increased, whereas similar weight losses were observed between treatments

[1] The authors thank PIC, Hendersonville, TN, for partial funding of this project.

[2] Pig Improvement Company (PIC), Hendersonville, TN.

[3] Food Animal Health and Management Center, College of Veterinary Medicine, Kansas State University.

in parity 3 and older sows. Total born and live born numbers and total litter weight were greater ($P < 0.006$) in parity 2 sows than in parity 3 and older sows. A late gestation feeding level × parity interaction was observed ($P < 0.01$) for average weight of both total born and live born pigs because of an increase in piglet birth weight as parity 2 sows were supplemented with 2 lb of additional feed in late gestation with a slight numeric decrease in parity 3 and older sows. Additional feed in late gestation increased ($P < 0.02$) average piglet weaning weight, with a large improvement observed in parity 2 sows. Total number weaned and total weight at weaning were increased ($P < 0.004$) in parity 2 sows compared with parity 3 and older sows. This trial indicates that adding extra feed to late gestation diets increased feed cost with no benefit in sow performance. In gilts, conception rate and litter weaning weight were increased during the second parity, but no other benefits were found.

Key words: gestation feeding, lactation, sow

Introduction

Implementing efficient feeding strategies for gestating sows is an important management practice needed for production of offspring as well as maintenance of sow health and longevity. As feed prices increase, it is important to mange sow feeding levels to meet the needs of animals without incurring unnecessary cost. Researchers from Kansas State University (K-State) have developed strategies for managing sow feeding levels based on individual sow weight and backfat thickness (Young et al., 2003[4]). Although nutrient requirements for fetal development are low during the first two-thirds of gestation, requirements increase exponentially in late gestation as fetal growth increases. Research has shown that increasing nutrients during late gestation can increase piglet birth weight and thereby increase weaning weight. However, other research trials have indicated little benefit to increasing feed intake in late gestation. Therefore, the objective of this trial was to observe the effects of increasing late gestating feeding levels on sow and litter performance over 2 lactation periods.

Procedures

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

A total of 108 gilts and sows (PIC 1050) and their litters were used in this study over 2 lactation periods. Treatments were structured as a 2 × 2 factorial design with main effects of feeding level (0 or 2 lb of additional feed from d 90 to farrowing) and parity group (gilts and sows). The trial was conducted for 2 successive parities. Thus, data are presented comparing gilts to sows for the first farrowing and then comparing parity 2 vs. parity 3 and greater for the second farrowing. Treatments were allotted to gilts and sows in a generalized block design with farrowing group as the blocking factor. Four farrowing groups of approximately 27 gilts and sows were used to obtain the 108 gilts and sows used for the trial.

On d 35 of gestation, gilts and sows were confirmed pregnant using real-time ultrasound and designated as candidates for inclusion in the study. Sows were primarily

[4] Young et al., Swine Day 2003, Report of Progress 920, pp. 19-32.

second and third parity with a few fourth parity sows. At the time of assignment, gilts and sows were weighed and backfat thickness was measured. Backfat thickness was measured at the last rib approximately 4 in. off the midline. From these measurements, sow feeding levels were assigned on the basis of previous research to meet the nutritional needs of the gestating female as outlined by the NRC (1998[5]) and to achieve an optimal body condition and backfat thickness. Feed box accuracy was determined to ensure appropriate gestation feeding levels.

On d 90, gilts and sows were weighed and late gestation feeding level treatments were assigned to animals and balanced for sow weight and backfat thickness. On d 112 of gestation, gilts and sows were weighed, backfat thickness was measured, and animals were moved to the farrowing facility. From d 112 until farrowing, gilts and sows remained on the same feeding level as offered from d 90 to 112. Upon farrowing, piglets were weighed and processed and mummified pigs and stillbirths were recorded. From these records, the number of pigs, total weight, and average weight were calculated for total born and live born piglets. Sows were weighed and backfat thickness was determined at farrowing. Cross-fostering was performed within 24 h after farrowing to standardize litter size within late gestation feeding level treatments. Total pigs, average birth weight, and total birth weight were also calculated for the piglets remaining on the sow at cross-fostering. Piglets were individually weighed at weaning to determine number weaned, average weaning weight, total litter weight, piglet weight gain, piglet daily weight gain, litter weight gain, and preweaning mortality. Gilts and sows were weighed and backfat thickness was measured at weaning. Upon weaning and re-breeding of the sows, weight and backfat thickness were used to set gestation feeding levels for subsequent performance. Days to return to estrus was determined on the basis of the first mating. Conception rate was calculated as number of sows confirmed pregnant on d 28 divided by number of sows bred. Gilts were then considered parity 2 (P2) sows and analyzed separately from parity 3 and greater (P3+) sows. Similar to the first gestation and lactation period, sow weight, backfat thickness measurements, and litter performance criteria were determined at similar days of pregnancy and lactation.

The composition of the both the gestation and lactation diets is shown in Table 1. The gestation and lactation diets were formulated to contain 0.66% and 1.10% total lysine, or 0.57% and 0.97% standardized ileal digestible lysine, respectively. For the first 3 d after farrowing, sows were gradually stepped up on feed, and after d 3, all sows were allowed ad libitum access to the lactation diet. Lactation sow feed disappearance was determined weekly to calculate ADFI and total feed intake for lactating sows. Temperature in the farrowing facility was maintained at a minimum of 68°F, and supplemental heat was provided to the piglets with heat lamps. On the basis of sow weight and backfat thickness measurements, changes in weight and backfat level were determined for each of the farrowing periods. Sow and litter weight gain in lactation were determined and used with total lactation feed intake to determine a ratio of feed intake to sow and litter weight gain. Finally, feed costs were determined for each sow gestation and lactation period.

Data were analyzed as a generalized block design with parity designation and late gestation feeding level as fixed effects and farrowing group as a random effect using the

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

MIXED procedure in SAS (SAS Institute, Inc., Cary, NC). Interactions between the fixed treatment effects and farrowing groups were pooled together with the error term because no significant interaction effects with farrowing group were detected. For all responses, sow or litter was used as the experimental unit.

Results

For the initial gestation and lactation period, no feeding level × parity interactions or feeding level differences were observed ($P > 0.29$) for backfat thickness or sow weight measurements on any particular day of gestation or lactation (Table 2). Gilts had increased ($P < 0.001$) backfat depth on d 35, 90, and 112 of gestation and at farrowing compared with sows. Gilts also had increased ($P < 0.001$) lactation backfat loss compared with sows. Sows were heavier ($P < 0.02$) on d 35 of gestation, after farrowing, and at weaning compared with gilts. Gilts and sows that were fed 2 lb of extra feed in late gestation had increased ($P < 0.001$) weight gain from d 90 to 112 compared with those that did not have their feeding level increased. Gilts had increased ($P < 0.001$) lactation weight loss (farrowing weight - weaning weight) and decreased ($P < 0.001$) weight change from d 90 to either farrowing or weaning comparison with sows.

For the initial lactation, feeding level × parity interactions were observed ($P < 0.04$) for ADFI and total feed intake for each week in lactation as well as for the overall lactation period (Table 3). This interaction was due to an increase in lactation feed intake when sow intake was increased in late gestation and a decrease in lactation feed intake when gilt intake was increased in late gestation. The interaction was of greater magnitude in wk 1 than in other weeks. Sows had greater ($P < 0.001$) ADFI each week and greater lactation feed intake during wk 2 and 3 and overall than gilts. Total gestation feed intake, gestation feed cost, and overall feed cost increased ($P < 0.04$) with increasing the late gestation feeding level. However, a feeding level × parity interaction was observed ($P < 0.001$) for lactation feed cost. Increasing late gestation feeding level decreased lactation feed cost in gilts because of the decrease in lactation feed intake, whereas a numeric increase in lactation feed cost was found in sows as feeding level increased in late gestation. Sows also had increased ($P < 0.001$) feed costs during gestation, lactation, and overall than gilts

For litter performance during the first lactation period, a feeding level × parity interaction was observed ($P < 0.04$) for average weight of total born and live born piglets (Table 4). Increased late gestation feeding level led to increased piglet birth weight in gilt litters and decreased piglet weight in sow litters. Gilts also had increased ($P < 0.02$) number and total weight of the total born, live born, and number after fostering and had an increased ($P < 0.05$) percentage of mummified pigs compared with sows. No difference was observed ($P > 0.39$) in the percentage of stillbirths. Gilts weaned larger ($P < 0.002$) litters and had increased ($P < 0.03$) total litter weaning weight and litter weight gain comparison with sows. However, providing gilts and sows with increased levels of late gestation feed offered no benefit ($P > 0.69$) in number weaned, weaning weight, piglet weight gain, or litter weight gain compared with maintaining a constant gestation feeding level. Sow and litter gain also increased ($P < 0.03$) in sows as compared to gilts. Upon weaning, sows had decreased ($P < 0.002$) days to estrus compared with gilts, and a late gestation feeding level × parity interaction was detected for conception rate. Gilts that received increased levels of late gestation feed had a

greater conception rate than those maintained on the same level, whereas a decrease in conception rate was observed when sows received increased late gestation feed.

All females remained on the original late gestation feeding level treatment for the subsequent gestation and lactation period. The sharp difference in conception rate of gilts between different late gestation feeding levels generated a substantial difference in number of gilts that could be used for subsequent performance (Table 5).

For the subsequent gestation and lactation period, no differences in sow weight and backfat thickness were detected ($P > 0.11$) between late gestation feeding levels or parity. However, a level × parity interaction was detected ($P < 0.005$) for lactation backfat loss. This interaction was reflective of an increase in backfat loss in P2 sows as the late gestation feeding level was increased and a decrease in backfat loss in P3+ sows with increasing late gestation feeding level. In addition, P3+ sows were heavier ($P < 0.02$) at farrowing and at weaning that P2 sows. A feeding level × parity interaction was detected ($P < 0.02$) for lactation weight loss; P2 sows lost a greater amount of weight when late gestation feeding level was increased, and similar weight losses were observed in P3+ sows at both late gestation feeding levels. However, increasing late gestation feeding levels increased ($P < 0.01$) weight gain from d 90 of gestation to either d 112 or farrowing in both P2 and P3+ sows.

For subsequent lactation feed intake, no interactions or feeding level differences were observed ($P > 0.09$) for total or daily sow feed intake (Table 6). In addition, P2 sows had decreased ($P < 0.05$) total and daily feed intake for wk 1 compared with P3+ sows and tended to have decreased ($P < 0.09$) overall total and daily lactation feed intake. The addition of increased levels of late gestation feed also increased ($P < 0.004$) gestation feed intake, gestation feed cost, and total feed cost.

Total born, live born, average pig weight, and total litter weight were increased ($P < 0.006$) in P2 sows compared with P3+ sows (Table 7). A late gestation feeding level × parity interaction was observed ($P < 0.01$) for average weight of both total born and live born pigs, and a similar trend was observed ($P < 0.07$) at cross-fostering. These interactions were reflective of increased piglet birth weight as P2 sows were fed the additional 2 lb of feed in late gestation, and a slight numeric decrease in P3+ sows. The cause of this increase in average weight could be related to the supplementation of extra feed in late gestation or it may be reflective of the numeric decrease in the number of pigs born. Despite the interaction, providing additional feed in late gestation tended to increase ($P < 0.07$) average pig weight for total born, live born, and those remaining at cross-fostering. Average pig weight at weaning also increased ($P < 0.02$) with supplementation of additional feed in gestation, with a large improvement observed in P2 sows. Total number weaned and total weight at weaning were increased ($P < 0.004$) in P2 sows compared with P3+ sows. Daily and overall piglet weight gain was increased ($P < 0.04$) with the addition of supplemental feed in late gestation, and daily and overall litter weight gain was increased ($P < 0.02$) in P2 sows compared with P3+ sows.

Discussion

This study has shown several important traits that should be evaluated when considering increasing late gestation feeding levels. The initial farrowing showed that increasing

the gestation feeding level for the last 3 wk of gestation resulted in an increase in weight gain of sows and gilts during this period but did not translate into an increase in litter weight and resulted in no difference in pig weaning weight. However, increasing the feeding level for gilts that were adequate or marginally excessive in their level of backfat at d 90 of gestation resulted in decreased lactation feed intake. Regardless of the late gestation feeding level, gilts lost an excessive amount of backfat thickness (approximately 5 mm) during the first lactation period. However, gilts that received increased feed in late gestation had better conception rates than those remaining on the original level. Subsequently, the P2 sows (previously gilts) that received additional feed in late gestation had increased average piglet birth and weaning weight during the subsequent lactation period. For the most part, there was no performance benefit to increasing late gestation feeding level in either lactation period for older sows. Increasing late gestation feeding level increased sow feed costs by $3.50 to $5.00 per sow per gestation and lactation combined periods. This trial indicates that adding extra feed to late gestation diets increased feed cost with no benefit in sow performance. In gilts, conception rate and litter weaning weight were increased during the second parity, but no other benefits were found.

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

Ingredient, %	Gestation	Lactation
Corn	80.75	65.28
Soybean meal (46.5% CP)	14.95	30.80
Monocalcium P (21% P)	1.70	1.45
Limestone	1.35	1.20
Salt	0.50	0.50
Vitamin premix	0.25	0.25
Trace mineral premix	0.15	0.15
Sow vitamin add pack	0.25	0.25
Phytase[2]	0.10	0.10
Total	100	100
Calculated analysis		
ME, kcal/lb	1,482	1,485
CP, %	13.8	19.9
Total lysine, %	0.66	1.10
SID[3] amino acids, %		
Lysine	0.57	0.97
Threonine	0.43	0.65
Methionine	0.21	0.29
Tryptophan	0.13	0.21
Isoleucine	0.48	0.75
Leucine	1.22	1.60
Ca, %	0.90	0.85
P, %	0.69	0.70
Available P, %[4]	0.52	0.48
Diet cost, $/ton[5]	194.61	228.24

[1] A total of 108 gilts and sows (PIC 1050) were used over 2 gestation and farrowing periods to determine the effect of providing an extra 2 lb of gestation diet in late gestation.
[2] Provided 272 phytase units per pound of diet.
[3] Standardized ileal digestible.
[4] Phytase provided 0.11% and 0.10% available P to the gestation and lactation diets, respectively.
[5] Diet costs were based on corn at $3.50/bu and soybean meal at $350/ton with a $12/ton processing and delivery fee.

Table 2. Effects of late gestation feeding level and parity designation on sow weight and backfat[1]

	Gilt		Sow			Probability, $P <$		
Late gestation feeding level[2]:	Normal	+ 2 lb	Normal	+ 2 lb	SEM	Level × Parity	Parity	Level
no.	22	21	33	32	---	---	---	---
Gestation length, d	114.9	115.4	115.5	116.0	---	---	---	---
Lactation length, d	20.8	20.6	19.9	19.4	---	---	---	---
Backfat measurements, mm[3]								
Gestation d 35	20.0	20.1	13.5	13.7	0.78	0.94	0.001	0.83
Gestation d 90	20.3	20.4	14.9	14.9	0.91	0.96	0.001	0.93
Gestation d 112	19.0	19.9	14.9	15.3	0.77	0.70	0.001	0.39
Farrowing	18.4	18.7	14.8	15.4	0.69	0.77	0.001	0.51
Weaning	15.1	14.5	13.4	13.9	0.75	0.38	0.09	0.94
Lactation backfat loss, mm[4]	3.4	4.3	1.3	1.4	0.57	0.30	0.001	0.22
Weights, lb								
Gestation d 35	415.8	412.8	432.9	434.7	11.42	0.76	0.02	0.94
Gestation d 90	497.0	498.2	506.1	504.7	13.36	0.89	0.40	0.99
Gestation d 112	528.9	542.0	541.8	551.5	13.25	0.87	0.27	0.25
Farrowing	485.4	491.3	520.0	527.8	12.57	0.92	0.001	0.44
Weaning	455.4	450.0	503.1	512.3	14.51	0.40	0.001	0.83
Weight changes, lb								
Farrowing to weaning	-30.1	-41.2	-16.7	-15.3	4.79	0.12	0.001	0.23
d 90 to 112	32.2	43.9	35.5	46.6	4.60	0.92	0.36	0.001
d 90 to farrowing	-10.9	-6.3	13.3	22.5	4.52	0.57	0.001	0.09
d 90 to weaning	-41.1	-47.3	-3.4	7.2	5.91	0.12	0.001	0.69

[1] A total of 108 gilts and sows (PIC 1050) were used over 2 farrowings to determine the effect of increasing feeding level in late gestation.
[2] Late gestation feeding levels were set at d 90 of gestation. Normal = the same level as designated at d 35 by BW and last rib backfat; +2 lb = 2 lb more than the d 35 level.
[3] Backfat measurements were determined by averaging both sides at the last rib approximately 4 in. off the midline.
[4] Lactation backfat loss = Farrowing backfat - Weaning backfat.

Table 3. Effects of late gestation feeding level and parity designation on lactation feed intake[1]

	Gilt		Sow			Probability, *P* <		
Late gestation feeding level[2]:	Normal	+ 2 lb	Normal	+ 2 lb	SEM	Level × Parity	Parity	Level
no.	22	21	33	32	---	---	---	---
Gestation d 35 feed amount, lb/d	4.6	4.5	5.7	5.7	---	---	---	---
Gestation d 90 feed amount, lb/d	4.6	6.5	5.7	7.7	---	---	---	---
Total gestation feed intake, lb[3]	522.6	573.7	657.8	708.2	16.41	0.99	0.001	0.001
Lactation ADFI, lb								
wk 1	9.9	6.8	10.6	11.6	0.89	0.001	0.001	0.03
wk 2	12.1	10.5	13.7	14.1	0.46	0.007	0.001	0.09
wk 3	13.2	12.1	14.0	14.5	0.81	0.04	0.001	0.43
Overall	11.7	10.0	12.9	13.5	0.49	0.001	0.001	0.10
Lactation total intake, lb								
wk 1	65.8	47.9	61.6	62.8	4.87	0.02	0.17	0.03
wk 2	84.9	73.7	96.1	98.7	3.25	0.007	0.001	0.09
wk 3	92.7	85.0	97.9	101.3	5.66	0.04	0.001	0.43
Overall	243.9	207.3	255.1	262.4	9.37	0.004	0.001	0.06
Feed cost, $/female[4]								
Gestation	50.85	55.82	64.01	68.91	1.597	0.99	0.001	0.001
Lactation	27.83	23.66	29.12	29.95	1.070	0.004	0.001	0.06
Total feed[5]	78.74	79.52	93.08	98.83	1.959	0.11	0.001	0.04

[1] A total of 108 gilts and sows (PIC 1050) were used over 2 farrowings to determine the effect of increasing feeding level in late gestation.
[2] Late gestation feeding levels were set at d 90 of gestation. Normal = the same level as designated at d 35 by BW and last rib backfat; +2 lb = 2 lb more than the d 35 level.
[3] Total gestation feed intake assumes that the same level as set on d 35 was used from d 0 to 35.
[4] Feed costs are based on corn at $3.50/bu and soybean meal at $350/ton.
[5] Total feed cost combines both gestation and lactation feed intake.

Table 4. Effects of late gestation feeding level and parity designation on piglet performance[1]

	Gilt		Sow			Probability, *P* <		
Late gestation feeding level[2]:	Normal	+ 2 lb	Normal	+ 2 lb	SEM	Level × Parity	Parity	Level
no.	22	21	33	32	---	---	---	---
Total born								
no.	14.6	14.0	11.9	12.9	0.82	0.20	0.004	0.70
avg. wt, lb[3]	3.10	3.29	3.38	3.14	0.130	0.04	0.55	0.80
Total wt, lb[3]	44.3	43.7	38.3	39.0	2.02	0.74	0.004	0.99
Mummies, %	1.86	3.95	1.25	0.84	1.075	0.18	0.05	0.36
Stillbirths, %	3.40	3.35	4.53	4.25	1.538	0.93	0.40	0.89
Live born								
no.	13.8	12.9	11.2	12.3	0.73	0.13	0.02	0.82
avg. wt, lb	3.13	3.32	3.39	3.15	0.127	0.04	0.67	0.78
Total wt, lb	43.0	42.2	36.8	37.4	1.93	0.67	0.002	0.96
Cross-fostering								
no.	12.5	12.4	11.2	11.5	0.34	0.58	0.001	0.63
avg. wt, lb[4]	3.22	3.25	3.28	3.18	0.072	0.18	0.93	0.53
Total wt, lb[4]	40.0	40.4	36.6	36.5	0.98	0.79	0.001	0.89
Weaning								
no.	11.5	11.5	10.6	10.5	0.32	0.91	0.002	0.98
avg. wt, lb	13.40	13.35	13.45	13.28	0.315	0.82	0.98	0.70
Total wt, lb	152.6	153.7	141.6	139.4	4.60	0.69	0.003	0.89
Piglet wt gain, lb								
Daily	0.48	0.48	0.50	0.50	0.018	0.99	0.10	0.97
Overall	10.16	10.08	10.19	10.11	0.305	0.99	0.92	0.77
Litter wt gain, lb								
Daily	5.43	5.47	5.27	5.31	0.215	0.99	0.36	0.83
Overall	112.6	113.2	105.0	103.0	4.40	0.72	0.03	0.86
Preweaning mortality	7.35	7.05	5.65	8.28	2.117	0.40	0.90	0.50
Sow and litter wt gain, lb[5]	82.5	71.9	88.2	87.6	6.66	0.28	0.03	0.23
Feed intake/sow and litter wt gain[6]	3.3	1.9	3.0	3.5	0.57	0.07	0.21	0.34
Subsequent performance								
Wean to breed, d	5.15	4.71	4.47	4.40	0.171	0.24	0.002	0.10
Conception rate, %	77.27	95.24	96.97	87.50	6.521	0.03	0.32	0.48

[1] A total of 108 gilts and sows (PIC 1050) were used over 2 farrowings to determine the effect of increasing feeding level in late gestation.
[2] Late gestation feeding levels were set at d 90 of gestation. Normal = the same level as designated at d 35 by BW and last rib backfat; +2 lb = 2 lb more than the d 35 level.
[3] Weights of total born reflect only pigs born alive or stillbirths and not mummified pigs.
[4] Cross-fostering weights reflect the total and mean birth weights of piglets that survived until fostering, which occurred at approximately 24 h.
[5] Sow and litter wt gain = (Sow weaning wt - Sow farrowing wt) + (litter wt gain).
[6] Feed intake/sow and litter wt gain= (Total lactation sow feed intake)/(Sow and litter wt gain during lactation).

Table 5. Effects of late gestation feeding level and parity designation on sow weight and backfat of subsequent performance[1]

	Parity 2		Parity 3+			Probability, P <		
Late gestation feeding level[2]:	Normal	+ 2 lb	Normal	+ 2 lb	SEM	Level × Parity	Parity	Level
no.	14	19	26	25	---	---	---	---
Gestation length, d	115.9	115.9	115.8	116.3	---	---	---	---
Lactation length, d	19.2	19.5	19.8	19.4	---	---	---	---
Backfat measurements, mm[3]								
Gestation d 90	15.4	16.5	14.7	15.5	1.32	0.88	0.32	0.25
Gestation d 112	15.2	16.8	15.0	16.1	1.34	0.77	0.63	0.12
Farrowing	14.8	16.2	14.9	15.8	1.35	0.79	0.87	0.20
Weaning	14.5	14.4	13.7	15.5	1.25	0.22	0.90	0.27
Lactation backfat loss, mm[4]	0.45	1.94	1.15	0.14	0.67	0.005	0.21	0.58
Weights, lb								
Gestation d 90	492.8	510.2	520.1	528.5	19.2	0.72	0.08	0.30
Gestation d 112	547.0	565.9	560.9	577.8	21.0	0.95	0.35	0.19
Farrowing	516.8	533.3	551.2	561.8	19.6	0.82	0.02	0.29
Weaning	504.5	501.6	531.5	549.4	18.8	0.40	0.003	0.54
Weight changes, lb								
Farrowing to weaning	-11.6	-31.5	-16.2	-12.6	7.03	0.02	0.12	0.08
d 90 to 112	40.1	55.3	40.4	49.8	3.56	0.20	0.27	0.001
d 90 to farrowing	8.8	23.0	25.7	33.9	6.56	0.48	0.002	0.01
d 90 to weaning	-1.3	-8.2	10.5	20.9	9.59	0.17	0.002	0.78

[1] A total of 88 of the original 108 gilts and sows (PIC 1050) were used to determine the effects of late gestation sow feeding level on a subsequent lactation period.

[2] Late gestation feeding treatments were set at d 90 of gestation. Normal = the same level as designated at breeding; +2 lb = 2 lb higher than that particular level.

[3] Backfat measurements were determined by averaging both sides at the last rib approximately 4 in. off the midline.

[4] Lactation backfat loss = Farrowing backfat - Weaning backfat.

Table 6. Effects of late gestation feeding level and parity designation on lactation feed intake of subsequent farrowing[1]

	Parity 2		Parity 3+			Probability, $P <$		
Late gestation feeding level[2]:	Normal	+ 2 lb	Normal	+ 2 lb	SEM	Level × Parity	Parity	Level
no.	14	19	26	25	---	---	---	---
Gestation d 0 feed amount, lb/d	5.7	5.6	5.7	5.8	---	---	---	---
Gestation d 90 feed amount, lb/d	5.7	7.6	5.7	7.8	---	---	---	---
Total gestation feed intake, lb	663.5	701.0	659.8	723.8	16.95	0.34	0.50	0.001
Lactation ADFI, lb								
wk 1	11.2	11.4	11.8	13.1	0.86	0.30	0.05	0.18
wk 2	14.1	13.4	13.8	14.5	0.72	0.13	0.46	0.96
wk 3	15.9	15.0	16.0	16.6	0.91	0.21	0.14	0.78
Overall	14.0	13.4	14.0	14.9	0.66	0.10	0.09	0.73
Lactation total intake, lb								
wk 1	57.8	61.9	69.9	71.7	7.55	0.81	0.03	0.54
wk 2	98.9	94.1	96.4	101.5	5.04	0.13	0.46	0.96
wk 3	111.3	104.9	112.3	116.4	6.37	0.21	0.14	0.78
Overall	267.6	261.3	278.3	289.3	15.52	0.39	0.06	0.82
Feed cost, $/female[3]								
Gestation	64.56	68.21	64.20	70.43	1.649	0.34	0.50	0.001
Lactation	30.54	29.82	31.76	33.01	1.344	0.39	0.06	0.82
Total feed[4]	95.14	98.03	95.98	103.43	2.195	0.20	0.08	0.004

[1] A total of 88 of the original 108 gilts and sows (PIC 1050) were used to determine the effects of late gestation sow feeding level on a subsequent lactation period.

[2] Late gestation feeding treatments were set at d 90 of gestation. Normal = the same level as designated at breeding; +2 lb = 2 lb higher than that particular level.

[3] Feed costs are based on corn at $3.50/bu and soybean meal at $350/ton.

[4] Total feed cost combines both gestation and lactation feed intake.

Table 7. Effects of late gestation feeding level and parity designation on piglet performance in a subsequent litter[1]

	Parity 2		Parity 3+			Probability, *P* <		
Late gestation feeding level[2]:	Normal	+ 2 lb	Normal	+ 2 lb	SEM	Level × Parity	Parity	Level
no.	14	19	26	25	---	---	---	---
Total born								
no.	15.1	13.5	12.3	12.2	0.89	0.29	0.006	0.28
avg. wt, lb[3]	3.17	3.69	3.18	3.10	0.180	0.01	0.02	0.07
Total wt, lb[3]	47.1	48.4	36.6	37.2	3.05	0.87	0.001	0.65
Mummies, %	0.94	1.26	1.71	0.77	0.796	0.35	0.84	0.65
Stillbirths, %	6.60	4.26	6.07	6.18	1.960	0.46	0.68	0.50
Live born								
no.	14.0	12.7	11.2	11.4	1.07	0.27	0.004	0.42
avg. wt, lb	3.17	3.71	3.21	3.13	0.18	0.01	0.03	0.05
Total wt, lb	44.6	46.5	34.6	35.2	3.17	0.75	0.001	0.53
Cross-fostering								
no.	12.0	11.8	11.1	11.4	0.55	0.57	0.08	0.87
avg. wt, lb[4]	3.28	3.65	3.21	3.21	0.15	0.07	0.009	0.06
Total wt, lb[4]	39.2	43.0	35.3	36.6	2.17	0.39	0.001	0.07
Weaning								
no.	11.2	11.2	10.2	10.1	0.56	0.81	0.004	0.82
avg. wt, lb	13.05	14.52	13.46	13.80	0.58	0.14	0.67	0.02
Total wt, lb	146.8	163.0	136.3	138.4	8.86	0.22	0.004	0.11
Piglet wt gain, lb								
Daily	0.51	0.56	0.52	0.55	0.02	0.46	0.89	0.02
Overall	9.77	10.87	10.25	10.59	0.51	0.24	0.77	0.04
Litter wt gain, lb								
Daily	5.58	6.13	5.09	5.25	0.35	0.38	0.004	0.12
Overall	107.57	120.15	101.07	101.68	7.81	0.24	0.02	0.19
Preweaning mortality, %	6.09	5.16	7.26	11.02	3.50	0.30	0.13	0.53
Sow and litter wt gain, lb[5]	95.0	87.8	85.1	89.7	8.74	0.31	0.48	0.82
Feed intake/sow and litter wt gain[6]	2.95	3.04	3.65	3.63	0.48	0.85	0.04	0.91

[1] A total of 88 of the original 108 gilts and sows (PIC 1050) were used to determine the effects of late gestation sow feeding level on a subsequent lactation period.

[2] Late gestation feeding treatments were set at d 90 of gestation. Normal = the same level as designated at breeding; +2 lb = 2 lb higher than that particular level.

[3] Weights of total born reflect only pigs born alive or stillbirths and not mummified pigs.

[4] Cross-fostering weights reflect the total and mean birth weights of piglets that survived until fostering, which occurred at approximately 24 h.

[5] Sow and litter wt gain during lactation = (Sow weaning wt - Sow farrowing wt) + litter wt gain.

[6] Feed intake/sow and litter wt gain = (Total lactation sow feed intake)/(Sow and litter wt gain during lactation).

Effects of Creep Diet Complexity on Individual Consumption Characteristics and Growth Performance of Neonatal and Weanling Pigs[1]

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Summary

In Exp. 1, 96 sows (PIC C29) and their litters were used to determine the effects of creep diet complexity on preweaning performance and the proportion of piglets consuming creep feed. The experimental treatments were: (1) no creep feed (n = 26), (2) simple creep diet (n = 26), and (3) complex creep diet (n = 44). Pigs fed the complex creep diet had greater ($P < 0.03$) ADG and tended to have greater ($P < 0.06$) total gain than pigs fed the simple creep diet, with no creep pigs intermediate. Litters fed the complex creep diet consumed twice the total (2.73 vs. 1.37 lb; $P < 0.0006$) and daily (0.91 vs. 0.45 lb; $P < 0.0006$) creep feed intake of litters fed the simple creep diet. The high-complexity creep diet improved ($P < 0.0001$) the proportion of eaters from 28% to 68%. A greater ($P < 0.10$) proportion of eaters were nursing in the middle and posterior teats (57% and 52%, respectively) than in the anterior teats (38%). In Exp. 2, 675 pigs from Exp. 1 (initial BW 14.1 lb and 21.2 ± 0.2 d) were used to determine whether social facilitation occurs between eaters and non-eaters in commercial nursery groups. The treatments were: non-eater group (pigs that were not provided any creep feed or non-eaters of creep feed), eater group (pigs that positively consumed creep feed), and mix group (pigs that were 51% non-eaters and 49% eaters). Each treatment had 25 pigs per pen and 9 replications (pens). In the initial 3 d postweaning, eaters had greater ($P < 0.01$) ADG and ($P < 0.002$) ADFI than non-eaters, with the mix group being intermediate. Overall ADG of the eater group was 6.2% higher ($P < 0.05$) than that of the non-eater group. For social facilitation to occur, weight gains of non-eaters in the mix pens should be either (1) closer to the weight gains of eaters in the mix pen or (2) greater than the weight gains of the non-eater group. Results showed that non-eaters within the mix pens failed both criteria. In conclusion, the high-complexity creep diet improved preweaning ADG, litter creep feed intake, and the proportion of eaters. Eaters had improved postweaning feed intake, daily gains, and weight uniformity and reduced postweaning lag. Mixing eaters with non-eaters within pens in large commercial groups did not stimulate feed intake and daily gains of non-eaters, which indicates that social facilitation did not occur.

Key words: behavior, creep feeding, diet complexity

Introduction

Maximizing postweaning pig performance is essential in improving lifetime growth efficiency and productivity. However, weaning is often characterized by a period of low feed intake caused by physical, physiological, and behavioral challenges that may result in a growth check and affect postweaning growth rates. Thus, improving feed intake

[1] Appreciation is expressed to Keesecker Agri-Business, Inc. for the use of pigs and facilities.

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of weaned pigs during this transition period may be critical in improving postweaning growth. Creep feeding studies that evaluated individual pigs rather than whole litters have consistently demonstrated the benefit of creating "eaters," which are pigs that positively consumed creep feed, on postweaning feed intake and growth. Identifying factors that can increase creep feed consumption and the proportion of pigs consuming creep feed may be important in improving the success of this practice.

It is hypothesized that creep diet complexity may be an important factor in stimulating feed intake. In previous studies, significant improvements were observed in both preweaning and postweaning feed intake when litters were fed a creep diet with greater complexity. However, no research has been conducted to evaluate the effects of creep diet complexity on individual consumption characteristics. It is also commonly speculated that weaned pigs that have preweaning experience to solid food may facilitate non-experienced pigs to discover food sources and initiate feeding when these pigs are housed together in large nursery groups. That is, pigs that have not consumed dry feed may "learn" from those that are eating. However, evidence of this social learning behavior is limited. Therefore, the objectives of this study were to determine (1) the effects of creep diet complexity on preweaning performance and the proportion of piglets consuming creep feed (Exp. 1) and (2) whether social facilitation occurs between eaters of creep feed and pigs that did not consume or had not been offered creep feed in a commercial nursery (Exp. 2).

Procedures

The experimental protocols used in this study were reviewed and approved by the Kansas State University Institutional Animal Care and Use Committee.

Experiment 1

A total of 96 sows (PIC C29) and their litters were used in this study conducted at a commercial sow facility in northeastern Kansas. Sows used in this experiment were from 3 batches of sows farrowed in February 2009. Cross-fostering was performed within 24 h after farrowing. At the start of the creep feeding experiment (d 18), sows were blocked according to date of farrowing and litter size and allotted to 3 experimental treatments in a randomized complete block design. In Treatment 1, litters were not provided any creep feed (no creep). In Treatments 2 and 3, litters were provided either a simple or complex creep diet, respectively (Table 1). There were 26 replicates for Treatments 1 and 2 and 44 replicates for Treatment 3. The higher number of replicates for Treatment 3 was intended to increase the number of eaters that were used for Exp. 2.

The simple creep diet contained 60% milo, 32% soybean meal, and 3% choice white grease, which was identical to the lactation diet offered to the sows. It was formulated to contain 1,589 kcal ME/lb and 0.97% standardized ileal digestible (SID) lysine. The complex creep diet was composed of 30% pulverized oat groats and 25% spray-dried whey with specialty protein sources such as 10% extruded soy protein concentrate, 6% spray-dried porcine plasma, and 6% select menhaden fish meal. It also contained 5% lactose and 5% choice white grease. The diet included very low levels of soybean meal (2.3%) and corn (6.15%). The diet was formulated to contain 1,585 kcal ME/lb, 1.56% SID lysine, and 23% lactose. Chromic oxide was added to both diets at 1.0% to serve

as a fecal marker. The simple creep diet was in meal form, and the complex creep diet was in pellet form (2-mm pellets). Both creep diets were offered ad libitum from d 18 until weaning on d 21 in a rotary creep feeder with hopper (Rotecna Mini Hopper Pan, Rotecna SA, Spain). A single lactation diet (1,589 kcal ME/lb, 0.97% SID lysine) was used in the experiment. Sows had free access to feed throughout lactation. Water was available at all times for sows and their litters through nipple and bowl drinkers, respectively.

Piglets were weighed individually at d 0 (birth), 18 (start of creep feeding), and 21 (weaning). A sufficient amount of creep feed was placed in the hopper of the creep feeder at the start of the study (d 18), and the initial weight of the creep feeder was weighed and recorded. Feeders were weighed daily to calculate daily and total creep feed intake for each litter. All creep-fed pigs were evaluated for consumption category at d 20 (48 h after creep feed was provided) by evaluating fecal material for the presence of green color provided by the chromic oxide marker in the creep diet. On the morning of the evaluation day, a fecal swab was obtained from each piglet. The pig was categorized as an eater if a green color was visible in the fecal sample. Piglets that tested negative on the first fecal sampling were sampled again 3 to 12 h before weaning (d 21). Piglets were categorized as non-eaters when no green color was detected in any of the collected samples. General health of the sows and piglets was checked daily, and use of medication was monitored. Temperature in the farrowing facility was maintained at a minimum of 20°C, and supplementary heat was provided to the piglets with heat lamps when needed.

The relationship between creep consumption category and teat order was also determined. Teat order was defined as the specific teat (pair) nursed by each piglet with respect to the anatomical location of the nursed mammary gland. In this study, individual pigs categorized as eaters were marked on their back, and non-eaters were unmarked. At d 20 (within 24 h before weaning), suckling bouts from 20 litters were photographed with a digital still camera. Litters with less than 50% eaters were chosen to obtain a good distribution of eaters and non-eaters. The photograph of each suckling bout was then used to determine teat location and rank of each individual piglet in the litter. A distribution of teat order in three classes was also made on the basis of the preferred teat pair suckled by the piglets: anterior (teat pairs 1 and 2), middle (teat pairs 3, 4, and 5), and posterior (teat pairs 6 and 7).

Experiment 2

From a total of 1,024 pigs weaned in Exp. 1, 675 pigs (PIC C29 × 327, initial BW 14.1 lb and 21.2 ± 0.2 d) were allotted to 3 treatments in a completely randomized design. The treatments for this study were: Treatment 1 - pigs that were not provided any creep feed or pigs that did not consume creep feed even when offered (non-eater), Treatment 2 - pigs that positively consumed creep feed (eater), and Treatment 3 - pigs that were 52% non-eaters and 48% eaters (mix). Eaters were used regardless of the complexity of the creep diet they consumed. Each treatment had 25 pigs per pen and 9 replications (pens). Each pen was equipped with one 10-hole self-feeder (Farmweld, Inc., Teutopolis, IL) and a cup drinker to provide ad libitum access to feed and water. The experiment was conducted at a commercial nursery facility in northeastern Kansas.

All pigs were fed a budget of 1 and 2 lb/pig of commercial SEW and transition diet, respectively. Pigs were fed a standard Phase 2 diet until the end of the study (d 28 postweaning). The total amount of feed offered in the first 3 d postweaning was recorded. To determine total and daily feed intake in the initial 3 d, feed was vacuumed out of the feeders and weighed. Pigs were weighed at d 0 (weaning), 3, 7, and 28 postweaning to calculate for periodic and cumulative ADG.

Data Analysis

In Exp. 1, data were analyzed as a randomized block design using the PROC MIXED procedure of SAS (SAS Institute Inc., Cary, NC) with litter as the experimental unit. The model included creep diet complexity and block as the fixed and random effect, respectively. Except for farrowing group 1, each block included 1 litter each of the no creep and simple creep treatment and 2 litters of the complex creep treatment. The extra litters fed complex diet were intended to provide an increased number of eaters for Exp. 2. The effects of creep diet complexity, weight category, and teat location on the proportion of eaters were analyzed using the Chi-square test in SAS. When treatment effect was a significant source of variation, differences were determined using the PDIFF option of SAS. In Exp. 2, data were analyzed as a completely randomized design using the PROC MIXED procedure of SAS with pen as the experimental unit. The model included consumption category and block as the fixed and random effects, respectively. When treatment effect was a significant source of variation, differences were determined using the PDIFF option of SAS. To test for evidence of social facilitation, the effect of consumption category was compared within the mix pens using PROC MIXED of SAS. Statistical significance and tendencies were set at $P < 0.05$ and $P < 0.10$ for all statistical tests.

Results and Discussion

Experiment 1

Sows had an average parity of 4.3 ± 0.4 and lactation length of 21.2 ± 0.2 d (Table 2). The average litter size at d 18 and 21 (weaning) was 10.7 ± 0.3 and 10.5 ± 0.3 piglets, respectively. Mortality rate during the creep feeding period (d 18 to 21) was 1.9% for all three treatments. Results indicated no differences ($P < 0.74$) in pig weaning weights; however, pigs fed the complex creep diet had greater (12.9%; $P < 0.03$) preweaning daily gains and tended to have higher (11.1%; $P < 0.06$) total gain than pigs fed the simple creep diet, with no creep pigs being intermediate. Total and daily gains of litters fed the complex creep diet were 4.1% and 5.0% higher than litters fed the simple creep diet, respectively; however, differences were not significant ($P > 0.58$). Likewise, there were no differences ($P < 0.70$) in litter weaning weights. This positive effect of increased diet complexity on preweaning weight gains may be related to the quality of the two creep diets used. The complex creep diet was formulated to match the digestive capacity of young pigs, so feed digestibility, palatability, and antigenic properties of the feed were considered. These same requirements were disregarded in the design of the simple creep diet. However, the lack of differences in pig and litter preweaning gains between the creep-fed and no creep pigs suggests that any benefit of increasing creep diet complexity was insufficient to see appreciable effects, especially when the duration of feeding and the amount consumed is considered.

Litters fed the complex creep diet consumed twice the total (2.73 vs. 1.37 lb; $P < 0.0006$) and daily (0.91 vs. 0.45 lb; $P < 0.0006$) creep feed intake of litters fed the simple creep diet (Figure 1). Creep diet complexity also influenced the proportion of pigs consuming creep feed in whole litters (Figure 2). Increasing the complexity of the creep diet improved ($P < 0.0001$) the proportion of eaters from 28% to 68%. This suggests that the higher creep feed intake observed in litters fed the complex creep diet was due to a greater number of pigs positively consuming creep feed. The proportion of eaters achieved in this study for the complex creep diet was consistent with our previous studies, in which the same creep diet, feeder design, and creep feeding duration were used. Relative to all the non-dietary and dietary factors previously investigated, diet complexity had the greatest influence in creating eaters. This indicates that the complexity of the creep diet may be one of the most important factors in stimulating individual pigs in the litter to consume creep feed.

Within the litters provided creep feed, there was no significant interaction between creep diet complexity and consumption category on individual pig performance prior to weaning (Table 3). Pigs that became eaters in creep-fed litters were lighter ($P < .0001$) at d 18 and at weaning regardless of the complexity of the creep diet. Eaters also tended to have lower ($P < 0.08$) preweaning total gains than non-eaters. Daily gains of eaters were 7.2% and 5.6% lower than those of non-eaters, but differences were not significant ($P > 0.12$). The distribution and performance of eaters and non-eaters according to weight category were also compared (Table 4). There were significant differences ($P < 0.0002$) in pig weights at d 18 and weaning, total gain, and daily gains between the bottom, middle, and top weight category for pigs fed either the simple or complex creep diet. A greater ($P < 0.0001$) percentage of eaters was observed among pigs in the bottom weight category for both creep-fed treatments; 47% in the simple creep diet and 83% in the complex creep diet. There was no interaction ($P > 0.50$; data not shown) between creep consumption category and weight class on any growth parameters in either the simple or complex creep treatments. In the current study, pigs identified as eaters were 7% to 8% smaller in body weight and were gaining 5% to 6% less than non-eaters prior to weaning regardless of the complexity of the creep diet. The higher proportion of eaters on the bottom weight category suggests that creep feeding is beneficial to smaller piglets within litters as an alternative source of nutrients during lactation.

It has been suggested that teat order may be related to creep feed consumption, in that pigs nursing in the posterior (less productive) teats may consume creep feed more readily than their counterparts nursing in anterior (more productive) teats. The relationship between teat order and creep consumption category is shown in Table 5. Overall, 37%, 45%, and 17% of the pigs were found nursing in the anterior (teat pairs 1 and 2), middle (teat pairs 3, 4, and 5), and posterior (teat pairs 6 and 7) teats. There were 49% eaters and 51% non-eaters in the litters evaluated. Results showed a tendency ($P < 0.10$) for differences in the proportion of eaters according to teat location. A greater proportion of eaters were found nursing in the middle and rear teats (57% and 52%, respectively) than in the front teats (38%). Typically, piglets that nurse from the rear teats are smaller and less competitive than those that nurse from front teats. The lower ability of smaller pigs to compete at the udder and extract milk may predispose these pigs to consume more creep feed when it is offered. The higher rate of eaters in the middle and rear teats in the current study may support this assumption.

Experiment 2

The effect of creep consumption category on nursery pig performance and weight variation within pens is shown in Table 6. The initial weight of the eater group (at d 21) was numerically lower than that of the non-eater group and tended ($P < 0.08$) to be lower than that of the mix group. The lower initial weight of the eater group was expected because it was a characteristic of the population of eaters weaned from Exp. 1. In the initial 3 d postweaning (d 21 to 24 of age), eaters had 43% greater (0.31 vs. 0.21 lb; $P < 0.01$) daily gains than non-eaters, with the mix group being intermediate. The mix group tended to have higher ($P < 0.08$) daily gains than the non-eater group. This was mainly due to differences in initial feed intake (first 3 d postweaning) between the groups. The eater group had higher ($P < 0.002$) ADFI than the non-eater and mix groups. The mix group also had higher ($P < 0.02$) ADFI than the non-eater group. There were no ($P > 0.23$) differences in F/G between the eater, non-eater, and mix groups during the initial 3-d period.

From d 3 to 7 postweaning (d 25 to 28 of age), there were no ($P > 0.66$) differences in daily gains between the three groups. In the first 7 d postweaning (d 21 to 28), the eater and mix groups had 12% to 10% higher overall daily gains, but differences were not significant ($P > 0.15$). Pig weights were similar ($P > 0.13$) between the three groups at d 24 and 28. From d 29 to 49, the eater group tended ($P < 0.07$) to have higher daily gains than the non-eater group, with the mix group being intermediate. Overall, daily gain of the eater group was 6.2% higher ($P < 0.05$) than that of the non-eater group, with the mix group being intermediate. There were no differences ($P > 0.14$) in pig weights at d 49 between the three groups. Though weight differences were numerical, it is worthy to note that despite starting at a lighter weight, eaters were the heaviest group and were 3% heavier (34.1 vs. 33.1 lb) than the non-eater group at d 49.

The difference in postweaning feed intake between eaters and non-eaters has been fairly consistent. Interestingly, most previous studies provided creep feed for 14 to 21 d and pigs were weaned at an older age (ranging from 24 to 31 d), whereas the current study had a shorter creep feeding duration (3 d prior to weaning) and pigs were weaned at a younger age (21 d). These results suggest that individual pigs that do consume creep feed prior to weaning consume more feed and achieve greater daily gains postweaning even when fed creep for a short duration and weaned at 3 wk of age. It is not known if the same responses can be expected in younger (< 3 wk) weaning ages.

At d 21 (weaning), there were no differences ($P > 0.16$) in initial pen CV between the three groups. However, the weight variation in the eater group was 1.3 to 1.6 percentage units higher than in the non-eater and mix groups. There were no differences in pen CV at d 24, 28, and 49; however, the reduction in pen CV in the eater group tended to be greater (-3.2% vs. -0.9%; $P < 0.06$) at d 28 than in the non-eater group, with the mix group being intermediate. Overall (d 21 to 49), the change in pen CV for the eater group was greater (-5.6%; $P < 0.03$) than for both the non-eater and mix groups. These results suggest that individual consumption characteristics of pigs prior to weaning may be an important factor in improving pig weight uniformity in the nursery. The greater reduction in weight variation in eater groups may possibly be driven by faster growth of smaller pigs, especially during the first week postweaning.

Creep consumption category influenced ($P < 0.0001$) the percentage of fall back pigs during the initial 3 d postweaning (Figure 3). Fall back pigs were those that did not gain weight or lost weight in the first 3 d postweaning. Overall, 25% of the total population of weaned pigs in the study did not gain or lost weight during the initial 3 d postweaning. However, eaters of creep feed responded better to weaning, with only 17% considered fall back pigs. For no creep pigs and non-eaters, 28% and 29%, respectively, of pigs lost weight. This indicates that positive consumption of creep feed preweaning can reduce postweaning lag, despite a large proportion of eaters being smaller than non-eaters and no creep pigs.

Social facilitation is a rudimentary form of social learning in which individuals discover resources by following group members that have already learned to exploit these resources. If social facilitation really occurs, transmission of information in locating and consuming a new food source between experienced (eaters) and inexperienced (non-eaters) pen mates may be important in reducing problems with low feed intake in newly weaned pigs and improving weaning transition. In the current study, the mix group had higher ($P < 0.02$) ADFI and tended to have higher ($P < 0.08$) daily gains than the non-eater group during the initial 3 d postweaning. Overall, the performance of the mix group was mostly intermediate to that of the eater and the non-eater groups.

The mix pens had 49% eaters and 51% non-eaters (Table 7). At d 21 (weaning), eaters were 1 lb lighter ($P < 0.02$) than non-eaters. From d 21 to 24, eaters had greater (0.36 vs. 0.15 lb; $P < 0.0001$) daily gains than non-eaters. This resulted in a 62% reduction (1 to 0.37 lb) in the weight differences between eaters and non-eaters after 3 d postweaning. From d 25 to 28, there were no ($P > 0.48$) differences in daily gains between eaters and non-eaters. However, eaters continued to have greater ($P < 0.04$) daily gains than non-eaters during d 21 to 28 and d 29 to 49 and overall daily gains (d 21 to 49). For social facilitation to occur, weight gains of non-eaters in the mix pens should be either (1) closer to the weight gains of eaters in the mix pen or (2) greater than the weight gains of the non-eater group. Results showed that non-eaters in the mix pens failed both criteria. In fact, the performance of eaters and non-eaters within the mix pens were similar to the performance of separate pens of eaters and non-eaters. This suggests that social facilitation did not occur between eaters and non-eaters.

In conclusion, increasing the complexity of the creep diet improved preweaning gains when creep feed was offered 3 d preweaning. The high-complexity diet improved litter creep feed consumption and the proportion of eaters in whole litters. Eaters had lower preweaning gains, lighter weaning weights, and tended to nurse more in the middle and posterior teats compared with non-eaters. Individual creep feed consumption characteristics influenced postweaning feed intake, daily gains, weight uniformity, and reduction of postweaning lag. Social facilitation did not occur in weaned pigs housed in large commercial groups.

Table 1. Composition (as-fed basis) of the simple and complex creep diets used in Exp. 1

Ingredient, %	Simple[1]	Complex[2]
Corn	---	6.25
Milo	60.40	---
Soybean meal, 46.5% CP	31.65	2.32
Spray-dried whey	---	25.00
Fine ground oat groats	---	30.00
Extruded soy protein concentrate	---	10.00
Spray-dried animal plasma	---	6.00
Select menhaden fish meal	---	6.00
Lactose	---	5.00
Choice white grease	3.00	5.00
Monocalcium P, 21% P	1.35	0.35
Chromic oxide	1.00	1.00
Antibiotic	---	1.00
Limestone	1.35	0.40
Zinc oxide	---	0.38
Salt	0.50	0.30
L-Lysine HCl	---	0.15
DL-methionine	---	0.15
Trace mineral premix	0.15	0.15
Vitamin premix	0.25	0.25
Sow add pack	0.25	---
Acidifier	---	0.20
Phytase	0.10	---
Vitamin E, 20,000 IU	---	0.05
Total	100.00	100.00
Calculated analysis		
CP, %	19.6	23.9
SID[3] lysine, %	0.97	1.56
ME, kcal/lb	1,589	1,585
SID lysine:ME ratio, g/Mcal	2.77	4.47
Ca, %	0.87	0.79
Available P, %	0.38	0.56

[1] Diet fed in pellet form (2-mm pellets).
[2] Diet fed in meal form.
[3] Standardized ileal digestible.

Table 2. Effects of creep diet complexity on pig and litter performance[1,2]

		Creep diet complexity			
Item	No creep	Simple	Complex	SE	*P*-value
no. of litters	26	26	44	---	---
no. of pigs/litter					
d 18 (start creep)	10.8	11.0	10.3	0.3	0.30
d 21 (weaning)	10.5	10.8	10.2	0.3	0.38
Weaning age, d	21.3	21.2	21.2	0.2	0.86
Pig weights, lb					
d 0 (post-fostering)	3.44	3.37	3.48	0.13	0.70
d 18 (start creep)	12.52	12.43	12.46	0.44	0.95
d 21 (weaning)	14.20	14.04	14.22	0.46	0.74
Total gain (d 18 to 21), lb	1.67[ab]	1.59[a]	1.76[b]	0.07	0.06
Daily gain (d 18 to 21), lb	0.64[ab]	0.61[a]	0.69[b]	0.03	0.03
Litter weights, lb					
d 0 (post-fostering)	36.44	37.04	36.05	1.92	0.90
d 18 (start creep)	131.90	134.00	127.58	6.66	0.60
d 21 (weaning)	149.16	151.04	145.22	7.21	0.70
Total gain (d 18 to 21), lb	17.24	17.02	17.72	0.73	0.72
Daily gain (d 18 to 21), lb	6.66	6.57	6.90	0.31	0.58

[1] Three groups of sows (PIC, total = 96, avg. parity = 4.3 ± 0.4) were blocked according to day of farrowing and allotted to 3 treatments: no creep = litter was not provided any creep feed, simple = litter was provided a simple creep diet, and complex = litter was provided a complex creep diet. Data were analyzed with litter as the experimental unit.

[2] Creep feed with 1.0% chromic oxide was offered ad libitum from d 18 to weaning (21 d) in a rotary feeder with hopper.

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

Table 3. Interactive effects of creep diet complexity and consumption category on preweaning performance of creep-fed pigs[1,2]

	Simple		Complex			*P*-value		
Item	Non-eater	Eater	Non-eater	Eater	SE	Complexity	Category	Complexity × Category
no.	203	79	145	304	---	---	---	---
Pig weight, lb								
d 0 (post-fostering)	3.37	3.35	3.46	3.44	0.13	0.62	0.63	0.87
d 18 (start creep)	12.65	11.62	13.07	12.17	0.44	0.40	<.0001	0.78
d 21 (weaning)	14.26	13.14	14.88	13.84	0.46	0.29	<.0001	0.82
Total gain, lb	1.62	1.51	1.79	1.71	0.01	0.02	0.08	0.84
Daily gain, lb	0.63	0.58	0.71	0.67	0.03	0.02	0.12	0.93

[1] Three groups of sows (PIC C29, total = 96, avg. parity = 4.3 ± 0.4) were blocked according to day of farrowing and allotted to 3 treatments: no creep = litter was not provided any creep feed, simple = litter was provided a simple creep diet, and complex = litter was provided a complex creep diet. In the simple and complex treatments, individual pigs were sampled at d 19 and 20 with fecal swabs to determine consumption category. Pigs were categorized as an eater if they showed green-colored feces in at least 1 of the 2 samplings; pigs were categorized as non-eaters when the samples were negative for green-colored feces. Data were analyzed with pig as the experimental unit.

[2] Creep feed with 1.0% chromic oxide was offered ad libitum from d 18 to weaning (21 d) in a rotary feeder with hopper.

Table 4. Effects of creep diet complexity on suckling pig performance according to weight category[1,2,3]

	Simple				Complex				
Item	Bottom	Middle	Top	SE	Bottom	Middle	Top	SE	*P*-value
no.	45	198	39	---	81	301	67	---	---
% of total	16	70	14	---	18	67	15	---	---
% eaters	47	25	23	---	83	65	62	---	---
Pig weight, lb									
d 18 (start creep)	9.04	12.43	15.83	0.22	8.09	12.94	17.44	0.20	<.0001
d 21 (weaning)	10.19	14.04	17.77	0.26	9.52	14.73	19.40	0.20	<.0001
Total gain, lb	1.14	1.61	1.95	0.08	1.43	1.79	1.97	0.07	<.0001
Daily gain, lb	0.43	0.63	0.72	0.04	0.57	0.71	0.77	0.03	0.0002

[1] Three groups of sows (PIC C29, total = 96, avg. parity = 4.3 ± 0.4) were blocked according to day of farrowing and allotted to 3 treatments: no creep = litter was not provided any creep feed, simple = litter was provided a simple creep diet, and complex = litter was provided a complex creep diet. Data were analyzed with pig as the experimental unit.

[2] Creep feed with 1.0% chromic oxide was offered ad libitum from d 18 to weaning (21 d) in a rotary feeder with hopper.

[3] Weight categories for each population: Top ≥ Least squares mean + 1 SD, Middle = Least squares mean ± 1 SD, Bottom ≤ Least squares mean - 1 SD.

Table 5. Proportion of eaters and non-eaters of creep feed according to teat location[1]

	Consumption category	
Teat location	Non-eater	Eater
no. of pigs		
Front	35	21
Middle	30	39
Rear	13	14
Percentage of pigs		
Front	62	38[a]
Middle	43	57[b]
Rear	48	52[b]

[1] Eaters of creep feed in a litter were marked; non-eaters were unmarked. Suckling bouts (n = 20 litters) were photographed within 24 h before weaning with a digital still camera to determine each individual pig's preferred teat (or pair) at d 21 of lactation. Front = teat pairs 1 and 2; middle = teat pairs 3, 4, and 5; rear = teat pairs 6 and 7.

[ab] Chi-square test: $P < 0.10$.

Table 6. Effects of creep consumption category on nursery pig performance and weight variation within pens[1,2]

	Consumption category				*P*-value		
Item	Non-eater (N)	Eater (E)	Mix (M)	SE	N vs. E	N vs. M	E vs. M
no. of pens	9	9	9	---	---	---	---
Pig weight, lb							
d 21 (weaning)	14.11	13.96	14.20	0.29	0.41	0.97	0.42
d 24	14.77	14.88	15.04	0.26	0.52	0.13	0.34
d 28	16.38	16.69	16.47	0.40	0.72	0.24	0.39
d 49	33.11	34.08	33.93	0.93	0.14	0.21	0.80
Daily gains, lb							
d 21 to 24	0.21	0.31	0.28	0.05	0.01	0.08	0.35
d 25 to 28	0.40	0.40	0.41	0.45	0.97	0.69	0.66
d 21 to 28	0.32	0.35	0.35	0.02	0.15	0.22	0.82
d 29 to 49	0.80	0.84	0.82	0.04	0.07	0.29	0.40
d 21 to 49	0.68	0.72	0.70	0.03	0.05	0.19	0.46
ADFI (d 21 to 24), lb	0.23	0.29	0.26	0.04	<.0001	0.02	0.002
F/G (d 21 to 24)	1.06	0.96	0.93	0.09	0.38	0.23	0.75
Pen CV[3], %							
d 21 (weaning)	23.8	25.1	23.5	0.8	0.26	0.78	0.16
d 24	22.3	22.5	21.3	0.9	0.83	0.42	0.29
d 28	22.9	21.8	21.2	0.9	0.40	0.19	0.63
d 49	20.7	19.5	19.6	1.0	0.40	0.43	0.96
CV[4] change, %							
d 21 to 24	-1.6	-2.5	-2.3	0.8	0.39	0.52	0.82
d 21 to 28	-0.9	-3.2	-2.3	0.8	0.06	0.26	0.43
d 21 to 49	-3.0	-5.6	-3.1	0.8	0.03	0.96	0.02

[1] A total of 675 pigs (PIC C29 × 327, initial BW 14.2 lb and 21.2 ± 0.2 d of age) were used with 25 pigs per pen and 9 replications per treatment. Group composition: non-eater = non-creep fed pigs and non-eaters of creep feed, creep = eaters of creep feed, and mix = 51% non-eaters and 49% eaters. Data were analyzed with pen as the experimental unit.

[2] All treatments were fed a budget of 1 and 2 lb/pig of a commercial SEW and transition diet, respectively.

[3] Coefficient of variation within pen.

[4] Difference in pen CV between two time points: final %CV - initial %CV.

Table 7. Postweaning growth performance of non-eater and eater pigs within mix pens (50% non-eaters:50% eaters)[1,2]

	Consumption category			
Item	Non-eater	Eater	SE	*P*-value
no.	113	108	---	---
% of total	51	49	---	---
Pig weights, lb				
d 21	14.81	13.82	0.31	0.02
d 24	15.26	14.88	0.31	0.38
d 28	17.04	16.58	0.33	0.35
d 49	33.42	34.02	0.82	0.54
Daily gains, lb				
d 21 to 24	0.15	0.36	0.04	<.0001
d 25 to 28	0.45	0.42	0.03	0.48
d 21 to 28	0.32	0.39	0.02	0.002
d 29 to 49	0.78	0.83	0.03	0.04
d 21 to 49	0.67	0.72	0.03	0.007

[1] A total of 675 pigs (PIC C29 × 327, initial BW 14.2 lb and 21.2 ± 0.2 d of age) were used with 25 pigs per pen and 9 replications per treatment. Group composition: non-eater = non-creep fed pigs and non-eaters of creep feed, creep = eaters of creep feed, and mix = 51% non-eaters and 49% eaters. In the mix treatment, differences between non-eater and eater pigs were analyzed with pen as the block and pig as the experimental unit.
[2] Pigs were fed a budget of 1 and 2 lb/pig of a commercial SEW and transition diet, respectively.

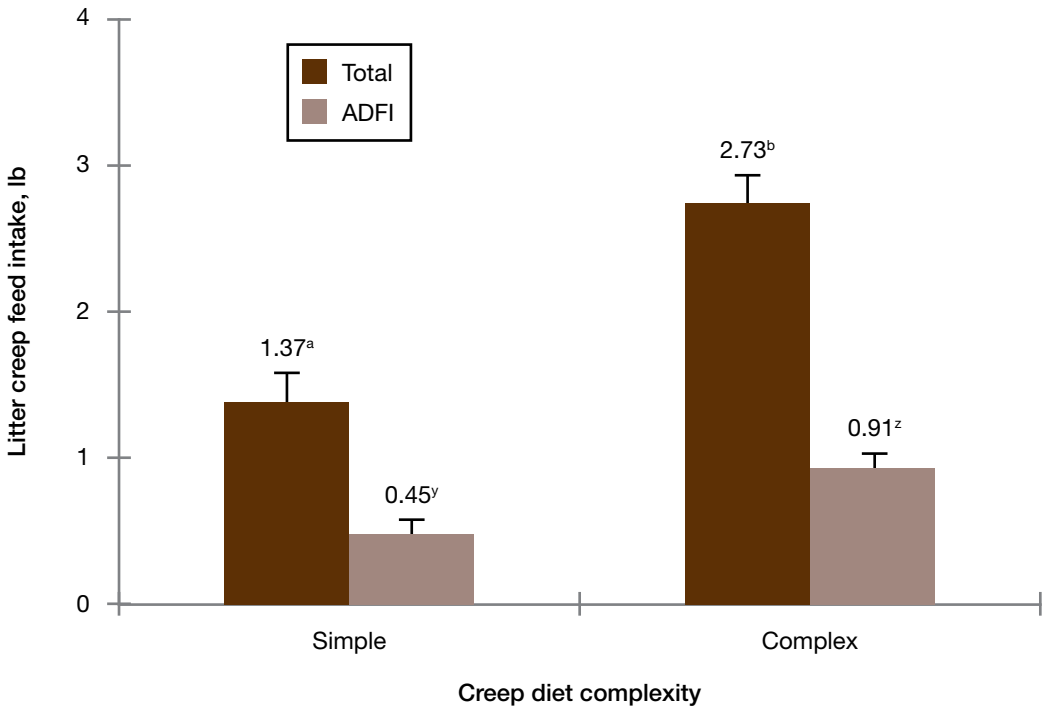

Figure 1. Total and daily creep feed intake of litters (mean ± SE) fed either simple or complex creep diets.
[ab]$P < .0006$; [yz]$P < .0006$.

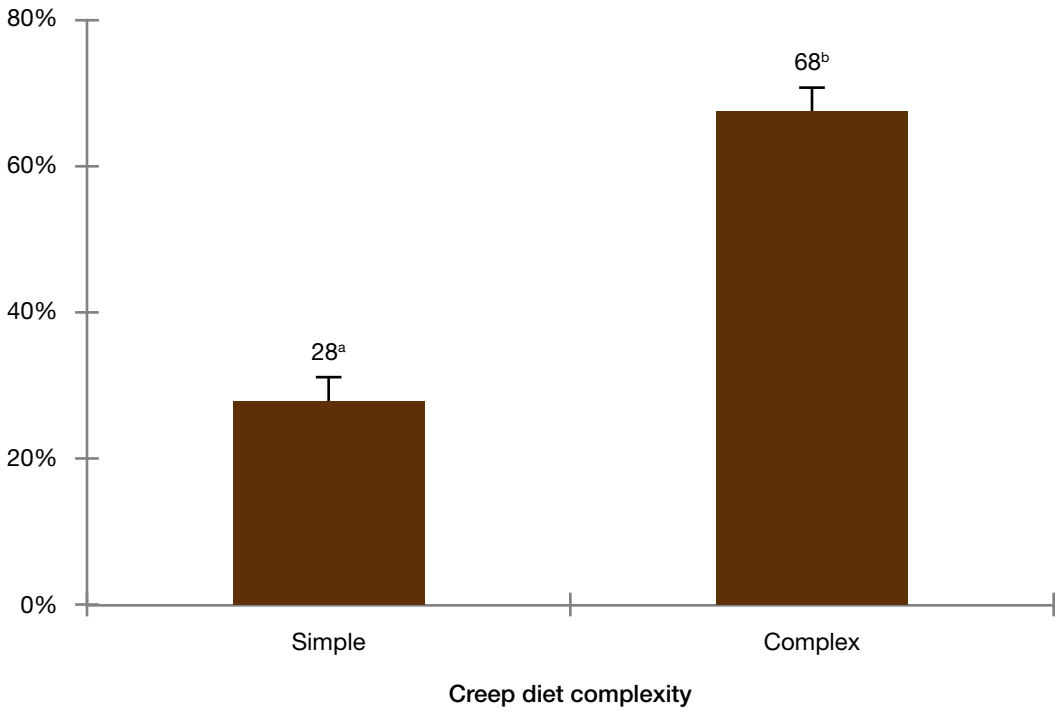

Figure 2. Effect of creep diet complexity on the proportion (mean percent ± SE) of eaters in whole litters.
$^{ab}P < .0001$.

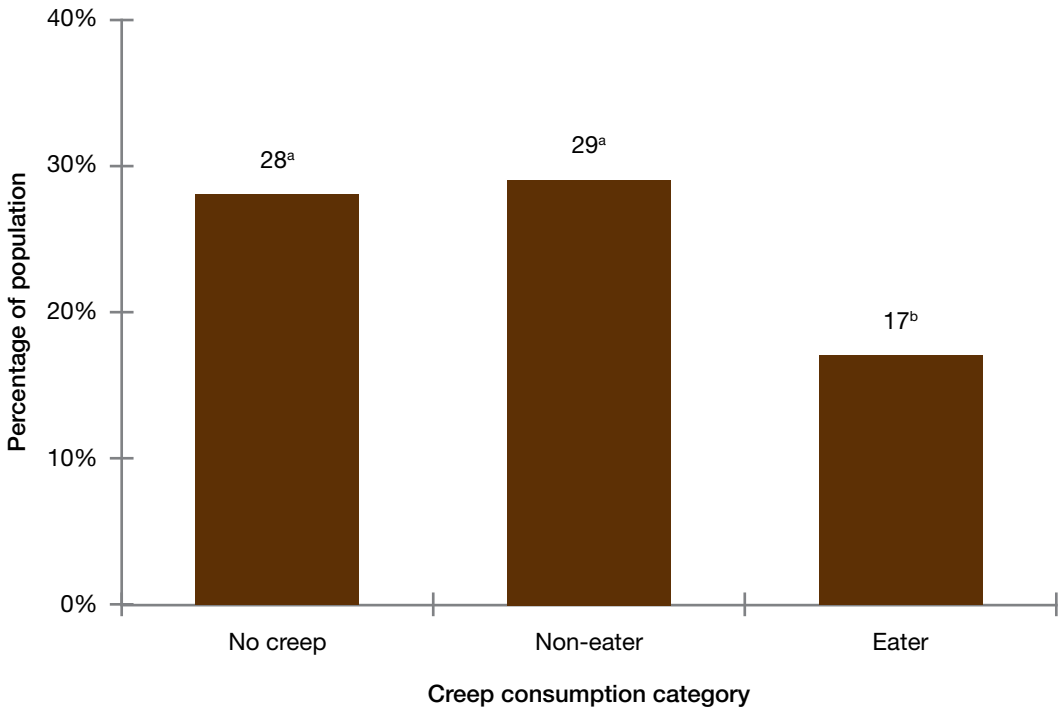

Figure 3. Percentage of fall back pigs during the initial 3 d postweaning within each creep consumption category.
Fall back pigs were those that did not gain weight or lost weight in the first 3 d postweaning. No creep = pigs that were not provided creep feed preweaning, non-eater = pigs that were negative for creep feed consumption, and eater = pigs that positively consumed creep feed. $\chi^2 = 18.0$; Category effect, $^{ab}P < .0001$.

Effects of Copper Sulfate and Zinc Oxide on Weanling Pig Growth and Plasma Mineral Levels

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Summary

A total of 216 weanling pigs (PIC TR4 × 1050, initially 13.6 lb and 21 d of age) were used in a 42-d growth trial to compare the effects of supplemental zinc and copper and changing mineral regimens on growth performance and plasma mineral levels. The 6 dietary treatments included a 2 × 2 factorial arrangement with main effects of added copper from copper sulfate (0 or 125 ppm) and added zinc from zinc oxide (0 or 3,000 ppm from d 0 to 14 and 0 or 2,000 ppm from d 14 to 42). For the final 2 treatments, either zinc oxide alone or the combinations of zinc and copper were fed from d 0 to 14, with copper sulfate fed from d 14 to 42. There were 6 pens per treatment with 6 pigs per pen. All diets were supplemented with an additional 165 ppm zinc and 16.5 ppm copper from the trace mineral premix. Plasma was collected from 2 pigs per pen on d 14 and 42. From d 0 to 14, ADG, ADFI, and F/G were improved ($P < 0.04$) with the addition of dietary zinc. Copper supplementation also tended to increase ($P < 0.07$) ADFI from d 0 to 14. From d 14 to 42, added copper increased ($P < 0.003$) ADG and ADFI. Over the entire trial, continuous supplemental zinc increased ($P < 0.03$) ADG and tended to increase ($P < 0.09$) ADFI. Dietary copper also increased ($P < 0.004$) ADG and ADFI when fed from d 0 to 42. The most advantageous values for ADG and ADFI were seen in the treatment containing high levels of zinc from d 0 to 14 and high copper levels from d 14 to 42. The addition of either zinc or copper increased ($P < 0.02$) feed cost per pound of gain. However, income over feed cost was improved ($P < 0.006$) with the addition of copper, with the greatest value obtained when high zinc was fed from d 0 to 14 and high copper was fed from d 14 to 42. Plasma zinc levels were increased ($P < 0.001$) with zinc supplementation on d 14. These results indicate the optimal mineral regimen was supplementing zinc oxide from d 0 to 14 and copper sulfate from d 14 to 42.

Key words: copper, growth promotion, zinc

Introduction

Zinc and copper are two minerals commonly added at pharmacological levels in weanling pig diets to serve as growth promoters. Research has shown that increased dietary zinc can increase growth rates and decrease the incidence of diarrhea for the first 2 to 4 wk after weaning. Zinc oxide (ZnO) is the most commonly used form of zinc. Dietary copper has also been shown to enhance growth rates in weanling pigs and growing pigs. Copper sulfate ($CuSO_4$) is the most common form. Historically, research on combining ZnO and $CuSO_4$ at pharmacological levels has shown growth rates similar to those

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when ZnO is used alone. However, Shelton et al. (2008[4]) reported additive effects to using pharmacological levels of both zinc from ZnO and copper from either $CuSO_4$ or tri-basic copper chloride. Therefore, the objective of this trial was to evaluate the effects of the addition of dietary copper or zinc for a longer duration than in past trials and to determine the impact of changing mineral regimens by using pharmacological levels of zinc early after weaning and high levels of dietary copper later in the nursery period.

Procedures

The protocol used in 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.

A total of 216 weanling pigs (PIC TR4 × 1050, initially 13.6 lb and 21-d of age) were used in a 42-d growth trial to compare the effects of supplemental zinc and copper and to observe the effects of changing mineral regimens for pigs from weaning to 50 lb. Pigs were allotted to pens by initial BW, and pens were assigned to treatments in a randomized complete block design, with both weight and location in the nursery serving as blocking factors. There were 6 pens per treatment with 6 pigs per pen. Treatments were arranged in a 2 × 2 factorial design with main effects of added copper from $CuSO_4$ (0 or 125 ppm) and added zinc from ZnO (0 or 3,000 ppm from d 0 to 14 and 0 or 2,000 ppm from d 14 to 42).Two additional treatments were included in which the added ZnO or ZnO and $CuSO_4$ diet was fed from d 0 to 14 with added $CuSO_4$ fed from d 14 to 42. The diets were fed in 2 phases: Phase 1 from d 0 to 14 and Phase 2 from d 14 to 42 (Table 1). Phase 1 and 2 diets were fed in meal form and formulated to contain 1.41% and 1.31% standardized ileal digestible lysine, respectively. Phase 1 diets contained 15% spray-dried whey and 3.75% fish meal, and Phase 2 diets were corn-soybean meal based. The trace mineral premix supplied 165 ppm zinc and 16.5 ppm copper to each of the diets. Added copper and zinc levels were achieved by replacing cornstarch with ZnO or $CuSO_4$.

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 floor and allowed for approximately 3 ft^2/pig. Weights and feed disappearance were measured every 14 d to determine ADG, ADFI, and F/G.

Blood samples were collected by jugular venipuncture from 2 randomly selected pigs per pen on d 14 and 42. Blood samples were chilled for approximately 1 h until they were centrifuged at 1,600 × *g* for 20 min. Plasma was then collected from each sample, frozen, and sent to Michigan State University for mineral analysis. Copper and zinc levels were determined by atomic absorption spectrophotometry. Phosphorus was measured by color spectrophotometry.

Feed cost per pound of gain, feed cost per pig, and income over feed cost were also calculated. Income over feed cost was calculated by assessing a value of $0.50 per pound of gain and subtracting the feed cost.

[4] Shelton et al., Swine Day 2008, Report of Progress 1001, pp. 62-73.

Pen was used as the experimental unit for all analysis, and data were analyzed using the MIXED procedure in SAS (SAS Institute Inc., Cary, NC). Main effects and potential interactions for added copper and zinc were tested using contrast statements. For Phase 1, both dietary treatments that were fed either the high zinc or high copper and zinc diet were pooled together to determine the main effects of copper and zinc. In Phase 2 as well as for the overall trial, only treatments that remained on the same mineral regimen for the entire trial were used to determine the main effects of copper and zinc.

Results and Discussion

Laboratory analysis of the diets indicated that diet copper and zinc levels were similar to those expected from diet formulation (Table 2).

Over the first phase (d 0 to 14), zinc supplementation improved ($P < 0.04$) ADG, ADFI, and F/G (Table 3). The addition of copper did not affect ADG or F/G but tended to increase ($P < 0.07$) ADFI from d 0 to 14. The greatest ADG and ADFI responses were seen when combining both added zinc and copper; however, they were only numerically greater (3%) than responses to zinc used alone.

From d 14 to 28, dietary zinc increased ($P < 0.04$) ADFI but not ADG. Thus, F/G became worse ($P < 0.02$) when zinc was included in the diet. Dietary copper also increased ($P < 0.003$) ADG and ADFI and tended to improve ($P < 0.06$) F/G. Adding copper and zinc together did not provide any benefit over feeding copper alone. As pigs were switched from supplemental zinc to added copper, an improvement ($P < 0.05$) in ADG was observed compared with maintaining a high level of zinc. Conversely, when switching from high levels of added copper and zinc to added copper, performance was not improved compared with the treatment containing both minerals.

A trend for a copper × zinc interaction was observed ($P < 0.06$) for ADG from d 28 to 42. This interaction is reflective of the numeric decrease in ADG when copper and zinc were used in combination compared with each used singularly. The addition of copper also resulted in an increase ($P < 0.04$) in ADFI and worsened F/G.

From d 14 to 42, added $CuSO_4$ increased ($P < 0.003$) ADG and ADFI. Added zinc worsened ($P < 0.05$) F/G and had no effect ($P > 0.10$) on ADG or ADFI. Average daily gain and ADFI were increased ($P < 0.05$) for pigs that were fed high levels of zinc from d 0 to 14 and then switched to high copper for d 14 to 42 compared with pigs fed high zinc in both phases.

Feeding pharmacological zinc continuously over the entire 42-d trial increased ($P < 0.03$) ADG and tended to increase ($P < 0.09$) ADFI. Copper supplementation also increased ($P < 0.004$) ADG and ADFI from d 0 to 42. These results agree with earlier research that indicated that improvements in growth performance from high levels of dietary copper or zinc were mostly due to improvements in feed intake. The most advantageous values for ADG and ADFI were observed in the treatment containing high levels of zinc in Phase 1 and high levels of copper in Phase 2. Pigs fed this treatment were 2.1 lb heavier than pigs fed only ZnO in both phases and 5.7 lb heavier than pigs fed the control diet.

For the entire trial, feed cost per pound of gain was increased (Table 4; $P < 0.02$) with the addition of copper or zinc as a result of the increase in diet cost with no improvements in F/G. Income over feed cost was improved ($P < 0.006$) with the addition of copper, with the greatest return obtained when high zinc was fed in Phase 1 and high copper in Phase 2. Adding zinc from d 0 to 14 and copper from d 14 to 28 resulted in $0.56 to $1.77 higher income over feed cost per pig than the other treatments.

No dietary effects were observed (Table 4; $P > 0.41$) for plasma copper level at d 14. However, plasma zinc levels were increased ($P < 0.001$) with added dietary zinc. Even more interesting was that treatments that were switched from either high zinc or high copper and zinc to high levels of copper had decreased plasma zinc levels than the treatments that remained on the same mineral regiment in both phases. On d 14, pigs were weighed and diets were switched at approximately 8:00 am, and then plasma was not collected until 1:00 p.m. The 5-h period in which pigs were allowed to eat the Phase 2 diet may have generated the decrease in plasma zinc. No dietary main effects were observed ($P > 0.16$) for plasma phosphorus at either d 14 or 42. On d 42, trends for a copper × zinc interaction were detected ($P < 0.08$) for both plasma copper and zinc. The plasma copper interaction was due to a numeric increase in plasma copper when copper was added to the diet alone, and compared with the control diet, no difference was observed when copper and zinc were both added. The plasma zinc interaction was due to the increase in plasma zinc when zinc was added alone in the diet, and there was no change when both copper and zinc were added.

The results from the first 28 d of this trial match results from our earlier study (Shelton et al., 2008), in which increases in ADG and ADFI were observed to adding both copper and zinc compared with adding each alone. However, the copper × zinc interaction for ADG observed from d 28 to 42 matches historical research showing reduced performance when combining zinc and copper compared with using either alone. Even though an additive response to copper and zinc was observed during the early portion of this trial, the regimen that achieved the greatest growth performance and economic return was the treatment in which zinc was fed in Phase 1 and copper was fed in Phase 2. This treatment regimen resulted in a 0.50 lb heavier pig and a return value of approximately $0.56 more per pig compared with adding both zinc and copper to the diets.

Table 1. Composition of diets[1]

Ingredient, %	Phase 1[2]	Phase 2[3]
Corn	48.72	60.74
Soybean meal (46.5% CP)	29.01	35.00
Spray-dried whey	15.00	---
Select menhaden fish meal	3.75	---
Monocalcium P (21% P)	1.05	1.60
Limestone	0.70	1.10
Salt	0.33	0.33
Vitamin premix	0.25	0.25
Trace mineral premix	0.15	0.15
Lysine HCl	0.30	0.30
DL-methionine	0.175	0.125
L-threonine	0.125	0.110
Cornstarch[4]	0.435	0.307
Total	100	100
Calculated analysis		
SID[5] amino acids, %		
Lysine	1.41	1.31
Isoleucine:lysine	60	63
Leucine:lysine	120	129
Methionine:lysine	36	33
Met & Cys:lysine	58	58
Threonine:lysine	62	62
Tryptophan:lysine	17	18
Valine:lysine	65	69
Total lysine, %	1.55	1.45
ME, kcal/lb	1,495	1,495
SID lysine:ME ratio, g/Mcal	4.28	3.97
CP, %	22.3	21.9
Ca, %	0.88	0.85
P, %	0.78	0.75
Available P, %	0.50	0.42
Available P:calorie, g/Mcal	1.51	1.26

[1] A total of 216 weanling pigs (PIC, initially 13.6 lb and 21 d of age) were used in a 42-d experiment with 6 pens per treatment.
[2] Pigs were fed Phase 1 from d 0 to 14.
[3] Pigs were fed Phase 2 from d 14 to 42.
[4] Cornstarch was replaced with ZnO at 7.7 lb/ton in Phase 1 and 5.1 lb/ton in Phase 2 and/or $CuSO_4$ at 1 lb/ton to create treatment diets.
[5] Standardized ileal digestible.

Table 2. Analyzed chemical composition of diets[1]

Added copper[2]:	No	Yes	No	Yes
Added zinc[3]:	No	No	Yes	Yes
Phase 1[4]				
Zinc, ppm	69 (196)	286 (196)	3,031 (3,196)	3,099 (3,196)
Copper, ppm	73.7 (26.2)	161.4 (151.2)	10.5 (26.2)	182.8 (151.2)
Phase 2[5]				
Zinc, ppm	204 (194)	256 (194)	1,823 (2,194)	1,819 (2,194)
Copper, ppm	19.1 (25.4)	162.3 (150.4)	26.1 (25.4)	180.0 (150.4)

Values in parentheses indicate the calculated expected value.

[1] A total of 216 weanling pigs (PIC, initially 13.6 lb and 21 d of age) were used in a 42-d experiment with 6 pens per treatment.

[2] Added copper from $CuSO_4$ was supplied at no (0 ppm) or yes (125 ppm) levels to that provided by the trace mineral premix supplementation of the basal diet (16.5 ppm Cu).

[3] Added zinc from ZnO was supplied at no (0 ppm) or yes (3,000 ppm in Phase 1 and 2,000 in Phase 2) levels to that provided by the trace mineral premix supplementation of the basal diet (165 ppm Zn from ZnO).

[4] Pigs were fed Phase 1 from d 0 to 14.

[5] Pigs were fed Phase 2 from d 14 to 42.

Table 3. Effects of zinc oxide and copper sulfate on weanling pig growth performance[1]

Phase 1 diet[2]:	Control	Cu	Zn	Cu and Zn	Zn	Cu and Zn		Probability, $P <$		
Phase 2 diet[3]:	Control	Cu	Zn	Cu and Zn	Cu	Cu	SEM	Zinc × Copper	Zinc	Copper
Initial wt, lb	13.6	13.6	13.6	13.6	13.6	13.6	0.74	0.12	0.49	0.59
d 0 to 14										
ADG, lb	0.32^{a}	0.40^{b}	0.47^{bc}	0.49^{c}	0.48^{bc}	0.49^{c}	0.029	0.23	0.001	0.14
ADFI, lb	0.49^{a}	0.58^{b}	0.57^{ab}	0.60^{b}	0.59^{b}	0.60^{b}	0.320	0.25	0.04	0.07
F/G	1.52^{a}	1.45^{a}	1.22^{b}	1.23^{b}	1.24^{b}	1.24^{b}	0.043	0.35	0.001	0.59
wt on d 14, lb	18.1^{a}	19.3^{ab}	20.2^{bc}	20.5^{c}	20.3^{bc}	20.5^{c}	0.96	0.22	0.001	0.14
d 14 to 28										
ADG, lb	1.03^{a}	1.17^{c}	1.06^{ab}	1.21^{c}	1.20^{c}	1.13^{bc}	0.047	0.80	0.29	0.001
ADFI, lb	1.45^{a}	1.61^{bc}	1.55^{ab}	1.72^{c}	1.65^{bc}	1.58^{abc}	0.069	0.99	0.04	0.003
F/G	1.40^{a}	1.37^{a}	1.47^{b}	1.42^{ab}	1.38^{a}	1.40^{a}	0.021	0.62	0.02	0.06
d 28 to 42										
ADG, lb	1.55^{a}	1.62^{ab}	1.62^{ab}	1.57^{ab}	1.64^{b}	1.60^{ab}	0.041	0.06	0.77	0.69
ADFI, lb	2.56^{a}	2.74^{b}	2.68^{ab}	2.71^{b}	2.75^{b}	2.72^{b}	0.090	0.17	0.40	0.04
F/G	1.65^{a}	1.69^{abc}	1.66^{ab}	1.73^{c}	1.68^{abc}	1.70^{bc}	0.026	0.58	0.24	0.003
d 14 to 42										
ADG, lb	1.29^{a}	1.40^{c}	1.33^{ab}	1.39^{bc}	1.42^{bc}	1.36^{bc}	0.039	0.32	0.39	0.001
ADFI, lb	2.01^{a}	2.17^{b}	2.11^{ab}	2.22^{b}	2.20^{b}	2.15^{b}	0.076	0.47	0.10	0.003
F/G	1.55	1.56	1.58	1.59	1.55	1.57	0.019	0.98	0.05	0.56
d 0 to 42										
ADG, lb	0.97^{a}	1.07^{bc}	1.04^{b}	1.09^{bc}	1.11^{c}	1.07^{bc}	0.033	0.30	0.03	0.003
ADFI, lb	1.50^{a}	1.64^{b}	1.59^{ab}	1.68^{b}	1.66^{b}	1.63^{b}	0.059	0.47	0.09	0.004
F/G	1.54	1.54	1.52	1.54	1.50	1.52	0.018	0.65	0.39	0.69
Final wt, lb	54.3^{a}	58.4^{b}	57.9^{b}	59.5^{b}	60.0^{b}	59.2^{b}	1.89	0.19	0.02	0.004

[1] A total of 216 weanling pigs (PIC, initially 13.6 lb and 21 d of age) were used in a 42-d experiment with 6 pens per treatment.

[2] Phase 1 diets were fed from d 0 to 14 after weaning: control (basal diet with no added Cu or Zn), Cu (125 ppm of added Cu from $CuSO_4$), Zn (3,000 ppm of added Zn from ZnO), and Cu and Zn (125 ppm of added Cu from $CuSO_4$ and 3,000 ppm of added Zn from ZnO).

[3] Phase 2 diets were fed from d 14 to 42 after weaning: control (basal diet with no added Cu or Zn), Cu (125 ppm of added Cu from $CuSO_4$), Zn (2,000 ppm of added Zn from ZnO), and Cu and Zn (125 ppm of added Cu from $CuSO_4$ and 2,000 ppm of added Zn from ZnO).

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

Table 4. Effects of zinc oxide and copper sulfate on the economics and plasma mineral concentrations of weanling pigs[1]

								Probability, $P <$		
Phase 1 diet[2]:	Control	Cu	Zn	Cu and Zn	Zn	Cu and Zn		Zinc ×		
Phase 2 diet[3]:	Control	Cu	Zn	Cu and Zn	Cu	Cu	SEM	Copper	Zinc	Copper
Economics, d 0 to 42										
Feed cost/lb gain, $[4]	0.212^{ab}	0.214^{ab}	0.216^{b}	0.218^{b}	0.210^{a}	0.213^{ab}	0.003	0.44	0.02	0.004
Feed cost/pig, $[4]	8.65^{a}	9.57^{b}	9.46^{b}	10.02^{b}	9.74^{b}	9.61^{b}	0.354	0.97	0.07	0.37
IOFC, $/pig[4,5]	11.70^{a}	12.79^{bc}	12.43^{b}	12.91^{bc}	13.47^{c}	12.90^{bc}	0.365	0.27	0.12	0.006
Plasma mineral concentrations										
d 14										
Copper, µg/mL	1.87	1.89	1.86	1.88	1.75	1.86	0.08	0.68	0.51	0.42
Zinc, µg/mL	0.53^{a}	0.55^{a}	0.95^{c}	0.93^{c}	0.74^{b}	0.73^{b}	0.066	0.81	0.001	0.92
Phosphorus, mg/mL	0.084^{ab}	0.083^{a}	0.086^{ab}	0.086^{ab}	0.094^{b}	0.086^{ab}	0.004	0.71	0.17	0.28
d 42										
Copper, µg/mL	1.94	2.13	2.06	1.97	1.97	2.10	0.077	0.08	0.78	0.54
Zinc, µg/mL	1.04^{a}	1.08^{a}	1.24^{b}	1.12^{ab}	1.13^{ab}	1.06^{a}	0.043	0.07	0.01	0.42
Phosphorus, mg/mL	0.092^{a}	0.089^{a}	0.092^{a}	0.092^{a}	0.098^{b}	0.088^{a}	0.002	0.42	0.38	0.38

[1] A total of 216 weanling pigs (PIC, initially 13.6 lb and 21 d of age) were used in a 42-d experiment with 6 pens per treatment.

[2] Phase 1 diets were fed from d 0 to 14 after weaning: control (basal diet with no added Cu or Zn), Cu (125 ppm of added Cu from $CuSO_4$), Zn (3,000 ppm of added Zn from ZnO), and Cu and Zn (125 ppm of added Cu from $CuSO_4$ and 3,000 ppm of added Zn from ZnO).

[3] Phase 2 diets were fed from d 14 to 42 after weaning: control (basal diet with no added Cu or Zn), Cu (125 ppm of added Cu from $CuSO_4$), Zn (2,000 ppm of added Zn from ZnO), and Cu and Zn (125 ppm of added Cu from $CuSO_4$ and 2,000 ppm of added Zn from ZnO).

[4] Feed costs were based on corn at $5.00/bu, soybean meal at $350/ton, zinc oxide at $121.87/cwt, and copper sulfate at $118.75/cwt.

[5] Income over feed cost = (Weight gain per pig × $0.50/lb) - feed cost per pig.

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

Effects of Copper Sulfate, Zinc Oxide, and NeoTerramycin on Weanling Pig Growth and Antibiotic Resistance Rate for Fecal *Escherichia coli*

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Summary

A total of 180 weanling pigs (PIC TR4 ×1050, initially 11.1 lb and 21 d of age) were used in a 42-d growth trial to compare the effects of supplemental zinc, copper, and in-feed antimicrobial on weanling pig growth and antibiotic resistance of fecal *Escherichia coli*. There were 5 dietary treatments with 6 pens per treatment and 5 pigs per pen. Pens were assigned to dietary treatments in a randomized complete block design. Treatments were arranged in a 2 × 2 factorial design with main effects of copper sulfate (0 or 125 ppm) and zinc oxide (0 or 3,000 ppm for 14 d and 0 or 2,000 for 28 d). The fifth treatment was in-feed antimicrobial (50 g/ton neomycin sulfate and 50 g/ton oxytetracycline HCl). All diets were supplemented with165 ppm zinc and 16.5 ppm copper from the trace mineral premix. Fecal samples were collected from 3 pigs per pen on d 14 and 42 to determine total coliform and *E. coli* counts as well as *E. coli* antibiotic resistance rates.

Pigs fed added zinc oxide had increased ($P < 0.04$) ADG and tended to have improved ($P < 0.09$) ADFI and F/G from d 0 to 14. From d 14 to 42, pigs fed added zinc oxide had poorer ($P < 0.007$) F/G than those with no added zinc oxide, and pigs fed added copper sulfate had improved ($P < 0.07$) F/G compared with those fed no added copper sulfate. Over the entire 42-d trial, a trend for a copper × zinc interaction was detected ($P < 0.09$) for ADG as pigs fed the addition of copper sulfate or zinc oxide had increased ADG over the control; however, when zinc and copper were combined, growth rate was similar to that when each was added singularly. Therefore, no additive effects were observed in this experiment from feeding a combination of high levels of dietary copper and zinc.

Dietary addition of copper sulfate, zinc oxide, or in-feed antibiotic had no effect ($P > 0.22$) on total coliform or *E. coli* concentrations on d 14 or 42. For d-14 isolates, zinc supplementation had no effect ($P > 0.43$) on *E. coli* resistance rate to chlortetracycline, neomycin, oxytetracycline, or tiamulin; however, copper supplementation tended to increase ($P < 0.10$) resistance to chlortetracycline and oxytetracycline. A copper × zinc interaction was detected ($P < 0.02$) for *E. coli* resistance to chlortetracycline and neomycin from isolates on d 42. These interactions were related to a significant decrease in resistance when copper sulfate was fed alone.

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High levels of zinc oxide improved performance in the early postweaning period, whereas high levels of copper sulfate offered numeric advantages in the later phase. Although the resistance rate varied with dietary treatment, no clear pattern was detected.

Key words: bacterial sensitivity, copper, zinc

Introduction

Pharmacological levels of dietary zinc and copper have often been used to increase growth in weanling pigs. Nursery studies have demonstrated that increased dietary zinc can promote growth rates and decrease diarrhea in weanling pigs. Zinc oxide (ZnO) is the most commonly used form of zinc in diets for nursery pigs. Dietary copper also has been shown to enhance growth rates in weanling pigs, and copper sulfate ($CuSO_4$) is the most commonly used form. Previous research indicates that using both ZnO and $CuSO_4$ in the diet results in growth rates similar to those when ZnO is used alone. However, Shelton et al. (2008)[3] observed additive growth responses to feeding both ZnO and $CuSO_4$. Another unresolved question related to the addition of pharmacological levels of copper and zinc is the potential effects on antibiotic sensitivity. Research has shown links between feeding increased levels of copper and resistance of *Enterococci* to copper as well as to vancomycin and erythromycin. Therefore, the objective of this trial was to determine the effects of pharmacological levels of copper and zinc or an in-feed antibiotic combination on weanling pig performance and antibiotic resistance of fecal *Escherichia coli*.

Procedures

The protocol used in 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.

A total of 180 weanling pigs (PIC TR4 ×1050, initially 11.1 lb and 21 d of age) were used in a 42-d growth trial to compare the effects of supplemental zinc, copper, and an in-feed antibiotic on weanling pig growth and antibiotic resistance of fecal *E. coli*. Pigs were allotted to pens by initial BW, and pens were assigned to treatments in a randomized complete block design with both weight and location in the nursery serving as blocking factors. There were 6 pens per treatment with 5 pigs per pen. Treatments were arranged as a 2 × 2 factorial design with main effects of added copper from $CuSO_4$ (0 or 125 ppm) and added zinc from ZnO (0 or 3,000 ppm from d 0 to 14 and 0 or 2,000 ppm from d 14 to 42) along with an additional treatment with an in-feed antibiotic that providing neomycin (50 g/ton) and oxytetracycline (50 g/ton). The trace mineral premix supplied a base level of 165 ppm zinc and 16.5 ppm copper in all diets. The diets were fed in 2 phases: Phase 1 from d 0 to 14 and Phase 2 from d 14 to 42 (Table 1). Phase 1 and 2 diets were fed in meal form and formulated to contain 1.41% and 1.31% standard ileal digestible lysine, respectively. Phase 1 diets contained 15% spray-dried whey and 3.75% fish meal, and Phase 2 diets were corn-soybean meal based. Treatment diets were prepared by replacing cornstarch with ZnO, $CuSO_4$, or in-feed antibiotic.

[3] Shelton et al., Swine Day 2008, Report of Progress 1001, pp. 62-73.

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 floor and allowed for approximately 3 ft^2/pig. Weights and feed disappearance were measured every 14 d to determine ADG, ADFI, and F/G.

On d 14 and 42, fecal samples were collected from 3 randomly selected pigs per pen. Fecal samples were diluted, plated, and subsequently counted to determine the number of colony forming units per gram of sample for both *E. coli* and total coliforms. One colony per sample was then isolated and retained for further analysis. Minimum inhibitory concentrations (MIC) of antibiotics were then determined on each isolate by the micro-broth dilution method (CLSI, 2002[4]). The antibiotics evaluated included chlortetracycline, neomycin, oxytetracycline, and tiamulin. The MIC for each isolate was compared with published MIC values to determine whether each isolate was resistant or susceptible. Isolates were classified as resistant if the MIC was 16 μg/mL or higher for oxytetracycline, chlortetracycline, and neomycin and 32 μg/mL or higher for tiamulin. Finally, a pen resistant rate was calculated on the basis of the resistance for each pen's 3 isolates.

Pen was used as the experimental unit for all analyses, and data were analyzed using the MIXED procedure in SAS (SAS Institute Inc., Cary, NC). Main effects and potential interactions for added dietary copper and zinc were tested using contrast statements. Bacterial counts were log transformed to achieve normality. Pair-wise comparison was also used to test the difference between the control and antibiotic treatment.

Results

Over the first phase (d 0 to 14), pigs fed added dietary ZnO had improved ($P < 0.02$) ADG (Table 2). Dietary zinc additions also tended to increase ($P < 0.09$) ADFI and improve ($P < 0.06$) F/G. The addition of $CuSO_4$ did not affect ($P > 0.19$) ADG or ADFI, but a trend was detected for poorer ($P < 0.06$) F/G from d 0 to 14 compared with pigs fed no added copper. Also, no improvements ($P > 0.59$) in ADG, ADFI, or F/G were observed for pigs supplemented with in-feed antibiotics compared with pigs fed no added zinc or copper.

From d 14 to 28, no improvements in ADG or F/G were observed ($P > 0.14$) from supplementing dietary copper or zinc. However, a trend for a copper × zinc interaction was detected ($P < 0.07$). This interaction was due to increases in ADFI over the control when either copper or zinc were used independently; however, when copper and zinc were used in combination, ADFI was intermediate of that when either was singularly. In-feed antibiotic supplementation also increased ($P < 0.01$) ADFI and tended to increase ($P < 0.10$) ADG over that of pigs fed no added zinc or copper.

From d 28 to 42, ZnO and $CuSO_4$ supplementation did not increase ($P > 0.18$) ADG or ADFI. However, a trend for improved F/G was observed ($P < 0.06$) with $CuSO_4$ addition, and a trend for worsened F/G was observed ($P < 0.09$) with zinc addition. Adding the in-feed antibiotic also had no effect ($P > 0.71$) on pig ADG, ADFI, or F/G compared with pigs fed the control diet.

[4] Clinical and Laboratory Standard Institute (CLSI). 2002. Performance Standards for Antimicrobial Disk and Dilution Susceptibility Tests for Bacteria Isolated from Animals. Approved Guideline-2nd ed. CLSI Document M31-A2. CLSI, Wayne, PA.

Over the entire Phase 2 (d 14 to 42), pigs fed the additional ZnO had poorer ($P < 0.007$) F/G and tended to have increased ($P < 0.07$) ADFI compared with those not receiving additional ZnO. Pigs fed supplemental $CuSO_4$ had improved ($P < 0.04$) F/G without increased ($P > 0.13$) ADG or ADFI from d 14 to 42. Antibiotic addition did not improve ($P > 0.28$) in ADG, ADFI, or F/G compared with control pigs.

A trend for a copper × zinc interaction was detected ($P < 0.09$) for ADG over the entire 42-d trial. The addition of copper or zinc increased ADG over the control; however, when copper and zinc were combined, pigs had reduced growth compared with that achieved when feeding each independently. Pharmacological levels of zinc also increased ($P < 0.04$) ADFI. Over the entire trial, the in-feed antimicrobial did not improve ($P > 0.28$) ADG, ADFI, or F/G.

Coliform and *E. coli* counts were not affected ($P > 0.22$) by dietary addition of $CuSO_4$, ZnO, or in-feed antimicrobials (Table 3). For d-14 isolates, dietary ZnO supplementation had no effect ($P > 0.43$) on the percentage of *E. coli* isolates classified as resistant for chlortetracycline, neomycin, oxytetracycline, or tiamulin. However, from d-14 isolates, $CuSO_4$ tended to increase ($P < 0.10$) the percentage of isolates resistant to chlortetracycline and oxytetracycline. Also, the in-feed antimicrobial tended to increase ($P < 0.10$) the percentage of isolates resistant to chlortetracycline and oxytetracycline compared with the controls. A copper × zinc interaction was detected ($P < 0.02$) for *E. coli* resistance to chlortetracycline and neomycin from isolates on d 42. These interactions were related to a significant decrease in the percentage of isolates classified as resistant when copper was fed alone. In-feed antibiotic and $CuSO_4$ dietary additions also tended to increase ($P < 0.10$) the percentage of *E. coli* isolates resistant to tiamulin on d 42.

Discussion

Results from this trial agree with previous research that showed that benefits from additional dietary zinc and copper were not additive in nature. The improvement in ADG and ADFI with ZnO supplementation from d 0 to 14 agrees with other research that shows that zinc improves growth early postweaning. Only marginal improvements were observed from adding cooper to the diet. Many other studies have shown a greater response to copper, which is usually apparent later in the nursery stage (d 14 to 42), than this study did. These results are in contrast with those of Shelton et al. (2008).

The copper × zinc interaction for *E. coli* resistance to chlortetracycline and neomycin from isolates on d 42 is an interesting observation from this study. We cannot explain a biological reason why resistance would drop dramatically when additional dietary copper was fed alone. It may have been an effect of sampling, as only 3 isolates per pen were used. Although the resistance rate varied with dietary treatment, no clear pattern was detected. Additional research is warranted to evaluate the effects of high levels of dietary copper and zinc additions on antibiotic resistance. In addition, more research is needed to understand the factors that may be affecting the effectiveness of high dietary levels of copper and zinc supplementation fed to increase growth rates of weanling pigs.

Table 1. Composition of diets[1]

Ingredient, %	Phase 1[2]	Phase 2[3]
Corn	48.72	60.74
Soybean meal (46.5% CP)	29.01	35.00
Spray-dried whey	15.00	---
Select menhaden fish meal	3.75	---
Monocalcium P (21% P)	1.05	1.60
Limestone	0.70	1.10
Salt	0.33	0.33
Vitamin premix	0.25	0.25
Trace mineral premix	0.15	0.15
Lysine HCl	0.30	0.30
DL-methionine	0.175	0.125
L-threonine	0.125	0.110
Cornstarch[4]	0.435	0.307
Total	100	100
Calculated analysis		
SID[5] amino acids, %		
Lysine	1.41	1.31
Isoleucine:lysine	60	63
Leucine:lysine	120	129
Methionine:lysine	36	33
Met & Cys:lysine	58	58
Threonine:lysine	62	62
Tryptophan:lysine	17	18
Valine:lysine	65	69
Total lysine, %	1.55	1.45
ME, kcal/lb	1,495	1,495
SID lysine:ME, g/Mcal	4.28	3.97
CP, %	22.3	21.9
Ca, %	0.88	0.85
P, %	0.78	0.75
Available P, %	0.50	0.42
Available P:calorie, g/Mcal	1.51	1.26

[1] A total of 180 weanling pigs (PIC, initially 11.1 lb and 21 d of age) were used in a 42-d experiment with 6 pens per treatment and 5 pigs per pen.
[2] Pigs were fed Phase 1 from d 0 to 14.
[3] Pigs were fed Phase 2 from d 14 to 42.
[4] Cornstarch was replaced with ZnO at 7.7 lb/ton in Phase 1 and 5.1 lb/ton in Phase 2, $CuSO_4$ at 1 lb/ton, or 5 lb/ton of Neo/Oxy 10/10 (Penfield Animal Health, Omaha, NE) to create treatment diets.
[5] Standardized ileal digestible.

Table 2. Effects of zinc oxide, copper sulfate, and antibiotic combination on weanling pig growth performance[1]

	Treatment[2]						Probability, $P<$			
	Control	Cu	Zn	Cu and Zn	Antibiotic	SEM	Zinc × Copper	Zinc	Copper	Antibiotic vs. Control
Initial wt, lb	11.1	11.1	11.1	11.1	11.1	0.049	0.82	0.86	0.91	0.89
d 0 to 14										
ADG, lb	0.37[a]	0.41[ab]	0.48[b]	0.46[b]	0.40[ab]	0.041	0.45	0.02	0.84	0.60
ADFI, lb	0.42[a]	0.49[ab]	0.50[ab]	0.52[b]	0.44[ab]	0.039	0.46	0.09	0.20	0.71
F/G	1.12[ab]	1.18[b]	1.03[a]	1.12[ab]	1.09[ab]	0.037	0.84	0.06	0.06	0.66
wt on d 14, lb	16.1[a]	16.6[ab]	17.7[b]	17.4[ab]	16.5[ab]	0.63	0.45	0.03	0.86	0.60
d 14 to 28										
ADG, lb	0.92	1.01	1.00	0.99	1.00	0.039	0.13	0.38	0.24	0.10
ADFI, lb	1.26[a]	1.36[ab]	1.42[b]	1.37[b]	1.40[b]	0.048	0.07	0.03	0.52	0.01
F/G	1.41	1.38	1.45	1.42	1.44	0.032	0.99	0.15	0.33	0.46
d 28 to 42										
ADG, lb	1.51	1.60	1.55	1.57	1.49	0.055	0.40	0.89	0.19	0.72
ADFI, lb	2.24	2.30	2.37	2.33	2.22	0.087	0.45	0.23	0.93	0.83
F/G	1.51[ab]	1.46[a]	1.55[b]	1.50[ab]	1.51[ab]	0.028	0.89	0.09	0.06	0.90
d 14 to 42										
ADG, lb	1.21[a]	1.30[b]	1.27[ab]	1.27[ab]	1.24[ab]	0.039	0.10	0.63	0.14	0.45
ADFI, lb	1.74[a]	1.82[ab]	1.89[b]	1.84[ab]	1.81[ab]	0.059	0.15	0.07	0.69	0.29
F/G	1.46[ab]	1.41[a]	1.50[b]	1.47[b]	1.47[b]	0.021	0.66	0.007	0.04	0.56
d 0 to 42										
ADG, lb	0.92[a]	1.00[b]	1.01[b]	0.99[ab]	0.95[ab]	0.034	0.09	0.15	0.21	0.39
ADFI, lb	1.29[a]	1.37[ab]	1.42[b]	1.40[b]	1.34[ab]	0.047	0.14	0.04	0.41	0.29
F/G	1.42	1.39	1.43	1.42	1.42	0.019	0.47	0.14	0.30	0.78
Final wt, lb	50.1	53.0	53.2	52.7	51.8	1.58	0.15	0.24	0.32	0.30

[1] A total of 180 weanling pigs (PIC, initially 11.1 lb and 21 d of age) were used in a 42-d experiment with 6 pens per treatment and 5 pigs per pen.

[2] Treatments were: control (basal diet with no added Cu or Zn), Cu (125 ppm of added Cu from $CuSO_4$), Zn (3,000 ppm from d 0 to 14 and 2,000 ppm from d 14 to 28 of added Zn from ZnO), Cu and Zn (125 ppm of added Cu from $CuSO_4$ and 3,000 ppm from d 0 to 14 and 2,000 ppm from d 14 to 28 of added Zn from ZnO), and antibiotic (55 ppm or 50 g/ton of neomycin and oxytetracycline from Neo/Oxy 10/10).

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

Table 3. Effects of zinc oxide, copper sulfate, and antibiotic combination on fecal bacteria counts and *E. coli* and antibiotic resistance[1]

	Treatment[2]						Probability, $P<$			
	Control	Cu	Zn	Cu and Zn	Antibiotic	SEM	Zinc × Copper	Zinc	Copper	Antibiotic vs. Control
Coliform counts, Log_{10} CFU/g										
d 14	6.2	5.8	6.2	5.6	6.0	0.50	0.82	0.81	0.25	0.68
d 42	5.5	4.9	5.1	5.0	4.9	0.49	0.52	0.72	0.30	0.23
E. coli count, Log_{10} CFU/g										
d 14	5.9	5.3	5.9	5.4	5.6	0.53	0.91	0.95	0.25	0.62
d 42	4.7	4.2	4.8	4.6	4.3	0.52	0.78	0.59	0.38	0.49
Antibiotic-resistant *E. coli* isolates, %										
d-14 isolates										
Chlortetracycline[3]	56	89	61	78	92	14.1	0.57	0.85	0.10	0.09
Neomycin[3]	33	33	28	28	44	15.0	1.00	0.68	1.00	0.56
Oxytetracycline[3]	72[ab]	94[ab]	67[a]	89[ab]	100[b]	11.2	1.00	0.63	0.07	0.10
Tiamulin[4]	100	94	100	100	94	3.5	0.44	0.44	0.44	0.28
d-42 isolates										
Chlortetracycline[3]	83[b]	47[a]	81[b]	89[b]	81[b]	9.6	0.02	0.03	0.10	0.81
Neomycin[3]	78[b]	25[a]	67[b]	83[b]	81[b]	11.2	0.01	0.05	0.13	0.87
Oxytetracycline[3]	94	72	86	89	94	8.4	0.16	0.63	0.27	1.00
Tiamulin[4]	90	100	94	100	100	3.7	0.59	0.59	0.06	0.09

[1] A total of 180 weanling pigs (PIC, initially 11.1 lb and 21 d of age) were used in a 42-d experiment with 6 pens per treatment and 5 pigs per pen.

[2] Treatments were: control (basal diet with no added Cu or Zn), Cu (125 ppm of added Cu from $CuSO_4$), Zn (3,000 ppm from d 0 to 14 and 2,000 ppm from d 14 to 28 of added Zn from ZnO), Cu and Zn (125 ppm of added Cu from $CuSO_4$ and 3,000 ppm from d 0 to 14 and 2,000 ppm from d 14 to 28 of added Zn from ZnO), and antibiotic (55 ppm or 50 g/ton of neomycin and oxytetracycline from Neo/Oxy 10/10).

[3] Isolates with a minimum inhibitory concentration of 16 µg/mL or higher for this antibiotic were considered resistant.

[4] Isolates with a minimum inhibitory concentration of 32 µg/mL or higher for this antibiotic were considered resistant.

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

An Evaluation of Peptone as a Specialty Protein Source in Diets for Nursery Pigs[1]

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Summary

Two experiments were conducted to evaluate the effects of select menhaden fish meal (SMFM), spray-dried animal plasma (SDAP), and two forms of a spray-dried ultrafiltrated porcine intestinal mucosa (Peptone 1 and 2; Protein Resources, West Bend, IA) on nursery pig performance. In Exp. 1, 216 weanling pigs (initial BW 11.9 lb) were fed either (1) a control diet containing no specialty protein sources or the control diet with (2) 4% SMFM during Phase 1 and 2% SMFM during Phase 2, (3) 4% SDAP during Phase 1 and no specialty protein sources during Phase 2, (4) 4% SDAP during Phase 1 and 2% SDAP during Phase 2, (5) 4% Peptone 1 during Phase 1 and no specialty protein sources during Phase 2, or (6) 4% Peptone 1 during Phase 1 and 2% Peptone 1 during Phase 2. Pigs were fed Phase 1 diets from d 0 to 10 postweaning followed by Phase 2 diets from d 10 to d 20 and a common Phase 3 diet that contained no specialty proteins for 7 d. From d 0 to 10 or d 0 to 27, there were no differences ($P > 0.05$) in ADG or F/G.

In Exp. 2, 180 weanling pigs (initial BW 13.0 lb) were fed either (1) a control diet containing no specialty protein sources or the control diet with (2) 4% SMFM during Phase 1 and 2% SMFM during Phase 2, (3) 4% SDAP during Phase 1 and no specialty protein sources during Phase 2, (3) 4% SDAP during Phase 1 and 2% SDAP during Phase 2, (5) 4% Peptone 2 during Phase 1 and no specialty protein sources during Phase 2, or (6) 4% Peptone 2 during Phase 1 and 2% Peptone during Phase 2. Pigs were fed Phase 1 diets from d 0 to 10 postweaning followed by a Phase 2 diet from d 10 to d 25. Pigs were then fed a common Phase 3 diet that contained no specialty proteins for 7 d. From d 0 to 10, pigs fed diets containing Peptone 2 had improved ($P < 0.10$) F/G compared with pigs fed the control diet. Overall (d 0 to 32), pigs fed 4% Peptone 2 during Phase 1 and 2% Peptone 2 during Phase 2 had improved ($P < 0.05$) ADG compared with pigs fed 4% SMFM during Phase 1 and 2% SMFM during Phase 2. Pigs fed 4% Peptone 2 during Phase 1 and 2% Peptone 2 during Phase 2 had improved ($P < 0.05$) F/G compared with pigs fed all other diets. In conclusion, the Peptone products evaluated in these studies can be used in nursery pig diets without negatively affecting pig growth performance. However, the lack of response to animal plasma in these experiments indicates that further research is warranted.

Key words: growth, protein source, spray-dried intestinal mucosa

Introduction

Weanling pig diets often contain animal protein sources, such as select menhaden fish meal (SMFM) and spray-dried animal plasma (SDAP), that are highly digestible, palat-

[1] The authors wish to thank Protein Resources, West Bend, IA, for providing the Peptone 1 and 2.

[2] Food Animal Health and Management Center, College of Veterinary Medicine, Kansas State University.

[3] Protein Resources, West Bend, IA.

able to young pigs, and have desirable amino acid profiles. Spray-dried animal plasma is widely used in diets immediately postweaning because it has consistently been shown to improve weanling pig performance during the first week after weaning by improving feed intake. Fish meal is often an economical way to increase essential amino acid content of diets when an upper limit is placed on the amount of soybean meal that can be used in the diet.

Another possible protein source for nursery diets is Peptone (Protein Resources, West Bend, IA), which is a product made by ultra-filtrating porcine intestinal mucosa. This filtration process removes some of the impurities from the amino-acid-rich peptides, which are then spray dried. The resulting material contains a high level of digestible peptides and amino acids. This newly developed protein source may provide an alternative to other traditional animal protein sources in nursery diets. Therefore, the objective of these experiments was to evaluate the effects of SMFM, SDAP, and Peptone on growth performance of weanling pigs.

Procedures

The protocol used in this experiment was approved by the Kansas State University (K-State) Institutional Animal Care and Use Committee. The study was conducted at the K-State Segregated Early Weaning Facility in Manhattan, KS.

A sample of Peptone 1 was collected and analyzed for nutrient composition (Table 1), and these values were used in diet formulation. Analyzed values were similar to those of SDAP, and because standardized ileal digestible (SID) values were not available for Peptone 1, diets were formulated with SID percentages for SDAP. For Peptone 2, analyzed amino acid values were unavailable at diet formulation. However, the analyzed CP level was similar to that of Peptone 1. Thus, diets were formulated with the same values as Peptone 1.

In Exp. 1, a total of 216 weanling pigs (PIC TR4 × 1050, initially 11.9 lb) were used in a 27-d growth trial. Pigs were blocked by weight and allotted to 1 of 6 diets. There were 6 pigs per pen and 6 pens per treatment. Each pen (5 × 5 ft) contained 1 self-feeder and 1 nipple waterer to provide ad libitum access to feed and water. Pigs were housed in the K-State Swine Teaching and Research Center.

The 6 experimental diets were: (1) control diet containing no specialty protein sources and the control diet with (2) 4% SMFM during Phase 1 and 2% SMFM during Phase 2, (3) 4% SDAP during Phase 1 and no specialty protein sources during Phase 2, (4) 4% SDAP during Phase 1 and 2% SDAP during Phase 2, (5) 4% Peptone 1 during Phase 1 and no specialty protein sources during Phase 2, and (6) 4% Peptone 1 during Phase 1 and 2% Peptone 1 during Phase 2 (Table 2). Phase 1 diets were fed from d 0 to 10, Phase 2 diets were fed from 10 to 20 d, and then all pigs were fed a common diet without any specialty protein sources for 7 d. All diets were fed in meal form. Average daily gain, ADFI, and F/G were determined by weighing pigs and measuring feed disappearance on d 5, 10, 17, 20, and 27 of the trial.

In Exp. 2, a total of 180 weanling pigs (PIC TR4 × 1050, initially 13.0 lb) were used in a 32-d growth trial. Pigs were blocked by weight and allotted to 1 of 6 diets. There were

5 pigs per pen and 6 pens per treatment. Each pen (5 × 5 ft) contained 1 self-feeder and 1 nipple waterer to provide ad libitum access to feed and water. Pigs were housed in the K-State Segregated Early Weaning Facility.

The 6 experimental diets were: (1) control diet containing no specialty protein sources and the control diet with (2) 4% SMFM during Phase 1 and 2% SMFM during Phase 2, (3) 4% SDAP during Phase 1 and no specialty protein sources during Phase 2, (3) 4% SDAP during Phase 1 and 2% SDAP during Phase 2, (5) 4% Peptone 2 during Phase 1 and no specialty protein sources during Phase 2, and (6) 4% Peptone 2 during Phase 1 and 2% Peptone during Phase 2 (Table 2). Phase 1 diets were fed from d 0 to 10, Phase 2 diets were fed from 10 to 25 d, and then all pigs were fed a common diet without specialty protein sources for 7 d. Phase 1 and 2 diets were pelleted, whereas the common Phase 3 diet was in meal form. Average daily gain, ADFI, and F/G were determined by weighing pigs and measuring feed disappearance on d 5, 10, 18, 25, and 32 of the trial.

Data were analyzed as a randomized complete block design with pen as the experimental unit. Analysis of variance used the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with treatment as a fixed effect. Point estimations were used to determine the effects of the addition of specialty proteins. Means were considered significant at $P < 0.05$ and trends at $P < 0.10$.

Results and Discussion

Crude protein levels were similar between the two Peptones, but Peptone 2 had more than 3.5 percentage units more lysine than Peptone 1 (Table 1). Peptone 2 also had greater Thr, Met, and Trp levels than Peptone 1. Some differences in Peptone chemical analysis were expected because the two different forms of specialty protein were ultra-filtrated with different filters. However, the amplitude of change in some amino acid values, such as Lys, was surprising given that the Peptones had similar CP levels. Peptone 2 contained 5 percentage units more moisture and had higher crude fat, Na, and Cl concentrations than Peptone 1. Peptone 1 and 2 had similar S levels (4.7%).

In Exp. 1, from d 0 to 10, pigs fed different diets had similar ($P > 0.10$) ADG. In addition, pigs fed the control diet tended to have improved ($P < 0.10$) F/G compared with pigs fed diets including Peptone 1 (Table 3). During Phase 2 (d 10 to 20), pigs previously fed 4% Peptone 1 during Phase 1 and the control diet during Phase 2 had improved ($P < 0.05$) ADG and ADFI compared with pigs previously fed 4% SDAP during Phase 1 and 2% SDAP during Phase 2 (Table 3). Pigs previously fed 4% Peptone 1 during Phase 1 and 2% Peptone 1 in Phase 2 and pigs fed the control diet tended to have improved ($P < 0.10$) ADG compared with pigs previously fed 4% SDAP during Phase 1 and 2% SDAP during Phase 2. Pigs previously fed 4% Peptone 1 during Phase 1 and 2% Peptone 2 during Phase 2 tended to have improved ($P < 0.10$) F/G compared with pigs previously fed 4% SDAP during Phase 1 and the control diet during Phase 2.

During the common period (d 20 to 27), ADG was similar ($P > 0.54$) among pigs previously fed different diets. Pigs previously fed the control diet in Phase 1 had greater ($P < 0.05$) ADFI than pigs previously fed 4% Peptone 1 during Phase 1 and tended to have greater ($P < 0.10$) ADFI than pigs previously fed SMFM. Also, pigs previously fed

4% SDAP during Phase 1 and the control diet during Phase 2 tended to have improved ($P < 0.10$) ADFI compared with pigs previously fed 4% Peptone 1 during Phase 1. Pigs previously fed diets containing 4% Peptone 1 during Phase 1 tended to have improved ($P < 0.10$) F/G compared with pigs previously fed 4% SDAP or the control diet during Phase 1. Overall (d 0 to 27), pigs fed all diets had similar ($P > 0.10$) ADG and ADFI. Pigs previously fed 4% Peptone 1 or SMFM during Phase 1 and 2% Peptone 2 or SMFM during Phase 2 tended to have improved ($P < 0.10$) F/G compared with pigs previously fed 4% SDAP during Phase 1 and the control diet during Phase 2.

In Exp. 2, from d 0 to 10, pigs fed diets containing Peptone 2 had improved ($P < 0.10$) F/G compared with pigs fed the control diet (Table 4). During Phase 2 (d 11 to 25), pigs fed different diets had similar ($P > 0.14$) ADG and ADFI (Table 4). Pigs previously fed diets containing 4% SMFM or Peptone 2 during Phase 1 and 2% SMFM or Peptone 2 during Phase 2 had improved ($P < 0.05$) F/G compared with pigs fed the control diet and tended to have improved ($P < 0.10$) F/G compared with pigs previously fed 4% SDAP during Phase 1 and 2% SDAP during Phase 2 or 4% Peptone 2 during Phase 1 and the control diet during Phase 2.

During the common period (d 25 to 32), pigs previously fed 4% Peptone 2 during Phase 1 and 2% Peptone 2 during Phase 2 tended to have improved ($P < 0.10$) ADG compared with pigs previously fed 4% SMFM during Phase 1 and 2% SMFM during Phase 2. Pigs previously fed different diets had similar ($P > 0.21$) ADFI. Pigs previously fed the control diet or diets containing 4% Peptone 2 during Phase 1 and 2% Peptone 2 during Phase 2 had improved ($P < 0.05$) F/G, whereas pigs previously fed 4% SDAP during Phase 1 and 2% SDAP during Phase 2 tended to have improved ($P < 0.10$) F/G compared with pigs previously fed 4% SMFM during Phase 1 and 2% SMFM during Phase 2.

Overall (d 0 to 32), pigs fed 4% Peptone 2 during Phase 1 and 2% Peptone 2 during Phase 2 had improved ($P < 0.05$) ADG compared with pigs fed 4% SMFM during Phase 1 and 2% SMFM during Phase 2 and tended to have improved ($P < 0.10$) ADG compared with pigs fed the control diet. Pigs fed all diets had similar ($P > 0.19$) ADFI. Finally, pigs fed 4% Peptone 2 during Phase 1 and 2% Peptone 2 during Phase 2 had improved ($P < 0.05$) F/G compared with pigs fed all other diets.

Adding SMFM resulted in no added benefit to weanling pig diets in this study; however, supplementing diets with SDAP yielded mixed effects. Little benefit was seen from adding SDAP in Exp. 1. However, improvements were seen in pig performance with SDAP supplementation in Exp. 2. Results of Exp. 2 are in agreement with previous research that has shown consistent growth performance improvements from supplementing weanling pig diets with SDAP. Generally, the improvements in pig growth performance are more prominent during the first week postweaning, and there is no added benefit in feeding SDAP after 1 wk postweaning. We saw a similar effect, as there was a significant improvement from adding SDAP from d 0 to 5 compared with the control, but there was no overall benefit at the end of the experiment.

It is unknown why diets with the same formulation yielded 2 different responses to specialty protein sources from 2 different groups of pigs housed in similar environments. The only difference between the diets was that diets in Exp. 1 were in meal form,

whereas those in Exp. 2 were pelleted. More research is needed, but it appears there may be a potential relationship between pelleting and level of response to SDAP supplementation.

Although there is no data showing the effects of Peptone on nursery pig growth performance, a similar protein product, dried porcine solubles, has shown consistent improvement in piglet growth performance. The Peptone products evaluated in these studies can be used in nursery pig diets without negatively affecting pig growth performance. The lack of a strong positive response to plasma and fish meal in these experiments indicates that further research is warranted to understand the response to Peptone in more challenging environments.

Table 1. Analyzed composition of Peptone (as-fed basis)[1]

Item	Peptone 1[2]	Peptone 2[3]
DM, %	96.60	91.23
CP, %	74.59	74.21
Crude fat, %	0.23	1.48
Ash, %	16.88	17.68
Ca, %	0.07	0.11
P, %	0.98	1.01
Na, %	5.33	6.57
Cl, %	0.42	2.88
S, %	4.67	4.69
Amino acids, %		
Arg	3.30	4.59
His	0.97	1.82
Ile	2.12	3.03
Leu	3.28	5.44
Lys	2.70	6.35
Met	0.62	1.02
Phe	1.35	2.46
Thr	1.99	3.01
Trp	0.33	0.44
Val	2.61	3.81
Ala	2.63	3.49
Cys	1.29	1.07
Gly	6.36	5.04
Orn	1.01	0.52
Pro	4.25	3.63
Ser	1.25	2.73
Tau	0.09	0.24
Tyr	1.07	2.54

[1] One sample of each was analyzed by the University of Missouri Agricultural Experiment Station Chemical Laboratories.

[2] Analyzed nutrient values were used in diet formulation. Analyzed values were similar to those of spray-dried animal plasma, and because standardized ileal digestible (SID) values were not available for Peptone 1, diets were formulated with SID percentages for spray-dried animal plasma.

[3] Analyzed amino acid values were unavailable at diet formulation. However, analyzed CP levels were similar to those of Peptone 1. Thus, diets were formulated with the same values as Peptone 1

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

	Phase 1[2]				Phase 2[3]				Phase 3[4]
Ingredient, %	Control	4% Fish meal	4% SDAP[5]	4% Peptone 1 or 2[6]	Control	2% Fish meal	2% SDAP[5]	2% Peptone 1 or 2[6]	Common
Corn	40.08	46.58	46.10	45.67	57.23	60.45	60.25	60.05	61.18
Soybean meal (46.5% CP)	40.28	30.35	30.37	30.34	37.82	32.86	32.87	32.85	33.85
SDAP	---	---	4.00	---	---	---	2.00	---	---
Peptone	---	---	---	4.00	---	---	---	2.00	---
Select menhaden fish meal	---	4.00	---	---	---	2.00	---	---	---
Spray-dried whey	15.00	15.00	15.00	15.00	---	---	---	---	---
Soybean oil	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.00
Monocalcium P (21% P)	0.93	0.45	0.70	0.83	1.15	0.90	1.00	1.08	1.65
Limestone	0.98	0.73	1.15	1.10	1.03	0.93	1.13	1.10	0.95
Salt	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.35
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-Lys·HCl	0.20	0.29	0.20	0.40	0.25	0.30	0.25	0.35	0.30
DL-Met	0.16	0.17	0.14	0.19	0.13	0.14	0.12	0.14	0.12
L-Thr	0.08	0.14	0.05	0.16	0.10	0.13	0.09	0.14	0.11
L-Val	---	---	---	0.02	---	---	---	---	---
Phytase[7]	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

continued

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

	Phase 1[2]				Phase 2[3]				Phase 3[4]
Ingredient, %	Control	4% Fish meal	4% SDAP[5]	4% Peptone 1 or 2[6]	Control	2% Fish meal	2% SDAP[5]	2% Peptone 1 or 2[6]	Common
Calculated analysis[8]									
Total Lys, %	1.61	1.60	1.60	1.59	1.49	1.48	1.48	1.48	1.42
SID[9] amino acids, %									
Lys	1.45	1.45	1.45	1.45	1.34	1.34	1.34	1.34	1.25
Met:Lys	33	35	31	34	33	35	31	33	31
Met & Cys:Lys	58	58	58	58	58	59	58	58	57
Thr:Lys	63	63	63	63	63	63	63	63	64
Trp:Lys	19	17	19	16	19	18	19	17	18
CP, %	24.3	22.9	23.3	23.0	22.8	22.1	22.3	22.2	21.4
ME, kcal/lb	1,517	1,530	1,528	1,515	1,530	1,536	1,536	1,530	1,518
SID Lys:ME, g/Mcal	4.34	4.30	4.30	4.34	3.97	3.96	3.96	3.97	4.23
Ca, %	0.80	0.80	0.80	0.80	0.75	0.75	0.75	0.75	0.80
P, %	0.69	0.66	0.66	0.66	0.66	0.65	0.64	0.64	0.75
Available P, %	0.48	0.48	0.48	0.48	0.42	0.42	0.42	0.42	0.42

[1] A total of 396 nursery pigs (initial BW 11.9 or 13.0 lb) were used in a 25- or 32-d growth assay to determine the effect of protein source on nursery pig growth performance.
[2] Phase 1 diets were fed from d 0 to 10.
[3] Phase 2 diets were fed from d 10 to 20 (Exp. 1) or from d 10 to 25 (Exp. 2).
[4] Phase 3 diets were fed from d 20 to 27 (Exp. 1) or from d 25 to 32 (Exp. 2).
[5] Spray-dried animal plasma
[6] Peptone 1 and 2 were used in Exp. 1 and 2, respectively.
[7] NatuPhos 600 (BASF Animal Nutrition, Mount Olive, NJ) provided 231 FTU/lb, with a release of 0.10% available P.
[8] Nutrient values for fish meal and SDAP were from NRC. 1998. Nutrient Requirements of Swine. 10th ed. Natl. Acad. Press, Washington, DC.
[9] Standardized ileal digestible.

Table 3. Effects of protein source on nursery pig performance (Exp. 1)[1]

Phase 1[2]:	Control	4% SDAP[4]	4% SDAP	4% Peptone 1	4% Peptone 1	4% Fish meal	
Phase 2[3]:	Control	Control	2% SDAP	Control	2% Peptone 1	2% Fish meal	SEM
d 0 to 10							
ADG, lb	0.41	0.46	0.47	0.46	0.43	0.45	0.035
ADFI, lb	0.41[b]	0.50[ab]	0.48[ab]	0.51[a]	0.49[ab]	0.47[ab]	0.034
F/G	1.01[a]	1.09[ab]	1.01[a]	1.12[ab]	1.15[b]	1.03[ab]	0.051
d 10 to 20							
ADG, lb	0.72[ab]	0.65[ab]	0.62[a]	0.73[b]	0.73[ab]	0.67[ab]	0.048
ADFI, lb	0.95[ab]	0.90[ab]	0.84[a]	0.99[b]	0.95[ab]	0.90[ab]	0.056
F/G	1.33	1.38	1.37	1.35	1.31	1.50	0.040
d 20 to 27							
ADG, lb	0.99	0.97	0.97	0.98	0.99	0.99	0.032
ADFI, lb	2.08[a]	2.02[ab]	2.00[ab]	1.83[b]	1.82[b]	1.87[ab]	0.080
F/G	2.10	2.09	2.07	1.88	1.85	1.91	0.094
d 0 to 27							
ADG, lb	0.66	0.66	0.65	0.69	0.69	0.67	0.031
ADFI, lb	1.01	1.03	1.00	1.02	1.01	0.98	0.022
F/G	1.54	1.57	1.54	1.48	1.48	1.48	0.052

[1] A total of 216 pigs (6 pigs per pen and 6 pens per treatment) with an initial BW of 11.9 lb were used in a 27-d experiment.
[2] Phase 1 diets were fed from d 0 to 10.
[3] Phase 2 diets were fed from d 10 to 20.
[4] Spray-dried animal plasma.
[ab] Within a row, means without a common superscript differ ($P < 0.05$).

Table 4. Effects of protein source on nursery pig performance (Exp. 2)[1]

Phase 1[2]:	Control	4% SDAP[4]	4% SDAP	4% Peptone 2	4% Peptone 2	4% Fish meal	
Phase 2[3]:	Control	Control	2% SDAP	Control	2% Peptone 2	2% Fish meal	SEM
d 0 to 10							
ADG, lb	0.39[b]	0.48[a]	0.41[ab]	0.41[ab]	0.46[ab]	0.40[b]	0.028
ADFI, lb	0.43[b]	0.50[a]	0.45[ab]	0.41[b]	0.43[b]	0.42[b]	0.023
F/G	1.12[b]	1.04[ab]	1.11[b]	1.01[ab]	0.95[a]	1.05[ab]	0.044
d 10 to 25							
ADG, lb	0.97	0.96	0.99	1.00	1.02	0.99	0.041
ADFI, lb	1.38	1.33	1.40	1.41	1.36	1.33	0.053
F/G	1.43[b]	1.39[ab]	1.41[ab]	1.42[ab]	1.33[a]	1.34[a]	0.043
d 25 to 32							
ADG, lb	1.32	1.33	1.31	1.35	1.39	1.23	0.082
ADFI, lb	2.00	2.07	2.00	2.12	2.07	2.00	0.095
F/G	1.52[a]	1.56[ab]	1.54[ab]	1.58[ab]	1.50[a]	1.64[b]	0.053
d 0 to 32							
ADG, lb	0.87[ab]	0.89[ab]	0.88[ab]	0.89[ab]	0.93[a]	0.86[b]	0.029
ADFI, lb	1.22	1.22	1.23	1.25	1.22	1.19	0.037
F/G	1.41[b]	1.38[b]	1.40[b]	1.41[b]	1.32[a]	1.39[b]	0.020

[1] A total of 180 pigs (6 pigs per pen and 6 pens per treatment) with an initial BW of 13.0 lb were used in a 28-d experiment.
[2] Phase 1 diets were fed from d 0 to 10.
[3] Phase 2 diets were fed from d 10 to 25.
[4] Spray-dried animal plasma.
[ab] Within a row, means without a common superscript differ ($P < 0.05$).

Evaluation of PEP2 in Nursery Pig Diets[1]

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Summary

A total of 300 nursery pigs (PIC 327 × 1050, initially 12.0 lb and 21 d of age) were used in a 25-d study to determine the effects of PEP2 (proteins enzymatically processed) on growth performance of weaned pigs. PEP2 is a combination of refined porcine intestinal mucosa co-dried with enzymatically processed vegetable protein. There were 5 dietary treatments: (1) negative control containing no specialty protein sources, (2) positive control containing 4% spray-dried animal plasma (SDAP) in Phase 1 and 4% select menhaden fish meal in Phase 2, (3) 4% PEP2, (4) 8% PEP2, and (5) 12% PEP2. All diets were fed in 2 phases, and treatments containing PEP2 had the same inclusion rate in both phases. Phase 1 diets were fed in pellet form from d 0 to 11 after weaning. Phase 2 diets were fed in meal form from d 11 to 25. In Phase 1, increasing PEP2 improved (linear; $P < 0.01$) F/G. However, pigs fed SDAP had greater ($P < 0.01$) ADG and improved F/G compared with pigs fed the PEP2 diets. In Phase 2, increasing PEP2 increased (quadratic; $P < 0.01$) ADG, and F/G. Pigs fed PEP2 had greater ($P < 0.01$) ADG and ADFI than pigs fed the positive control diet containing fish meal. Overall (d 0 to 25), pigs fed the positive control diet had improved ($P < 0.01$) ADG and F/G compared with those fed the negative control. Pigs fed the diet containing PEP2 had similar performance to pigs fed the positive control diets. In conclusion, although pigs fed SDAP in Phase 1 had better ADG and F/G than pigs fed the increasing levels of PEP2, in Phase 2, pigs fed PEP2 had greater ADG and improved F/G compared with pigs fed 4% select menhaden fish meal.

Key words: fish meal, PEP2, spray-dried animal plasma

Introduction

There is a continual search for quality protein sources that can be used in nursery pig diets. Producers want a low-cost alternative to spray-dried animal plasma (SDAP) to lower feed costs, increase feed intake immediately after weaning, and improve overall nursery growth performance.

Previous research conducted at Kansas State University (Jones et al., 2008[4]) found that nursery pigs fed a coproduct of heparin production, which is derived from porcine intestinal mucosa (DPS 50; Nutra-Flo Company, Sioux City, IA), showed improved growth performance compared with pigs fed select menhaden fish meal. Recently, a new, similar product has become available: PEP2 (proteins enzymatically processed; Protein Resources, West Bend, IA). This protein source is also derived from heparin

[1] The authors wish to thank Protein Resources, West Bend, IA, for providing the PEP2 and partial financial support.

[2] Food Animal Health and Management Center, College of Veterinary Medicine, Kansas State University.
[3] Protein Resources, West Bend, IA.

[4] Jones et al., Swine Day 2008, Report of Progress 1001, pp. 52-61.

manufacturing. It is composed of a blend of porcine intestinal mucosa and vegetable protein that has been enzymatically processed and then co-dried. Because of improvements in the collection procedures in the plant, PEP2 has lower sulfur and ash levels than many of the previous mucosal products that have been tested.

Even though research has indicated improved growth performance in nursery pigs fed products similar to PEP2, we can only hypothesize that similar improvements in growth performance will be seen with PEP2. Thus, the objective of the study was to evaluate the effects of PEP2 on weanling pig performance.

Procedures

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

A sample of PEP2 was collected and analyzed for CP, crude fat, mineral, and amino acid content (Table 1). The values obtained from the analysis were used in the diet formulation. The standardized digestibilities for individual amino acids in animal plasma were used to estimate the digestible amino acid levels in PEP2. The phosphorus in PEP2 was assumed to be 61% available for diet formulation.

Three hundred nursery pigs (PIC 337 ×1050, initially 12.0 lb and 21 d of age) were used in a 25-d trial to evaluate the effect of PEP2 on growth performance of weaned pigs. Pigs were allotted to 1 of 5 dietary treatments. There were 5 pigs per pen and 12 pens per treatment. Pigs were provided unlimited access to feed and water via a 4-hole dry self-feeder and a cup waterer in each pen (5 × 5 ft).

The 5 dietary treatments were: (1) negative control containing no specialty protein sources, (2) positive control containing 4% SDAP in Phase 1 and 4% select menhaden fish meal in Phase 2, (3) 4% PEP2, (4) 8% PEP2, and (5) 12% PEP2. All diets were fed in 2 phases, and treatments containing PEP2 had the same inclusion rate in both phases. Phase 1 diets were fed in pellet form from d 0 to 11 after weaning (Table 2). Phase 2 diets were fed in meal form from d 11 to 25 (Table 3). Average daily gain, ADFI, and F/G were determined by weighing pigs and measuring feed disappearance on d 0, 5, 11, 18, and 25.

Data were analyzed as a completely randomized design with pen as the experimental unit. Analysis of variance was performed using the MIXED procedure in SAS (SAS Institute, Inc., Cary, NC). Contrast statements used were: (1) linear and quadratic effects of increasing PEP2, (2) mean of PEP2-fed pigs vs. that of pigs fed the positive control, and (3) positive control vs. negative control.

Results and Discussion

In Phase 1 (d 0 to 11), pigs fed the positive control diet had improved ($P < 0.04$) ADG and F/G compared with pigs fed the negative control diet (Table 4). Additionally, increasing PEP2 inclusion improved (linear; $P< 0.01$) F/G. However, pigs fed SDAP had greater ($P < 0.05$) ADG and ADFI as well as an improved ($P < 0.04$) F/G compared with pigs fed PEP2.

During Phase 2 (d 11 to 25), pigs fed the positive control diet had improved ($P < 0.01$) ADG and F/G compared with pigs fed the negative control diet. Furthermore, ADG and ADFI of pigs fed PEP2 were greater ($P < 0.01$) than those for pigs fed the positive control diet (SDAP and then switched to fish meal on d 11). Increasing PEP2 improved (quadratic; $P < 0.01$) ADG and F/G.

Overall (d 0 to 25), pigs fed the positive control diet had improved ($P < 0.01$) ADG and F/G compared with pigs fed the negative control diet. There were no differences in ADG or ADFI, but F/G improved ($P < 0.02$) for pigs fed SDAP followed by fish meal compared with pigs fed the PEP2 diets. Increasing PEP2 in the diet improved ADG and F/G (quadratic; $P < 0.02$) compared with the negative control diet, with the greatest improvement observed as PEP2 increased from 0 to 4%.

In conclusion, in Phase 1, pigs fed SDAP had better ADG and F/G than pigs fed the treatments containing PEP2. However, in Phase 2, when pigs were switched from the positive control (SDAP to fish meal), ADG and F/G improved for pigs fed PEP2, with the greatest improvement observed in pigs fed 4% PEP2. These results suggest that 4% or higher levels of PEP2 can replace fish meal in Phase 2 diets and that PEP2 may be a suitable replacement for a plasma-fish meal regimen in Phase 1 and 2 diets for weaned pigs.

Table 1. Analyzed composition of protein enzymatically processed (PEP2)[1]

Nutrient	%	Amino acids	%
DM	92.0	Arginine	3.46
CP	55.2	Histidine	1.28
Crude fat	11.6	Isoleucine	2.43
Crude fiber	1.2	Leucine	4.22
Ash	9.0	Lysine	3.70
Ca	0.27	Methionine	0.88
P	0.82	Phenylalnine	2.47
S	1.2	Theronine	2.18
		Tryptophan	0.65
		Valine	2.76

[1] Amino acids were analyzed by the University of Missouri Agricultural Experiment Station Chemical Laboratories, and the analyzed values were used in diet formulation. Other analytical values were from Midwest Laboratories, Inc.

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

			Proteins enzymatically processed (PEP2)[3]		
Ingredient, %	Negative control	Positive control	4%	8%	12%
Corn	37.80	43.80	43.30	44.55	45.75
Soybean meal, (46.5% CP)	40.40	30.50	30.50	25.30	20.10
Spray-dried animal plasma	---	4.00	---	---	---
PEP2	---	---	4.00	8.00	12.00
Spray-dried whey	15.00	15.00	15.00	15.00	15.00
Soybean oil	3.00	3.00	3.00	3.00	3.00
Monocalcium P (21% P)	1.40	1.18	1.40	1.30	1.25
Limestone	0.88	1.05	0.93	1.00	1.03
Salt	0.30	0.30	0.30	0.30	0.30
Zinc oxide	0.38	0.38	0.38	0.38	0.38
Vitamin premix	0.25	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15	0.15
Lysine HCl	0.20	0.20	0.35	0.35	0.35
DL-Methionine	0.16	0.14	0.21	0.21	0.21
L-Threonine	0.08	0.05	0.14	0.13	0.14
L-Valine	---	---	0.08	0.08	0.08
Total	100	100	100	100	100
Calculated analysis					
SID amino acids, %[4]					
Lysine	1.45	1.45	1.45	1.45	1.45
Isoleucine:lysine	65	60	59	58	57
Methionine:lysine	33	30	36	36	36
Met & Cys:lysine	58	58	58	58	58
Threonine:lysine	62	62	62	62	62
Tryptophan:lysine	19.1	18.8	17.0	17.0	16.9
Valine:lysine	69	69	69	69	69
Total lysine, %	1.61	1.60	1.59	1.59	1.58
CP, %	24.2	23.2	22.5	22.3	22.2
ME kcal/lb	1,546	1,557	1,542	1,538	1,535
Ca, %	0.85	0.85	0.85	0.85	0.85
P, %	0.79	0.76	0.77	0.75	0.74
Available P, %	0.48	0.48	0.48	0.48	0.48

[1] A total of 300 nursery pigs (initial BW 12.0 lb) were used in a 25-d trial to determine the effects of PEP2 on nursery pig growth performance.
[2] Phase 1 diets were fed from d 0 to 11.
[3] Protein Resources, West Bend, IA.
[4] Amino acid digestibility values for plasma were used as the estimate of standardized amino acid digestibility of amino acids in PEP2.

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

			Proteins enzymatically processed (PEP2)[3]		
Ingredient, %	Negative control	Positive control	4%	8%	12%
Corn	55.10	62.90	62.05	63.25	64.50
Soybean meal, (46.5% CP)	40.10	28.75	28.75	23.50	18.30
Select menhaden fish meal	---	4.00	---	---	---
PEP2	---	---	4.00	8.00	12.00
Spray-dried whey	---	---	---	---	---
Soybean oil	1.00	1.00	1.00	1.00	1.00
Monocalcium P (21% P)	1.60	1.10	1.55	1.53	1.45
Limestone	0.92	0.72	1.02	1.05	1.10
Salt	0.35	0.35	0.35	0.35	0.35
Zinc oxide	0.25	0.25	0.25	0.25	0.25
Vitamin premix	0.25	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15	0.15
Lysine HCl	0.15	0.30	0.35	0.35	0.35
DL-Methionine	0.09	0.12	0.15	0.15	0.15
L-Threonine	0.04	0.11	0.13	0.13	0.13
L-Valine	---	---	---	0.01	0.01
Total	100	100	100	100	100
Calculated analysis					
SID amino acids, %[4]					
Lysine	1.32	1.32	1.32	1.32	1.32
Isoleucine:lysine	69	61	60	59	58
Methionine:lysine	32	35	34	35	35
Met & Cys:lysine	58	58	58	58	58
Threonine:lysine	62	62	62	62	62
Tryptophan:lysine	19.9	16.9	16.9	16.9	16.9
Valine:lysine	75	68	68	68	68
Total lysine, %	1.47	1.45	1.45	1.45	1.44
CP, %	23.6	21.7	21.4	21.3	21.1
ME kcal/lb	1,513	1,526	1,511	1,507	1,503
Ca, %	0.80	0.80	0.80	0.80	0.80
P, %	0.77	0.73	0.73	0.73	0.71
Available P, %	0.42	0.42	0.42	0.42	0.42

[1] A total of 300 nursery pigs (initial BW 12.0 lb) were used in a 25-d trial to determine the effects of PEP2 on nursery pig growth performance.
[2] Phase 2 diets were fed from d 11 to 25.
[3] Protein Resources, West Bend, IA
[4] Amino acid digestibility values for plasma were used as the estimate of standardized amino acid digestibility of amino acids in PEP2.

Table 4. Effects of proteins enzymatically processed (PEP2) on nursery pig performance[1]

Item	Negative control[2]	Positive control[3]	PEP2[4] 4%	PEP2[4] 8%	PEP2[4] 12%	SEM	Negative vs. Positive	Positive vs. PEP2	*P*-value Linear	*P*-value Quadratic
d 0 to 11										
ADG, lb	0.43	0.49	0.41	0.42	0.43	0.02	0.04	<0.01	0.85	0.55
ADFI, lb	0.43	0.46	0.41	0.43	0.43	0.02	0.32	0.05	0.89	0.50
F/G	1.04	0.94	1.00	1.02	1.00	0.05	<0.01	0.04	<0.01	0.64
d 11 to 18										
ADG, lb	0.82	0.88	0.96	0.94	0.92	0.03	0.01	<0.01	<0.01	<0.01
ADFI, lb	1.23	1.20	1.28	1.30	1.25	0.03	0.35	<0.01	0.50	0.07
F/G	1.50	1.36	1.34	1.38	1.36	0.03	<0.01	0.78	<0.01	<0.01
d 0 to 25										
ADG, lb	0.65	0.71	0.71	0.71	0.70	0.02	<0.01	0.93	0.02	0.02
ADFI, lb	0.88	0.87	0.89	0.91	0.89	0.02	0.74	0.27	0.64	0.35
F/G	1.37	1.23	1.26	1.29	1.27	0.01	<0.01	0.02	<0.01	<0.01

[1] A total of 300 nursery pigs (initial BW 12.0 lb) were used in a 25-d trial to determine the effects of PEP2 on nursery pig growth performance.
[2] Contained no specialty protein products
[3] Contained 4% spray-dried animal plasma in Phase 1 (d 0 to 11) and 4% select menhaden fish meal in Phase 2 (d 11 to 25).
[4] Protein Resources, West Bend, IA.

Effects of Experimental Design and Its Role in Interpretation of Results

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Summary

A total of 256 weanling pigs (PIC TR4 × 1050, initially 13.8 lb and 21 d of age) were used in a 28-d growth trial to compare allotment methods of a completely randomized design (CRD) and a randomized complete block design (RCBD). Two treatments were used to compare these designs: a negative control with no antibiotic or growth promoter and a positive control with 35 g/ton of Denagard (Novartis Animal Health), 400 g/ton of chlortetracycline, and zinc from zinc oxide at 3,000 and 2,000 ppm in Phases 1 and 2, respectively. Experimental diets were fed in 2 phases: Phase 1 from d 0 to 14 and Phase 2 from d 14 to 28. Eight replications of each dietary treatment were used for each experimental design. The first statistical model examined dietary treatment, experimental design, and the design × dietary treatment as fixed factors. With the exception of pens in the CRD having a trend for improved ($P < 0.07$) F/G from d 0 to 14 compared with pens in the RCBD, no other design or design × dietary treatment differences were detected ($P > 0.11$) for any responses variables, indicating that treatment means reacted similarly in each of the experimental designs.

In both the CRD and the RCBD, pig weights were increased ($P < 0.003$) with supplementation of growth promoters on d 14 and 28. Variation of weight within pen remained the same in the CRD from d 0 to 28 at approximately 20% but increased from 3% on d 0 to 10% on d 28 for the RCBD. Dietary addition of growth promoters increased ($P < 0.003$) ADG and ADFI and improved F/G ($P < 0.04$) in both the CRD and RCBD from d 0 to 14, with lower *P*-values for the CRD than the RCBD. From d 14 to 28, the CRD detected an increase ($P < 0.001$) in ADG and ADFI with dietary addition of growth promoters, and the RCBD detected an increase ($P < 0.001$) only in ADFI. Over the entire 28-d trial, growth promoters increased ($P < 0.001$) ADG and ADFI and improved ($P < 0.03$) F/G in the CRD and increased ($P < 0.02$) ADG and ADFI in the RCBD. Lower standard errors for the difference were also estimated for ADG and F/G in the CRD than in the RCBD from d 0 to 28.

The average corrected relative efficiency for each of the three periods was 2.08 for ADG, 5.05 for ADFI, and 0.80 for F/G. The gain and intake values suggest that the added variation explained by blocks in the RCBD was beneficial for achieving a more reduced estimate of σ^2_{error} compared with analyzing that particular data set as a CRD. The variance ratios of the CRD to RCBD from d 0 to 28 depict the different responses well with ADG at 0.67, ADFI at 1.70, and F/G at 0.22. When these ratios were compared with an F-test, they were well below the upper critical limit of 4.60, suggesting that the CRD offered estimates for σ^2_{error} similar to those of the RCBD. With the same estimate for σ^2_{error}, the non-centrality parameter for each design would be similar, and therefore, the increase in degrees of freedom (DF) for the error term would lead to greater power

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to detect differences in the CRD. Additional studies are needed to verify these results and determine whether blocking is an efficient use of error DF.

Key words: allotment, experimental design, data interpretation

Introduction

Experimental design is a major factor that must be considered when planning research trials. The primary designs used in swine production and nutrition research include the completely randomized design (CRD) and the randomized complete block design (RCBD). Modifications or additions to these designs can be performed to generate more complex designs, such as a Latin square, that typically are used in specific instances when experimental units are limited. One of the main functions of the experimental design is to dictate the process of allotting treatments to experimental units (EU). But no matter what design is used, it is important to balance studies by having equal replication of each treatment factor to maximize the power available to detect treatment differences.

The CRD is the simplest of all designs; treatments are allotted to EU independently of any factors. This design allows for the most degrees of freedom (DF) for the error term in the model to test for treatment differences. However, the CRD can be unreliable if the EU are not homogenous. Non-homogeneity of EU can cause inflated error variance components and can increase the chance of a type 2 error. In the RCBD, treatments are allotted to EU on the basis of some factor, commonly referred to as the blocking factor, which should reduce the error variance if the blocking factor is important. The blocking factor groups EU based on that particular factor into a block, with each treatment having a minimum of one EU in each block. The primary function of blocking is to obtain groups of homogenous EU. Blocking factors vary according to the type of trial and may be different depending on the desired treatment structures. One of the assumptions in this design is that treatments would respond similarly in each block or that there were no true block × treatment interactions because the mean square calculated as the block × treatment source estimates the error variance structure for the model. One way to examine the blocking factor's effectiveness is to determine its relative efficiency (RE). Relative efficiency is a calculation performed after the trial is completed to show the ratio between an estimated error term if the study were conducted as a CRD and the error term for the RCBD. It also describes the increased number of experimental units that are needed in a CRD to achieve the same error variance component term as in a RCBD. For example, if the RE for a particular response variable was calculated to be 2.00, one could assume that the estimate for the error variance component was 2.00 times greater in the CRD than the RCBD, and theoretically, the CRD would need twice as many experimental units to achieve the same estimate error variance component as a RCBD.

It has been a common practice to block nursery studies to achieve a reduced estimate for the error component of an experiment. Often these studies are blocked simultaneously by location in the barn and initial weight. Both of these factors could affect performance and affect the interpretation of results if not equalized across treatments. The main goal of this trial was to determine the impact of blocking by initial BW and location on trial interpretation.

Procedures

The procedures used in this experiment were 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.

A total of 256 weanling pigs (PIC TR4 × 1050, initially 13.8 lb and 21 d of age) were used in a 28-d growth trial to compare allotment methods of a CRD and a RCBD. Two treatments were used to compare these designs: a negative control with no antibiotic or growth promoter and a positive control with growth promoting levels of antibiotics and pharmacological levels of zinc. The positive control contained 35 g/ton of Denagard (Novartis Animal Health), 400 g/ton of chlortetracycline, and zinc from zinc oxide at 3,000 and 2,000 ppm in Phases 1 and 2, respectively. Experimental diets were fed in 2 phases: Phase 1 from d 0 to 14 and Phase 2 from d 14 to 28 (Table 1). Phase 1 and 2 diets were fed in meal form and formulated to contain 1.41% and 1.31% standardized ileal digestible lysine, respectively. Phase 1 diets contained 15% spray-dried whey and 3.75% fish meal, and Phase 2 diets were based on corn and soybean meal. Eight replications of each dietary treatment were used for each experimental design.

For the allotting of pens, a group of 4 pens located in the same location were randomized such that 2 pens would be used in the CRD, 2 pens would be used in the RCBD, and the RCBD pens would contain each of the 2 dietary treatments. This was performed throughout barn, and at the conclusion of allotting pens to designs, all pens on the CRD were randomized to treatments with equal replication. For the allotting of pigs to pens, initially weaned pigs were split to each of the 2 designs such that each design would have equal weights and variations of weights for all pigs. In addition, to reduce any bias, both gender and litter were balanced between experimental designs. Pigs assigned to the CRD were allotted to pens so that the average weight and within-pen variation of weight were similar between all pens. Pigs in the RCBD were blocked by weight and put into the location blocks.

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 floor and allowed for approximately 3 ft^2/pig. Weights and feed disappearance were measured every 14 d to determine ADG, ADFI, and F/G. In addition, variation of pig weight within pen was examined by comparing the CV. After statistics were analyzed for each design, uncorrected and corrected RE were calculated from the RCBD for the growth performance responses. The uncorrected RE was determined by dividing an estimated CRD error variance term (σ^2_{error}) by the σ^2_{error} for the RCBD. The corrected RE was derived by multiplying the uncorrected RE and a correction for DF value. A more detailed description of these calculations and terms is available by Kuehl (2000[3]). In addition to the RE, an F-test was conducted for the ratio of the CRD error variance component to the RCBD error variance component. This F-test was a 2-tailed test and used the CRD error DF for the numerator and the RCBD error DF for the denominator. The lower critical limit was set at 0.30, and the upper critical limit was at 4.60.

[3] Kuehl, R. O. 2000. Design of Experiments: Statistical Principles of Research Design and Analysis. Duxbury Press, Pacific Grove, CA. pp. 272-275.

Three different SAS (SAS Institute Inc., Cary, NC) models were used to describe the effects of experimental design on trial interpretation. The first model used data combined from the CRD and RCBD and was analyzed as a 2 × 2 factorial design with the 2 experimental designs (CRD or RCBD) and the 2 dietary treatments treated as fixed factors with no random effects. The remaining models were used to analyze each of the 2 designs independently. The model for the CRD used the dietary treatment as a fixed effect with a random effect of pen within dietary treatment. For the RCBD, dietary treatment was again used as a fixed effect, block was used as a random effect, and the block × dietary treatment was used as a random effect to estimate the error variance component. For each model, pen was used as the experimental unit and analysis of variance (ANOVA) was conducted using the MIXED procedure in SAS.

Results and Discussion

The results from the first model (Table 2) used data sets from both designs. This model examined dietary treatment, experimental design, and the design × dietary treatment as fixed factors with no blocking factors. Equal variance was assumed for both experimental designs; however, it could be that these 2 designs have unequal variances. The main focus of this model was to determine if the treatments means behaved similarly in each design and if overall performance differed in each experimental design. With the exception of pens in the CRD having a trend for improved ($P < 0.07$) F/G from d 0 to 14 compared with pens in the RCBD, no other design or design × dietary treatment differences were detected ($P > 0.11$) for any responses variables. On the basis of these results, it appears that treatment means were similar in each of the experimental designs.

After determining that performance was similar between treatments in each of the experimental designs, models were generated to evaluate the effects of each design separately. Examples of the ANOVA tables for both the CRD and RCBD are shown for overall ADG (d 0 to 28) in Tables 3 and 4, respectively. The variance term used to test for treatment effects is labeled as Pen (Treatment) in the CRD and Treatment × Block in the RCBD. It is also important to determine the difference in DF for the error term of each design. The error term for the CRD has 14 DF, and that for the RCBD design has 7 DF. This difference will affect the power of the F-test in the ANOVA model for each design. The error DF are used as the denominator DF in the ANOVA F-test, and decreasing the DF will decrease the power to detect differences, all things being equal. However, if blocking decreases the estimate of σ^2_{error}, power will increase by increasing the non-centrality parameter. Typically, the loss of DF is more than compensated by the increase in the non-centrality parameter, thereby making the block design an advantageous use of those DF.

In both the CRD and the RCBD, pig weights were increased ($P < 0.003$) with supplementation of growth promoters on d 14 and 28 (Table 5). Variation of pig weight within pen did not differ ($P > 0.52$) on d 0, 14, or 28 with the addition of growth promoters in either experimental design. However, in the CRD, variation of weight within pen remained the same from d 0 to 28 at approximately 20% but increased from 3% on d 0 to 10% on d 28 for the RCBD. The difference in within-pen variation between the 2 designs is reflective of the allotment of pigs to EU. The increase in within-pen variation when pigs begin with more uniform weight variation (RCBD) is in agreement with other studies.

Dietary addition of growth promoters increased ($P < 0.003$) ADG and ADFI and improved F/G ($P < 0.04$) in both the CRD and RCBD from d 0 to 14 (Table 6). The *P*-values were lower in the CRD than the RCBD because of the increase in denominator DF used in the ANOVA model and similar standard error for difference in means (SED). From d 14 to 28, the CRD detected an increase ($P < 0.001$) in ADG and ADFI with dietary addition of growth promoters, and the RCBD detected an increase ($P < 0.001$) only in ADFI. The reason why the RCBD did not detect ($P > 0.10$) an improvement in ADG with promoters was an increase in the SED compared with that for the CRD. Over the entire 28-d trial, growth promoters increased ($P < 0.001$) ADG and ADFI and improved ($P < 0.03$) F/G in the CRD. However, for the RCBD, only ADG and ADFI were increased ($P < 0.02$). For the entire trial, reduced SED were also estimated for ADG and ADFI in the CRD compared with the RCBD.

The effects of experimental design on the variance components and RE for each of the performance responses are shown in Table 7. It should be noted that the σ^2_{error} and σ^2_{block} are estimates of the true variation components for the entire population of EU. On the basis of these estimates in the RCBD, the RE as well as a ratio of the variance components between the 2 experimental designs were calculated. The uncorrected RE ranged from 0.65 to 10.63, and the corrected RE ranged from 0.59 to 9.64 for each of the growth responses. Each of the three response criteria seemed to follow a pattern for RE regardless of the time period. The average corrected RE for each of the 3 periods was 2.08 for ADG, 5.05 for ADFI, and 0.80 for F/G. The gain and intake values suggest that the added variation explained by blocks in the RCBD was beneficial for achieving a more reduced estimate of σ^2_{error} compared to analyzing that particular data set as a CRD. However, when a different allotment scheme was performed in the CRD, the variance ratio of the CRD to the RCBD ranged from 0.22 to 3.50. The ratios from d 0 to 28 depict the different responses well, with ADG at 0.67, ADFI at 1.70, and F/G at 0.22. These suggest that under a CRD allotment performed in this manner, an estimate for σ^2_{error} was obtained that was similar to that for the RCBD.

The variance ratio between the 2 designs indicated that the CRD estimated σ^2_{error} values for each response variable similar to those for the RCBD. Compared with the critical limits of 0.30 and 4.60 for an F-test between the 2 variance components, the lack of difference becomes even clearer. Observed values greater than the upper limit would suggest that the RCBD had a reduced estimate for σ^2_{error}. No values were near in proximity to the upper limit. However, ratios for F/G from d 14 to 28 and d 0 to 28 were below the lower limit, suggesting the CRD had reduced estimates for σ^2_{error} compared with the RCBD. If blocking had been effective, it should be expected to observe the variance ratios above the upper critical limit.

This experiment also suggests that using a generalized block design, which has more than 1 replication per block, may be a strategy to increase homogeneity of EU but reduce the number of DF assigned to blocks. This generalized block design would also allow for testing of interactions between treatments and blocking factors. Research has shown that various products may behave differently among different weight groups of pigs. To estimate this response, a weight × treatment interaction term is needed in the statistical model, and the generalized block design would accommodate that particular term.

In conclusion, researchers who typically block pigs by weight or some other factor can use RE to determine whether blocking offers better estimates for σ^2_{error} than a CRD. Relative efficiency is a quick method of quantifying the benefit received from a blocking factor. This single study suggests that for this nursery facility in which researchers can control the homogeneity of the average pen pig weight, the CRD estimates for σ^2_{error} are similar to those in a RCBD. With the same estimate for σ^2_{error}, the non-centrality parameter for each design would be similar, and therefore, the increase in DF for the error term would lead to a greater power to detect differences among treatments. Additional studies are needed to verify these results as well as to compare designs in different facilities and stages of production to determine whether blocking is an efficient use of error DF.

Table 1. Composition of diets[1]

	Phase 1[2]		Phase 2[3]	
Growth promoters[4]	No	Yes	No	Yes
Ingredient, %				
Corn	49.19	48.15	61.07	60.17
Soybean meal (46.5% CP)	28.98	29.06	34.97	35.03
Spray-dried whey	15.00	15.00	---	---
Select menhaden fish meal	3.75	3.75	---	---
Monocalcium P (21% P)	1.05	1.05	1.60	1.60
Limestone	0.70	0.70	1.10	1.10
Salt	0.33	0.33	0.33	0.33
Vitamin premix	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15
Lysine HCl	0.30	0.30	0.30	0.30
DL-methionine	0.175	0.175	0.125	0.125
L-threonine	0.125	0.125	0.110	0.110
Zinc oxide	---	0.384	---	0.256
Denagard	---	0.175	---	0.175
Chlortetracycline	---	0.400	---	0.400
Total	100.00	100.00	100.00	100.00
Calculated analysis				
SID[5] amino acids, %				
Lysine	1.41	1.41	1.31	1.31
Isoleucine:lysine	60	60	63	63
Leucine:lysine	120	120	129	129
Methionine:lysine	36	36	33	33
Met & Cys:lysine	58	58	58	58
Threonine:lysine	62	62	62	62
Tryptophan:lysine	17	17	18	18
Valine:lysine	65	65	69	69
Total lysine, %	1.55	1.55	1.45	1.45
ME, kcal/lb	1,495	1,495	1,495	1,495
SID lysine:ME, g/Mcal	4.28	4.28	3.97	3.97
CP, %	22.3	22.3	21.9	21.9
Ca, %	0.88	0.88	0.85	0.85
P, %	0.78	0.78	0.75	0.75
Available P, %	0.50	0.50	0.42	0.42
Available P:calorie, g/Mcal	1.51	1.51	1.26	1.26

[1] A total of 256 weanling pigs (PIC, initially 13.3 lb and 21 d of age) were used in a 28-d trial to compare the effects of experimental design on data interpretation.
[2] Pigs were fed Phase 1 from d 0 to 14.
[3] Pigs were fed Phase 2 from d 14 to 28.
[4] Growth promoters included zinc from zinc oxide at 3,000 ppm in Phase 1 and 2,000 ppm in Phase 2, Denagard at 35 g/ton, and chlortetracycline at 400 g/ton.
[5] Standardized ileal digestible.

Table 2. Effects of experimental design on nursery performance[1]

	Design			Probability, $P <$		
Item	CRD[2]	RCBD[3]	SED	Design × Treatment	Design	Treatment
d 0 to 14						
ADG, lb	0.49	0.47	0.027	0.45	0.44	0.001
ADFI, lb	0.58	0.58	0.030	0.65	1.00	0.001
F/G	1.20	1.24	0.023	0.70	0.07	0.001
d 14 to 28						
ADG, lb	1.07	1.07	0.045	0.44	0.99	0.006
ADFI, lb	1.56	1.55	0.058	0.85	0.81	0.001
F/G	1.46	1.45	0.021	0.16	0.68	0.14
d 0 to 28						
ADG, lb	0.78	0.77	0.033	0.39	0.73	0.001
ADFI, lb	1.07	1.06	0.042	0.72	0.83	0.001
F/G	1.38	1.38	0.016	0.12	0.67	0.38
Weights, lb						
d 0	13.8	13.8	1.00	1.00	0.99	0.99
d 14	20.7	20.4	1.26	0.80	0.79	0.04
d 28	35.6	35.5	1.89	0.70	0.92	0.02

[1] A total of 256 weanling pigs (PIC TR4 ×1050, initially 13.8 lb) were used in a 28-d study with 8 pigs per pen to determine the effect of experimental design on trial interpretation.
[2] Completely randomized design.
[3] Randomized complete block design.

Table 3. Analysis of variance table for the completely randomized design for ADG from d 0 to 28

Source	DF	Sum of squares	Mean square	F value	Pr > F
Treatment	1	0.090671	0.090671	31.1	< 0.0001
Pen (treatment)	14	0.040849	0.002918		
Corrected total	15	0.131520			

Table 4. Analysis of variance table for the randomized complete block design for ADG from d 0 to 28

Source	DF	Sum of squares	Mean square	F Value	Pr > F
Treatment	1	0.042007	0.042007	9.7	0.0171
Block	7	0.096222	0.013746		
Treatment × Block	7	0.030423	0.004346		
Corrected total	15	0.168151			

Table 5. Effects of experimental design and the addition of growth promoters on pig weights and variation in pig weight within pens[1]

	Completely randomized design				Randomized complete block design			
Growth promoter[2]:	No	Yes	SED	Probability, *P* <	No	Yes	SED	Probability, *P* <
d 0								
Avg. wt, lb	13.8	13.8	0.03	0.87	13.8	13.8	0.01	0.64
Avg. pen CV for pig wt, %[3]	20.3	20.8	0.72	0.52	3.1	3.1	0.12	0.99
d 14								
Avg. wt, lb	19.5	21.8	0.39	0.001	19.5	21.3	0.27	0.001
Avg. pen CV for pig wt, %[3]	20.4	20.7	0.80	0.67	9.5	10.4	1.67	0.64
d 28								
Avg. wt, lb	33.5	37.7	0.75	0.001	33.9	37.1	1.87	0.003
Avg. pen CV for pig wt, %[3]	18.6	18.4	1.21	0.89	10.2	9.6	1.20	0.63

[1] A total of 256 weanling pigs (PIC TR4 × 1050, initially 13.8 lb 21 d of age) were used in a 28-d study with 8 pigs per pen to determine the effect of experimental design on trial interpretation.
[2] Growth promoters included zinc from zinc oxide at 3,000 ppm in Phase 1 and 2,000 ppm in Phase 2, Denagard at 35 g/ton, and chlortetracycline at 400 g/ton.
[3] Depicts the in-pen variation in pig weight for each design and treatment combination.

Table 6. Effects of experimental design on interpretation of the growth effects of addition of growth promters[1]

	Completely randomized design				Randomized complete block design			
Growth promoter[2]:	No	Yes	SED	Probability, *P* <	No	Yes	SED	Probability, *P* <
d 0 to 14								
ADG, lb	0.41	0.57	0.029	0.001	0.41	0.54	0.019	0.003
ADFI, lb	0.51	0.65	0.034	0.001	0.52	0.64	0.028	0.003
F/G	1.24	1.15	0.029	0.007	1.28	1.20	0.029	0.04
d 14 to 28								
ADG, lb	1.00	1.14	0.030	0.001	1.03	1.11	0.044	0.11
ADFI, lb	1.46	1.67	0.044	0.001	1.46	1.65	0.024	0.001
F/G	1.46	1.46	0.018	0.91	1.42	1.48	0.037	0.14
d 0 to 28								
ADG, lb	0.70	0.85	0.027	0.001	0.72	0.82	0.033	0.02
ADFI, lb	0.98	1.16	0.037	0.001	0.99	1.14	0.029	0.002
F/G	1.40	1.36	0.016	0.03	1.38	1.39	0.026	0.68

[1] A total of 256 weanling pigs (PIC TR4 × 1050, initially 13.8 lb 21 d of age) were used in a 28-d study with 8 pigs per pen to determine the effect of experimental design on trial interpretation.
[2] Growth promoters included zinc from zinc oxide at 3,000 ppm in Phase 1 and 2,000 ppm in Phase 2, Denagard at 35 g/ton, and chlortetracycline at 400 g/ton.

Table 7. Effects of experimental design on the variance components and estimation of the error terms[1]

Design:	CRD[2]	RCBD[3]		Uncorrected	Corrected	Variance ratio
Variance components:	σ^2_{error}	σ^2_{block}	σ^2_{error}	RE[4]	RE[5]	CRD:RCBD[6]
d 0 to 14						
ADG, lb	0.0033	0.0027	0.0015	2.67	2.42	2.20
ADFI, lb	0.0047	0.0036	0.0031	2.07	1.87	1.51
F/G	0.0033	0.0008	0.0033	1.23	1.11	1.00
d 14 to 28						
ADG, lb	0.0036	0.0099	0.0076	2.21	2.01	0.47
ADFI, lb	0.0079	0.0233	0.0023	10.63	9.64	3.50
F/G	0.0013	-0.0019	0.0075	0.76	0.69	0.17
d 0 to 28						
ADG, lb	0.0029	0.0047	0.0043	2.01	1.82	0.67
ADFI, lb	0.0055	0.0105	0.0033	4.01	3.64	1.70
F/G	0.0010	-0.0016	0.0044	0.65	0.59	0.22

[1] A total of 256 weanling pigs (PIC TR4 × 1050, initially 13.8 lb 21 d of age) were used in a 28-d study with 8 pigs per pen to determine the effect of experimental design on trial interpretation.
[2] Completely randomized design.
[3] Randomized complete block design.
[4] Uncorrected relative efficiency = estimated σ^2_{error} for CRD / σ^2_{error} for RCBD and estimated σ^2_{error} for CRD = (SSblock+r(t-1) MSE)/(rt-1) where r = the number of blocks and t = the number of treatments.
[5] Corrected relative efficiency = uncorrected relative efficiency × degrees of freedom correction, and the degrees of freedom correction = (df for RCBD + 1)(df for CRD + 3) / (df for RCBD + 3)(df for CRD + 1).
[6] Variance ratio CRD: RCBD = σ^2_{error} for CRD / σ^2_{error} for RCBD.

Efficacy of Different Commercial Phytase Sources and Development of a Phosphorus Release Curve[1]

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Summary

Two experiments used 184 pigs (PIC, 22.7 and 21.3 lb BW, respectively) to develop an available P (aP) release curve for commercial phytase products. In Exp. 1 and 2, pigs were fed a basal diet (0.06% aP) and 2 levels of added aP from inorganic P (monocalcium P) to develop a standard curve. In Exp. 1, 100, 175, 250, or 500 phytase units (FTU)/kg OptiPhos (Enzyvia LLC, Sheridan, IN) or 200, 350, 500 or 1,000 FTU/kg Phyzyme XP (Danisco Animal Nutrition, Marlborough, UK) was added to the basal diet. In Exp. 2, 250, 500, 750, or 1,000 FTU/kg OptiPhos; 500, 1,000, or 1,500 FTU/kg Phyzyme XP; or 1,850 or 3,700 phytase units (FYT)/kg Ronozyme P (DSM Nutritional Products, Basel, Switzerland), was added to the basal diet. Manufacturer-guaranteed phytase levels were used in diet formulation. Diets were analyzed for phytase using both the Phytex and AOAC methods. Pigs were blocked by sex and weight and allotted to individual pens with 8 pens per treatment. Pigs were euthanized on d 21, and fibulas were analyzed for bone ash. In Exp. 1, pigs fed increasing monocalcium P had improved (linear; $P = 0.01$) ADG, G/F, and percentage bone ash. Similarly, pigs fed increasing monocalcium P in Exp. 2 tended to have improved (quadratic; $P = 0.09$) ADG in addition to significantly improved (linear; $P \leq 0.001$) G/F and percentage bone ash. In Exp. 1, pigs fed increasing OptiPhos had increased (linear; $P \leq 0.02$) ADG, G/F, and percentage bone ash. Likewise, pigs fed increasing OptiPhos in Exp. 2 had improved (linear; $P \leq 0.001$) ADG and G/F, as well as increased (quadratic; $P \leq 0.001$) percentage bone ash. In Exp. 1, pigs fed increasing Phyzyme XP had increased (linear; $P \leq 0.04$) ADG and G/F and tended to have improved (linear; $P = 0.06$) percentage bone ash. Pigs fed increasing Phyzyme XP in Exp. 2 had increased (quadratic; $P \leq 0.001$) G/F and percentage bone ash. In Exp. 2, pigs fed increasing Ronozyme P had improved (linear; $P \leq 0.001$) ADG in addition to increased (quadratic; $P \leq 0.03$) G/F and percentage bone ash. When AOAC analyzed values and bone ash are used as the response variable, aP release for up to 1,000 FTU/kg of *Escherichia coli*-derived phytases (OptiPhos and Phyzyme XP) can be predicted by the equation ($y = -0.000000125x^2 + 0.000236245x + 0.015482000$), where x is the phytase level in the diet.

Key words: bone strength, phytase, phytase source

[1] Appreciation is expressed to JBS United for providing the pigs and facilities and for partial funding of this trial.

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Introduction

Phosphorus is one of the most significant minerals in swine nutrition. It is essential for bone development, plays a key role in metabolic processes such as the formation of cellular membranes, and is vital for enzymatic systems involved in fat and carbohydrate metabolism.

In cereal grains and oilseed meals, a large amount of P is in the form of phytic acid (myo-inositol hexaphosphate). The P in phytic acid is largely unavailable to the pig. Thus, a phytase enzyme is added to diets to enhance the pig's ability to use P from phytic acid. Many trials have been conducted to evaluate different sources of the phytase enzyme, including some prominent versions of the enzyme obtained from *Escherichia coli* or *Aspergillus oryzae*.

Because manufacturers have their own individual analytical techniques, it is often confusing to compare phytase sources by a single analytical method. To avoid this confusion, the current study used inclusion rates as directed by the product labels, which gives field-applicable available P (aP) release values. To further clarify comparisons, the current industry standard analysis (AOAC) was also conducted on all phytase samples.

Current data from JBS United demonstrates that 0.12% aP can be replaced in a corn-soybean meal-based diet with 250 phytase units (FTU)/kg OptiPhos (Enzyvia LLC, Sheridan, IN). Recommendations for Phyzyme XP (Danisco Animal Nutrition, Marlborough, UK) and Ronozyme P (DSM Nutritional Products, Basel, Switzerland) are that 500 FTU/kg or 1,850 phytase units (FYT)/kg, respectively, should be used to replace 0.10% aP. Phytase may be added at levels less than that needed to replace the 0.12% or 0.10% P. However, more data is needed to determine a response curve for OptiPhos, Phyzyme XP, and Ronozyme P. The development of dose response curves for *P* release could allow the optimum use of the different sources of the enzyme at all levels.

Our objectives for these trials were to evaluate the effects of three different sources of commercially available phytase on late nursery pig performance and to develop a P release curve.

Procedures

In Exp. 1, a total of 88 barrows (initially 22.7 lb) were used in a 21-d growth trial. Pigs were blocked by weight and allotted to 1 of 11 dietary treatments. In Exp. 2, a total of 104 pigs (initially 21.3 lb) were used in a 21-d growth trial. Pigs were blocked by sex and weight and allotted to 1 of 13 dietary treatments. In both experiments, there was 1 pig per pen and 8 pens per treatment. Each pen (31.6 × 39 in.) contained a 2-hole, dry self-feeder and a nipple water to provide ad libitum access to feed and water. The study was conducted in 4 adjacent rooms in the Discovery Nursery at JBS United's Burton Russell Research Farm in Frankfurt, IN. Samples of phytase and inorganic phosphorus premixes and complete feed were taken at the time of diet preparation and analyzed for phytase.

A common starter diet (meal form) containing 0.06% aP was fed to pigs for 6 d prior to the experiment while pigs were being acclimated to the barn. In Exp. 1 and 2, pigs were fed a basal diet (0.06% aP) and 2 levels of added aP monocalcium P (0.075 and 0.15 for Exp. 1 and 0.07 and 0.14 for Exp. 2) to develop a standard curve. In Exp. 1, 100, 175, 250, or 500 FTU/kg OptiPhos or 200, 350, 500, or 1,000 FTU/kg Phyzyme XP was added to the basal diet. In Exp. 2, 250, 500, 750, or 1,000 FTU/kg OptiPhos; 500, 1,000, or 1,500 FTU/kg Phyzyme XP; or 1,850 or 3,700 FYT/kg Ronozyme P was added to the basal diet.

In Exp. 1, all treatment diets were constructed from a single basal diet (Table 1) made in two batches at the Kansas State University (K-State) Animal Science Feed Mill. Each bag was marked with batch and bagging order. The first 3 and last 2 bags of each batch were not used in diet preparation. Individual treatments were mixed from the basal diet at the K-State Poultry Feed Mill. A total of 197.5 lb of each batch of the basal diet were used to create 395 lb of each treatment diet. Each of the 2 batches contributed 98.75 lb (a total of 197.5 lb) and was mixed for 2 min. Five pounds (2 lb phytase premix and 3 lb P premix) of premix was added to the mixer while the mixer hands were on the upside, and the diet was mixed for an additional 2 min. The additional 98.75 lb of each batch of the basal diet was added, and the diet was mixed for an additional 2 min. Approximately 30 lb of feed was removed from the mixer discharge and deposited back into the top of the mixer. The treatment was mixed for an additional 6 min, for a total treatment addition mixing time of 12 min. Treatments were bagged into 30-lb bags and tagged with labels including the K-State and JBS United protocol number and correlating treatment letter.

In Exp. 2, premixes were manufactured at K-State and shipped to Sheridan, IN, where they were added to a single basal diet (Table 1), which was made in 3 batches at the Burton Russell Research Farm Feed Mill in Frankfort, IN. Each bag was marked with batch and bagging order. The first and last 2 bags of each batch were not used in diet preparation trial. A total of 92, 152, and 150 lb of batches 1, 2, and 3 of the basal diet, respectively, were used to create 394 lb of each treatment diet. Half of each batch (a total of 197 lb) was added to the mixer and mixed for 2 min. Six pounds (2 lb phytase premix and 4 lb inorganic P premix) of premix was added to the mixer while the mixer hands were on the upside, and the diet was mixed for an additional 2 min. The remainder each batch of the basal diet was added, and the diet was mixed for an additional 2 min. Approximately 30 lb of feed was removed from the mixer discharge and deposited back into the top of the mixer. The treatment was mixed for an additional 2 min for a total treatment addition mixing time of 8 min. Treatments were bagged into 30-lb bags and tagged with labels including the K-State and JBS United protocol number and correlating treatment letter.

In both experiments, treatment premixes were made at the K-State Swine Research Laboratory. The phytase premixes consisted of a phytase source (OptiPhos, Phyzyme XP, or Ronozyme P) and/or cornstarch. The same lot of each OptiPhos and Phyzyme XP were used to make both Exp. 1 and 2 premixes. Phytase was stored in a freezer for approximately 3 mo between experiments. The negative control and diets with monocalcium P were made with no phytase and 2 lb of cornstarch. In Exp. 1, a single batch of the 500 FTU/kg OptiPhos premix and the 1,000 FTU/kg Phyzyme XP premix was manufactured and analyzed for lysine, Ca, P, and phytase content (Table 2). Micro-

ingredients were also analyzed for Ca (Table 3). In Exp. 2, a single batch of the 1,000 OptiPhos premix, 1,500 FTU/kg Phyzyme XP premix, and 3,700 FYT/kg Ronozyme P premix was made and analyzed for Ca, P, and phytase content. Cornstarch was added in increasing levels to the base mixes to dilute them to the various phytase levels used in the trials. In both experiments, the P premixes consisted of monocalcium phosphate (21% P) and/or sand of similar particle size. The negative control and diets containing phytase were made with no monocalcium P and 3 (Exp. 1) or 4 (Exp. 2) lb of sand. Premixes were analyzed for Ca and P, and phytase analysis was conducted according to the AOAC and Phytex methods (Table 4).

Treatment diets were fed in meal form for 21 d. Average daily gain, ADFI, and G/F were determined by weighing pigs and measuring feed disappearance on d 0 and 21 of the trial. Animals were euthanized via lethal injection with Euthanasia-III Solution (Exp. 1; Med-Pharmex) or Beuthanasia-D Special (Exp. 2; Schering-Plough) according to the K-State Institutional Animal Care and Use Committee standards. The right fibula was removed without cartilage caps from each animal, autoclaved, and boiled for 45 to 60 min. Fibulas were cleaned of adhering tissue, dried at 105°C for 24 h, and ashed in a muffle furnace at 600°C for 24 h. Total ash weight and percentage ash were measured.

Data Analysis

All values that were at least three SD away from the mean of each response criteria were considered outliers. In Exp. 1, 4 pigs with outliers for growth data (ADG, ADFI, or G/F) were removed from both the growth and bone (ash weight and percentage ash) results. Two pigs with outliers for percentage ash were removed from the ash weight and percentage ash results but were used for the calculation of growth data. One pig with an outlier for ash weight was removed from the ash weight results but was used in the calculation of percentage ash and growth data. Three fibulas were broken during analysis, preventing ash weight and percentage ash for these fibulas from being calculated. Growth data from these pigs were used. In Exp. 2, 1 pig was deemed an outlier for G/F and was removed from all data. One pig was considered an outlier for percentage ash and was removed from the ash weight and percentage ash results but was used for the calculation of growth data.

Data were analyzed as a randomized complete block design with pig as the experimental unit. Treatment was fixed, whereas pigs and room were randomly assigned. Analysis of variance was performed using the MIXED procedure of SAS (SAS Institute Inc., Cary, NC). Results were considered to be significant if their *P*-values were ≤ 0.05 and were considered to be a trend if their *P*-values were ≤ 0.10. Main effects from Exp. 1 showed that all treatments that included inorganic P remained in the linear portion of the quadratic curve of phytase release, and so all treatments were used for analysis. Conversely, main effects from Exp. 2 showed that the treatment supplemented with an additional 0.21% aP from inorganic P (0.27% total aP) was in the quadratic portion of the phytase curve. Because aP release curves must be generated from data that are only in the linear portion of this curve, the treatment was removed from all data analysis. For reference, adding 0.21% aP from monocalcium P (0.27% total aP) resulted in pigs with an ADG of 1.10 lb/d, an ADFI of 1.57 lb/d, a G/F of 0.70, a bone ash weight value of 775 mg, and a bone ash percentage of 41.9.

A regression equation was calculated for ADG, G/F, ash weight, and percentage ash to predict the percentage aP released from the *E. coli*-derived phytases, given each response criteria. First, the total intake of aP from the diet was calculated and termed to be the dosage of aP administered to each pig through its diet. Dosage for pigs fed the negative control, OptiPhos, Phyzyme XP, and Ronozyme P diets was the product of 0.06 and individual grams of feed intake. In Exp. 1, dosage for pigs fed the negative control diet plus 0.075% aP from the monocalcium P diet was the product of 0.135 and individual grams of feed intake. Dosage for pigs fed the negative control plus 0.15% aP from the monocalcium P diet was the product of 0.21 and individual grams of feed intake. In Exp. 2, dosage for pigs fed the negative control diet plus 0.07% a*P* from the monocalcium P diet was the product of 0.13 and individual grams of feed intake. Dosage for pigs fed the negative control plus 0.14 a*P* from the monocalcium P diet was the product of 0.20 and individual grams of feed intake.

Using these aP dosages, regression was used to determine the aP release from each phytase source for a given aP dosage (intercept) and the aP release from each response variable for a given aP dosage (slope). The percentage aP released from each phytase source (Y) was then calculated by adding the value of aP release from each phytase source for a given aP dosage to the product of the value of aP release from each response variable for a given aP dosage and the value of the response variable (X).

Results

In Exp. 1, lysine and P analysis of the diets resulted in concentrations similar to those used in diet formulation (Table 2). However, Ca levels were higher than expected because of higher than anticipated Ca levels in the microingredients. The high Ca levels resulted in high Ca to total P ratios (2.04 to 2.20) for the negative control and all phytase diets. As previous research suggests, these ratios likely decreased ADG and G/F. However, these ratios did not appear to affect percentage bone ash or the aP release levels calculated from percentage bone ash. Lower Ca:P ratios were used in Exp. 2, in which analysis of the diets resulted in concentrations similar to those used in diet formulation.

According to the AOAC analysis, the phytase concentration in OptiPhos was nearly 3.1 and 2.5 times the concentration listed on the label by the manufacturer for Exp. 1 and 2, respectively (Tables 5 and 6). The phytase level in Phyzyme XP was at the concentration listed on the label by the manufacturer in Exp. 1 and 0.7 times the listed concentration in Exp. 2. Ronozyme P was used and analyzed only in Exp. 2, in which the analyzed values were similar to levels reported on the label by the manufacturer.

Results of the AOAC analysis in both experiments indicated that, as expected, phytase levels increased linearly as more phytase premix was added to the diet. Phytase analysis with the Phytex assay found much lower phytase levels for all premixes and diets. Results from the Phytex analysis assay were not as consistent with added dietary levels as the AOAC assays; however, the Phytex assay was conducted only by one laboratory, whereas the AOAC assay was an average of results from three (Exp. 1) or two (Exp. 2) laboratories. Within laboratory, the Phytex assay was less consistent with our calculated values than any single AOAC assay.

Experiment 1

Pigs fed increasing monocalcium P had improved (linear; $P = 0.01$) ADG, ADFI, G/F, bone ash weight, and percentage ash (Tables 7 and 8). Pigs fed increasing OptiPhos had improved (linear; $P \leq 0.02$) ADG, G/F, and bone percentage ash, as well as increased (quadratic; $P = 0.05$) bone ash weight. Pigs fed increasing Phyzyme XP had improved (linear; $P \leq 0.04$) ADG and G/F, as well as a tendency for increased (linear; $P = 0.06$) percentage bone ash.

Percentage aP released from each phytase source varied depending on the response criteria used to calculate the value (Table 9). The lowest aP release value for both phytase sources was calculated with ADG as the response criteria. The aP release values calculated with G/F as the response criteria were nearly identical for all levels of OptiPhos, whereas levels generally increased with increasing Phyzyme XP to an overall release value that was similar for both phytase sources. The aP release values calculated from bone ash weight were similar for all levels of Phyzyme XP, with the exception of 500 FTU/kg. However, the calculated aP release values were not as consistent for OptiPhos, as evidenced by the second lowest phytase dose releasing the highest percentage aP. The clearest response to percentage aP release was calculated with percentage bone ash as the response criteria. As both OptiPhos and Phyzyme XP levels increased, calculated a*P* increased in a quadratic fashion to the highest phytase dose.

Experiment 2

Pigs fed increasing monocalcium P had improved (linear; $P < 0.001$) G/F and percentage bone ash, improved (quadratic; $P = 0.01$) ADFI, and a tendency for improved (linear; $P = 0.07$, quadratic; $P = 0.09$) ADG (Tables 10 and 11). Pigs fed increasing OptiPhos had improved (linear; $P \leq 0.01$) ADG, G/F, and bone ash weight, increased (quadratic; $P < 0.001$) percentage bone ash, and tended to have increased (linear; $P = 0.07$) ADFI. Pigs fed increasing Phyzyme XP had improved (linear; $P < 0.001$) percentage bone ash, improved (quadratic; $P = 0.05$) G/F, and tended to have increased (linear; $P = 0.09$) bone ash weight. Pigs fed increasing Ronozyme P had improved (linear; $P \leq 0.004$) ADG, ADFI, and bone ash weight, as well as improved (quadratic; $P \leq 0.03$) G/F and percentage bone ash.

Percentage aP released from each phytase source and level again varied depending on the response criteria used to calculate the value (Table 12). The lowest aP release value for 250 FTU/kg of OptiPhos was calculated from ADG. The lowest aP release values for 500, 750, and 1,000 FTU/kg of OptiPhos was calculated from bone ash weight. In contrast, the highest aP release level for all OptiPhos levels was calculated from bone ash percentage. The lowest aP release level for 500 FTU/kg of Phyzyme XP was calculated from bone ash percentage, whereas the lowest levels for 1,000 and 1,500 FTU/kg of Phyzyme XP were calculated from ADG. The highest aP release level for 500 FTU/kg of Phyzyme XP was calculated from G/F, whereas the highest levels for 1,000 and 1,500 FTU/kg of Phyzyme XP were calculated from bone ash percentage. Finally, the lowest aP release level for 1,850 and 3,700 FTU/kg of Ronozyme P was calculated from bone ash weight and G/F, respectively. The highest aP release level for both Ronozyme *P* levels was calculated from bone ash percentage.

Experiments 1 and 2

By using the average values of the AOAC phytase assays from both *E. coli* phytase sources, the response to various criteria were plotted against the analyzed phytase level. Approximately 77% of the variation in response in percentage bone ash was explained by the analyzed phytase level in the diet (Figure 1). Similarly, by plotting the aP released for each phytase level against the analyzed AOAC phytase level, a P release curve was calculated. With percentage bone ash as the response criteria, approximately 73% of the variation in aP release was explained by the analyzed phytase level in the diet (Figure 2). When AOAC analyzed values and bone ash are used as the response variable, aP release for up to 1,000 FTU/kg of *E. coli*-derived phytases (OptiPhos and Phyzyme XP) can be predicted by the equation ($y = -0.000000125x^2 + 0.000236245x + 0.015482000$), where x is the phytase level in the diet.

Previous K-State recommendations, based on Kornegay (1996) P release curves[5], agree well with the phytase release suggested by the aP curve developed from percentage bone ash (Figure 3). The curve previously used by K-State was valid only to 700 FTU/kg, whereas the new curve suggested by this research is valid to 1,000 FTU/kg.

Discussion

Higher phytase concentrations in the AOAC analysis compared with the Phytex analysis were expected because of the key differences between the Phytex assay used by the manufacturer of OptiPhos and the AOAC method. The Phytex assay extracts P with a 0.2M sodium citrate buffer, whereas the AOAC assay uses a 0.2M sodium acetate buffer, Tween 20, and bovine serum albumin. The Phytex assay incubation time is 15 min; the AOAC assay incubation time is 60 min. Additionally, the color reagent used to measure the P released from phytic acid has a wavelength of 820 nm in the Phytex assay and 415 nm in the AOAC assay. Finally, the Phytex assay diafiltrates feed samples to remove high background P levels from monocalcium or dicalcium P before they are assayed; the AOAC assay does not.

The influence of *E. coli*-derived phytase source on level of percentage bone ash follows the typical quadratic response for aP release that has been shown in previous research. The 77% of variation in percentage bone ash that was explained by analyzed phytase value was the highest of any of the measured variables (63, 36, and 39 for ADG, GF, and bone ash weight, respectively). This reinforces that percentage bone ash was the best variable to use to predict aP release. The predicted aP release values from trials in which analyzed AOAC values were used agree largely with Kornegay's summary for *E. coli*-derived phytase levels, suggesting that we can predict aP release levels from *E. coli*-derived phytases when their AOAC assayed value is less than 1,000 FTU/kg. More research needs to be conducted to further evaluate release values for higher phytase levels.

In summary, when percentage bone ash was used as the response criteria, the aP release for these phytase sources was similar to the manufacturers' recommendations when the products were used according to label phytase levels (0.12% for 250 FTU/kg of

[5] Kornegay, E. T., 1996. Nutritional, environmental and economical consideration for using phytase in pig and poultry diets. Pages 277-302 in Nutrient Management of Food Animals to Enhance and Protect the Environment. E. T. Kornegay, ed. CRC Press, Boca Raton, FL.

OptiPhos, 0.10% for 500 FTU/kg of Phyzyme XP, and 0.10% for 1,850 FTU/kg of Ronozyme P). When analyzed on an AOAC basis, the a*P* release curves for the *E. coli* phytases had similar release curves, at least up to 1,000 FTU/kg.

Table 1. Composition of experimental control diets (as-fed basis)[1]

Ingredient, %	Exp. 1	Exp. 2
Corn	57.98	58.11
Soybean meal, 46.5% CP	34.98	35.01
Additive premixes[2]	0.50	0.60
Soybean oil	3.00	3.00
Limestone	1.50	0.25
Salt	0.35	0.35
Vitamin premix	0.25	0.25
Trace mineral premix	0.15	0.15
Lysine-HCl	0.17	0.17
DL-methionine	0.07	0.07
L-threonine	0.05	0.05
Mecadox	1.00	1.00
Total	100.00	100.00
Calculated analysis		
SID[3] lysine, %	1.20	1.20
Total lysine, %	1.34	1.34
SID amino acid ratios		
Isoleucine:lysine ratio	68	68
Leucine:lysine ratio	138	139
Methionine:lysine ratio	39	30
Met & Cys:lysine ratio	58	57
Threonine:lysine ratio	64	62
Tryptophan:lysine ratio	20	19
Valine:lysine ratio	76	74
Crude protein, %	21.4	21.5
ME, kcal/lb	1,565	1,569
SID lysine:ME ratio, g/Mcal	3.51	3.48
Ca, %	0.71	0.49
P, %	0.40	0.39
Available P, %	0.06	0.06

[1] Pigs were fed experimental diets from d 0 to 21 of the trial.
[2] Premixes were added by hand for each treatment and consisted of 3 or 4 lb P premix.
[3] Standardized ileal digestible.

Table 2. Analyzed nutrient composition of ingredients (Exp. 1)

	Lysine, %		Calcium, %		Phosphorus, %		Ca:P
Item	Forumlated[1]	Analyzed[2]	Forumlated[1]	Analyzed[3]	Forumlated[1]	Analyzed[3]	Analyzed[3]
OptiPhos 2000[4]		0.11		16.35		0.07	233.57
Phyzyme XP 1200[5]		0.14		0.05		0.26	0.19
OptiPhos base premix[6]		0.03		2.82		0.04	70.50
Phyzyme XP base premix[6]		0.02					
Negative control	1.34	1.27	0.71	0.92	0.40	0.41	2.24
0.075% aP[7] from monocalcium P	1.34	1.30	0.77	1.00	0.48	0.49	2.04
0.15% aP from monocalcium P	1.34	1.25	0.84	0.90	0.55	0.58	1.55
100 FTU OptiPhos	1.34	1.32	0.71	0.90	0.40	0.41	2.20
175 FTU OptiPhos	1.34	1.34	0.71	0.98	0.40	0.41	2.39
250 FTU OptiPhos	1.34	1.30	0.71	0.90	0.40	0.43	2.09
500 FTU OptiPhos	1.34	1.37	0.71	0.95	0.40	0.43	2.21
200 FTU Phyzyme XP	1.34	1.32	0.71	0.93	0.40	0.43	2.16
350 FTU Phyzyme XP	1.34	1.36	0.71	1.00	0.40	0.42	2.38
500 FTU Phyzyme XP	1.34	1.31	0.71	0.92	0.40	0.43	2.14
1,000 FTU Phyzyme XP	1.34	1.30	0.71	0.97	0.40	0.43	2.26

[1] Nutrient values provided by the manufacturer.
[2] Mean value of 2 samples analyzed in duplicate.
[3] Mean value of 4 samples analyzed in duplicate.
[4] Enzyvia LLC, Sheridan, IN.
[5] Danisco A/S Corporation, Marlborough, UK.
[6] Created from the pure product and cornstarch.
[7] Available P.

Table 3. Calcium concentration of microingredients (Exp. 1)

Ingredient	Analyzed[1]
Antibiotic	18.18
Trace mineral premix	10.44
Vitamin premix	16.93

[1] Mean value of 2 samples analyzed in duplicate.

Table 4. Analyzed nutrient composition of ingredients (Exp. 2)

	Calcium, %		Phosphorus, %		Ca:P
Item	Forumlated[1]	Analyzed	Forumlated[1]	Analyzed	Analyzed
Negative control	0.49	0.48	0.39	0.36	1.33
0.07% aP[2] from monocalcium P	0.55	0.53	0.46	0.43	1.23
0.14% aP from monocalcium P	0.61	0.58	0.53	0.48	1.21
250 FTU OptiPhos[3]	0.49	0.53	0.39	0.36	1.47
500 FTU OptiPhos[3]	0.49	0.47	0.39	0.36	1.31
750 FTU OptiPhos[3]	0.49	0.48	0.39	0.36	1.33
1,000 FTU OptiPhos[3]	0.49	0.49	0.39	0.36	1.36
500 FTU Phyzyme XP[4]	0.49	0.53	0.39	0.37	1.43
1,000 FTU Phyzyme XP[4]	0.49	0.50	0.39	0.37	1.35
1,500 FTU Phyzyme XP[4]	0.49	0.47	0.39	0.37	1.27
1,850 FYT Ronozyme P[5]	0.49	0.49	0.39	0.36	1.36
3,700 FYT Ronozyme P[5]	0.49	0.47	0.39	0.36	1.31

[1] Nutrient values provided by the manufacturer.
[2] Available P.
[3] Enzyvia LLC, Sheridan, IN.
[4] Danisco A/S Corporation, Marlborough, UK.
[5] DSM Nutritional Products, Basel, Switzerland.

Table 5. Analyzed phytase content of diets (Exp. 1)

	Additional aP[1] from monocalcium P			OptiPhos[2], FTU/kg				Phyzyme XP[3], FTU/kg			
Analyzed[4]	None[5]	0.075%	0.15%	100	175	250	500	200	350	500	1,000
AOAC assay, FTU/kg											
Laboratory A	50	70	55	335	635	740	1,635	180	465	450	1,225
Laboratory B	33	87	57	344	530	719	1,528	241	385	415	1,100
Laboratory C	88	202	119	354	516	729	1,363	219	370	423	789
Average AOAC assay	57	119	77	344	560	729	1,509	213	407	429	1,038
Phytex assay, FTU/kg	52	86	71	275	270	300	605	225	285	280	385
Average AOAC ratio[6]				3.5	2.9	2.9	2.7	1.1	1.1	0.8	0.8
Phytex ratio[7]				2.8	1.5	1.2	1.2	1.1	0.8	0.6	0.4

[1] Available P.
[2] Enzyvia LLC, Sheridan, IN.
[3] Danisco A/S Corporation, Marlborough, UK
[4] Average of samples taken at the beginning and end of the experiment.
[5] Contained 0.06% aP.
[6] Ratio of AOAC analysis to formulated values.
[7] Ratio of Phytex analysis to formulated values.

Table 6. Analyzed phytase content of diets (Exp. 2)

	Added aP[1] from monocalcium P			OptiPhos[2], FTU/kg				Phyzyme XP[3], FTU/kg			Ronozyme P[4], FYT/kg	
Analyzed	None[5]	0.07%	0.14%	250	500	750	1,000	500	1,000	1,500	1,850	3,700
AOAC assay, FTU/kg												
Laboratory A	50	50	40	710	1,330	2,000	2,600	290	760	1,140	1,790	3,920
Laboratory B	65	105	63	637	1,123	1,697	2,357	447	656	1,042	1,597	3,635
Avg. AOAC assay	58	78	52	674	1,227	1,849	2,479	369	708	1,091	1,694	3,778
Phytex assay, FTU/kg	70	84	160	360	670	800	900	180	240	550	930	1,900
Avg. AOAC ratio[6]				2.69	2.45	2.46	2.48	0.74	0.71	0.73	0.92	1.02
Phytex ratio[7]				1.44	1.34	1.07	0.90	0.36	0.24	0.37	0.50	0.51

[1] Available P.
[2] Enzyvia LLC, Sheridan, IN.
[3] Danisco A/S Corporation, Marlborough, UK.
[4] DSM Nutritional Products, Basel, Switzerland.
[5] Contained 0.06% aP.
[6] Ratio of average AOAC analyses to formulated values.
[7] Ratio of Phytex analyses to formulated values.

Table 7. Effects of different sources of *E. coli*-derived phytase on nursery pig performance (Exp. 1)[1]

	Additional aP[2] from monocalcium P			OptiPhos[3], FTU/kg				Phyzyme XP[4], FTU/kg			
Item	None[5]	0.075%	0.15%	100	175	250	500	200	350	500	1,000
d 0 to 21											
ADG, lb	0.81	1.12	1.32	0.86	0.86	0.92	1.01	0.81	0.87	0.92	0.92
ADFI, lb	1.64	1.96	1.95	1.53	1.58	1.62	1.74	1.56	1.68	1.62	1.61
G/F	0.51	0.57	0.67	0.56	0.56	0.57	0.58	0.52	0.52	0.57	0.58
Bone ash weight, mg	473	579	777	504	650	616	594	586	610	546	593
Bone ash, %	35.6	39.4	41.8	36.2	38.2	39.6	41.1	37.0	39.0	37.9	40.0

[1] A total of 88 pigs (1 pig per pen and 8 pens per treatment) with an initial BW of 22.7 lb. Pigs were fed the control diet (0.06% aP) during a 6-d pretest period and then fed experimental diets for 21 d.
[2] Available P.
[3] Enzyvia LLC, Sheridan, IN.
[4] Danisco A/S Corporation, Marlborough, UK.
[5] Contained 0.06% aP.

Table 8. Probability table of different sources of *E. coli*-derived phytase on nursery pig performance (Exp. 1)[1]

	Monocalcium P		OptiPhos[2]		Phyzyme XP[3]		
Item	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	SE
d 0 to 21							
ADG, lb	0.01	0.26	0.01	0.88	0.04	0.50	0.046
ADFI, lb	0.01	0.07	0.11	0.22	0.92	0.88	0.075
G/F	0.01	0.54	0.02	0.14	0.01	0.64	0.023
Bone ash weight, mg	0.01	0.47	0.07	0.05	0.27	0.30	55.0
Bone ash, %	0.01	0.69	0.01	0.56	0.06	0.59	1.65

[1] A total of 88 pigs (1 pig per pen and 8 pens per treatment) with an initial BW of 22.7 lb. Pigs were fed the control diet (0.06% available P) during a 6-d pretest period and then fed experimental diets for 21 d.
[2] Enzyvia LLC, Sheridan, IN.
[3] Danisco A/S Corporation, Marlborough, UK.

Table 9. Calculated available P release values based on different response criteria (Exp. 1)

	OptiPhos[1], FTU/kg				Phyzyme XP[2], FTU/kg				
Item	100	175	250	500	200	350	500	1,000	SE
Response criteria									
ADG, lb	0.029	0.029	0.046	0.063	0.013	0.022	0.042	0.044	0.012
G/F	0.099	0.096	0.097	0.089	0.068	0.056	0.093	0.102	0.018
Bone ash weight, mg	0.055	0.127	0.105	0.084	0.092	0.094	0.070	0.094	0.028
Bone ash, %	0.059	0.086	0.117	0.121	0.069	0.094	0.082	0.120	0.028

[1] Enzyvia LLC, Sheridan, IN.
[2] Danisco A/S Corporation, Marlborough, UK.

Table 10. Effects of different sources of *E. coli*-derived phytase on nursery pig performance (Exp. 2)[1]

	Additional aP[2] from monocalcium P			OptiPhos[3], FTU/kg				Phyzyme XP[4], FTU/kg			Ronozyme P[5], FTU/kg	
Item	None[6]	0.07%	0.14%	250	500	750	1,000	500	1,000	1,500	1,850	3,700
d 0 to 21												
ADG, lb	0.89	1.07	1.03	1.05	1.11	1.15	1.15	1.02	1.00	0.98	1.06	1.27
ADFI, lb	1.43	1.69	1.49	1.58	1.62	1.65	1.62	1.49	1.48	1.43	1.53	1.83
G/F	0.63	0.64	0.69	0.66	0.68	0.69	0.71	0.69	0.67	0.68	0.70	0.70
Bone ash weight, mg	626	601	696	731	734	744	799	625	773	681	691	799
Bone ash, %	34.2	39.6	41.2	41.6	41.9	42.7	43.6	37.1	41.9	42.0	41.1	42.3

[1] A total of 128 pigs (1 pig per pen and 8 pens per treatment) with an initial BW of 21.3 lb. Pigs were fed the control diet (0.06% aP) during a 6-d pretest period and then fed experimental diets for 21 d.
[2] Available P.
[3] Enzyvia LLC, Sheridan, IN.
[4] Danisco A/S Corporation.
[5] DSM Nutritional Products, Basel, Switzerland.
[6] Contained 0.06% aP.

Table 11. Main effects of different sources of *E. coli*-derived phytase on nursery pig performance (Exp. 2)[1]

	Probabilities, P <								
	Monocalcium P		OptiPhos[2]		Phyzyme XP[3]		Ronozyme P[4]		
Item	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	SE
d 0 to 21									
ADG, lb	0.07	0.09	0.001	0.11	0.33	0.18	0.001	0.76	0.079
ADFI, lb	0.54	0.01	0.07	0.21	0.96	0.43	0.001	0.28	0.112
G/F	0.001	0.19	0.001	0.24	0.01	0.05	0.001	0.03	0.019
Bone ash weight, mg	0.23	0.26	0.01	0.56	0.09	0.28	0.004	0.67	60.2
Bone ash, %	0.001	0.07	0.001	0.001	0.001	0.10	0.001	0.01	1.21

[1] A total of 128 pigs (1 pig per pen and 8 pens per treatment) with an initial BW of 21.3 lb. Pigs were fed the control diet (0.06% available P) during a 6-d pretest period and then fed experimental diets for 21 d.
[2] Enzyvia LLC, Sheridan, IN.
[3] Danisco A/S Corporation.
[4] DSM Nutritional Products, Basel, Switzerland.

Table 12. Effects of different sources of *E. coli*-derived phytase on nursery pig available P (aP) release (Exp. 2)[1]

	OptiPhos[2], FTU/kg				Phyzyme XP[3], FTU/kg			Ronozyme P[4], FTU/kg		
Item	250	500	750	1,000	500	1,000	1,500	1,850	3,700	SE
Predicted aP, %										
ADG	0.075	0.084	0.090	0.093	0.079	0.072	0.073	0.084	0.098	0.008
G/F	0.079	0.082	0.082	0.092	0.098	0.095	0.099	0.097	0.070	0.015
Bone ash weight	0.088	0.079	0.079	0.091	0.072	0.104	0.090	0.081	0.074	0.012
Bone ash, %	0.127	0.115	0.125	0.142	0.056	0.137	0.146	0.117	0.103	0.021

[1] A total of 128 pigs (1 pig per pen and 8 pens per treatment) with an initial BW of 21.3 lb. Pigs were fed the control diet (0.06% aP) during a 6-d pretest period and then fed experimental diets for 21 d.
[2] Enzyvia LLC, Sheridan, IN.
[3] Danisco A/S Corporation.
[4] DSM Nutritional Products, Basel, Switzerland.

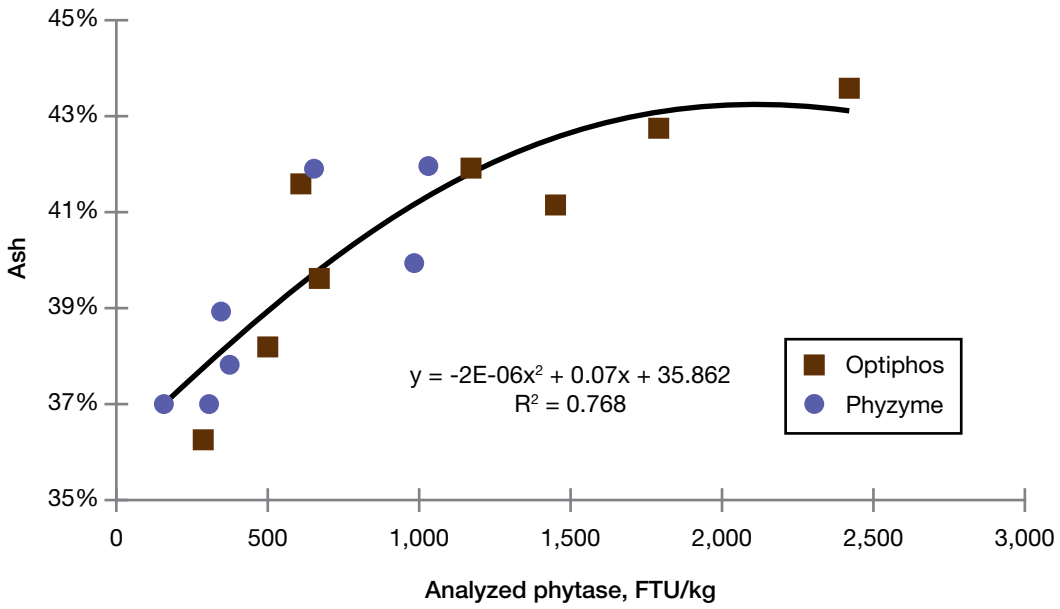

Figure 1. Influence of *E. coli*-derived phytase source and level on percentage bone ash.

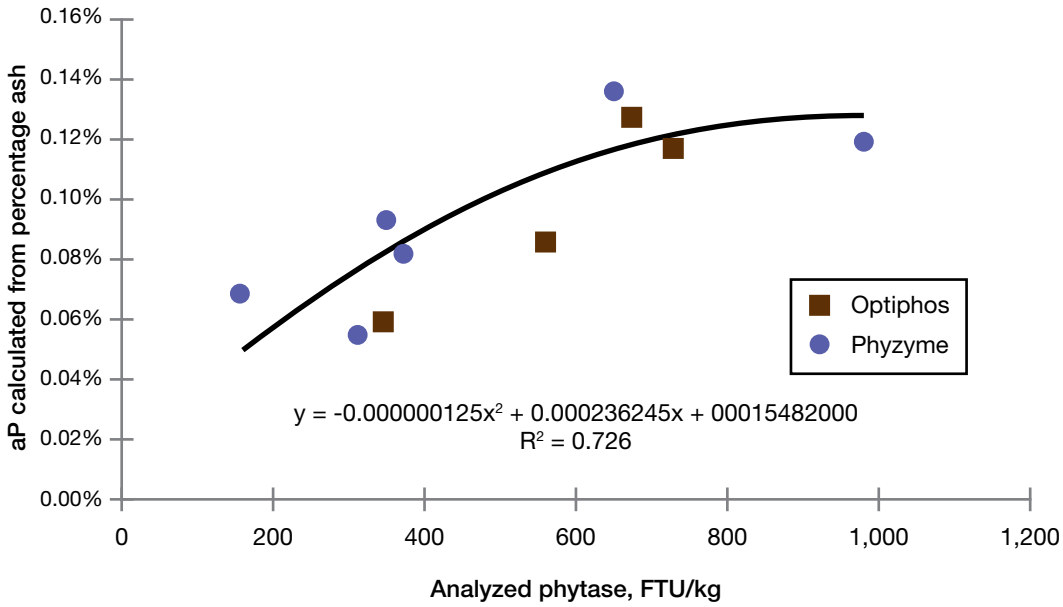

Figure 2. Influence of *E. coli*-derived phytase source and level on predicted available P (aP) release calculated from percentage bone ash.

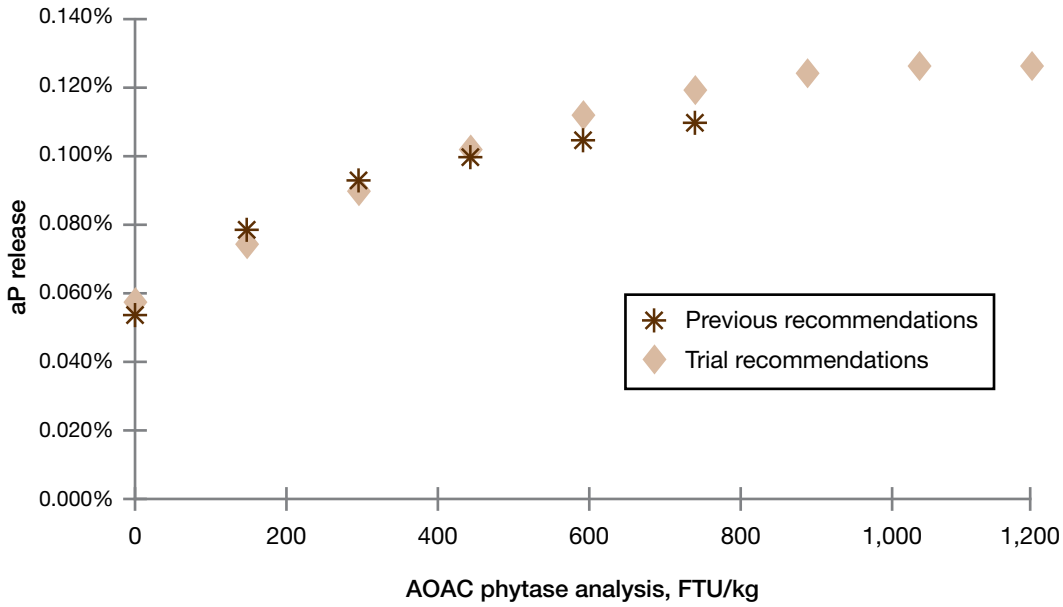

Figure 3. Differences between available P (aP) release values from this trial and previous Kansas State University recommendations.

Comparison of Different Antimicrobial Sequences on Nursery Pig Performance and Economic Return

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Summary

A total of 1,008 weanling pigs (12.0 lb and 19 d of age) were used in a 42-d experiment to compare different antibiotic regimens on growth performance and economic return. From d 0 to 11 and d 11 to 21, pigs were fed diets containing no antibiotic, a combination of Denagard (Novartis Animal Health, Greensboro, NC) at 35 g/ton and chlortetracycline at 400 g/ton (Denagard/CTC), or Pulmotil (Elanco, Greenfield, IN; 363 g/ton from d 0 to 11 and 181 g/ton from d 11 to 21). From d 21 to 42, pigs previously fed Denagard/CTC or Pulmotil were fed diets containing no medication, Denagard/CTC, or a combination of Mecadox (Philbro Animal Health Corp., Ridgefield Park, NJ) at 25 g/ton and oxytetracycline at 400 g per ton (Mecadox/OTC). Adding Denagard/CTC or Pulmotil to the diet from d 0 to 11 and d 11 to 21 improved ($P < 0.01$) ADG, ADFI, F/G, and income over feed cost (IOFC). There were no differences ($P > 0.21$) in ADG or ADFI between pigs fed Denagard/CTC and pigs fed Pulmotil; however, pigs fed Denagard/CTC tended to have better ($P < 0.09$) F/G from d 0 to 21. Feed cost was also lower ($P < 0.01$) and IOFC was greater ($P < 0.03$) from d 0 to 21 for pigs fed Denagard/CTC than for pigs fed Pulmotil. Adding Denagard/CTC or Mecadox/OTC to the diet from d 21 to 42 increased ($P < 0.05$) ADG, ADFI, and IOFC compared with feeding no antibiotic, but there were no differences ($P > 0.17$) in pig performance or IOFC between pigs fed Denagard/CTC and Mecadox/OTC. For the overall trial, adding antibiotics to the diet during any phase improved ($P < 0.05$) ADG, ADFI, F/G, and IOFC. These results demonstrate that adding antibiotics to the nursery diet improved pig performance and economical return on this commercial farm.

Key words: antimicrobial

Introduction

Past research has continually demonstrated that including antibiotics in nursery pig diets improves pig growth performance (Hays, 1978[4]; Zimmerman, 1986[5]; Cromwell,

[1] Swine Nutrition Services, Inc., Anchor, Il.
[2] Novartis Animal Health, Greensboro, NC.
[3] Department of Diagnostic Medicine/Pathobiology, Kansas State University.
[4] Hays, V. W. 1978. Effectiveness of feed additive usage of antibacterial agents in swine and poultry production. Report to the Office of Technology Assessment. U.S. Government Printing Office, Washington, DC.
[5] Zimmerman, D. R. 1986. Role of subtherapeutic levels of antimicrobials in pig production. J. Anim. Sci. 62(Suppl. 3):6-17.

2001[6]; Dritz et al., 2002[7]; Steidinger et al., 2008[8]). The greatest response is normally through an increase in feed intake, which increases daily gain. Although the benefit of including feed-grade antibiotics in the nursery stage is well documented, limited data are available comparing various antibiotic regimens for nursery pigs. In the 2008 Swine Day Report of Progress (Steidinger et al., 2008), we reported beneficial responses to antibiotics fed in nursery pig diets. In that study, we compared pigs fed different regimens and combinations including Denagard (Novartis Animal Health, Greensboro, NC) and chlortetracycline (Denagard/CTC) with pigs fed Mecadox (Philbro Animal Health Corp., Ridgefield Park, NJ) and oxytetracycline (Mecadox/OTC). Any of the antibiotic regimens tested improved growth performance and income over feed cost (IOFC) compared with pigs fed no antibiotic. In fact, removing antibiotics from the diet during any phase resulted in lower IOFC. Therefore, the purpose of this trial was to validate the response to antibiotics observed in our earlier study (Steidinger et al., 2008) and to compare the growth and economic response of some different antibiotic regimens that are commonly used in the commercial swine industry.

Procedures

A total of 1,008 pigs (12.0 lb and 19 d of age) were used in a 42-d experiment. Pigs were from a PRRSv positive, but stable, pig flow. The pig flow had a history of both enteric and respiratory challenge with a variety of organisms involved including *Pasteurella multocida*. Denagard/CTC was selected as one of the interventions based on the diagnostic history. Pigs were weaned into a 4-room nursery facility. Each room contained 12 pens (6 × 10 ft) with wire flooring and a single bowl waterer and 4-hole dry feeder. All pigs received the same 3-stage diets (d 1 to 10, 10 to 21, and 21 to 42; Phases 1, 2, and 3, respectively); feed medication was the only difference between treatment groups (Table 1).

The research site had a finishing barn within 75 ft of the nursery building. Historical mortality was 2% to 10%, with pigs seroconverting to PRRSv by wk 3 in the nursery. Pigs were vaccinated for *Mycoplasma hyopneumoniae* and received ½ dose circovirus vaccine at 2 and 4 wk postplacement.

All pigs were weaned on the same day and blocked by weight into each of the treatment groups. There were 7 treatment groups (144 pigs per treatment; 1,008 pigs total); each treatment group consisted of 6 or 7 pens with 21 pigs per pen. All pigs were monitored daily, and animals exhibiting severe clinical signs were humanely euthanized according to Novartis Animal Health animal welfare policy.

Dietary treatments were arranged as a 2 × 3 factorial design plus a negative control (Table 2).The negative control did not contain antibiotics during any period. For the factorial, pigs received either Denagard/CTC or Pulmotil (Elanco, Greenfield, IN) from d 0 to 10 and d 10 to 21 and then 1 of 3 diets from d 21 to 42 (negative control, Denagard/CTC, or Mecadox/OTC. When Denagard/CTC was fed, Denagard was

[6] Cromwell, G. L. 2001. Antimicrobial and promicrobial agents. Pages 401-426 in Swine Nutrition. A. J. Lewis and L.L. Southern, eds. CRC Press, New York.
[7] Dritz, S. S., M. D. Tokach, R. D. Goodband, and J. L. Nelssen. 2002. Effects of administration of antimicrobials in feed on growth rate and feed efficiency of pigs in multisite production systems. J. Amer. Vet. Med. Assoc. 220:1690-1695.
[8] Steidinger et al., Swine Day 2008, Report of Progress 1001, pp. 74-81.

added at 35 g/ton and CTC at 400 g/ton. For Mecadox/OTC, Mecadox was included at 25 g/ton and OTC at 400 g/ton. When Pulmotil was fed during the first 2 phases, it was included in the diet at 363 g/ton during Phase 1 and 181 g/ton during Phase 2.

Water and feed were available to all pigs ad libitum for the duration of the study. Feed samples were collected from the feed mill to confirm medication level for all diet phases and treatment groups. Feed samples also were collected from 1 feeder of each treatment group for all diet phases. All feed samples were analyzed for the appropriate medication and its concentration (Table 3).

All pigs were weighed on d 0, 11, 21, and 42 to calculate ADG, ADFI, and F/G. Any pigs treated for health-related problems were recorded to calculate the number of treatments per pen. Actual feed cost at the time of the experiment was used to calculate feed cost per pig and feed cost per pound of gain. Income over feed cost was calculated as pound of gain × the value of the gain - feed cost per pig. Two different values of gain ($0.50/lb or $1.00/lb) were used to account for the impact of weight gained in the nursery on pig weight at market. The $0.50/lb assumes that weight gained in the nursery remains at market without becoming greater or smaller. The $1.00/lb assumes that each 1 lb gained in the nursery becomes 2 lb at market. Previous research has demonstrated that each 1 lb gained in the nursery is worth 1 to 4 lb at market depending on the research trial (Tokach et al., 1995[9]; Steidinger et al., 2008).

Data were analyzed using the MIXED procedure of SAS (SAS Institute Inc., Cary, NC) with pen as the experimental unit for all response criteria. The statistical model included the fixed effect of treatment and random effect of nursery room. The data was derived from 6 or 7 replicate pens across 4 nursery rooms in a balanced incomplete block design. Single degree of freedom contrasts were used to determine the response to antibiotic inclusion in the diet during each phase and any differences between Denagard/CTC and Pulmotil during Phases 1 and 2 and between Denagard/CTC and Mecadox/OTC during Phase 3.

Results and Discussion

No adverse effects to inclusion of the antibiotics in the feed were noted during any phase of the study. Overall pig mortality during the study was similar to historical expected mortality. Laboratory analysis confirmed antibiotic inclusion in the test diets (Table 3). Analyzed levels in the feed were lower than targeted levels for CTC and Denagard but higher than target for OTC. The low levels of OTC in the control diets were unexpected. The reason may have been contamination during sampling. We don't believe the contamination occurred hrough feed mixing because feed batches without antibiotic were manufactured before batches with antibiotic to minimize any potential for carryover. The reason for the discrepancy in OTC and CTC levels in the Phase 3 diets is also unknown. The target level was 400 g/ton, but testing results revealed 803 g/ton for OTC and 279 g/ton for CTC.

[9] Tokach, M. D., J. E. Pettigrew, L. J. Johnston, M. Overland, J. W. Rust, and S. G. Cornelius. 1995. Effect of adding fat and(or) milk products to the weanling pig diet on performance in the nursery and subsequent grow-finish stages. J. Anim. Sci. 73:3358.

Adding Denagard/CTC or Pulmotil to the diet from d 0 to 11 and d 11 to 21 improved ($P < 0.01$) ADG, ADFI, F/G, and IOFC (Tables 4, 5, and 6). Adding Denagard/CTC to the diet also lowered ($P < 0.03$) feed cost per pound of gain during both phases, whereas feeding Pulmotil resulted in a similar ($P > 0.22$) feed cost per pound of gain compared with the control. Pigs fed Denagard/CTC had lower ($P < 0.01$) feed cost per pig and feed cost per pound of gain and higher ($P < 0.03$) IOFC than pigs fed Pulmotil from d 0 to 21 (Phases 1 and 2). Including Denagard/CTC in the diet from d 0 to 21 after weaning resulted in 4.1 lb more weight gain per pig and a net increase in IOFC of $1.35/pig when gain was valued at $0.50/lb and $3.46/pig when the value of gain was increased to $1.00/lb. Including Pulmotil in the diet from d 0 to 21 resulted in 3.5 lb more weight gain per pig than the control and a net increase in IOFC of $0.71/pig or $2.47/pig when valued at $0.50 and $1.00/lb, respectively. Thus, Denagard/CTC resulted in weight gain similar to that of Pulmotil, but with a greater IOFC ($0.64/pig to 0.99/pig depending on the value of gain).

Adding antibiotics to the diet from d 21 to 42 improved ADG ($P < 0.01$) and ADFI ($P = 0.02$) and tended to improve F/G ($P = 0.08$). There were no differences in performance ($P > 0.46$) between pigs fed Denagard/CTC and pigs fed Mecadox/OTC. Although adding antibiotics to the diet increased ($P < 0.01$) feed cost per pig and feed cost per pound of gain, the weight gain benefit resulted in increased ($P < 0.01$) IOFC when antibiotics were added to the diet. Pigs fed Mecadox/OTC had lower ($P = 0.03$) feed cost per pound of gain than pigs fed Denagard/CTC; however, there were no differences ($P > 0.17$) between the two antibiotics for IOFC. It is unknown whether the response in this phase may have been influenced by the higher tested OTC level in the Mecadox/OTC treatment relative to the CTC level in the Denagard/CTC treatment. The reason that we believe that the antibiotic level may have influenced the response is that pigs fed Denagard/CTC tended to grow faster than pigs fed Mecadox/OTC when compared with the same antibiotic combinations used during the Phase 2 period in our previous study (Steidinger et al., 2008).

For the overall trial, adding antibiotics to the diet from d 0 to 11, 11 to 21, and 21 to 42 improved ($P < 0.05$) ADG, ADFI, and F/G. Overall feed cost per pig was increased ($P < 0.01$) by the addition of antibiotics to the diet during any phase. Adding antibiotics to the diet also increased ($P < 0.04$) overall feed cost per pound of gain; however, overall IOFC was increased ($P < 0.04$) when antibiotics were added to the diet from d 0 to 21 and d 21 to 42. These results confirm the results of our first experiment (Steidinger et al., 2008) that adding antibiotics to the nursery diet improved pig performance and economic returns on this commercial farm.

Table 1. Composition of control diets

Item	Phase 1	Phase 2	Phase 3
Ingredient, %			
Corn[1]	42.62	41.21	40.37
Soybean meal (46.5% CP)	23.52	30.79	25.47
Whey permeate	20	7.5	- - -
Dried distillers grains with solubles	2.5	15	30
Spray-dried animal plasma	3.65	- - -	- - -
Menhaden fish meal	3.35	- - -	- - -
Fat, AV blend	1.501	2.077	1.425
Limestone	0.673	1.076	1.275
Monocalcium P, 21% P	0.424	0.702	0.052
Salt	0.25	0.25	0.4
L-lysine HCl	0.371	0.450	0.458
DL-methionine	0.205	0.154	0.072
L-threonine	0.127	0.114	0.089
Zinc oxide	0.375	0.25	- - -
Vitamin premix[2]	0.15	0.15	0.125
Trace mineral premix[3]	0.125	0.125	0.125
Copper sulfate	0.075	0.075	0.075
Sweetener	0.025	0.025	- - -
Phytase 1200	0.0625	0.0625	0.0625
Total	100.00	100.00	100.00
Calculated analysis			
SID lysine[4], %	1.45	1.36	1.25
Total lysine, %	1.58	1.52	1.41
SID amino acid ratios			
Met & Cys:lysine, %	59	60	57
Threonine:lysine, %	61	61	60
Tryptophan:lysine, %	17	17	17
Valine:lysine, %	63	67	66
ME, Kcal/lb	1,544	1,546	1,488
Lactose, %	16.0	6.0	---
Phytase, units/kg	680	680	680
CP, %	21.8	22.9	21.8
Fat, %	4.1	5.8	5.3
Ca, %	0.71	0.70	0.7
P, %	0.68	0.63	0.64
Available P, %	0.55	0.45	0.35

[1] Antibiotics replaced corn in the control diets to form the experimental treatments.
[2] Provided following vitamins per pound of complete diet: vitamin A, 4,995 IU; vitamin D 750 IU; vitamin E, 24 IU; vitamin K, 2.0 mg; vitamin B_{12}, 17.6 ug; niacin, 22.5 mg; pantothenic acid, 12.5 mg; and riboflavin, 3.8 mg.
[3] Contained the following minerals: copper, 1.32%; iodine, 240 ppm; iron, 10%; manganese, 2.8%; selenium, 240 ppm; and zinc, 12%.
[4] Standardized ileal digestible.

Table 2. Dietary antibiotics in each phase

Treatment	d 0 to 11	d 11 to 21	d 21 to 42
1	No medication	No medication	No medication
2	Denagard/CTC[1]	Denagard/CTC	Denagard/CTC
3	Pulmotil, 363 g	Pulmotil, 181 g	Denagard/CTC
4	Denagard/CTC	Denagard/CTC	No medication
5	Pulmotil, 363 g	Pulmotil, 181 g	No medication
6	Denagard/CTC	Denagard/CTC	Mecadox/OTC[2]
7	Pulmotil, 363 g	Pulmotil, 181 g	Mecadox/OTC

[1] Chlortetracycline, 400 g/ton.
[2] Oxytetracycline, 400 g/ton.

Table 3. Analyzed antibiotic levels in each phase, g/ton

	Carbadox	Oxytetracycline	Chlortetracycline	Tiamulin	Pulmotil
Phase 1					
Control	1.53	8.49	<0.91	0	< 45.4
Denagard/CTC[1]	---	---	298	10.1	---
Pulmotil	---	---	---	---	295
Phase 2					
Control	2.25	5.28	<0.91	0	< 45.4
Denagard/CTC	---	---	379	20.3	---
Pulmotil	---	---	---	---	181
Phase 3					
Control	< 1.14	36.1	2.76	0	< 45.4
Mecadox 25g/OTC[2]	13.4	803	---	---	---
Denagard/CTC	---	---	279	17.5	---

[1] Chlortetracycline, 400 g/ton.
[2] Oxytetracycline, 400 g/ton.

Table 4. Influence of antimicrobial additions to the diet on pig performance[1]

	Treatment							
	1	2	3	4	5	6	7	
d 0 to 10:	No med	Den/CTC[2]	Pulmotil	Den/CTC	Pulmotil	Den/CTC	Pulmotil	
d 10 to 21:	No med	Den/CTC	Pulmotil	Den/CTC	Pulmotil	Den/CTC	Pulmotil	
d 21 to 42:	No med	Den/CTC	Den/CTC	No med	No med	Mec/OTC[3]	Mec/OTC	SEM
d 0 to 11								
ADG, lb	0.19	0.32	0.31	0.31	0.30	0.33	0.30	0.024
ADFI, lb	0.30	0.39	0.38	0.41	0.39	0.41	0.41	0.023
F/G	1.59	1.26	1.26	1.33	1.33	1.28	1.35	0.085
d 11 to 21								
ADG, lb	0.50	0.76	0.74	0.80	0.73	0.79	0.74	0.50
ADFI, lb	0.77	0.99	1.01	1.01	0.97	1.01	0.98	0.77
F/G	1.63	1.31	1.38	1.26	1.33	1.29	1.33	1.63
d 21 to 42								
ADG, lb	0.93	1.03	1.06	0.92	0.93	1.05	1.11	0.06
ADFI, lb	1.43	1.62	1.59	1.46	1.49	1.59	1.64	0.106
F/G	1.56	1.57	1.49	1.58	1.59	1.52	1.48	0.048
d 0 to 21								
ADG, lb	0.34	0.53	0.51	0.54	0.51	0.55	0.51	0.035
ADFI, lb	0.52	0.68	0.68	0.70	0.66	0.70	0.67	0.037
F/G	1.60	1.29	1.35	1.28	1.33	1.28	1.34	0.044
d 0 to 42								
ADG, lb	0.63	0.78	0.78	0.73	0.72	0.80	0.81	0.043
ADFI, lb	0.98	1.14	1.12	1.07	1.07	1.14	1.14	0.065
F/G	1.57	1.47	1.44	1.47	1.50	1.44	1.43	0.037
Weight, lb								
d 0	12.4	11.9	11.8	12.1	12.2	11.8	11.7	1.02
d 11	14.5	15.4	15.2	15.5	15.5	15.5	15.1	1.17
d 21	19.6	23.1	22.6	23.5	22.8	23.3	22.6	1.61
d 42	39.4	44.9	44.8	42.7	42.4	45.4	45.8	2.60
Survival, %	95.8%	96.3%	99.3%	100.0%	99.3%	99.3%	98.0%	1.3%

[1] Each mean represents 6 (treatment 1) or 7 pens with 21 pigs per pen for a total of 1,008 pigs.
[2] Denagard, chlortetracycline.
[3] Mecadox, oxytetracycline.

Table 5. Influence of antimicrobial additions to the diet on feed economics[1]

	Treatment							
	1	2	3	4	5	6	7	
d 0 to 10:	No med	Den/CTC[2]	Pulmotil	Den/CTC	Pulmotil	Den/CTC	Pulmotil	
d 10 to 21:	No med	Den/CTC	Pulmotil	Den/CTC	Pulmotil	Den/CTC	Pulmotil	
d 21 to 42:	No med	Den/CTC	Den/CTC	No med	No med	Mec/OTC[3]	Mec/OTC	SEM
Feed cost, $/pig								
d 0 to 11	0.73	1.02	1.19	1.06	1.22	1.06	1.26	0.068
d 11 to 21	0.98	1.39	1.58	1.41	1.52	1.42	1.53	0.086
d 21 to 42	2.95	3.81	3.74	3.01	3.07	3.60	3.70	0.234
d 0 to 21	1.70	2.41	2.76	2.47	2.73	2.48	2.78	0.141
d 0 to 42	4.68	6.21	6.42	5.47	5.78	6.07	6.46	0.329
Feed cost, $/lb gain								
d 0 to 11	0.351	0.296	0.358	0.313	0.377	0.302	0.38	0.021
d 11 to 21	0.205	0.183	0.216	0.177	0.209	0.181	0.209	0.007
d 21 to 42	0.153	0.176	0.167	0.155	0.156	0.163	0.159	0.005
d 0 to 21	0.250	0.219	0.261	0.217	0.259	0.218	0.265	0.009
d 0 to 42	0.179	0.191	0.198	0.179	0.192	0.182	0.192	0.004
Income over feed cost 1, $/pig[4]								
d 0 to 11	0.33	0.73	0.48	0.66	0.46	0.75	0.41	0.099
d 11 to 21	1.53	2.42	2.10	2.58	2.13	2.51	2.15	0.179
d 21 to 42	6.78	7.00	7.40	6.61	6.74	7.42	7.91	0.43
d 0 to 21	1.84	3.13	2.55	3.25	2.59	3.26	2.51	0.251
d 0 to 42	8.57	10.07	9.84	9.85	9.30	10.65	10.35	0.604
Income over feed cost 2, $/pig[4]								
d 0 to 11	1.39	2.48	2.14	2.38	2.12	2.57	2.07	0.226
d 11 to 21	4.04	6.22	5.77	6.58	5.77	6.44	5.84	0.435
d 21 to 42	16.51	17.80	18.55	16.24	16.55	18.44	19.52	1.054
d 0 to 21	5.38	8.69	7.83	8.96	7.88	8.99	7.77	0.612
d 0 to 42	21.83	26.35	26.10	25.16	24.38	27.38	27.16	1.494

[1] Base diet costs were $442.60/ton from d 0 to 11; $252.31/ton from d 11 to 21; and $196.63/ton from d 21 to 42. Medication costs per ton were $27.85 for Denagard/CTC (Den/CTC), $18.65 for Mecadox/OTC (Mec/OTC), and $122.54 for 363 g of Pulmotil ($61.77 for 181 g of Pulmotil).
[2] Denagard, chlortetracycline.
[3] Mecadox, oxytetracycline.
[4] Income over feed cost 1 assumed a value of gain at $0.50/lb. Income over feed cost 2 assumed a value of gain of $1.00/lb.

Table 6. Statistical differences for performance and economic data, (*P* <)

	Contrasts[1]							
	1	2	3	4	5	6	7	8
d 0 to 11								
ADG, lb	<0.01	<0.01	<0.01	0.32	0.01	0.04	0.03	0.90
ADFI, lb	<0.01	<0.01	<0.01	0.55	0.07	0.29	0.04	0.36
F/G	<0.01	<0.01	<0.01	0.67	0.02	0.02	0.10	0.45
d 11 to 21								
ADG, lb	<0.01	<0.01	<0.01	0.21	0.04	0.10	0.05	0.77
ADFI, lb	<0.01	<0.01	<0.01	0.66	0.05	0.09	0.10	0.96
F/G	<0.01	<0.01	<0.01	0.16	0.05	0.16	0.05	0.57
d 21 to 42								
ADG, lb	0.09	0.19	0.05	0.32	<0.01	0.01	<0.01	0.46
ADFI, lb	0.15	0.20	0.15	0.80	0.02	0.05	0.03	0.86
F/G	0.66	0.94	0.45	0.30	0.08	0.27	0.07	0.48
d 0 to 21								
ADG, lb	<0.01	<0.01	<0.01	0.21	0.02	0.06	0.03	0.82
ADFI, lb	<0.01	<0.01	<0.01	0.48	0.05	0.13	0.08	0.82
F/G	<0.01	<0.01	<0.01	0.09	0.01	0.04	0.03	0.89
d 0 to 42								
ADG, lb	<0.01	<0.01	<0.01	0.92	<0.01	0.01	<0.01	0.55
ADFI, lb	0.03	0.04	0.05	0.86	0.03	0.09	0.05	0.81
F/G	0.01	0.01	0.01	0.96	0.02	0.09	0.02	0.55
Weight, lb								
d 0	0.54	0.57	0.55	0.96	0.43	0.53	0.49	0.95
d 11	0.40	0.37	0.49	0.74	0.87	0.88	0.89	0.99
d 21	0.02	0.02	0.05	0.52	0.34	0.46	0.38	0.91
d 42	0.05	0.06	0.06	0.99	0.02	0.08	0.04	0.73
Survival, %	0.03	0.06	0.04	0.74	0.89	0.61	0.79	0.48

continued

Table 6. Statistical differences for performance and economic data, (*P* <)

	Contrasts[1]							
	1	2	3	4	5	6	7	8
Feed cost, $/pig								
d 0 to 11	<0.01	<0.01	<0.01	<0.01	0.01	0.09	0.01	0.37
d 11 to 21	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.02	0.93
d 21 to 42	0.01	0.02	0.01	0.80	<0.01	<0.01	<0.01	0.47
d 0 to 21	<0.01	<0.01	<0.01	0.01	0.01	0.03	0.01	0.72
d 0 to 42	<0.01	<0.01	<0.01	0.22	<0.01	<0.01	<0.01	0.87
Feed cost, $/lb gain								
d 0 to 11	0.50	0.03	0.33	<0.01	0.32	0.21	0.70	0.42
d 11 to 21	0.24	<0.01	0.47	<0.01	0.99	0.74	0.72	0.53
d 21 to 42	0.08	0.05	0.19	0.28	<0.01	<0.01	0.14	0.03
d 0 to 21	0.27	<0.01	0.22	<0.01	0.85	0.80	0.94	0.88
d 0 to 42	0.04	0.34	<0.01	<0.01	0.02	0.01	0.34	0.08
Income over feed cost 1, $/pig[2]								
d 0 to 11	0.01	<0.01	0.24	<0.01	0.10	0.13	0.20	0.82
d 11 to 21	<0.01	<0.01	0.01	0.01	0.10	0.25	0.10	0.65
d 21 to 42	0.31	0.59	0.17	0.21	0.01	0.12	<0.01	0.17
d 0 to 21	<0.01	<0.01	0.01	<0.01	0.09	0.18	0.12	0.86
d 0 to 42	0.02	0.02	0.06	0.41	0.02	0.15	0.01	0.31
Income over feed cost 2, $/pig[2]								
d 0 to 11	<0.01	<0.01	0.01	0.04	0.03	0.08	0.07	0.96
d 11 to 21	<0.01	<0.01	<0.01	0.06	0.05	0.15	0.07	0.72
d 21 to 42	0.15	0.32	0.09	0.27	<0.01	0.02	<0.01	0.31
d 0 to 21	<0.01	<0.01	<0.01	0.03	0.04	0.11	0.07	0.83
d 0 to 42	0.01	0.01	0.02	0.70	0.01	0.05	0.01	0.44

[1] Contrast 1 = Response to antibiotic in Phases 1 and 2 (Treatment 1 vs. all others).
Contrast 2 = Denagard/CTC vs. no medication in Phases 1 and 2 (Treatments 1 vs. 2, 4, and 6).
Contrast 3 = Pulmotil vs. no medication in Phases 1 and 2 (Treatments 1vs. 3, 5, and 7).
Contrast 4 = Denagard/CTC vs. Pulmotil (Treatments 2, 4, and 6 vs. 3, 5, and 7).
Contrast 5 = Response to antibiotic in Phase 3 (Treatments 1, 4, and 5 vs. 2, 3, 6 and 7).
Contrast 6 = Denagard/CTC vs. no medication in Phase 3 (Treatments 1, 4, and 5 vs. 2 and 3).
Contrast 7 = Mecadox/OTC vs. no medication in Phase 3 (Treatments 1, 4, and 5 vs. 6 and 7).
Contrast 8 = Denagard/CTC vs. Mecadox/OTC in Phase 3 (Treatments 2 and 3 vs. 6 and 7).
[2] Income over feed cost 1 assumed a value of gain at $0.50/lb. Income over feed cost 2 assumed a value of gain of $1.00/lb.

Effects of Feeding Varied Levels of Balanced Protein on Growth Performance and Carcass Composition of Growing and Finishing Pigs[1,2]

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Summary

A total of 1,003 barrows and gilts (PIC 337 × 1050, initially 113.5 lb) were used in an 88-d study to determine effects of various levels of balanced amino acid density on growth performance and carcass characteristics. Balanced amino acid refers to balancing the dietary amino acids according to the ideal protein ratio, at least for the first 4 limiting amino acids; the other amino acids may be at or higher than required levels. In this study, this balance was accomplished by using supplemental amino acids and formulating to meet the first 4 limiting amino acids: lysine, threonine, methionine, and tryptophan. Three experimental diets were tested using 6 replicate gilt and 7 replicate barrow pens per treatment. These diets were tested over 2 different phases, a grower phase (d 0 to 28) and a finishing phase (d 28 to 88). Dietary treatments included a diet that met the NRC (1998)[5] requirements, a diet that met Evonik Degussa (Hanau, Germany) requirements, and a diet that was formulated to be 10% greater than Evonik Degussa recommendations. No gender × dietary treatment interactions were observed ($P > 0.30$) for any of the growth or carcass characteristics. During the growing phase, ADG and F/G improved (linear; $P < 0.03$) as amino acid density increased in the diet. Also, gilts had decreased ($P < 0.001$) ADFI and improved ($P < 0.001$) F/G from d 0 to 28 compared with barrows. During the finishing phase, no differences were observed ($P > 0.62$) in ADG, ADFI, or F/G from increasing dietary lysine or balanced protein levels. Gilts had decreased ($P < 0.001$) ADG and ADFI compared with barrows. Over the entire 88-d trial, F/G improved (linear; $P < 0.04$) and a trend was detected for improved (linear; $P < 0.06$) ADG as dietary amino acid density increased. No dietary treatment differences were observed ($P > 0.28$) for carcass yield, backfat depth, loin depth, percentage lean, live value, or calculated income over feed cost. In this experiment, increasing the amino acid density (dietary lysine level) over the NRC (1998) requirement offered improvements in the grower phase but not the finishing phase.

Key words: amino acid, lysine

Introduction

A current emphasis in the pork industry is to maximize lean growth in pigs through genetic selection and proper nutrition. Maximum lean growth can be achieved only when nutrients, specifically amino acids and energy, are supplied in the diet at the

[1] Appreciation is expressed to New Horizon Farms for the use of pigs and facilities and to Richard Brobjorg, Scott Heidebrink, and Marty Heintz for technical assistance.
[2] The authors thank Evonik Degussa for partial funding of this project.
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[4] Food Animal Health and Management Center, College of Veterinary Medicine, Kansas State University.
[5] NRC. 1998. Nutrient Requirements of Swine. 10th ed. Natl. Acad. Press, Washington, DC.

appropriate amount. Amino acid requirements can be influenced by many factors, including dietary protein level, dietary energy density, environmental temperature, sex, and lean growth potential of the pig. Lysine is the first limiting amino acid in most practical swine diets. It is a common practice to first define the adequate lysine level in the diet and then derive the required level of other essential amino acids from lysine on the basis of an ideal protein ratio, thus giving a balanced protein diet. A balanced protein diet contains sufficient levels of each essential amino acid to meet the biological needs of the animal while minimizing the amounts of excess amino acids.

Some recent studies have suggested that the dietary lysine requirements for pigs with high genetic potential for lean gain are higher than the NRC (1998) estimated requirement values. For example, Main et al. (2002[6]) reported that the optimal total lysine:ME ratio for maximizing growth parameters in 130- to 190-lb gilts was 2.80 g/Mcal. In addition, Shelton et al. (2008[7]) observed improvements in ADG and F/G up through 2.55 g SID lysine/Mcal ME in 185- to 245-lb gilts. Therefore, it is important to evaluate the optimal level of balanced amino acids in the diet to maximize the rate and efficiency of pig lean tissue growth and carcass quality of modern high lean growth pigs.

Procedures

Procedures in this experiment were approved by the Kansas State University Institutional Animal Care and Use Committee. The experiment was conducted at a commercial research finishing facility in southwestern Minnesota. The facility was double curtain sided with completely slatted flooring. Pens were 10 × 18 ft and were equipped with a 5-hole conventional dry feeder and a cup waterer.

Pigs (PIC 337 × 1050) were moved to the finisher at approximately 60 lb and placed into single-sex pens with 27 pigs per pen. Pens were randomly allotted to a gender treatment prior to the arrival of the pigs. Pigs were fed standard grower diets that were adequate in all nutrients (NRC, 1998) for approximately 5 wk until the beginning of the trial.

A total of 1,003 barrows and gilts (initially 113.5 lb) were then selected and used in an 88-d study to determine effects of various levels of balanced amino acid density on growth performance and carcass characteristics. Three experimental diets were tested using 6 replicates (pens) of gilts and 7 pens of barrows per treatment. Experimental diets were allotted to gender-specific pens in a completely randomized design, and initial weight was equalized across dietary treatments within gender.

Three experimental diets with different amino acid densities were tested for the growing phase (d 0 to 28; approximately 120 to 170 lb BW) and the finishing phase (d 28 to 88; approximately 170 to 280 lb BW; Table 1). The low diet was formulated to contain the dietary amino acid content according to the NRC (1998) requirements. The moderate diet was formulated to the current recommendations of Evonik Degussa (Hanau, Germany). The high diet was formulated to be 10% greater than the moderate diet. All diets within each phase contained similar NE concentrations. The total and standardized

[6] Main et al., Swine Day 2002, Report of Progress 897, pp. 135-150.
[7] Shelton et al., Swine Day 2008, Report of Progress 1001, pp. 82-92.

ileal digestible (SID) amino acid values of ingredients were based on the AminoDat 3.0 database in diet formulation.

Pig weights (by pen) and feed disappearance were measured throughout the trials. On the basis of these measurements, ADG, ADFI, and F/G were calculated for each pen. At the conclusion of the growth portion of the trial, the majority of the pigs were marketed to a USDA-inspected packing plant, and carcass data were collected. Any pigs weighing less than 200 lb (n = 15 head) were removed and not included in the market data. Pen data for yield, backfat depth, loin depth, and percentage lean were determined by the packing plant. Yield reflects the percentage of HCW in the live weight (obtained at the packing plant). Live value, feed cost per pound of gain, and income over feed cost (IOFC) were also calculated. Live value was determined by taking a base carcass price $61.45, adding lean premiums, subtracting discounts, and converting to a live weight basis. Income over feed cost was determined on a per head basis by taking the full value for each pig and subtracting the feed costs incurred during the trial.

Data were then analyzed as a 2 × 3 factorial design (2 genders and 3 dietary treatments) using the PROC MIXED procedure in SAS (SAS Institute Inc., Cary, NC). Dietary lysine values were used as dose levels to test for linear and quadratic responses to dietary treatments. Pen was used as the experimental unit in all analyses.

Results and Discussion

Analyzed amino acid levels for the major ingredients and diets are shown in Table 2. Ingredient samples reflect the mean of 4 subsamples that were analyzed using near-infrared spectroscopy. Diet samples reflect means of 2 subsamples that were analyzed utilizing wet chemistry amino acid analysis. Formulated diet values are included in parenthesis. The analyzed diet levels coincided with formulated values.

No gender × dietary treatment interactions were observed ($P > 0.30$, Table 3) for any of the growth or carcass characteristics. During the growing phase (d 0 to 28), ADG and F/G improved (linear; $P < 0.03$) as amino acid density increased in the diet. The most advantageous values were seen in the high treatment, indicating that the lysine requirement is greater than current NRC (1998) requirement estimates. Gilts had lower ADFI and better F/G ($P < 0.001$) than barrows.

During the finishing phase (d 28 to 88), no dietary treatment differences were observed ($P > 0.62$) for ADG, ADFI, or F/G, indicating that the low amino acid density diet was adequate to meet the requirement of the finishing pigs in this study. However, the analyzed total lysine content (0.65%) in the finisher diets was about 8% higher than the NRC (1998) recommendation of 0.60%. Gilts had decreased ($P < 0.001$) ADG and ADFI compared with barrows. Despite the lack of response in the finishing phase, F/G improved (linear; $P < 0.04$) and ADG tended to increase (linear; $P < 0.06$) over the entire 88-d trial as amino acid density increased in the diets. In both barrow and gilt treatments, the most beneficial values were seen in the high treatment. Overall, gilts also had decreased ($P < 0.001$) ADG and ADFI and improved ($P < 0.01$) F/G in compared with barrows.

Similar to the finishing phase growth data, no dietary treatment differences were observed ($P > 0.28$) for carcass yield, backfat depth, loin depth, percentage lean, live value, or IOFC. Feed cost per pound of gain increased (linear; $P < 0.004$) as dietary amino acid density increased, which was not surprising because the improvements in feed efficiency were not substantial enough to offset the added diet cost. In addition, gilts had improved ($P < 0.02$) backfat depth, loin depth, and percentage lean figures compared with barrows. These improvements in carcass composition resulted in increases ($P < 0.001$) in the live value and IOFC of the gilts. Also, the improvement in F/G for gilts resulted in improved ($P < 0.01$) feed cost per pound of gain.

Lysine requirement studies have been conducted with this genetic line (PIC 337 × 1050) in these facilities by Main et al. (2002) and Shelton et al. (2008). The ADG and F/G responses to the SID lysine:ME ratio for the grower portion of the current study are compared with responses in the earlier studies in Figures 1 and 2, respectively. Both the Main et al. (2002) and Shelton et al. (2008) studies showed the impact of increasing SID lysine:calorie ratio for gilts. The present study shows lower pig growth performance than the earlier studies; however, the requirement of 2.58 g SID lysine/Mcal ME seen by Shelton et al. (2008) matches the improvements found through the high level (2.62 g SID lysine/Mcal ME) in this study.

The ADG and F/G responses for the finishing portion of this study are compared with results of several earlier trials in Figures 3 and 4, respectively. All weight categories were not similar for all studies. Therefore, a variety of weights groups were graphed in each figure. Figure 3 shows that ADG for pigs fed the lowest lysine level in this trial (NRC requirement) was similar to the ADG in Shelton et al. (2008). However, improvements in gain due to increasing dietary lysine were seen in the earlier study, but no benefits were observed in the present study. As seen from Figure 4, F/G showed a similar pattern; Shelton et al. (2008) showed benefits to feeding lysine levels higher than the NRC (1998) requirement, but the present study showed no benefit. This raises questions as to the difference in response between trials. The present study used different formulation techniques than the earlier trials. Also, diets in this trial had much lower energy levels than diets used by Shelton et al. (2008) and Main et al. (2002), with 3% and 6% added fat, respectively. The difference in fat levels helps explain the overall increase in F/G in the present trial. Feed efficiency results from this portion of the trial are similar to responses seen by Main et al. (2002), in that for 170- to 225-lb and 220- to 265-lb gilts, only a slightly higher response was determined above the NRC (1998) requirement.

This study indicates that in the grower stage, feeding diets with higher lysine levels than previously recommended can improve gains and efficiency. In the finishing stage, however, the NRC (1998) recommendations were adequate to meet the biological needs of the animal for growth and conversion of feed to lean tissue.

Table 1. Diet composition and calculated analysis (as-fed basis)

	Growing phase (d 0 to 28)			Finishing phase (d 28 to 88)		
Ingredient, %	Low[1]	Moderate[2]	High[3]	Low[1]	Moderate[2]	High[3]
Corn	80.04	78.25	72.65	82.23	78.74	73.90
Soybean meal	17.40	18.65	23.30	15.60	18.75	22.76
Biolys[4]	0.12	0.36	0.31	---	0.16	0.11
DL-Methionine	---	0.08	0.09	---	0.03	0.05
L-Threonine	---	0.06	0.05	---	0.03	0.02
L-Tryptophan	---	0.01	0.01	---	---	---
Choice white grease	0.09	0.25	1.31	---	0.15	1.06
Monocalcium P	0.96	0.95	0.92	0.87	0.85	0.83
Limestone	0.95	0.95	0.92	0.87	0.86	0.84
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin and trace mineral premix	0.09	0.09	0.09	0.08	0.08	0.08
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis						
Standardized ileal digestible (SID) amino acids, %						
Lysine	0.66	0.81	0.89	0.55	0.71	0.78
Isoleucine:lysine	76	64	66	85	74	74
Leucine:lysine	183	152	149	213	175	169
Methionine:lysine	32	36	37	38	35	35
Met & Cys:lysine	64	63	63	74	65	65
Threonine:lysine	70	65	65	78	70	70
Tryptophan:lysine	20	19	19	22	19	20
Valine:lysine	88	75	75	100	85	86
CP, %	14.54	15.23	16.93	13.78	15.13	16.6
Total Lys, %	0.76	0.92	1.00	0.66	0.82	0.90
ME, kcal/lb	1,512	1,518	1,539	1,513	1,518	1,532
NE, kcal/lb	1,084	1,084	1,084	1,084	1,084	1,084
SID lysine:ME, g/Mcal	1.98	2.42	2.62	1.65	2.12	2.31
SID lysine:NE, g/Mcal	2.76	3.39	3.72	2.30	2.97	3.26
Total Ca, %	0.60	0.60	0.60	0.55	0.55	0.55
Available P, %	0.25	0.25	0.25	0.23	0.23	0.23
Diet cost, $/ton[5]	269.02	284.25	294.49	264.85	273.96	284.03

[1] Low = NRC (1998) requirement estimates.
[2] Moderate = Evonik Degussa recommendations.
[3] High = 10% greater than Diet 2.
[4] Biolys contains 50.7% L-Lys (Evonik Degussa GmbH, Hanau, Germany).
[5] Prices based on June 2008 (Informa economics).

Table 2. Chemical composition of ingredients and diets

	Ingredients		Grower diets			Finisher diets		
Item, %[1]	Corn	Soybean meal	Low[2]	Moderate[3]	High[4]	Low[2]	Moderate[3]	High[4]
CP	7.0	46.4	13.8 (14.5)	13.9 (15.3)	16.6 (17.0)	12.8 (13.8)	14.1 (15.1)	15.8 (16.6)
Arginine	0.34	3.36	0.85	0.87	1.00	0.79	0.86	1.00
Histidine	0.20	1.26	0.37	0.38	0.42	0.36	0.38	0.43
Isoleucine	0.24	2.08	0.58	0.59	0.65	0.53	0.57	0.66
Leucine	0.84	3.49	1.31	1.34	1.41	1.24	1.28	1.39
Lysine	0.23	2.83	0.75 (0.76)	0.86 (0.92)	1.01 (1.01)	0.65 (0.66)	0.78 (0.82)	0.89 (0.90)
Methionine	0.14	0.64	0.23 (0.24)	0.29 (0.32)	0.34 (0.36)	0.22 (0.23)	0.26 (0.28)	0.31 (0.31)
Met + Cys	0.29	1.33	0.47 (0.50)	0.53 (0.59)	0.61 (0.64)	0.46 (0.47)	0.52 (0.54)	0.57 (0.59)
Phenylalanine	0.35	2.32	0.69	0.71	0.78	0.64	0.68	0.77
Threonine	0.25	1.83	0.54 (0.55)	0.57 (0.62)	0.65 (0.68)	0.50 (0.52)	0.55 (0.59)	0.62 (0.65)
Tryptophan	0.06	0.64	0.16 (0.16)	0.17 (0.18)	0.20 (0.20)	0.15 (0.15)	0.16 (0.17)	0.19 (0.19)
Valine	0.33	2.22	0.67	0.68	0.74	0.62	0.66	0.74
Alanine	---	---	0.77	0.79	0.83	0.73	0.76	0.82
Aspartic acid	---	---	1.35	1.38	1.57	1.23	1.35	1.56
Cysteine	0.15	0.69	0.24	0.25	0.27	0.24	0.25	0.27
Glutamic acid	---	---	2.50	2.55	2.81	2.34	2.48	2.80
Glycine	---	---	0.56	0.58	0.64	0.53	0.57	0.65
Proline	---	---	0.91	0.92	0.97	0.87	0.90	0.97
Serine	---	---	0.67	0.68	0.77	0.63	0.67	0.76

Values in parentheses represent calculated values.

[1] Ingredients means were based on 4 subsamples from various ingredient batches with analysis by near-infrared spectroscopy, and diet samples reflect the means of 2 samples from different diet batches and were analyzed by wet chemistry amino acid analysis.

[2] Low = NRC (1998) requirement estimates.

[3] Moderate = Evonik Degussa recommendations.

[4] High = 10% greater than Diet 2.

Table 3. Effects of feeding various levels of balanced protein density on growth and carcass composition of growing and finishing pigs[1]

	Barrow			Gilt				Probability, *P*				
								Gender ×			Lysine	
Dietary treatment:[2]	Low	Moderate	High	Low	Moderate	High	SEM	Lysine	Gender	Lysine	Linear	Quadratic
Initial wt, lb	113.9	113.7	113.9	113.2	113.2	113.2	1.17	0.99	0.50	0.99	0.99	0.92
d 0 to 28												
ADG, lb	1.96	1.98	2.16	1.93	2.01	2.03	0.061	0.41	0.32	0.06	0.03	0.34
ADFI, lb	5.30	5.26	5.31	4.95	5.01	4.78	0.117	0.45	0.001	0.67	0.57	0.53
F/G	2.71	2.66	2.46	2.57	2.50	2.36	0.048	0.80	0.001	0.001	0.001	0.03
Intermediate wt, lb	169.9	170.0	174.4	168.7	169.7	169.9	2.12	0.57	0.24	0.35	0.22	0.44
d 28 to 88												
ADG, lb	1.91	1.87	1.91	1.72	1.76	1.76	0.036	0.49	0.001	0.86	0.63	0.78
ADFI, lb	6.35	6.30	6.45	5.74	5.81	5.71	0.113	0.56	0.001	0.95	0.75	0.91
F/G	3.34	3.38	3.38	3.34	3.29	3.26	0.062	0.56	0.18	0.97	0.82	0.88
Final wt, lb	278.9	283.6	285.3	268.5	272.3	272.9	2.53	0.93	0.001	0.09	0.03	0.77
d 0 to 88												
ADG, lb	1.92	1.91	1.99	1.79	1.84	1.85	0.030	0.31	0.001	0.11	0.06	0.37
ADFI, lb	6.00	5.94	6.07	5.47	5.54	5.40	0.103	0.42	0.001	0.99	0.98	0.93
F/G	3.12	3.12	3.05	3.06	3.01	2.93	0.044	0.77	0.01	0.07	0.04	0.27
Carcass measurements												
Yield, %[3]	74.97	74.91	74.74	75.00	75.03	75.06	0.427	0.95	0.65	0.98	0.86	0.91
Backfat depth, in.	0.82	0.84	0.82	0.68	0.67	0.66	0.02	0.77	0.001	0.75	0.61	0.57
Loin depth, in.	2.40	2.41	2.45	2.47	2.56	2.49	0.042	0.43	0.02	0.47	0.29	0.53
Lean, %	53.5	53.3	53.7	55.9	56.3	56.3	0.388	0.67	0.001	0.71	0.43	0.80
Live value, $/cwt[4]	45.69	45.53	46.13	47.27	47.85	47.70	0.459	0.65	0.001	0.62	0.35	0.84
Feed cost/lb gain, $[5]	0.42	0.43	0.44	0.41	0.42	0.42	0.006	0.73	0.01	0.02	0.004	0.82
IOFC, $/head[5,6]	56.99	56.43	54.72	62.76	62.62	61.74	1.93	0.95	0.001	0.66	0.43	0.66

[1] A total of 1,003 barrows and gilts (PIC 337 × 1050) were housed at 27 pigs/pen with 7 barrow and 6 gilt replications per lysine level in an 88-d trial.

[2] Low = NRC (1998) requirement (0.66% SID lysine in the first period and 0.55% in the second); Moderate = Evonik Degussa recommendations (0.81% SID lysine in the first period and 0.71% in the second); and High = 10% above Degussa recommendations (0.88% SID lysine in the first period and 0.78% in the second).

[3] Yield is expressed in terms of the amount of weight in the hot carcass in relation to the live weight obtained at the abattoir.

[4] Value was determined by using a base carcass price of $61.45, adding premiums, and subtracting discounts.

[5] Feed prices are based on June 2008 (Informa economics).

[6] Income over feed costs = value per head - feed costs during trial period.

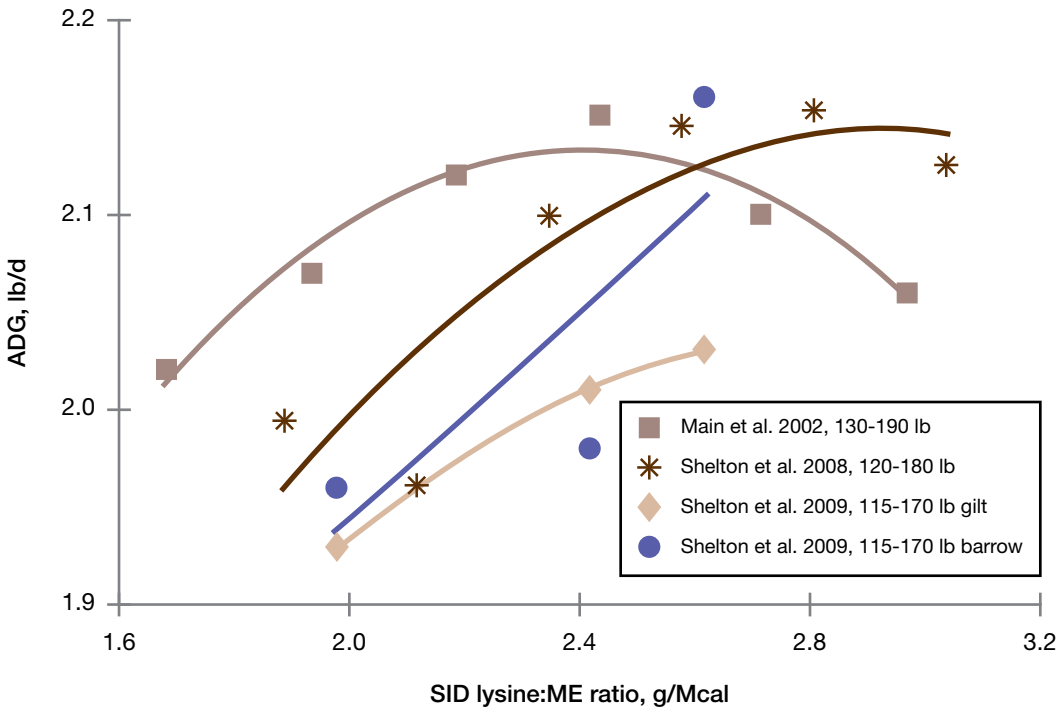

Figure 1. Comparisons of ADG response in relation to SID lysine:calorie ratio from several studies with similar pig weights.

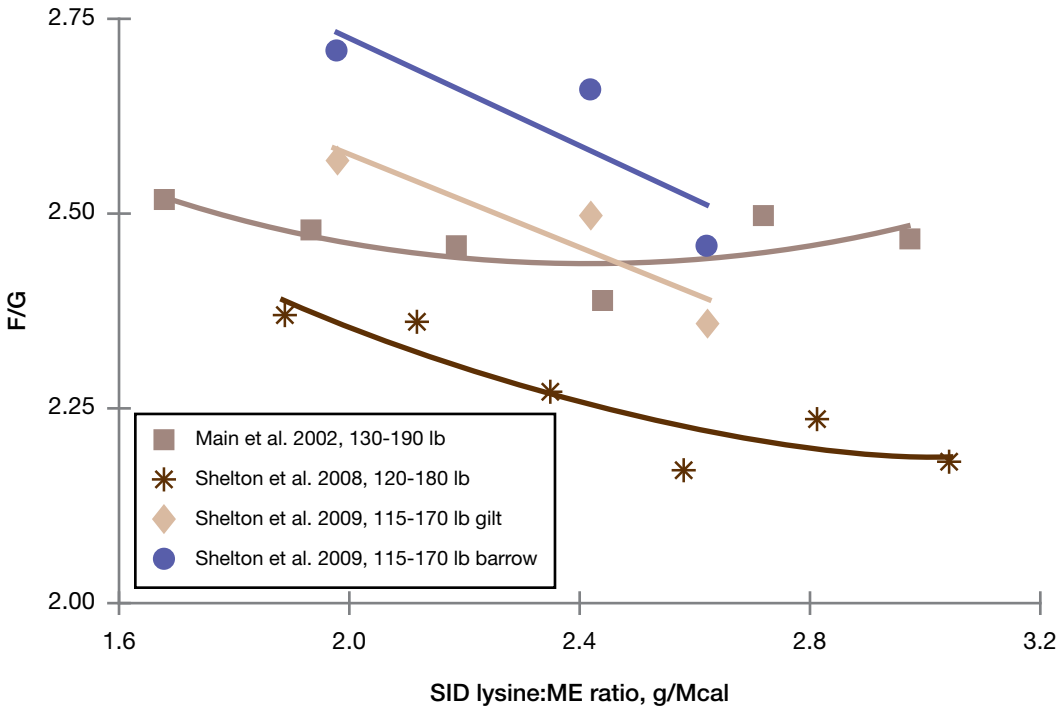

Figure 2. Comparisons of F/G response in relation to dietary SID lysine:calorie ratio from several studies with similar pig weights.

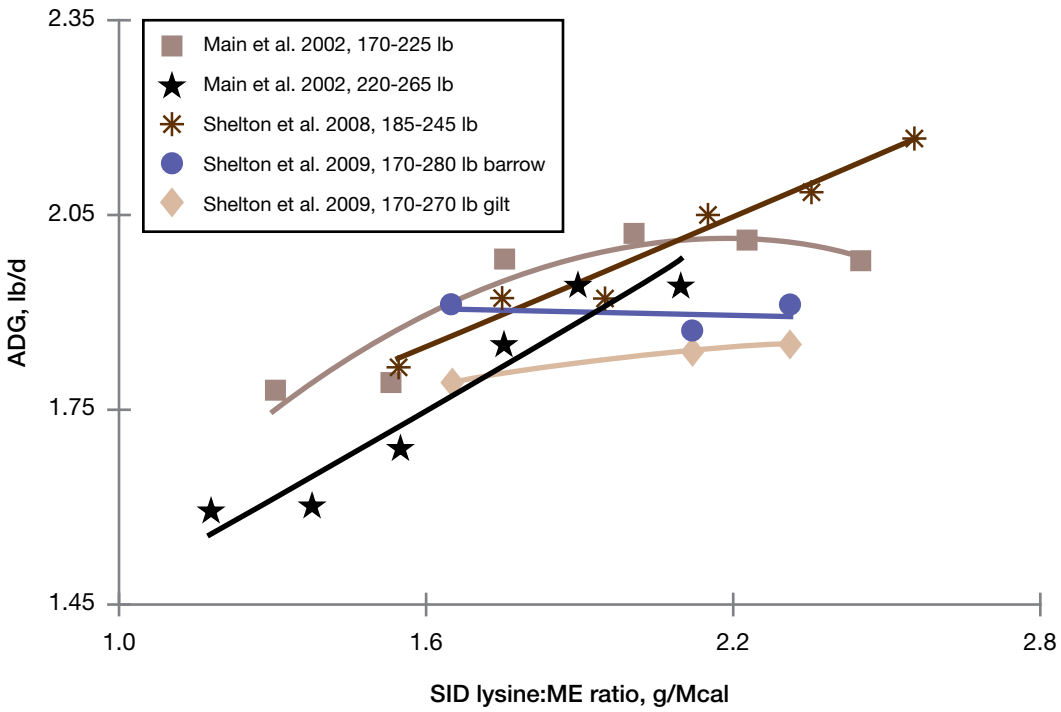

Figure 3. Comparisons of ADG response in relation to dietary SID lysine:calorie ratio from several studies with similar pig weights.

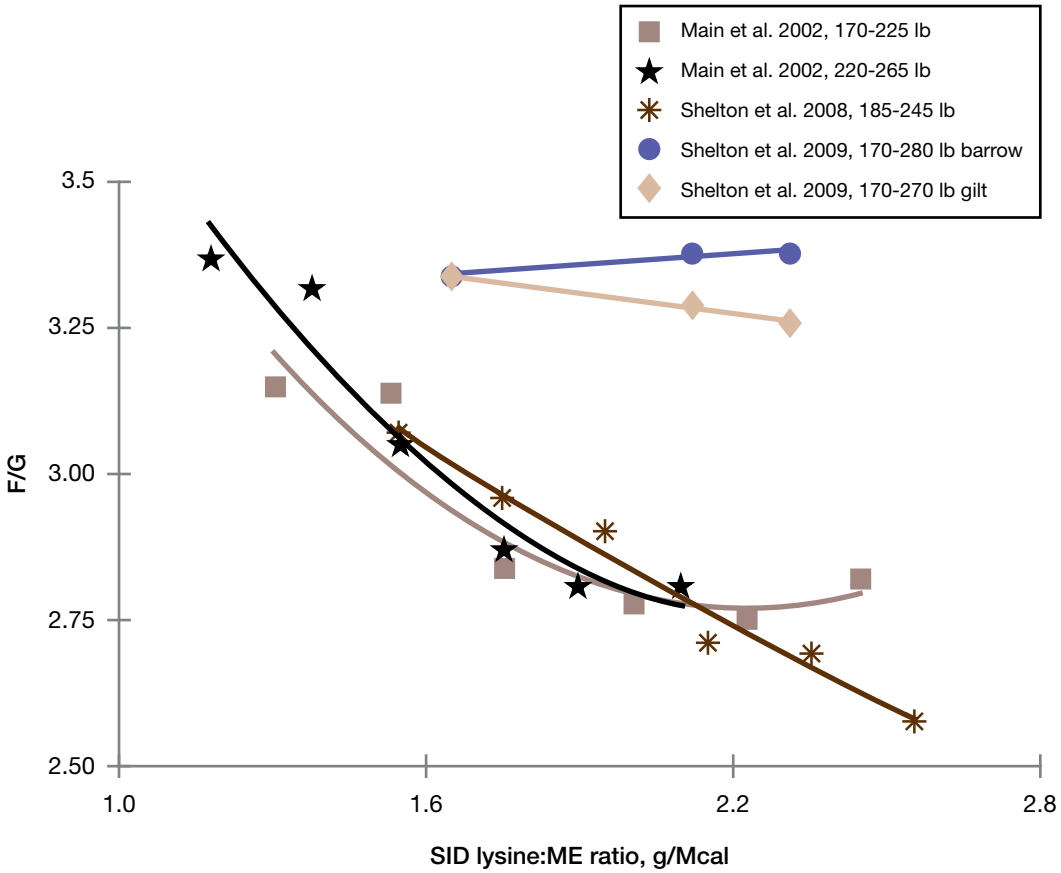

Figure 4. Comparisons of F/G response in relation to dietary SID lysine:calorie ratio from several studies with similar pig weights.

Effects of Increasing Standardized Ileal Digestible Lysine:Calorie Ratio on the Growth Performance of Growing-Finishing Pigs

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Summary

A total of 1,080 pigs (PIC TR4 × 1050) were used in four 28-d experiments to determine the lysine requirements of growing-finishing pigs reared in the new Kansas State University finishing barn. Low- and high-lysine corn-soybean meal-based diets with no added fat were formulated for each experiment by varying the amounts of corn, soybean meal, L-lysine HCl, DL-methionine, and L-threonine. Six lysine levels were evaluated in each experiment, with intermediate lysine levels obtained by blending the low- and high-lysine diets. There were 6 pens containing an equal number of barrows and gilts for each treatment, with 6 or 8 pigs per pen. Pens were blocked by initial count and BW. In Exp. 1, 252 pigs (initially 80.7 lb) were fed diets with standardized ileal digestible lysine:calorie (SID lys:cal) ratios of 2.09, 2.39, 2.69, 2.99, 3.29, or 3.59 g/Mcal ME. Increasing the SID lys:cal ratio improved (linear; $P < 0.04$) ADG and F/G. Optimum performance and income over feed cost (IOFC) was observed at 2.69 g SID lys/Mcal, or a dietary level of 1.01% total lysine and 0.90% SID lysine. In Exp. 2, 288 pigs (initially 122.9 lb) were fed diets with SID lys:cal ratios of 2.12, 2.35, 2.58, 2.81, 3.04, or 3.27 g/Mcal. Increasing the SID lys:cal ratio tended (quadratic; $P < 0.12$) to increase ADG and improved (linear; $P < 0.02$) F/G. Optimum performance and IOFC was observed at 2.35 g SID lys/Mcal, or a dietary level of 0.88% total and 0.78% SID lysine. In Exp. 3, 252 pigs (initially 177.2 lb) were fed diets with SID lys:cal ratios of 1.49, 1.79, 2.09, 2.39, 2.69, or 2.98 g/Mcal. Increasing the SID lys:cal ratio tended (linear; $P < 0.06$) to improve ADG and improved (linear; $P < 0.001$) F/G. Optimum performance and IOFC was observed at 2.09 g SID lys/Mcal, or a dietary level of 0.80% total and 0.70% SID lysine. In Exp. 4, 288 pigs (initially 224.3 lb) were fed the same SID lys:cal ratios as in Exp. 3. Increasing the SID lys:cal ratio decreased (linear; $P < 0.04$) ADFI, F/G, carcass yield, and IOFC. Despite a linear improvement in F/G, ADG did not improve above 1.79 g SID lys/Mcal, which resulted in the best IOFC. This requirement is equivalent to 0.69% total and 0.60% SID lysine. These experiments agree with previous recommendations for growing-finishing pigs of this genotype. For pigs weighing 80 to 143 lb, 123 to 190 lb, 177 to 235 lb, and 224 to 284 lb, growth performance and IOFC were optimal with SID lys:cal ratios of 2.69, 2.35, 2.09, and 1.79 g SID lys/Mcal ME (or 0.90%, 0.78%, 0.70% and 0.60% SID lysine) in corn-soybean meal diets without added fat.

Key words: income over feed cost, lysine

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Introduction

Lysine is the first limiting amino acid in corn-soybean meal-based swine diets. For this reason, more research has focused on identifying the life-cycle lysine requirements of swine than any other amino acid. Understanding the lysine requirements is essential for developing cost-effective nutrition programs. It is also important to have a basic understanding of the lysine requirements for pigs in their environment at a particular farm before attempting further dietary amino acid or energy research. These experiments are among the first to be carried out in the new growing-finishing research barn at the Kansas State University (K-State) Swine Teaching and Research Center.

Currently, amino acid requirements are often expressed on a standardized ileal digestible (SID) basis to account for differences in digestibility across commonly used feedstuffs. This improves our ability to formulate diets that meet pigs' amino acid requirements with a variety of ingredients. The SID lysine requirement is often expressed as a ratio of SID lysine to the ME content of the diet because the ME density of the diet can influence intake, growth rate, and efficiency of gain. Identifying the lysine requirements in these terms has resulted in improvements in growth performance and the ability to manage feed costs and has reduced the environmental impact of swine production.

With the continued progress in swine genetics to improve the efficiency of pork production and other desirable characteristics, periodic reevaluation of lysine requirements is necessary. Also, the development of highly efficacious, commercial vaccines for the prevention of porcine circovirus type 2 (PCV2) has resulted in remarkable improvements in the performance of growing pigs. Recent research at K-State (Shelton et al., 2008[2]) indicates that the lysine requirement for healthy, PCV2-vaccinated pigs may be higher than previous requirement estimates.

Therefore, the objective of these experiments was to determine the lysine requirements of high-health, PRRS-negative, PCV2-vaccinated, growing-finishing pigs in the new K-State growing-finishing research barn.

Procedures

Procedures used in these experiments were approved by the K-State Institutional Animal Care and Use Committee. These experiments were conducted in the new growing-finishing research barn at the K-State Swine Teaching and Research Center. The facility was a totally enclosed, environmentally controlled, mechanically ventilated barn. This facility had 2 identical rooms containing forty 8 × 10 ft pens with adjustable gates facing the alleyway. The adjustable gates allowed individual pen adjustments for pig space. Each pen was equipped with a Farmweld (Teutopolis, IL) dry, single-sided self-feeder with 2 eating spaces located in the fence line and a cup waterer. Pens were located over a completely slatted concrete floor with a 4-ft pit underneath for manure storage. The facility was also equipped with 12 feed storage bins and a computerized feeding system (FeedPro; Feedlogic Corp., Willmar, MN) that delivered, recorded, and blended diets as specified. The equipment provided pigs with ad libitum access to their dietary treatment and water.

[2] Shelton et al., Swine Day 2008, Report of Progress 1001, pp. 82-97.

A total of 252 (initially 80.7 lb), 288 (initially 122.9 lb), 252 (initially 177.2 lb), and 288 (initially 224.3 lb) pigs (PIC TR4 × 1050) were used in Exp. 1, 2, 3, and 4, respectively. All pigs had been vaccinated previously with 2 doses of a commercial PCV2 vaccine according to label recommendations and as prescribed by the farm veterinarian. There were 36 pens containing either 6 or 8 pigs per pen in each experiment, depending on the block and the number of available barrows and gilts within each group. Pens containing 8 pigs were provided 8 × 10 ft of space, and pens containing 6 pigs were provided 8 × 8 ft of space. In all of the pens, half of the pigs were gilts (3 or 4), and the other half were barrows (3 or 4).

In each experiment, pens were allotted by initial count and weight to 1 of the 6 dietary treatments in a randomized complete block design with 6 pens per treatment. Pen weights and feed disappearance were measured throughout each of the four 28-d experiments. Average daily gain, ADFI, F/G, average weight, daily SID lysine intake, SID lysine intake per pound of gain, value of live gain per pig (using $44.53/cwt live), feed cost per pound of gain, feed cost per pig, and income over feed cost (IOFC) were determined in each experiment. In Exp. 4, all pigs were harvested at the conclusion of the feeding period, and carcass data were collected to evaluate carcass characteristics. Economic comparisons within each experiment were based on the same prices applied across all experiments. However, the values of live gain per pig estimates in Exp. 4 were adjusted using the carcass base price ($57.83/cwt) and collected yield data.

Diets used in these experiments were corn-soybean meal based (Table 1). Low- and high-lysine diets with no added fat were formulated for each experiment by varying amounts of corn, soybean meal, L-lysine HCl, DL-methionine, and L-threonine. Within each experiment, the low- and high-lysine diets were blended to achieve the desired intermediate lysine concentrations and maintain acceptable amino acid patterns on an SID basis. The 6 treatments within each experiment were achieved using 100:0, 80:20, 60:40, 40:60, 20:80, and 0:100 blends of the 2 diets. The diets were formulated to meet all other nutritional requirements recommended by NRC (1998[3]). In Exp. 1, the calculated SID lysine:calorie ratios used were 2.09, 2.39, 2.69, 2.99, 3.29, and 3.59 g/Mcal ME. Corresponding total and SID lysine concentrations were 0.79%, 0.90%, 1.01%, 1.11%, 1.22%, and 1.33% and 0.70%, 0.80%, 0.90%, 1.00%, 1.10%, and 1.20%, respectively. In Exp. 2, the calculated SID lysine:calorie ratios used were 2.12, 2.35, 2.58, 2.81, 3.04, and 3.27 g/Mcal ME. Corresponding total and SID lysine concentrations were 0.80%, 0.88%, 0.96%, 1.05%, 1.13%, and 1.22% and 0.71%, 0.78%, 0.86%, 0.93%, 1.01%, and 1.09%, respectively. For both Exp. 3 and 4, the calculated SID lysine:calorie ratios used were 1.49, 1.79, 2.09, 2.39, 2.69, and 2.98 g/Mcal ME. Corresponding total and SID lysine concentrations were 0.58%, 0.69%, 0.80%, 0.90%, 1.01%, and 1.12% and 0.50%, 0.60%, 0.70%, 0.80%, 0.90%, and 1.00%, respectively. During the experiments, diet samples were collected from the feeders to verify that the desired total amino acid values were achieved. Also in each of the experiments, 8 lb/ton of FeO was included as a red marker in either the low- or high-lysine diet. This provided a visual aid to validate delivery of the appropriate blend to the assigned feeders.

At the conclusion of each experiment, data were analyzed for linear and quadratic effects of increasing SID lysine:calorie ratios using the PROC MIXED procedure of

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

SAS (SAS Institute Inc., Cary, NC). Pen was the experimental unit used in all data analyses.

Results

For each experiment, analyzed concentrations of amino acids for the feed samples collected were similar to the calculated total values (within the acceptable limits for analytical variation).

In Exp. 1 (80 to 143 lb BW), ADG and F/G improved (linear; $P < 0.04$, Table 2) with increasing SID lysine:calorie ratio, with the greatest improvements through 2.69 g SID lysine/Mcal ME. As expected, daily SID lysine intake was increased (linear; $P < 0.001$) with increasing dietary lysine. Lysine intake per pound of gain also increased (linear; $P < 0.001$) with increasing dietary lysine. Approximately 9.5 g SID lysine per pound of gain was required for optimal performance. The value of live gain per pig increased (linear; $P < 0.04$) with increasing SID lysine:calorie ratio and was maximized at 2.69 g SID lysine/Mcal ME. Feed cost per pound of gain and feed cost per pig were increased (linear; $P < 0.001$) with increasing SID lysine:calorie ratios. Therefore, IOFC was reduced (linear; $P < 0.001$) with increasing SID lysine:calorie ratios, with the greatest IOFC observed for pigs fed 2.69 g SID lysine/Mcal ME. These data illustrate that both the biologic and economic responses were optimized at an SID lysine:calorie ratio of 2.69 g SID lysine/Mcal ME. Using a typical corn and soybean meal diet without added fat, this is equivalent to a total lysine content of 1.01%, or an SID content of 0.90%.

In Exp. 2 (123 to 190 lb BW), although not significant, ADG numerically increased (quadratic; $P < 0.12$, Table 3) with increasing SID lysine:calorie ratio from 2.12 to 2.35, where it appeared to plateau, and became numerically lowest at the highest lysine level (3.27 g SID lysine/Mcal ME). Average daily feed intake decreased (linear; $P < 0.001$) when the ratio exceeded 2.35 g SID lysine/Mcal ME. Feed efficiency was improved (linear; $P < 0.02$) with increasing SID lysine:calorie ratio. Despite the linear response, the greatest incremental improvement in F/G occurred when the SID lysine:calorie ratio was increased from 2.12 to 2.35. Together these responses indicate that the requirement was around 2.35 g SID lysine/Mcal ME. Daily SID lysine intake and SID lysine intake per pound of gain increased (linear; $P < 0.001$) with increasing SID lysine. Optimal performance was observed at approximately 9.8 g SID lysine per pound of gain. Although not significant, the value of live gain per pig increased (quadratic; $P < 0.12$) with increasing SID lysine:calorie ratio and was numerically the greatest at 2.35 g SID lysine/Mcal ME. Feed cost per pound of gain and feed cost per pig increased (linear; $P < 0.001$) with increasing SID lysine:calorie ratio. These responses resulted in a reduction (linear; $P < 0.001$) in IOFC with increasing SID lysine:calorie ratio, with the greatest IOFC observed for pigs fed 2.35 g SID lysine/Mcal ME. Biologic and economic responses were optimized at a SID lysine:calorie ratio of 2.35 g SID lysine/Mcal ME. This is equivalent to a total lysine content of 0.88% in a corn and soybean meal diet without added fat, or 0.78% on an SID basis.

In Exp. 3 (177 to 235 lb BW), ADG tended (linear; $P < 0.06$, Table 4) to increase with increasing SID lysine:calorie ratio and achieved the maximum at 2.09 g SID lysine/Mcal ME. Feed efficiency was improved (linear; $P < 0.001$) with increasing SID

lysine:calorie ratio; however, the greatest incremental improvement in F/G occurred when the SID lysine:calorie ratio was increased from 1.79 to 2.09. These responses suggest a requirement of 2.09 g SID lysine/Mcal ME. As in the previous experiments, daily SID lysine intake and SID lysine intake per pound of gain increased (linear; $P < 0.001$) with increasing SID lysine. Optimal performance was observed at approximately 9.8 g SID lysine per pound of gain. The value of live gain per pig also tended (linear; $P < 0.06$) to increase with increasing SID lysine:calorie ratio and was greatest at 2.09 g SID lysine/Mcal ME. Feed cost per pound of gain and feed cost per pig increased (linear; $P < 0.001$) with increasing SID lysine:calorie ratio. These responses resulted in a reduction (linear; $P < 0.03$) in IOFC with increasing SID lysine:calorie ratio, with the greatest IOFC observed for pigs fed 2.09 g SID lysine/Mcal ME. These data illustrate that both the biologic and economic responses were optimized at a SID lysine:calorie ratio of 2.09 g SID lysine/Mcal ME. In a corn and soybean meal diet without added fat, this is equivalent to a total lysine content of approximately 0.80%, or an SID content of 0.70%.

In Exp. 4 (224 to 284 lb BW), although not significant, ADG numerically increased (linear; $P < 0.13$, Table 5) with increasing SID lysine:calorie ratio from 1.49 to 1.79, where it appeared to plateau. Average daily feed intake decreased (linear; $P < 0.04$) when the ratio exceeded 1.79 g SID lysine/Mcal ME. Feed efficiency was improved (linear; $P < 0.001$) with increasing SID lysine:calorie ratio, and the best F/G was observed at 2.69 g SID lysine/Mcal ME. However, the greatest incremental improvement in F/G occurred when the SID lysine:calorie ratio was increased from 1.49 to 1.79. There were no differences observed in HCW or the various measurements of carcass lean and fat content. However, carcass yield decreased (linear; $P < 0.02$) with increasing SID lysine:calorie ratio, and the greatest incremental decrease occurred when the SID lysine:calorie ratio was increased from 1.79 to 2.09. Together these responses indicate that the requirement is around 1.79 g SID lysine/Mcal ME. As expected, the daily SID lysine intake and SID lysine intake per pound of gain increased (linear; $P < 0.001$) with increasing SID lysine. Optimal performance was observed at approximately 9.3 g SID lysine per pound of gain. Although not significant, the value of live gain per pig increased (quadratic; $P < 0.10$) with increasing SID lysine:calorie ratio and was numerically the greatest at 1.79 g SID lysine/Mcal ME. Feed cost per pound of gain and feed cost per pig increased (linear; $P < 0.001$) with increasing SID lysine:calorie ratio. These responses resulted in a reduction (linear; $P < 0.001$) in IOFC with increasing SID lysine:calorie ratio, with the greatest IOFC observed for pigs fed 1.79 g SID lysine/Mcal ME. These data illustrate that both the biologic and economic responses were optimized at a SID lysine:calorie ratio of 1.79 g SID lysine/Mcal ME. This is equivalent to a total lysine content of 0.69% in a corn and soybean meal diet without added fat, or 0.60% on an SID basis.

Discussion

When the lysine requirements for growing-finishing pigs are expressed using SID lysine:calorie ratios, the results obtained in these experiments are very similar to the latest recommendations for pigs of this genotype reported by the genetic supplier (Figure 1, PIC nutrient specifications, May 2008). These ratios also agree with current K-State recommendations developed from previous research on growing-finishing pigs

of this genotype (Main et al., 2002[4]). The utility of expressing the lysine requirement using these ratios is further supported by the differences in dietary energy densities used by different researchers. Main et al. (2002) used diets containing 6% choice white grease, whereas diets used in the current experiments did not contain added fat.

Research reported last year by Shelton et al. (2008) suggested that the required SID lysine:calorie ratios are higher than previously reported. They observed that ratios of at least 3.16, 2.58, and 2.55 g SID lysine/Mcal ME were necessary to achieve optimal performance and economic return for 85- to 140-lb, 120- to 180-lb, and 185- to 245-lb gilts, respectively. These ratios are considerably higher than the recent PIC and K-State (Main et al., 2002) recommendations previously described, and it has been suggested that improvements in growth (primarily the rate of protein deposition) from genetic progress and/or PCV2 vaccination have increased the requirement. However, pigs in the current experiments were also vaccinated for PCV2 and had much greater ADG and ADFI than pigs in all the previously mentioned experiments. Yet the estimated requirements from the current experiments are similar to the PIC recommendations and findings of Main et al. (2002) when reported as SID lysine:calorie ratios.

Another potential explanation for some of the differences in estimated SID lysine:calorie requirements is the potential differences between the calculated and realized energy values obtained in the various experiments. Reductions in grain particle size improve the digestibility of energy and other nutrients. The studies conducted by Shelton et al. (2008) were conducted in the same facilities and used the same genotype as Main et al.'s (2002) studies. The feed for their experiments also originated from the same mill. However, the targeted particle size at this mill was 700 to 750 microns in 2002 (similar to the targeted corn particle size of 700 microns in the current experiments) but was reduced to 400 to 450 microns in 2008 to help cope with rising feed costs and tightening margins. A 300-micron reduction in the corn particle size could result in a significant change in the "realized" ME concentration. Shelton et al. (2008) did not report any adjustment in the energy value for the corn in their diets, but it is possible that the ME value for corn was underestimated. An adjusted energy value to account for differences in grain particle size might have resulted in slightly lower estimates of SID lysine:calorie ratios.

Although there appear to be differences between recent lysine requirement estimates when expressed as SID lysine:calorie ratios, the apparent differences in the SID lysine requirements are less if the growth responses observed are used to express the requirements in terms of grams of SID lysine intake per pound of gain (Figure 2). When the estimated requirements from Main et al. (2002), Shelton et al. (2008), and the current experiments are expressed as grams of SID lysine intake per pound of gain, the requirements appear to be roughly 9 to 10 g of SID lysine per pound of gain throughout the growing-finishing period. A comparison of the responses on this basis may be useful in accounting for some of the differences in ADFI, potential genetic improvements in relative F/G, and/or differences in dietary energy density across studies.

In summary, these data demonstrate that growing-finishing pigs require approximately 9.5 g of SID lysine per pound of gain from 80 to 284 lb BW. Although these data agree

[4] Main et al., Swine Day 2002, Report of Progress 897, pp. 135-150.

with currently recommended SID lysine:calorie ratios, the research reported by Shelton et al. (2008) indicates that the SID lysine requirements may be higher when expressed in these terms. However, requirement estimates for SID lysine greater than those reported here need further validation. As demonstrated in these studies, over-fortifying diets with amino acids can be costly. Growth performance and IOFC may be optimized with SID lysine:calorie ratios of 2.69, 2.35, 2.09, and 1.79 g SID lysine/Mcal ME for pigs weighing 80 to 143 lb, 123 to 190 lb, 177 to 235 lb, and 224 to 284 lb, respectively. Corresponding recommendations for typical corn and soybean meal diets without added fat are 1.01%, 0.88%, 0.80%, and 0.70% total lysine, or 0.90%, 0.78%, 0.70%, and 0.60% SID lysine, respectively.

Table 1. Diet composition[1]

	Exp. 1		Exp. 2		Exp. 3 and 4	
Ingredient, % Lysine level:	Low	High	Low	High	Low	High
Corn	82.06	66.82	82.37	66.76	87.31	70.81
Soybean meal (46.5% CP)	15.18	30.48	15.64	30.86	10.40	27.17
Monocalcium P (21% P)	0.60	0.55	0.30	0.20	0.35	0.30
Limestone	0.85	0.85	0.80	0.83	0.85	0.85
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.13	0.13	0.13	0.13	0.10	0.10
Trace mineral premix	0.13	0.13	0.13	0.13	0.10	0.10
L-lysine HCl	0.15	0.30	0.15	0.15	0.05	0.15
DL-methionine	---	0.13	---	0.03	---	0.04
L-threonine	0.02	0.13	---	0.03	---	0.04
Phytase 600	0.13	0.13	0.13	0.13	0.09	0.09
FeO[2]	0.40	---	---	0.40	0.40	---
Total	100.00	100.00	100.00	100.00	100.00	100.00
Cost, $/lb[3]	0.099	0.120	0.099	0.117	0.092	0.113
Calculated analysis						
Standardized ileal digestible (SID) amino acids						
Lysine, %	0.70	1.20	0.71	1.09	0.50	1.00
Isoleucine:lysine, %	71	62	71	69	83	69
Leucine:lysine, %	178	134	177	148	228	153
Methionine:lysine, %	31	34	31	29	40	31
Met & Cys:lysine, %	64	60	64	57	82	60
Threonine:lysine, %	65	65	63	62	75	65
Tryptophan:lysine, %	19	18	19	20	21	19
Valine:lysine, %	83	70	83	77	101	78
CP, %	14.2	20.3	14.4	20.2	12.3	18.9
Total lysine, %	0.79	1.33	0.80	1.22	0.58	1.12
ME, kcal/lb	1,510	1,516	1,521	1,519	1,521	1,520
SID lysine:ME, g/Mcal	2.09	3.59	2.12	3.27	1.49	2.98
Ca, %	0.51	0.55	0.44	0.48	0.45	0.49
P, %	0.46	0.51	0.40	0.44	0.39	0.45
Available P, %[4]	0.30	0.30	0.23	0.23	0.23	0.23

[1] The low- and high-lysine diets in each experiment were blended in proportions of 100:0, 80:20, 60:40, 40:60, 20:80, and 0:100 using the Feedlogic system, which provided 6 equally spaced concentrations of lysine for treatments.
[2] Iron oxide was included in one of the diets in each experiment to provide a red marker for diet identification and for visual verification of the blended, intermediate treatments in each experiment.
[3] Diet costs were based on corn at $4.00/bu and 46.5% soybean meal at $380/ton.
[4] Included approximately 0.10% to 0.12% P release from added phytase.

Table 2. Effects of standardized ileal digestible (SID) lysine:calorie ratio on 80- to 143-lb pigs (Exp. 1)[1]

SID lysine, %:	0.70	0.80	0.90	1.00	1.10	1.20		Probability, *P* <	
Item SID lysine, g/Mcal ME:	2.09	2.39	2.69	2.99	3.29	3.59	SEM	Linear	Quadratic
Initial wt, lb	80.5	80.6	80.7	80.8	80.9	80.5	2.4	---[2]	---
ADG, lb	2.16	2.19	2.28	2.25	2.26	2.26	0.03	0.04	---
ADFI, lb	5.35	5.32	5.30	5.34	5.25	5.18	0.11	---	---
F/G	2.47	2.43	2.32	2.38	2.32	2.29	0.04	0.001	---
Ending wt, lb	141.1	141.9	144.6	143.6	144.3	143.8	2.9	---	---
Daily SID lysine intake, g	16.98	19.29	21.62	24.22	26.19	28.19	0.46	0.001	---
SID lysine intake/lb gain, g	7.85	8.81	9.47	10.80	11.57	12.48	0.17	0.001	---
Value of gain/pig (live), $[3]	26.98	27.30	28.45	27.99	28.23	28.17	0.43	0.04	---
Feed cost/lb gain, $[4]	0.24	0.25	0.25	0.27	0.27	0.28	0.01	0.001	---
Feed cost/pig, $	14.77	15.33	15.91	16.69	17.05	17.45	0.33	0.001	---
IOFC, $/pig[5]	12.21	11.97	12.53	11.30	11.18	10.72	0.34	0.001	---

[1] A total of 252 pigs (PIC TR4 × 1050) were housed with 3 replications of 6 pigs per pen and 3 replications of 8 pigs per pen in a 28-d experiment.
[2] Probability, $P > 0.13$.
[3] Based on a live price of $44.53/cwt.
[4] Diet costs were based on corn at $4.00/bu and 46.5% soybean meal at $380/ton.
[5] Income over feed cost = value of gain/pig - feed cost/pig.

Table 3. Effects of standardized ileal digestible (SID) lysine:calorie ratio on 123- to 190-lb pigs (Exp. 2)[1]

SID lysine, %:	0.71	0.78	0.86	0.93	1.01	1.09		Probability, *P* <	
Item SID lysine, g/Mcal ME:	2.12	2.35	2.58	2.81	3.04	3.27	SEM	Linear	Quadratic
Initial wt, lb	122.6	122.7	123.0	123.2	123.2	122.9	2.0	---[2]	---
ADG, lb	2.36	2.43	2.43	2.40	2.41	2.35	0.04	---	0.12
ADFI, lb	6.71	6.72	6.65	6.61	6.47	6.39	0.08	0.001	---
F/G	2.85	2.76	2.74	2.76	2.69	2.72	0.04	0.02	---
Ending wt, lb	188.7	190.8	190.9	190.3	190.7	188.7	2.6	---	---
Daily SID lysine intake, g	21.61	23.77	25.96	27.90	29.65	31.60	0.27	0.001	---
SID lysine intake/lb gain, g	9.19	9.78	10.71	11.64	12.31	13.47	0.16	0.001	---
Value of gain/pig (live), $[3]	29.40	30.32	30.25	29.91	30.03	29.28	0.45	---	0.12
Feed cost/lb gain, $[4]	0.28	0.28	0.29	0.30	0.31	0.32	0.01	0.001	---
Feed cost/pig, $	18.56	19.28	19.78	20.34	20.57	20.98	0.21	0.001	---
IOFC, $/pig[5]	10.84	11.04	10.47	9.57	9.46	8.30	0.41	0.001	---

[1] A total of 288 pigs (PIC TR4 × 1050) were housed with 6 replications of 8 pigs per pen in a 28-d experiment.
[2] Probability, $P > 0.13$.
[3] Based on a live price of $44.53/cwt.
[4] Diet costs were based on corn at $4.00/bu and 46.5% soybean meal at $380/ton.
[5] Income over feed cost = value of gain/pig - feed cost/pig.

Table 4. Effects of standardized ileal digestible (SID) lysine:calorie ratio on 177- to 235-lb pigs (Exp. 3)[1]

SID lysine, %:	0.50	0.60	0.70	0.80	0.90	1.00		Probability, *P* <	
Item SID lysine, g/Mcal ME:	1.49	1.79	2.09	2.39	2.69	2.98	SEM	Linear	Quadratic
Initial wt, lb	177.0	176.9	176.9	177.1	178.0	177.0	2.7	---[2]	---
ADG, lb	1.96	1.98	2.14	2.07	2.02	2.14	0.06	0.06	---
ADFI, lb	6.58	6.49	6.64	6.68	6.24	6.45	0.16	---	---
F/G	3.36	3.29	3.10	3.23	3.10	3.02	0.05	0.001	---
Ending wt, lb	232.0	232.4	236.9	235.1	235.2	236.8	3.4	---	---
Daily SID lysine intake, g	14.92	17.68	21.08	24.23	25.51	29.25	0.57	0.001	---
SID lysine intake/lb gain, g	7.62	8.94	9.84	11.71	12.66	13.69	0.17	0.001	---
Value of gain/pig (live), $[3]	24.46	24.70	26.72	25.82	25.23	26.63	0.78	0.06	---
Feed cost/lb gain, $[4]	0.33	0.34	0.33	0.35	0.35	0.35	0.01	0.001	---
Feed cost/pig, $	18.20	18.63	19.73	20.53	19.88	21.17	0.49	0.001	---
IOFC, $/pig[5]	6.26	6.07	6.99	5.28	5.30	5.47	0.45	0.03	---

[1] A total of 252 pigs (PIC TR4 × 1050) were housed with 3 replications of 6 pigs per pen and 3 replications of 8 pigs per pen in a 28-d experiment.
[2] Probability, $P > 0.13$.
[3] Based on a live price of $44.53/cwt.
[4] Diet costs were based on corn at $4.00/bu and 46.5% soybean meal at $380/ton.
[5] Income over feed cost = value of gain/pig - feed cost/pig.

Table 5. Effects of standardized ileal digestible (SID) lysine:calorie ratio on 224- to 284-lb pigs (Exp. 4)[1]

SID lysine, %:	0.50	0.60	0.70	0.80	0.90	1.00		Probability, *P* <	
Item SID lysine, g/Mcal ME:	1.49	1.79	2.09	2.39	2.69	2.98	SE	Linear	Quadratic
Initial wt, lb	224.3	224.3	224.2	224.2	224.4	224.4	2.7	---[2]	---
ADG, lb	2.11	2.22	2.22	2.24	2.24	2.22	0.05	0.13	---
ADFI, lb	7.44	7.58	7.47	7.41	7.29	7.26	0.13	0.04	---
F/G	3.53	3.41	3.36	3.30	3.21	3.28	0.05	0.001	---
Ending wt, lb	281.4	284.3	284.2	284.8	284.8	284.3	3.4	---	---
Daily SID lysine intake, g	16.88	20.62	23.72	26.88	29.41	32.94	0.50	0.001	---
SID lysine intake/lb gain, g	8.00	9.28	10.67	11.99	13.12	14.86	0.17	0.001	---
HCW, lb	208.7	210.4	208.7	209.7	208.5	208.9	2.3	---	---
Yield, %	74.2	74.0	73.4	73.6	73.2	73.5	0.2	0.02	---
Backfat depth, in.	0.96	0.90	0.87	0.93	0.91	0.92	0.03	---	---
Loin depth, in.	2.43	2.54	2.43	2.49	2.45	2.44	0.04	---	---
NPPC fat-free lean, %	48.4	49.5	49.8	49.0	49.2	49.1	0.5	---	---
Carcass base price, $/cwt				57.83					
Total revenue/carcass, $	118.28	121.03	119.99	120.07	119.92	119.77	1.68	---	---
Value of gain/pig (live), $[3]	23.97	25.55	25.35	25.52	25.49	25.23	0.53	---	0.10
Feed cost/lb gain, $[4]	0.32	0.33	0.34	0.35	0.35	0.37	0.01	0.001	---
Feed cost/pig, $	18.46	19.67	20.25	20.93	21.18	22.19	0.38	0.001	---
IOFC, $/pig[5]	5.51	5.88	5.11	4.59	4.31	3.05	0.46	0.001	---

[1] A total of 288 pigs (PIC TR4 × 1050) were housed with 6 replications of 8 pigs per pen in a 28-d experiment.
[2] Probability, $P > 0.13$.
[3] Determined from the carcass base price × the yield × total live gain during the experiment.
[4] Diet costs were based on corn at $4.00/bu and 46.5% soybean meal at $380/ton.
[5] Income over feed cost = value of live gain/pig - feed cost/pig.

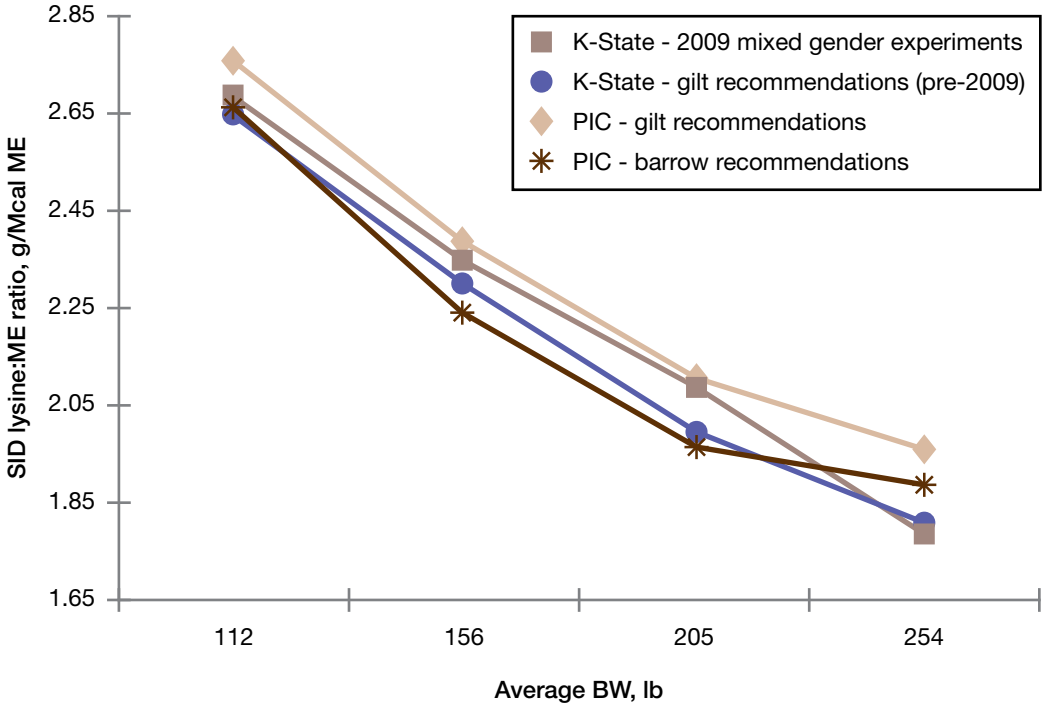

Figure 1. Recommended SID lysine:calorie ratios for growing-finishing pigs.

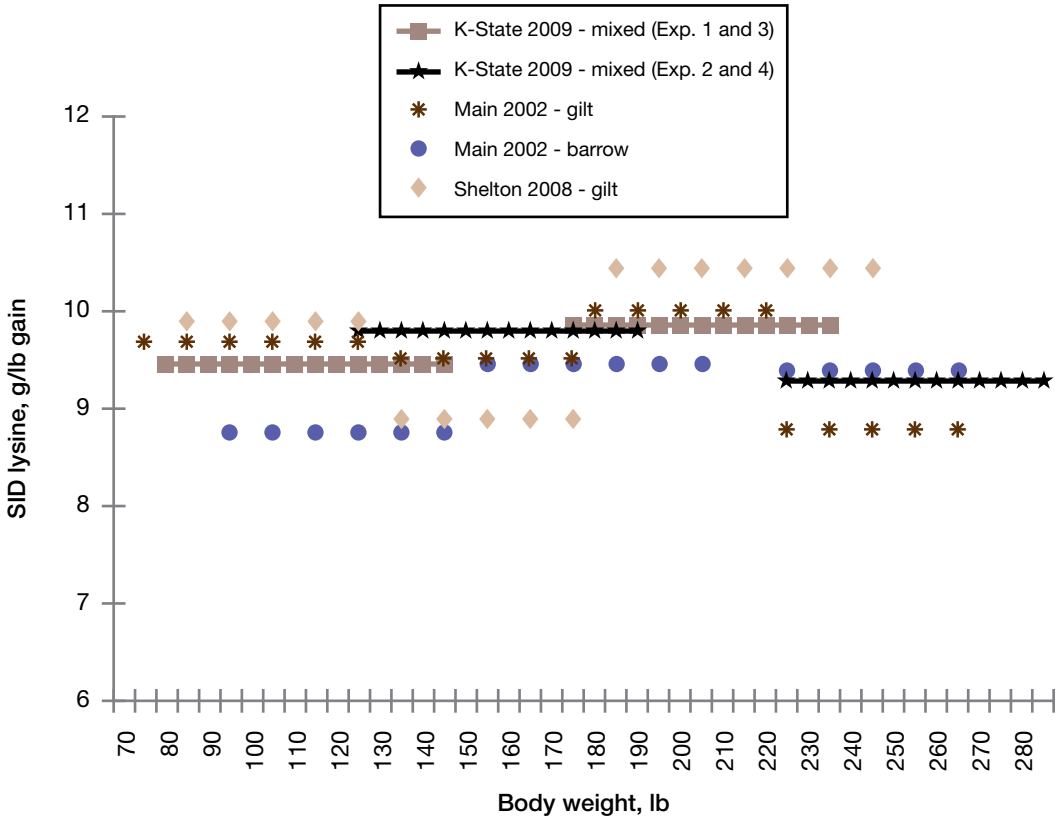

Figure 2. Observed intakes of SID lysine per pound of gain at the recommended levels of SID lysine across experiments.
Length of line indicates body weight range of pigs in each experiment.

Effects of Porcine Circovirus Type 2 Vaccine and Increasing Standardized Ileal Digestible Lysine:Calorie Ratio on Growth Performance and Carcass Composition of Growing and Finishing Pigs[1,2]

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Summary

A series of 4 experiments was conducted to determine the effect of porcine circovirus type 2 (PCV2) vaccination on the lysine requirement of growing and finishing pigs. Experiments 1 and 2 evaluated the requirement for 85- to 140-lb gilts and barrows, respectively. Experiments 3 and 4 evaluated the requirement for 225- to 275-lb gilts and 215- to 260-lb barrows, respectively. Data from each trial were analyzed as 2 × 4 factorial designs with 2 PCV2 vaccination treatments (vaccinates and non-vaccinates) and 4 levels of increasing standardized ileal digestible (SID) lysine:ME ratio (2.24, 2.61, 2.99, and 3.36 g/Mcal in Exp. 1 and 2 and 1.49, 1.86, 2.23, and 2.61 g/Mcal in Exp. 3 and 4).

No PCV2 vaccination × SID lysine:ME ratio interactions were observed ($P > 0.14$) in any of the 4 studies. In Exp. 1 and 2, PCV2 vaccinates had increased ($P < 0.04$) ADG, ADFI, final weight, and daily SID lysine intake and tended to have improved ($P < 0.09$) F/G compared with non-vaccinates. In Exp. 1, ADG and F/G improved (quadratic; $P < 0.03$) as the SID lysine:ME ratio increased, with increases through 2.99 g/Mcal. In Exp. 2, increasing the SID lysine:ME ratio improved (linear; $P < 0.001$) F/G and increased (linear; $P < 0.001$) daily SID lysine intake and SID lysine intake per pound of gain. Thus, 3.36 g SID lysine/Mcal ME appears to maximize efficiency for 85- to 140-lb barrows.

In Exp. 3, PCV2 vaccinates had improved ($P < 0.02$) F/G and increased ($P < 0.03$) final weight, SID lysine intake per pound of gain, and backfat thickness compared with non-vaccinates. Both ADG and F/G improved (quadratic; $P < 0.05$) as the SID lysine:ME ratio increased, with ADG improving through 1.86 g/Mcal and F/G improving through 2.23 g/Mcal, indicating the requirement may be between those levels. In Exp. 4, both ADG and ADFI were decreased ($P < 0.04$) in vaccinates compared with non-vaccinates. In this study, ADG, F/G, daily SID lysine intake, and SID lysine intake per pound of gain increased (linear; $P < 0.001$) and F/G improved (linear; $P < 0.001$) through the highest level of 2.61 g lysine/Mcal, with the greatest magnitude of change when lysine was increased from 2.23 to 2.61 g/Mcal. Because of the lack of any interactions between dietary SID lysine level and PCV2 vaccination, it appears that PCV2

[1] Appreciation is expressed to New Horizon Farms for the use of pigs and facilities and to Richard Brobjorg, Scott Heidebrink, and Marty Heintz for technical assistance.
[2] The authors thank Ajinimoto Heartland Inc. for partial funding of this project.
[3] Food Animal Health and Management Center, College of Veterinary Medicine, Kansas State University.
[4] Ajinimoto Heartland Inc., Chicago, IL.

vaccination did not increase the lysine requirement for growing and finishing barrows and gilts. On the basis of these studies, which used corn-soybean meal-based diets with 3% added fat, the requirement was 1.04% SID lysine or 1.17% total lysine for 85- to 135-lb gilts, 1.17% SID lysine or 1.31% total lysine for 85- to 140-lb barrows, 0.78% SID lysine or 0.88% total lysine for 225- to 275-lb gilts, and 0.91% SID lysine or 1.02% total lysine for 215- to 260-lb barrows.

Key words: amino acid requirements, lysine, porcine circovirus type 2 (PCV2) vaccine

Introduction

Evaluating amino acid requirements of the current high-lean pig genotypes is essential for generating cost-effective diets for growing and finishing pigs. Recent research by Shelton et al. (2008a[5], 2008b[6]) has shown an increase in the lysine requirement from requirements estimated 6 yr ago (Main et al., 2002[7]) in the same facilities with the same genetic lines. Also, recent research (Jacela et al., 2007a[8], 2007b[9]; Potter et al., 2008[10]) has shown an increase in growth rates and final weights of growing and finishing pigs administered porcine circovirus type 2 (PCV2) vaccine. Combined with the advancement within genetic lines, the increase in growth rate as a function of PCV2 vaccine may be one of the main factors driving the increase in the lysine requirement. Therefore, the main objective of these experiments was to evaluate the effects of increasing dietary lysine level in PCV2-vaccinated and non-vaccinated growing and finishing pigs.

Procedures

Procedures in this experiment were approved by the Kansas State University Institutional Animal Care and Use Committee. The experiment was conducted at a commercial research finishing facility in southwestern Minnesota. The facility was double curtain sided with completely slatted flooring. Pens were 10 × 18 ft and were equipped with a 5-hole conventional dry feeder and a cup waterer.

A total of 2,571 barrows and gilts (PIC 337 × 1050) were weaned into a wean-to-finish facility. Pens were double stocked with 56 pigs per pen, and gilts and barrows were penned separately. Two vaccination treatments for PCV2 were then allotted by pen at placement: no vaccine or vaccination with 2 doses of commercial PCV2 vaccine (Circumvent PCV; Intervet Inc., Millsboro, DE) given at placement into the wean-to-finish barn and again 21 d after the initial vaccination. All pigs were also inoculated with serum containing PRRS virus as part of this production system's protocol. When the barn average pig weight reached approximately 55 lb, the barn was split out by moving gilt pens to an adjacent barn to be used in Exp. 1 and 3 and splitting barrows pens in half in the original barn for use in Exp. 2 and 4. Additional details regarding the effect of vaccination on nursery performance are presented in another article in this report of progress (Shelton et al., 2009[11]).

[5] Shelton et al., Swine Day 2008, Report of Progress 1001, pp. 82-92.
[6] Shelton et al., Swine Day 2008, Report of Progress 1001, pp. 93-97.
[7] Main et al., Swine Day 2002, Report of Progress 897, pp. 135-150.
[8] Jacela et al., Swine Day 2007, Report of Progress 985, pp. 5-9.
[9] Jacela et al., Swine Day 2007, Report of Progress 985, pp. 10-16.
[10] Potter et al., Swine Day 2008, Report of Progress 1001, pp. 5-13.
[11] Shelton et al., Swine Day 2009, Report of Progress 1020, pp. 28-32.

A total of 1,008 gilts (initially 84.5 lb) and 1,002 barrows (initially 85.7 lb) were then selected and used in Exp. 1 and 2, respectively, for 28 d. Four experimental diets were used in Exp. 1 and 2 with standardized ileal digestible (SID) lysine:ME ratios of 2.24, 2.61, 2.99, and 3.36 g/Mcal, which correspond to SID levels of 0.78%, 0.91%, 1.04%, and 1.17% or total lysine levels of 0.88%, 1.02%, 1.17%, and 1.31% (Table 1). After the conclusion of Exp. 1 and 2, all pigs were placed on diets that were above the determined lysine requirement. Also, before beginning Exp. 3 and 4, initial marketing occurred in which pigs were removed from each pen, with more pigs removed from vaccinated pens to attempt to minimize the difference in pig density and initial weight between the PCV2 vaccinates and non-vaccinates.

A total of 930 gilts (initially 224.3 lb) and 825 barrows (initially 215.4 lb) were then selected and used in Exp. 3 and 4 for 28 and 21 d, respectively. Four experimental diets were again used with SID lysine:ME ratios of 1.49, 1.86, 2.23, and 2.61 g/Mcal, which correspond to dietary SID lysine levels of 0.52%, 0.65%, 0.78%, and 0.91% or total lysine levels of 0.59%, 0.74%, 0.88%, and 1.02% (Table 2). At the conclusion of Exp. 3 and 4, all pigs were marketed to a USDA-inspected packing plant.

For each experiment, dietary treatments were allotted to both PCV2-vaccinated and non-vaccinated pens in a completely randomized design. Each experiment had 5 replications for each diet and vaccine treatment combination. All treatment diets were corn-soybean meal based with 0.15% added L-lysine HCl. Corn and soybean meal levels were altered to achieve the desired SID lysine:ME ratio in the diet. In addition, all diets contained 3% added fat from choice white grease. Diets were formulated to meet all other requirements recommended by NRC (1998[12]). Diet samples were collected from each diet in each experiment and analyzed for amino acid concentrations.

Pig weights (by pen) and feed disappearance were measured throughout the experiments. On the basis of these measurements, ADG, ADFI, F/G, daily SID lysine intake, and SID lysine intake per pound of gain were calculated for each pen. At the conclusion of the growth portion of Exp. 3 and 4, the pigs were marketed to a USDA-inspected packing plant and carcass data were collected. Pen data for yield, backfat depth, loin depth, percentage lean, fat-free lean index, and live value were determined by the packing plant. Yield reflects the percentage of HCW relative to live weight (obtained at the packing plant). Live value was determined by taking a base carcass price of $55.90, adding lean premiums, subtracting discounts, and converting to a live weight basis. Feed cost per pound of gain and income over feed cost (IOFC) were also calculated. For Exp. 1 and 2, IOFC was determined on a per-head basis by valuing each pig's weight gain at $0.50/lb and subtracting feed costs associated with the trial period. In Exp. 3 and 4, IOFC was determined on a per-head basis by subtracting the feed costs incurred during the trial from the full value for each pig.

Data were then analyzed as a completely randomized design with treatments arranged as 2 × 4 factorial designs for each experiment (2 PCV2 vaccine treatments and 4 dietary lysine levels). Growth and carcass data were analyzed using the MIXED procedure in SAS (SAS Institute Inc., Cary, NC), and pen counts were analyzed using the GENMOD procedure in SAS. Dietary lysine values were used as dose levels to test for

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

linear and quadratic responses to dietary treatments. Pen was used as the experimental unit in all analyses.

Results and Discussion

Analyzed amino acid levels for diets from Exp. 1, 2, 3 and 4 are shown in Tables 3, 4, 5, and 6, respectively. Formulated diet values are included in parenthesis. For each experiment, the analyzed concentrations of amino acids for the feed samples collected were similar to the calculated total values (within the acceptable limits for analytical variation). Also for each experiment, no PCV2 vaccine ×lysine interactions were detected ($P > 0.14$) for any of the growth or carcass data (Tables 7, 8, 9, and 10).

In Exp. 1 (85- to 135-lb gilts), PCV2-vaccinated pigs tended ($P < 0.08$) to be heavier (3.5 lb) at initiation of the trial and had an increased ($P < 0.001$) number of pigs per pen (3.6 pigs per pen) compared with non-vaccinates (Table 7). This initial difference is due to the increase in removals and decrease in pretrial performance of non-vaccinated pens that resulted from the inoculation of PRRS. Vaccinates had increased ($P < 0.001$) ADG, ADFI, final weight, daily SID lysine intake, and IOFC and tended to have improved ($P < 0.09$) F/G compared with non-vaccinates. In addition, at the conclusion of the experiment, pens vaccinated with PCV2 vaccine maintained a greater ($P < 0.001$) pen head count (5.0 more pigs per pen) than non-vaccinates. Average daily gain, F/G, and IOFC improved (quadratic; $P < 0.03$) as the SID lysine:ME ratio increased, with increases through 2.99 g/Mcal. Increasing the lysine level of the diet also increased (linear; $P < 0.02$) daily lysine intake and SID lysine per pound of gain. These results indicate that 2.99 g SID lysine/Mcal ME, or approximately 9.76 g of SID lysine per pound of gain, was sufficient to meet the needs of 85- to 135-lb gilts.

In Exp. 2 (85- to 140-lb barrows), similar to the gilts, PCV2 vaccinates tended to be heavier ($P < 0.06$) at the start of the experiment and had increased ($P < 0.001$) initial pen head counts (4.4 more pigs per pen) compared with non-vaccinates (Table 8). Vaccination for PCV2 also increased ($P < 0.04$) ADG, ADFI, final weight, daily lysine intake, and IOFC and tended to improve ($P < 0.08$) F/G. At the conclusion of Exp. 2, pen counts were greater ($P < 0.001$) for PCV2-vaccinated pens than for non-vaccinated pens by 7 pigs. Increasing the SID lysine:ME ratio of the diet improved F/G ($P < 0.001$) and increased (linear; $P < 0.001$) daily SID lysine intake and SID lysine intake per pound of gain. As evidenced by the improvements in F/G, these results suggest that 3.36 g SID lysine/Mcal ME, or 11.34 g of SID lysine per pound of gain, maximized the efficiency of 85- to 140-lb barrows.

In Exp. 3 (225- to 275-lb gilts), the increased ($P < 0.002$) starting weight and pen head count was maintained for PCV2-vaccinated pens, but the difference was reduced to only 2 more pigs per pen, which is less than the earlier difference of 5 pigs per pen that was a result of removing more pigs from vaccinated pens at initial barn marketing, which began just prior to the start of Exp. 3 and 4 (Table 9). No difference in ADG or ADFI was detected ($P > 0.23$) between PCV2 vaccinates and non-vaccinates. However, PCV2 vaccinates had improved ($P < 0.02$) F/G and increased ($P < 0.03$) final weight, final head count, SID lysine intake per pound of gain, and backfat. As seen from the improvements in feed efficiency, PCV2 vaccinates had a small improvement ($P < 0.02$) in feed cost per pound of gain, and the increase in final weight drove

the increase ($P < 0.001$) in IOFC for vaccinates compared with non-vaccinates. Both ADG and F/G improved (quadratic; $P < 0.05$) as the SID lysine:ME ratio increased, with ADG improving to 1.86 g/Mcal and F/G improving through 2.23 g/Mcal. Feed intake tended to decrease (linear; $P < 0.09$) as dietary lysine increased. But despite the decreases in feed intake, daily SID lysine intake and SID lysine intake per pound of gain increased (linear; $P < 0.001$) with increases in dietary lysine. No lysine level effects were observed ($P > 0.23$) for any of the carcass criteria. Feed cost per pound of gain improved (quadratic; $P < 0.001$) and IOFC tended to increase (quadratic; $P < 0.10$) as lysine increased in the diet, with the greatest values obtained at 2.23 g/Mcal for non-vaccinates and 1.86 g/Mcal for vaccinates. Results from this experiment indicate that approximately 1.86 g SID lysine/Mcal ME was required to maximize growth and 2.23 g SID lysine/Mcal ME was required to maximize efficiency and generate the most economic value.

In Exp. 4 (215- to 260-lb barrows), there was a difference ($P < 0.001$) in the initial average pen head count, with vaccinated pens having almost 3 more pigs per pen than non-vaccinated pens. However, there was no difference ($P > 0.85$) in starting weight between vaccination treatments (Table 10). Both ADG and ADFI were decreased ($P < 0.04$) in vaccinated pens compared with non-vaccinated pens, and the average pen head count was increased ($P < 0.001$) at the conclusion of the trial for vaccinated pens. In this study, ADG, F/G, daily SID lysine intake, and SID lysine intake per pound of gain increased (linear; $P < 0.01$) through the highest level of 2.61 g/Mcal, with the greatest change occurring when lysine level increased from 2.23 to 2.61 g/Mcal. Similar to Exp. 3, no differences in any of the carcass characteristics were observed ($P > 0.15$) as the SID lysine:ME ratio increased. Results from this trial indicate that feeding up to 2.61 g SID lysine/Mcal ME, or 12.39 g SID lysine per pound of gain, improved performance for 215- to 260-lb barrows.

Results from the first 2 experiments indicate that 85- to 135-lb BW gilts required 2.99 g SID lysine/Mcal ME and 85- to 140-lb BW barrows required 3.36 g SID lysine/Mcal ME to maximize performance. These requirements reflect a SID lysine level of 1.04% (1.17% total) for gilts and 1.17% (1.31% total) for barrows in a corn-soybean meal-based diet with 3% added fat. These results are similar to the requirement reported by Shelton et al. (2008a) that PCV2-vaccinated gilts from 85 to 140 lb required 3.16 g SID lysine/Mcal ME. One item that could be a confounding factor in the present studies is the different number of pigs per pen. This was a result of the effectiveness of the PCV2 vaccine and changes in death loss and reduced number of cull pigs. However, research published by Gonyou et al. (2006[13]) indicates that pig space should not have been an issue in Exp. 1 and 2 between vaccinated and non-vaccinated pens because pens had not reached the critical k-value (0.0336) at which space becomes a liming factor for growth rate.

Shelton et al. (2008a) reported linear increases in growth and feed efficiency through 2.55 g SID lysine/Mcal ME for 185- to 245-lb gilts. Results from Exp. 3 and 4 showed that the optimal SID lysine:ME ratio for 225- to 275-lb gilts appears to be approxi-

[13] Gonyou, H. W., M. C. Brum, E. Bush, J. Deen, S. A. Edwards, T. Fangman, J. J. McGlone, M. Meunier-Salaun, R. B. Morrison, H. Spoolder, P. L. Sundberg, and A. K. Johnson. 2006. Application of broken-line analysis to assess floor space requirements of nursery and grower-finisher pigs expressed on an allometric basis. J. Anim. Sci. 84:229-235.

mately 2.23 g/Mcal and that the optimal level for 215- to 260-lb barrows is 2.61 g/Mcal. The gilt requirement of 2.23 g SID lysine/Mcal ME corresponds to a corn-soybean meal-based diet with 3% fat containing 0.78% SID lysine, or 0.88% total lysine, and the barrow requirement of 2.61 g/Mcal reflects a diet with 0.91% SID lysine, or 1.02% total lysine. Despite the barrows being heavier, the high requirement in Exp. 4 is similar to the requirement observed by Shelton et al. (2008a), indicating there may be advantages to feeding increased SID lysine:ME ratios in the early stages of finishing. In Exp. 3 and 4, pig space would have been a limiting factor based on the critical k-value as described by Gonyou et al. (2006). The PCV2 vaccinates would be at a disadvantage for growth and efficiency compared with non-vaccinates because of limited pig space.

Because no interactions between dietary SID lysine level and PCV2 were observed, it appears that the overall increase in performance with PCV2 vaccination did not increase the lysine requirement for growing and finishing barrows and gilts. With only minor differences, the SID lysine:ME ratio that optimized growth and economic return was similar between PCV2 vaccinates and non-vaccinates.

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

	SID[3] lysine:ME, g/Mcal			
	2.24	2.61	2.99	3.36
	SID lysine, %			
Ingredient, %	0.78	0.91	1.04	1.17
Corn	75.52	70.16	64.81	59.44
Soybean meal (45% CP)	19.38	24.74	30.09	35.45
Choice white grease	3.00	3.00	3.00	3.00
Monocalcium P (21% P)	0.54	0.51	0.48	0.45
Limestone	0.90	0.90	0.90	0.90
Salt	0.35	0.35	0.35	0.35
L-threonine	0.005	0.015	0.020	0.030
Methionine hydroxy analog	---	0.015	0.045	0.070
Vitamin and trace mineral premix	0.10	0.10	0.10	0.10
Phytase[4]	0.013	0.013	0.013	0.013
Liquid lysine (60% lysine)	0.195	0.195	0.195	0.195
Total	100.00	100.00	100.00	100.00
Calculated analysis				
SID amino acids, %				
Lysine	0.78	0.91	1.04	1.17
Isoleucine:lysine	70	69	69	69
Leucine:lysine	167	156	148	142
Methionine:lysine	29	29	30	31
Met & Cys:lysine	61	59	58	58
Threonine:lysine	62	62	62	62
Tryptophan:lysine	19	19	20	20
Valine:lysine	81	79	77	76
ME, kcal/lb	1,580	1,580	1,579	1,579
Total lysine, %	0.88	1.02	1.17	1.31
CP, %	15.4	17.5	19.5	21.6
Ca, %	0.53	0.54	0.56	0.57
P, %	0.46	0.47	0.49	0.51
Available P, %[5]	0.27	0.27	0.27	0.27
Diet cost, $/ton[6]	185.47	194.45	203.51	212.67

[1] A total of 1,008 gilts (PIC 337 × 1050) were used in this 28-d trial with 5 replications per PCV2 vaccination and diet combination.
[2] A total of 1,002 barrows (PIC 337 × 1050) were used in this 28-d trial with 5 replications per PCV2 vaccination and diet combination.
[3] Standardized ileal digestible.
[4] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN) provided 227 phytase units per pound of diet.
[5] Phytase provided 0.10% available P to the diet.
[6] Diets costs were based on corn at $4.00/bu and soybean meal at $300/ton.

Table 2. Composition of diets, Exp. 3[1] and 4[2] (as-fed basis)

	SID[3] lysine:ME, g/Mcal			
	1.49	1.86	2.23	2.61
	SID lysine, %			
Ingredient, %	0.52	0.65	0.78	0.91
Corn	86.46	81.12	75.77	70.41
Soybean meal (45% CP)	8.66	14.01	19.36	24.72
Choice white grease	3.00	3.00	3.00	3.00
Monocalcium P (21% P)	0.4	0.375	0.35	0.32
Limestone	0.85	0.85	0.85	0.85
Salt	0.35	0.35	0.35	0.35
L-threonine	---	0.01	0.02	0.035
Methionine hydroxy analog	---	---	0.005	0.025
Vitamin and trace mineral premix	0.08	0.08	0.08	0.08
Phytase[4]	0.013	0.013	0.013	0.013
Liquid lysine (60% Lys)	0.195	0.195	0.195	0.195
Total	100.00	100.00	100.00	100.00
Calculated analysis				
SID amino acids, %				
Lysine	0.52	0.65	0.78	0.91
Isoleucine:lysine	71	70	70	69
Leucine:lysine	204	182	167	156
Methionine:lysine	35	32	30	30
Met & Cys:lysine	73	66	61	60
Threonine:lysine	65	65	64	65
Tryptophan:lysine	18	18	19	19
Valine:lysine	89	84	81	79
ME, kcal/lb	1,585	1,585	1,584	1,584
Total lysine, %	0.59	0.74	0.88	1.02
CP, %	11.4	13.4	15.5	17.5
Ca, %	0.45	0.46	0.48	0.49
P, %	0.39	0.40	0.42	0.43
Available P, %[5]	0.23	0.23	0.23	0.23
Diet cost, $/ton[6]	169.62	178.31	187.10	196.33

[1] A total of 930 gilts (PIC 337 × 1050) were used in this 28-d trial with 5 replications per PCV2 vaccination and diet combination.
[2] A total of 825 barrows (PIC 337 × 1050) were used in this 21-d trial with 5 replications per PCV2 vaccination and diet combination.
[3] Standardized ileal digestible.
[4] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN) provided 227 phytase units per pound of diet.
[5] Phytase provided 0.10% available P to the diet.
[6] Diets costs were based on corn at $4.00/bu and soybean meal at $300/ton.

Table 3. Chemical composition of diets (Exp. 1)[1]

	SID[2] lysine:ME, g/Mcal			
	2.24	2.61	2.99	3.36
	SID lysine, %			
Item, %	0.78	0.91	1.04	1.17
CP	13.8 (15.4)[3]	15.4 (17.5)	17.4 (19.5)	19.3 (21.6)
Essential amino acids				
Arginine	0.88	1.03	1.17	1.34
Histidine	0.38	0.42	0.47	0.53
Isoleucine	0.60 (0.62)	0.69 (0.71)	0.78 (0.81)	0.88 (0.91)
Leucine	1.28 (1.43)	1.43 (1.57)	1.58 (1.71)	1.72 (1.84)
Lysine	0.86 (0.88)	0.99 (1.02)	1.11 (1.17)	1.27 (1.31)
Methionine	0.25 (0.25)	0.28 (0.29)	0.30 (0.34)	0.33 (0.39)
Met + Cys	0.48 (0.54)	0.53 (0.60)	0.58 (0.68)	0.64 (0.76)
Phenylalanine	0.75	0.85	0.95	1.06
Threonine	0.57 (0.57)	0.63 (0.66)	0.71 (0.75)	0.81 (0.84)
Tryptophan	0.16 (0.17)	0.18 (0.20)	0.22 (0.23)	0.24 (0.26)
Valine	0.65 (0.72)	0.74 (0.82)	0.83 (0.91)	0.94 (1.01)
Nonessential amino acids				
Alanine	0.76	0.83	0.91	0.99
Aspartic acid	1.39	1.63	1.85	2.14
Cysteine	0.23	0.25	0.28	0.31
Glutamic acid	2.47	2.81	3.15	3.54
Glycine	0.57	0.65	0.73	0.84
Proline	0.83	0.88	0.93	1.00
Serine	0.70	0.79	0.89	1.00
Tyrosine	0.41	0.48	0.52	0.61

[1] A total of 1,008 gilts (PIC 337 × 1050) were used in this 28-d trial with 5 replications per PCV2 vaccination and diet combination.
[2] Standardized ileal digestible.
[3] Values in parentheses indicate formulated values.

Table 4. Chemical composition of diets (Exp. 2)[1]

	SID[2] lysine:ME, g/Mcal			
	2.24	2.61	2.99	3.36
	SID lysine, %			
Item, %	0.78	0.91	1.04	1.17
CP	13.6 (15.4)[3]	15.1 (17.5)	17.3 (19.5)	19.1 (21.6)
Essential amino acids				
Arginine	0.86	0.99	1.17	1.29
Histidine	0.38	0.42	0.48	0.52
Isoleucine	0.57 (0.62)	0.66 (0.71)	0.75 (0.81)	0.81 (0.91)
Leucine	1.28 (1.43)	1.38 (1.57)	1.54 (1.71)	1.65 (1.84)
Lysine	0.85 (0.88)	0.96 (1.02)	1.12 (1.17)	1.23 (1.31)
Methionine	0.25 (0.25)	0.27 0.29)	0.30 (0.34)	0.33 (0.39)
Met + Cys	0.48 (0.54)	0.52 (0.60)	0.58 (0.68)	0.63 (0.76)
Phenylalanine	0.76	0.83	0.94	1.04
Threonine	0.56 (0.57)	0.62 (0.66)	0.71 (0.75)	0.78 (0.84)
Tryptophan	0.15 (0.17)	0.17 (0.20)	0.21 (0.23)	0.20 (0.26)
Valine	0.65 (0.72)	0.72 (0.82)	0.83 (0.91)	0.91 (1.01)
Nonessential amino acids				
Alanine	0.78	0.82	0.90	0.99
Aspartic acid	1.39	1.58	1.85	2.04
Cysteine	0.23	0.25	0.28	0.30
Glutamic acid	2.48	2.74	3.13	3.43
Glycine	0.58	0.64	0.73	0.82
Proline	0.97	1.01	1.04	1.19
Serine	0.70	0.77	0.89	0.97
Tyrosine	0.42	0.47	0.51	0.56

[1] A total of 1,002 barrows (PIC 337 × 1050) were used in this 28-d trial with 5 replications per PCV2 vaccination and diet combination.
[2] Standardized ileal digestible.
[3] Values in parentheses indicate formulated values.

Table 5. Chemical composition of diets (Exp. 3)[1]

	SID[2] lysine:ME, g/Mcal			
	1.49	1.86	2.23	2.61
	SID lysine, %			
Item, %	0.52	0.65	0.78	0.91
CP	9.8 (11.4)[3]	10.8 (13.4)	13.7 (15.5)	15.2 (17.5)
Essential amino acids				
Arginine	0.61	0.69	0.89	1.02
Histidine	0.28	0.31	0.38	0.44
Isoleucine	0.43 (0.42)	0.48 (0.52)	0.61 (0.62)	0.70 (0.71)
Leucine	1.05 (1.16)	1.08 (1.30)	1.29 (1.44)	1.47 (1.57)
Lysine	0.57 (0.59)	0.68 (0.74)	0.87 (0.88)	0.96 (1.02)
Methionine	0.17 (0.20)	0.21 (0.23)	0.25 (0.26)	0.28 (0.30)
Met + Cys	0.35 (0.43)	0.40 (0.48)	0.48 (0.54)	0.53 (0.61)
Phenylalanine	0.58	0.61	0.76	0.84
Threonine	0.39 (0.41)	0.45 (0.50)	0.57 (0.59)	0.64 (0.68)
Tryptophan	0.10 (0.11)	0.12 (0.14)	0.16 (0.17)	0.18 (0.20)
Valine	0.49 (0.53)	0.52 (0.62)	0.66 (0.72)	0.74 (0.82)
Nonessential amino acids				
Alanine	0.65	0.67	0.78	0.87
Aspartic acid	0.93	1.07	1.41	1.62
Cysteine	0.18	0.19	0.23	0.25
Glutamic acid	1.81	1.97	2.49	2.83
Glycine	0.41	0.46	0.58	0.65
Proline	0.75	0.29	1.11	1.27
Serine	0.50	0.56	0.70	0.79
Tyrosine	0.33	0.34	0.42	0.47

[1] A total of 930 gilts (PIC 337 × 1050) were used in this 28-d trial with 5 replications per PCV2 vaccination and diet combination.
[2] Standardized ileal digestible.
[3] Values in parentheses indicate formulated values.

Table 6. Chemical composition of diets (Exp. 4)[1]

	SID[2] lysine:ME, g/Mcal			
	1.49	1.86	2.23	2.61
	SID lysine, %			
Item, %	0.52	0.65	0.78	0.91
CP	9.7 (11.4)[3]	10.9 (13.4)	13.6 (15.5)	15.1 (17.5)
Essential amino acids				
Arginine	0.60	0.71	0.92	0.98
Histidine	0.28	0.32	0.38	0.41
Isoleucine	0.43 (0.42)	0.49 (0.52)	0.62 (0.62)	0.66 (0.71)
Leucine	1.05 (1.16)	1.11 (1.30)	1.31 (1.44)	1.40 (1.57)
Lysine	0.56 (0.59)	0.68 (0.74)	0.87 (0.88)	0.93 (1.02)
Methionine	0.20 (0.20)	0.19 (0.23)	0.25 (0.26)	0.26 (0.30)
Met + Cys	0.38 (0.43)	0.38 (0.48)	0.48 (0.54)	0.51 (0.61)
Phenylalanine	0.58	0.64	0.76	0.83
Threonine	0.42 (0.41)	0.45 (0.50)	0.58 (0.59)	0.64 (0.68)
Tryptophan	0.10 (0.11)	0.12 (0.14)	0.16 (0.17)	0.17 (0.20)
Valine	0.48 (0.53)	0.53 (0.62)	0.67 (0.72)	0.72 (0.82)
Nonessential amino acids				
Alanine	0.64	0.67	0.78	0.84
Aspartic acid	0.93	1.10	1.44	1.56
Cysteine	0.18	0.19	0.23	0.25
Glutamic acid	1.81	2.03	2.54	2.73
Glycine	0.41	0.47	0.58	0.63
Proline	0.59	0.67	0.71	1.18
Serine	0.50	0.57	0.71	0.77
Tyrosine	0.32	0.36	0.43	0.45

[1] A total of 825 barrows (PIC 337 × 1050) were used in this 21-d trial with 5 replications per PCV2 vaccination and diet combination.
[2] Standardized ileal digestible.
[3] Values in parentheses indicate formulated values.

Table 7. Effects of SID lysine:ME ratio and PCV2 vaccination on 85- to 135-lb gilts (Exp. 1)[1]

	PCV2 vaccine[2]									Probability, $P <$				
	No				Yes								Lysine	
SID lysine:ME, g/Mcal:	2.24	2.61	2.99	3.36	2.24	2.61	2.99	3.36	SEM	Vaccine × Lysine	Vaccine	Lysine	Linear	Quadratic
Initial wt, lb	82.7	82.7	82.7	82.8	86.3	86.2	86.3	86.2	2.75	0.99	0.08	0.99	0.99	0.99
Initial pen head count	23.0	23.8	23.0	23.8	26.8	27.2	27.0	27.0	0.86	0.97	0.001	0.88	0.72	0.88
ADG, lb	1.52	1.60	1.72	1.64	1.78	1.92	1.90	1.84	0.04	0.33	0.001	0.002	0.02	0.002
ADFI, lb	3.58	3.61	3.56	3.50	4.05	4.06	3.94	3.85	0.08	0.88	0.001	0.22	0.06	0.45
F/G	2.36	2.26	2.07	2.15	2.28	2.12	2.07	2.09	0.06	0.71	0.09	0.001	0.001	0.03
Final wt, lb	128.0	130.9	133.1	130.3	136.0	140.0	139.8	137.8	2.98	0.99	0.001	0.48	0.46	0.18
Final pen head count	21.2	22.0	21.6	22.8	26.8	27.2	26.8	27.0	0.80	0.68	0.001	0.84	0.37	0.93
Daily SID lysine intake, g	12.68	14.92	16.78	18.58	14.33	16.77	18.56	20.43	0.39	0.99	0.001	0.001	0.001	0.37
SID lysine intake/lb gain, g	8.36	9.32	9.78	11.39	8.07	8.76	9.74	11.11	0.26	0.80	0.13	0.001	0.001	0.09
Feed cost/lb gain, $[3]	0.22	0.22	0.21	0.23	0.21	0.21	0.21	0.22	0.006	0.75	0.10	0.07	0.14	0.04
IOFC, $/pig[3,4]	9.81	10.36	11.48	10.22	11.87	13.16	12.78	11.73	0.463	0.39	0.001	0.03	0.60	0.004

[1] A total of 1,008 gilts (PIC 337 × 1050) were used in this 28-d trial with 5 replications per PCV2 vaccination and diet combination.
[2] Vaccination for PCV2 was administered at placement into the wean-to-finish facility and again 3 wk later.
[3] Diets costs were based on corn at $4.00/bu and soybean meal at $300/ton.
[4] Income over feed cost = (Weight gain per pig × $0.50/lb) - feed cost per pig.

Table 8. Effects of SID lysine:ME ratio and PCV2 vaccination on 85- to 140-lb barrows (Exp. 2)[1]

	PCV2 vaccine[2]									Probability, $P <$				
	No				Yes								Lysine	
SID lysine:ME, g/Mcal:	2.24	2.61	2.99	3.36	2.24	2.61	2.99	3.36	SEM	Vaccine × Lysine	Vaccine	Lysine	Linear	Quadratic
Initial wt, lb	83.4	83.4	83.4	83.5	87.9	88.0	87.8	88.0	3.24	0.99	0.06	0.99	0.97	0.99
Initial pen head count	23.0	22.4	22.6	23.4	27.4	27.0	27.4	27.2	0.80	0.94	0.001	0.89	0.82	0.49
ADG, lb	1.77	1.72	1.91	1.91	2.06	2.08	2.05	2.11	0.07	0.44	0.001	0.39	0.13	0.66
ADFI, lb	4.37	4.13	4.20	4.05	4.74	4.74	4.52	4.51	0.15	0.77	0.001	0.31	0.07	0.86
F/G	2.48	2.41	2.20	2.12	2.31	2.29	2.21	2.15	0.05	0.15	0.08	0.001	0.001	0.77
Final wt, lb	136.3	139.1	141.7	143.0	145.7	146.5	145.1	147.4	3.94	0.87	0.04	0.77	0.30	0.99
Final pen head count	21.4	18.8	19.8	20.4	27.2	26.6	27.4	27.0	1.01	0.74	0.001	0.48	0.78	0.25
Daily SID lysine intake, g	15.45	17.03	19.80	21.47	16.77	19.58	21.32	23.95	0.65	0.71	0.001	0.001	0.001	0.96
SID lysine intake/lb gain, g	8.79	9.95	10.37	11.27	8.16	9.43	10.42	11.40	0.22	0.22	0.13	0.001	0.001	0.37
Feed cost/lb gain, $[3]	0.23	0.23	0.22	0.23	0.21	0.22	0.23	0.23	0.005	0.17	0.09	0.61	0.50	0.64
IOFC, $/pig[3,4]	11.00	10.42	12.10	11.97	13.58	13.23	12.89	13.08	0.592	0.24	0.001	0.63	0.47	0.56

[1] A total of 1,002 barrows (PIC 337 × 1050) were used in this 28-d trial with 5 replications per PCV2 vaccination and diet combination.
[2] Vaccination for PCV2 was administered at placement into the wean-to-finish facility and again 3 wk later.
[3] Diets costs were based on corn at $4.00/bu and soybean meal at $300/ton.
[4] Income over feed cost = (Weight gain per pig × $0.50/lb) - feed cost per pig.

Table 9. Effects of SID lysine:ME ratio and PCV2 vaccination on 225- to 275-lb gilts (Exp. 3)[1]

	PCV2 vaccine[2]									Probability, $P <$				
	No				Yes								Lysine	
SID lysine:ME, g/Mcal:	1.49	1.86	2.23	2.61	1.49	1.86	2.23	2.61	SEM	Vaccine × Lysine	Vaccine	Lysine	Linear	Quadratic
Initial wt, lb	220.7	220.5	220.6	220.7	227.8	228.0	227.8	228.0	3.02	0.99	0.002	0.99	0.98	0.98
Initial pen head count	20.4	20.2	20.4	20.6	22.6	22.2	22.4	22.4	0.77	0.99	0.001	0.98	0.94	0.72
ADG, lb	1.62	1.83	1.84	1.80	1.68	1.84	1.85	1.92	0.06	0.79	0.24	0.005	0.003	0.05
ADFI, lb	5.99	5.98	5.78	5.71	5.90	5.90	5.64	5.82	0.14	0.79	0.60	0.21	0.09	0.75
F/G	3.72	3.28	3.14	3.18	3.52	3.20	3.05	3.04	0.07	0.77	0.02	0.001	0.001	0.001
Final wt, lb	266.0	271.7	272.2	271.5	275.5	279.6	279.7	281.7	3.22	0.97	0.001	0.27	0.10	0.36
Final pen head count	20.4	20.2	20.4	20.4	22.2	22.2	22.4	22.4	0.78	0.99	0.001	0.99	0.85	0.93
Daily SID lysine intake, g	14.14	17.64	20.44	23.56	13.91	17.39	19.94	24.0	0.44	0.72	0.70	0.001	0.001	0.86
SID lysine intake/lb gain, g	8.79	9.67	11.10	13.12	8.29	9.44	10.78	12.6	0.21	0.85	0.02	0.001	0.001	0.007
Carcass measurements														
Backfat, in.	0.63	0.61	0.59	0.62	0.65	0.65	0.64	0.65	0.026	0.84	0.03	0.67	0.62	0.32
Lean, %	56.4	55.9	56.5	56.0	56.3	56.5	56.4	56.4	0.70	0.91	0.71	0.97	0.89	0.91
Loin depth, in.	2.41	2.45	2.47	2.44	2.47	2.53	2.45	2.47	0.07	0.86	0.35	0.87	0.95	0.51
Yield, %	75.6	75.7	75.9	75.5	76.4	75.6	75.5	75.4	0.50	0.54	0.87	0.67	0.25	0.94
FFLI, %[3]	50.9	51.1	51.4	51.0	50.8	50.9	50.9	50.9	0.28	0.86	0.18	0.67	0.54	0.35
Economics														
Live value, $/cwt	48.08	48.83	49.17	48.09	49.03	49.01	48.87	48.93	0.53	0.48	0.21	0.58	0.97	0.18
Feed cost/lb gain, $[4]	0.32	0.29	0.29	0.31	0.30	0.29	0.29	0.30	0.006	0.81	0.02	0.005	0.80	0.001
IOFC, $/pig[4,5]	113.66	116.90	118.11	114.80	120.73	122.24	121.99	121.86	1.99	0.75	0.001	0.34	0.47	0.10

[1] A total of 930 gilts (PIC 337 × 1050) were used in this 28-d trial with 5 replications per PCV2 vaccination and diet combination.
[2] Vaccination for PCV2 was administered at placement into the wean-to-finish facility and again 3 wk later.
[3] Fat-free lean index.
[4] Diets costs were based on corn at $4.00/bu and soybean meal at $300/ton.
[5] Income over feed cost = value per pig - feed costs during trial period.

Table 10. Effects of SID lysine:ME ratio and PCV2 vaccination on 215- to 260-lb barrows (Exp. 4)[1]

	PCV2 vaccine[2]									Probability, $P <$				
	No				Yes								Lysine	
SID lysine:ME, g/Mcal:	1.49	1.86	2.23	2.61	1.49	1.86	2.23	2.61	SEM	Vaccine × Lysine	Vaccine	Lysine	Linear	Quadratic
Initial wt, lb	215.1	215.2	214.8	215.1	215.5	215.6	215.7	215.7	4.34	0.99	0.86	0.99	0.99	0.99
Initial day pen head count	18.2	19.0	19.2	18.2	22.8	22.6	22.6	22.4	0.99	0.93	0.001	0.93	0.88	0.53
ADG, lb	2.02	2.14	2.15	2.25	1.90	2.01	2.09	2.25	0.04	0.36	0.02	0.001	0.001	0.81
ADFI, lb	6.70	7.15	7.12	6.80	6.48	6.57	6.85	6.70	0.18	0.62	0.04	0.19	0.31	0.06
F/G	3.32	3.34	3.32	3.03	3.42	3.27	3.29	2.97	0.09	0.76	0.80	0.001	0.001	0.07
Final wt, lb	259.0	260.2	259.9	262.2	255.9	257.9	259.8	263.0	3.99	0.96	0.68	0.63	0.21	0.84
Final pen head count	18.0	19.0	19.0	18.2	22.4	22.6	22.4	22.4	1.01	0.92	0.001	0.96	0.96	0.49
Daily SID lysine intake, g	15.80	21.07	25.20	28.07	15.29	19.38	24.25	27.65	0.58	0.69	0.04	0.001	0.001	0.07
SID lysine intake/lb gain, g	7.84	9.85	11.74	12.51	8.07	9.64	11.64	12.27	0.26	0.79	0.65	0.001	0.001	0.005
Carcass measurements														
Backfat, in.	0.77	0.75	0.76	0.77	0.81	0.79	0.77	0.76	0.024	0.74	0.24	0.70	0.29	0.63
Lean, %	54.0	54.1	54.0	53.8	53.0	53.4	53.9	54.0	0.48	0.59	0.29	0.79	0.37	0.66
Loin depth, in.	2.30	2.26	2.25	2.22	2.14	2.21	2.28	2.27	0.07	0.38	0.52	0.92	0.63	0.72
Yield, %	74.3	74.6	74.6	74.1	74.8	74.8	74.8	74.8	0.51	0.95	0.25	0.96	0.93	0.60
FFLI, %[3]	48.8	49.1	49.0	48.9	48.2	48.5	48.8	49.0	0.28	0.55	0.11	0.47	0.16	0.48
Economics														
Live value, $/cwt	40.71	41.42	41.10	40.52	40.83	41.37	41.73	42.31	0.65	0.50	0.19	0.70	0.35	0.51
Feed cost/lb gain, $[4]	0.28	0.30	0.31	0.30	0.29	0.29	0.31	0.29	0.008	0.77	0.86	0.04	0.11	0.04
IOFC, $/pig[4,5]	93.49	94.52	92.93	92.36	92.90	94.44	94.98	97.47	2.96	0.77	0.45	0.95	0.63	0.94

[1] A total of 825 barrows (PIC 337 × 1050) were used in this 21-d trial with 5 replications per PCV2 vaccination and diet combination.
[2] Vaccination for PCV2 was administered at placement into the wean-to-finish facility and again 3 wk later.
[3] Fat-free lean index.
[4] Diets costs were based on corn at $4.00/bu and soybean meal at $300/ton.
[5] Income over feed cost = value per pig - feed costs during trial period.

Effects of Increasing Hominy Feed in Diets on Finishing Pig Performance[1]

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Summary

A total of 1,035 finishing pigs (initially 79.4 lb) were used in an 84-d growth trial to evaluate the effects of increasing hominy feed on finishing pig growth performance. Pens of pigs were blocked by average initial pig BW and randomly allotted to 1 of 4 dietary treatments (10 pens per treatment) with initial weights balanced across the treatment groups. Treatments were increasing levels (0%, 12.5%, 25%, and 37.5%) of corn hominy feed added to a corn-soybean meal-based diet. All treatment diets were fed in 4 phases, and hominy feed inclusion was constant among phases. Increasing hominy feed resulted in a linear decrease ($P < 0.01$) in ADG and ADFI from d 0 to 84. Regardless of treatment, there was no difference ($P > 0.35$) in F/G. The lower feed consumption and poorer growth performance resulted in pigs fed diets containing any level of hominy feed weighing less than pigs fed standard corn-soybean meal-based diets at the end of the trial.

These data indicate that adding corn hominy feed as an alternative ingredient in swine diets is a viable option; however, a decrease in performance should be considered when deciding if it is cost-effective to include hominy feed in finishing diets.

Key words: alternative ingredient, hominy feed, growth

Introduction

Corn by-products produced from a variety of processing procedures are widely used as alternative feed ingredients in swine diets. These ingredients are used with the intent of reducing feed cost. However, if inclusion of these ingredients also affects performance, the benefit of reduced cost must be weighed against the economic value of lost performance. Corn hominy feed is fed as an alternative ingredient to reduce dependency on ground corn. Corn is composed of 3 main fractions: bran, endosperm, and germ. The major contributions from these fractions are fiber, starch, and protein and oil, respectively. Hominy feed is a by-product of the dry-milling production of the corn grits, cornmeal, and corn flour industry, which primarily uses the endosperm fraction. Depending on the product produced, hominy feed consists of the remaining corn bran, corn germ, and some starch. Generally, hominy feed is reported to have a higher fiber and protein content and a lower dietary energy value than corn (corn ME = 1,551 kcal/lb, corn hominy feed ME = 1,456 kcal/lb; NRC, 1998[3]). Therefore, the objective of this trial was to determine the effects of feeding increasing amounts of hominy feed on ADG, ADFI and F/G of commercial finishing pigs.

[1] Appreciation is expressed to J-Six Enterprises, Seneca, KS, for their assistance and for providing the pigs and facilities used in this experiment.

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

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

Procedures

Procedures used in this study were approved by the Kansas State University Institutional Animal Care and Use Committee. A total of 1,035 finishing pigs (initially 79.4 lb) were used in an 84-d growth trial performed in a commercial research finishing barn. The barn, located in northeastern Kansas, was naturally ventilated and double curtain sided with completely slatted flooring. Barrows and gilts were comingled within pens in approximately equal numbers, with 23 to 27 pigs per pen (10 × 18 ft). Each pen was equipped with a double swinging waterer and a 3-hole dry self-feeder to allow ad libitum access to water and feed. An automated feeding system (FeedPro; Feedlogic Corp., Willmar, MN) was used in the barn to deliver and measure feed amounts added to individual pen feeders. Pens of pigs were blocked by average initial pig BW and randomly allotted to 1 of 4 dietary treatments, resulting in 10 replicate pens per treatment. Initial weight and gender distribution were balanced across the 4 dietary treatment groups. Dietary treatments were increasing levels (0%, 12.5%, 25%, and 37.5%) of hominy feed. A sample of the hominy feed was collected and analyzed for DM, CP, ADF, NDF, crude fiber, ash, Ca, P, and fat (Table 1). Metabolizable energy was calculated using the following equations:

$$GE = 4{,}143 + (56 \times \%\ \text{ether extract}) + (15 \times \%\ CP) - (44 \times \%\ Ash)$$[4]

$$DE = 949 + (0.789 \times GE) - (43 \times \%\ Ash) - (41 \times \%\ NDF)$$[5]

$$ME = DE \times (1.003 - (0.0021 \times \%\ CP))$$[5]

All diets were fed in 4 phases based on formulations for average pig weights of 80 to 130, 130 to 180, 180 to 230, and 230 to 310 lb (Tables 2 and 3). Pens of pigs were weighed and feed intake was collected on d 0, 12, 26, 40, 54, 70, and 84. From these data, ADG, ADFI, and F/G were calculated.

Data were analyzed as a randomized complete block design using the GLIMMIX procedure of SAS (SAS Institute Inc., Cary, NC) with pen as the experimental unit. Level of hominy feed was a fixed effect, and weight block was a random effect. Differences between treatments were determined by using least squares means ($P < 0.05$). The effects of increasing hominy feed in the diet were determined by linear and quadratic polynomial contrasts.

Results and Discussion

Of the 40 pens of pigs that were initially started on test, 5 pens were taken off test during the trial, and data for these pens after removal were managed as missing observations in the analysis (Table 4). Reasons for pen removal included diet delivery errors or loss of pen integrity due to pigs from 2 pens becoming mixed during the trial.

From d 0 to 84 as the level of corn hominy feed increased from 0 to 37.5%, ADG and ADFI decreased (linear; $P < 0.01$). There was no effect of hominy feed on F/G ($P > 0.35$). Weight on d 84 decreased (linear; $P < 0.01$) as more hominy feed was included in the

[4] Ewan, R. C. 1989. Predicting the energy utilization of diets and feed ingredients by pigs. Pages 271-274 in Energy Metabolism, European Association of Animal Production Bulletin No. 43, Y. van der Honing and W. H. Close, eds. Pudoc Wageningen, Netherlands. As cited in NRC. 1998. Nutrient Requirements of Swine, 10th ed. Natl. Acad. Press, Washington, DC.

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

diet. At off test, these performance differences resulted in pigs fed diets containing 37.5% hominy feed weighing almost 15 lb less than pigs fed the diet without hominy feed.

Although these diets were formulated to a similar lysine percentage, the lysine:calorie ratio was allowed to vary because of initial best estimates of energy value for corn hominy feed. The NRC (1998) ME value of hominy feed (1,456 kcal/lb) was used for diet formulation. As hominy feed increased and corn quantity decreased, the calculated energy value of the diet decreased. Analysis of the corn hominy product used in this trial showed that this product had lower percentages of NDF, ADF, and fat than the NRC (1998) reported values for hominy feed. This product appears to have ADF, NDF, and fat content closer to the NRC (1998) published values for corn (2.9%, 9.6%, and 3.9%, respectively). It is assumed that the lower fiber content would raise the energy value of this product, compared with published values for corn hominy, but at least a portion of this energy advantage is lost because of the product's lower fat content. The calculated ME for the product used in this trial was 1,569 kcal/lb, which is slightly higher than the NRC (1998) published ME value for corn (1,551 kcal/lb). The similar energy values for corn and corn hominy in this trial explain why increasing corn hominy inclusion did not affect F/G. However, the decrease in growth rate and feed intake suggest that besides the energy content, there is some other factor associated with the hominy feed that could be affecting growth rate. One factor of concern is diet flowability. Out-of-feed events occurred during this trial because of diets bridging in the bins. Although it seemed that this occurred most with the diet containing high levels of corn hominy feed, the number of times diets bridged in the bins for each treatment was not recorded. These observations are noteworthy, and the feed interruptions likely affected growth performance; however, the severity of the effects of out-of-feed events is unknown. A second factor could be that the hominy feed may be affecting palatability of the diet and thus decreasing feed intake. This explanation seems less likely because hominy feed has been reported to be quite palatable.

These data indicate that increasing corn hominy feed in the diet reduced growth rate and feed consumption. Therefore, using corn hominy feed as an alternative ingredient to provide energy to swine diets is a viable option; however, a decrease in performance should be considered when deciding if it is cost-effective to include corn hominy feed in finishing diets.

Table 1. Analysis of corn hominy feed and NRC published values for hominy feed

Item, %	Analysis as-fed	Hominy feed[1]
DM	90.4	90
CP	9.5	10.3
Fat	4.4	6.7
ADF	3.6	8.1
NDF	10.0	28.5
CF	2.8	---
Ash	2.35	---
Ca	0.02	0.05
P	0.51	0.43

[1] NRC (1998) published values for corn grits by-product (hominy feed) on an as-fed basis.

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

	Diet[2]			
	Phase 1		Phase 2	
Hominy feed, %:	0	37.5	0	37.5
Ingredient, %				
Corn	72.23	36.15	77.96	41.86
Soybean meal (46.5% CP)	25.59	24.20	20.01	18.62
Corn hominy feed	---	37.50	---	37.50
Monocalcium phosphate (21% P)	0.50	0.48	0.40	0.40
Limestone	0.88	0.88	0.88	0.88
Salt	0.35	0.35	0.35	0.35
Vitamin premix with phytase	0.15	0.15	0.13	0.13
Trace mineral premix	0.15	0.15	0.13	0.13
L-lysine HCl	0.15	0.15	0.15	0.15
Total	100.00	100.00	100.00	100.00
Calculated analysis				
SID[3] amino acids, %				
Lysine	0.96	0.96	0.82	0.82
Isoleucine:lysine	70	70	70	70
Leucine:lysine	155	152	166	162
Methionine:lysine	28	27	29	29
Met & Cys:lysine	57	56	61	59
Threonine:lysine	61	62	62	64
Tryptophan:lysine	19	20	19	20
Valine:lysine	79	81	81	83
SID Lysine:ME, g/Mcal	2.87	2.94	2.45	2.51
ME, kcal/lb[4]	1,516	1,481	1,519	1,484
Total lysine, %	1.08	1.09	0.93	0.93
CP, %	18.18	18.33	16.08	16.22
Ca, %	0.53	0.53	0.50	0.50
P, %	0.48	0.53	0.44	0.49
Available P, %	0.27	0.27	0.24	0.24

[1] Phase 1 diets were fed from approximately 80 to 130 lb; Phase 2 diets were fed from 130 to 180 lb.
[2] Treatment diets shown contain 0% or 37.5% hominy feed; additional diets contained 12.5% and 25.0% corn hominy.
[3] Standardized ileal digestible.
[4] The NRC (1998) ME value for hominy feed (1,456 kcal/lb) was used for diet formulation. Based on chemical analysis and subsequent calculation, the ME value of the hominy feed used in the trial was 1,569 kcal/lb. Therefore, the actual ME values for the diets containing 37.5% corn hominy were 1,523 and 1,526 kcal/lb for Phase 1 and 2 diets, respectively.

Table 3. Phase 3 and 4 diet composition (as-fed basis)[1]

	Diet[2]			
	Phase 3		Phase 4	
Hominy feed, %:	0	37.5	0	37.5
Ingredient, %				
Corn	81.99	45.89	85.17	49.07
Soybean meal (46.5% CP)	16.03	14.64	12.85	11.46
Corn hominy feed	---	37.50	---	37.50
Monocalcium phosphate (21% P)	0.48	0.45	0.50	0.45
Limestone	0.85	0.88	0.83	0.88
Salt	0.35	0.35	0.35	0.35
Vitamin premix with phytase	0.08	0.08	0.08	0.08
Trace mineral premix	0.08	0.08	0.08	0.08
L-lysine HCl	0.15	0.15	0.15	0.15
Total	100.00	100.00	100.00	100.00
Calculated analysis				
SID[3] amino acids, %				
Lysine	0.72	0.72	0.64	0.64
Isoleucine:lysine	71	71	71	71
Leucine:lysine	176	171	187	181
Methionine:lysine	31	31	33	32
Met & Cys:lysine	64	62	67	65
Threonine:lysine	63	65	64	66
Tryptophan:lysine	19	19	18	19
Valine:lysine	83	86	85	88
SID Lysine:ME, g/Mcal	2.15	2.20	1.91	1.95
Metabolizable energy, kcal/lb[4]	1,521	1,485	1,521	1,486
Total lysine, %	0.82	0.82	0.73	0.73
CP, %	14.57	14.71	13.36	13.50
Ca, %	0.49	0.49	0.48	0.48
P, %	0.44	0.49	0.43	0.47
Available P, %	0.22	0.22	0.22	0.22

[1] Phase 3 diets were fed from approximately 180 to 230 lb; Phase 4 diets were fed from 230 to 310 lb.
[2] Treatment diets shown contain 0% or 37.5% hominy feed; additional diets contained 12.5% and 25.0% corn hominy.
[3] Standardized ileal digestible.
[4] The NRC (1998) ME value for hominy feed (1,456 kcal/lb) was used for diet formulation. Based on chemical analysis and subsequent calculation, the ME value of the hominy feed used in the trial was 1,569 kcal/lb. Therefore, the actual ME values for the diets containing 37.5% corn hominy were 1,528 and 1,528 kcal/lb for Phase 3 and 4 diets, respectively.

Table 4. Effect of corn hominy feed inclusion in swine diets on growth performance of finishing pigs[1]

	Corn hominy feed, %					Probability, *P* <	
Item	0.0	12.5	25.0	37.5	SEM[2]	Linear	Quadratic
Pen numbers[3]							
Pen count (d 0)	10	10	10	10	---	---	---
Pen count (d 84)	8	9	10	8	---	---	---
d 0 to 84							
ADG, lb	2.24	2.13	2.11	2.05	0.02	<0.01	0.19
ADFI, lb	6.32	5.90	5.91	5.72	0.09	<0.01	0.18
F/G	2.82	2.78	2.80	2.78	0.03	0.35	0.64
Weight, lb							
d 0	79.4	78.8	79.4	79.6	2.0	0.68	0.49
d 84	268.2	257.8	258.9	253.3	2.6	<0.01	0.21

[1] Initially, a total of 1,035 pigs (barrows and gilts) were used with 23 to 27 pigs per pen and 10 pens per treatment.
[2] SEM among treatment groups differed because of missing observations. The highest SEM among the treatment groups is reported.
[3] Pens were removed from test because of diet delivery error or loss of pen integrity.

Determination of Amino Acid Digestibility and Calculated Energy Values in High-Protein Sorghum Dried Distillers Grains with Solubles in Growing Pigs[1]

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Summary

An experiment was conducted to determine the digestibility of amino acids (AA) and energy in high-protein sorghum dried distillers grain with solubles (DDGS). Six growing barrows (initially 50 lb) surgically fitted with T-cannulas were randomly assigned to 1 of 2 dietary treatments in a 2-period crossover design. The treatments were a diet with the high-protein sorghum DDGS (50% of the diet) as the only protein source and an N-free diet for determining basal endogenous AA loss. Both diets contained 0.25% chromic oxide as an indigestible marker. Fecal and ileal digesta samples were collected during each period for energy and AA analysis. On the basis of these analyses, apparent (AID) and standardized (SID) ileal digestibility and energy values were calculated. The analyzed CP of the product was 44.5% with a lysine:CP ratio of 3.6%. Crude fat, ADF, and NDF were 2.9, 16.1, and 18.8%, respectively. The AID for lysine, methionine, threonine, and tryptophan were 51.9, 73.0, 60.6, and 71.7%, respectively. The SID values were 53.7, 73.8, 63.0, and 73.8% for lysine, methionine, threonine, and tryptophan, respectively. The analyzed GE of the product was 2,317 kcal/lb of DM. The calculated DE, ME, and NE values were 1,759; 1,610; and 1,023 kcal/lb of DM, respectively. In conclusion, the high-protein sorghum DDGS is higher in CP, AA, Ca, and P but lower in AA digestibility and energy compared with reported values for traditional DDGS.

Key words: amino acid, digestibility, dried distillers grains with solubles, sorghum

Introduction

The United States is the largest producer of sorghum worldwide (472 million bu); Kansas ranks first, producing 40% of U.S. production. Currently, more than 80% of all grain sorghum produced in Kansas is used as livestock feed. Because of the high starch content of sorghum (≈75%), the biofuel industry in Kansas uses sorghum for ethanol production. As of January 2009, a total of 12 dry mill ethanol plants are currently in operation in Kansas with a total capacity of about 450 million gal of ethanol per year. This means that dried distillers grains with solubles (DDGS), a coproduct of ethanol production, is becoming more available for livestock producers in Kansas.

With the technological improvements in ethanol production, companies are also continuously developing value-added ethanol coproducts. White Energy Inc., through its ethanol plant in Russell, KS, produces a high-protein, sorghum-based DDGS for

[1] Appreciation is expressed to White Energy, Inc., Russell, KS, for supplying the high-protein DDGS product.

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use in feeding livestock. The high-protein DDGS is produced by a method called post-fermentation fractionation, which removes a majority of the fiber and oil from a traditional DDGS coproduct. Because this is a relatively new coproduct with potential for use in swine diets, determining the digestibility of nutrients in this DDGS product is needed for more accurate diet formulation. The objective of this experiment was to establish the amino acid (AA) and energy digestibility of a high-protein sorghum DDGS in growing pigs.

Procedures

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

Six growing barrows (initially 50 lb) fitted with a T-cannula on their right flank were randomly allotted to 1 of 2 test diets in a crossover design. The first diet contained 50% of a sorghum-based DDGS; the second diet was N-free for determining basal AA endogenous losses from the small intestine (Table 1). Both diets had chromic oxide added at 0.25% as an indigestible marker. Before the start of the trial, all pigs were put on a common diet for 9 d. The pigs were housed in individual stainless steel metabolism crates with a nipple drinker that allowed unlimited access to water. There were 2 periods in the experiment. Each period consisted of 4 d of adaptation to the diet, fecal sample collection (grab samples) on d 5 and 6, and ileal digesta collection for 10 h each day on d 6 and 7. Each pig was weighed at the beginning of each period before being fed with the next dietary treatment to determine the amount of feed needed per day at a level 3 times the estimated maintenance requirement for energy. Daily feed allocation was divided into 2 equal amounts and was given twice daily at 0600 and 1800 h. Feed was withdrawn at the end of the first period before giving the next test diet to avoid carryover effect. Fecal samples were collected in the mornings of d 5 and 6 and stored in a freezer. Digesta samples were collected by attaching a latex balloon to the cannula. Balloons were removed every 30 min or as soon as they became full and were emptied in a 1-L plastic collection container. All collected samples were stored in a freezer until further processing and chemical analysis were conducted.

At the end of the collection phase, each period's worth of fecal and digesta samples from each pig were combined and homogenized. Subsamples were obtained from the homogenized feces, dried in a forced-air oven at 140°F, and ground for energy analysis. Subsamples of the homogenized digesta were freeze-dried and ground for AA analysis. Energy concentration in the diets, DDGS, and fecal samples were determined using bomb calorimetry. Proximate and AA analyses were conducted on the high-protein sorghum DDGS, diets, and digesta samples. Atomic absorption spectroscopy was used to determine chromic oxide concentration in the diet, fecal samples, and digesta samples. Amino acid analysis for the diets, sorghum DDGS, and ileal digesta samples was conducted at the Agriculture Experiment Station Chemical Laboratories at the University of Missouri-Columbia.

The apparent ileal digestibility (AID) for AA (%) in the high-protein sorghum DDGS diet was calculated using the equation:

$$AID = [1 - (AAd/AAf) \times (Crf/Crd)] \times 100\%$$

where AAd is the concentration of the AA in the ileal digesta (g/kg of DM), AAf is the concentration of the AA in the diets (g/kg of DM), Crf is the chromium concentration in the diet (g/kg of DM), and Crd is the chromium concentration in the ileal digesta (g/kg of DM).

The basal endogenous loss of each AA (g/kg of DMI) at the ileum was determined from the digesta samples obtained when the pigs were fed with the N-free diet with the equation:

$IAA_{end} = [AAd \times (Crf/Crd)]$

By using the values for AID and IAA_{end}, the standardized ileal digestibility (SID) value for each AA (%) was then calculated as:

$SID = [AID + (IAA_{end}/AAf)]$

Digestible energy, ME, and NE values of the high-protein sorghum DDGS were calculated using the following equations:

$DE = -174 + (0.848 \times GE) + \{2 \times [100 - (CP + EE + Ash + NDF)]\} - (16 \times \%\ ADF)$
(Ewan, 1989)[3]

$ME = 1 \times DE - 0.68 \times CP$
(Noblet and Perez, 1993)[4]

$NE = (.726 \times ME) + (13.3 \times EE) + (3.9 \times starch) - (6.7 \times CP) - (8.7 \times ADF)$
(Noblet et al., 1994)[5]

Results and Discussion

The nutrient composition of the high-protein sorghum DDGS used in the experiment is reported in Table 2. The analyzed CP of the product was 44.5% on an as-fed basis, which is approximately 17% higher than the published average CP value in traditional corn DDGS. The crude fat concentration was only 2.9%, which is lower than the average amount of fat found in traditional DDGS. The ADF value of 16.1% for the high-protein sorghum DDGS product was higher and the NDF value of 18.8% was lower than published traditional corn DDGS values. In addition, both Ca and P concentrations were higher in the high-protein sorghum DDGS than in traditional DDGS.

Amino acid analysis of the DDGS product showed that all AA were present in higher proportions as a result of the high CP value. The recommended lysine:CP ratio for a good-quality DDGS is at least 2.8%. The lysine content of the product was 1.6% on an

[3] Ewan, R.C. 1989. Predicting the energy utilization of diets and feed ingredients by pigs. Pages 271-274 in Energy Metabolism, European Association of Animal Produciton, Bulletin no. 43. Y. van der Honing, W.H. Close, eds. Pudoc, Wageningen, Netherlands.
[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(2):344-354.

as-fed basis, which is approximately double what is found in traditional DDGS. This translates to a lysine:CP ratio of 3.6%, indicating a good-quality DDGS.

Although CP and AA profile values of a feed ingredient can indicate its quality, determining how much of the available AA can actually be digested and absorbed in the small intestine is more important when formulating diets and evaluating the product. The AID for lysine, methionine, threonine, and tryptophan were 51.9, 73.0, 60.6, and 71.7%, respectively (Table 3). After the AID values were corrected for basal endogenous AA loss, the SID values were calculated to be 53.7, 73.8, 63.0, and 73.8% for lysine, methionine, threonine, and tryptophan, respectively. These values are lower than those found in traditional corn DDGS with the exception of tryptophan. The overall poorer digestibility of AA was expected because sorghum is known to have lower digestibility of proteins compared to corn, but other factors during processing may have contributed to the lower digestibility of these nutrients.

The calculated energy values for the high-protein sorghum DDGS are listed in Table 4. The DE for this DDGS product was 1,759 kcal/lb of DM, which, as expected, was lower than the DE in traditional DDGS (1,854 kcal/lb DM) because of its lower fat content. The values for ME and NE were 1,610 and 1,023 kcal/lb of DM, respectively.

The results of this experiment showed that the high-protein sorghum DDGS has a higher level of CP and higher proportions of AA, Ca, and P than traditional DDGS. However, this ethanol coproduct has lower AA digestibility and lower energy than traditional DDGS. Therefore, specific AA digestibility and energy values for this high-protein sorghum DDGS product may be used in formulating diets to meet the nutritional requirements of swine.

Table 1. Composition of test diets (as-fed basis)

Ingredient, %	Sorghum DDGS	N-free
Cornstarch	43.40	80.90
High-protein sorghum DDGS[1]	50.00	---
Soybean oil	1.00	3.00
Monocalcium P (21% P)	0.00	1.75
Limestone	1.35	0.40
Salt	0.35	0.45
Vitamin premix	0.25	0.25
Trace mineral premix	0.15	0.15
Sow add pack	0.25	0.25
Potassium chloride	---	0.50
Magnesium oxide	---	0.10
Chromic oxide	0.25	0.25
Solka-Floc	---	3.00
Sucrose	3.00	9.00
Total	100.0	100.0
Calculated analysis, %		
Total lysine	0.57	0.00
CP	24.00	0.00
Ca	0.59	0.48
P	0.73	0.37
Available P	0.56	0.37

[1] Dried distillers grains with solubles from White Energy, Inc., Russell, KS.

Table 2. Analyzed nutrient composition of high-protein sorghum DDGS[1]

Nutrient, %	DM basis	As-fed basis
DM	100.00	92.29
CP	48.22	44.50
Crude fat	3.14	2.90
ADF	17.45	16.10
NDF	20.37	18.80
Ca	0.13	0.12
P	0.82	0.76
Ash	5.01	4.62
Amino acids, %		
Arginine	1.85	1.71
Histidine	1.11	1.02
Isoleucine	2.18	2.01
Leucine	5.89	5.44
Lysine	1.73	1.60
Methionine	0.85	0.78
Phenylalanine	2.47	2.28
Threonine	1.79	1.65
Tryptophan	0.39	0.36
Valine	2.63	2.43
Alanine	3.86	3.56
Aspartic acid	3.48	3.21
Cysteine	0.80	0.74
Glutamic acid	7.68	7.09
Glycine	1.64	1.51
Proline	3.11	2.87
Serine	1.96	1.81
Tyrosine	1.87	1.73

[1] Dried distillers grains with solubles from White Energy, Inc., Russell, KS.

Table 3. Standardized and apparent ileal digestibility (%) of amino acids in high-protein sorghum DDGS[1,2]

Amino acid	SID[3]	AID[4]
Indispensable amino acids		
Arginine	77.97	76.08
Histidine	62.62	61.38
Isoleucine	69.71	68.64
Leucine	73.74	73.09
Lysine	53.71	51.86
Methionine	73.78	73.04
Phenylalanine	72.85	71.89
Threonine	63.01	60.57
Tryptophan	73.84	71.72
Valine	68.08	66.52
Dispensable amino acids		
Alanine	68.39	67.42
Aspartic acid	63.67	62.02
Cysteine	65.51	63.70
Glutamic acid	69.60	68.73
Glycine	46.31	40.10
Proline	59.95	54.27
Serine	70.72	68.76
Tyrosine	71.56	70.46

[1] Values are means of 6 pigs (initially 50 lb) used in a crossover design.
[2] Dried distillers grains with solubles from White Energy, Inc., Russell, KS.
[3] Standardized ileal digestibility.
[4] Apparent ileal digestibility.

Table 4. Energy values of high-protein sorghum DDGS[1,2]

Energy, kcal/lb	DM basis	As-is basis
GE	2,317	2,129
DE[3]	1,759	1,616
ME[3]	1,610	1,479
NE[3]	1,023	940

[1] Values are means of 6 observations per treatment.
[2] Dried distillers grains with solubles from White Energy, Inc., Russell, KS.
[3] See procedures section for equations used to calculate DE, ME, and NE.

Effect of Dried Distillers Grains with Solubles Withdrawal Regimens on Finishing Pig Performance and Carcass Characteristics[1]

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Summary

A total of 962 pigs (PIC L337 × 1050, initial BW = 86.1 lb) were used to determine the effect of dried distillers grains with solubles (DDGS) withdrawal regimens on growth performance and carcass traits. Pigs were randomly assigned to 1 of 6 treatments (6 pens per treatment) balanced by average BW within gender. Treatments were: (1) a corn-soybean meal-based diet without DDGS fed for 89 d (control), (2) 30% DDGS fed from d 0 to 48 and 0% DDGS fed from d 48 to 89, (3) 30% DDGS fed from d 0 to 69 and 0% DDGS fed from d 69 to 89, (4) 30% DDGS fed from d 0 to 48 and 15% DDGS fed from d 48 to 89, (5) 30% DDGS fed from d 0 to 69 and 15% DDGS fed from d 69 to 89, and (6) 30% DDGS diet fed from d 0 to 89. All diets contained 3% added fat. Pig BW, ADG, ADFI, and F/G were determined every 14 d. At the end of the trial, carcass fat quality was evaluated. There were no treatment × gender interactions ($P > 0.21$) for any criteria evaluated. Although there were some differences in F/G within phases, there were no overall differences ($P > 0.35$) in growth performance among treatments. Final weight numerically decreased as total DDGS level increased. Feeding continuously or withdrawing DDGS from the diet, regardless of the amount or duration, had no significant effect ($P > 0.39$) on any of the carcass criteria measured. Pigs fed DDGS had increased ($P < 0.01$) iodine value of fat depots compared with control pigs. When the DDGS withdrawal duration increased (Treatments 6, 3, 2, and 1), iodine values for all fat depots decreased (linear; $P < 0.01$). Feed cost per pig was highest ($P < 0.05$) when 0% DDGS was fed or withdrawn 6 wk before marketing (Treatments 1 and 2) and lowest when DDGS was added in the diets until at least 3 wk before marketing (Treatments 3, 4, 5, and 6). However, the reduction in feed cost did not significantly improve ($P > 0.57$) revenue or income over feed cost. In summary, DDGS reduction or withdrawal 3 or 6 wk before market did not affect growth performance or totally alleviate its negative effect on carcass fat iodine value.

Key words: carcass, dried distillers grains with solubles, growth

Introduction

Use of dried distillers grains with soluble (DDGS) in swine diets has become common in the swine industry over the past several years. Aside from being a relatively inexpensive ingredient, DDGS is a good source of energy and amino acids. Availability of phosphorus in DDGS is also high compared with corn, which reduces the need to

[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] Food Animal Health and Management Center, College of Veterinary Medicine, Kansas State University.
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add inorganic phosphorus in the diet. Thus, DDGS is a suitable alternative to other common energy and protein sources such as corn and soybean meal.

Unfortunately, the use of DDGS in pig diets has some disadvantages. In some studies, growth performance of pigs was negatively affected when DDGS was added to diets, especially at high levels (30% or greater). Another disadvantage is the negative effect of DDGS on carcass yield and fat quality. Soft carcass fat with a high iodine value (IV) has consistently been observed in pigs fed high levels of DDGS. Thus, it has been suggested that DDGS should be withdrawn from finishing diets several weeks prior to market to alleviate its negative effect on carcass quality. However, the optimum level and timing of DDGS reduction that will result in ameliorating its negative effects on fat quality (as measured by IV) warrants further investigation.

Therefore, we conducted this study to evaluate the effects of decreasing or withdrawing DDGS at different times before marketing on growth performance, carcass characteristics, and carcass fat quality of finishing pigs.

Procedures

This study was approved by and conducted in accordance with the guidelines of the Kansas State University Institutional Animal Care and Use Committee. The experiment was conducted in a commercial research finishing barn in southwestern Minnesota. The barns were naturally ventilated and double curtain sided. Pens had completely slatted flooring and deep pits for manure storage. Each pen was equipped with a 5-hole stainless steel dry self-feeder and a 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 on an individual pen basis.

A total of 962 pigs (PIC L337 × 1050, initial BW = 86.1 lb) were randomly assigned to 1 of 6 treatments balanced by average BW within gender. There were 6 single-gender pens (3 pens of barrows and 3 pens of gilts) per treatment. Pigs were fed a common nursery diet based on corn and soybean meal with 15% DDGS for approximately 27 d before the start of the experiment. Treatments were: (1) a corn-soybean meal-based diet without DDGS fed for 89 d (control), (2) 30% DDGS fed from d 0 to 48 and 0% DDGS fed from d 48 to 89, (3) 30% DDGS fed from d 0 to 69 and 0% DDGS fed from d 69 to 89, (4) 30% DDGS fed from d 0 to 48 and 15% DDGS fed from d 48 to 89, (5) 30% DDGS fed from d 0 to 69 and 15% DDGS fed from d 69 to 89, and (6) 30% DDGS diet fed from d 0 to 89 (Table 1). Diets contained 3% added fat and were fed in 4 phases formulated to contain a minimum of 2.70, 2.43, 2.05, and 2.72 standardized ileal digestible lysine/Mcal ME during Phases 1 to 4, respectively. In diet formulation, the DDGS used in this experiment was assumed to have the same ME content as corn. Dietary Phases 1 to 4 were fed from approximately 80 to 130, 130 to 185, 185 to 230, and 230 to 270 lb, respectively. Pigs from each pen were weighed as a group and feed disappearance was determined every 2 wk to determine ADG, ADFI, and F/G.

On d 76 of the experiment, the 3 heaviest pigs from each pen (determined visually) were sold in accordance with the normal marketing procedure of the farm. At the end of the experiment, pigs were individually tattooed according to pen number to allow for

carcass data collection at the packing plant and data retrieval by pen. Pigs were transported to JBS Swift and Company (Worthington, MN) for processing and carcass data collection. Standard carcass criteria of loin and backfat depth, HCW, percentage lean, and yield were collected. Fat-free lean index was calculated using the equation: 50.767 + (0.035 × HCW) - (8.979 × backfat).

Two average-weight pigs from every pen were tattooed with unique identification numbers to distinguish them from the rest of the pigs when the whole finishing group was marketed. From these pigs, fat samples from jowl fat, backfat, and belly fat were collected and processed for fatty acid analysis using gas chromatography. Fatty acids from each of the fat samples were expressed as a percentage of the total fatty acids. Iodine value, expressed as g/100 g of fat, was then calculated based on the fatty acid profile of each sample according to the following equation[4]:

$$IV = [C16:1] \times 0.95 + [C18:1] \times 0.86 + [C18:2] \times 1.732 + [C18:3] \times 2.616 + [C20:1] \times 0.785 + [C22:1] \times 0.723$$

where the brackets imply concentration (percentage) of the fatty acid.

Statistical analysis was performed by analysis of variance using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). Data were analyzed as a completely randomized design with pen as the experimental unit. The main effects of the different treatment regimens, gender, and their interaction were tested. Backfat, loin depth, percentage lean, and fat-free lean index were adjusted to a common carcass weight. Linear and polynomial contrasts were used to determine the effects of withdrawal duration and level of DDGS reduction (100%, 50%, and 0%). Contrast coefficients for withdrawal duration (0, 20, 41, and 89 d) were determined for unequally spaced treatments by using the IML procedure of SAS. The main effects of duration of DDGS reduction (3 vs. 6 wk) and level of DDGS reduction (100% vs. 50%) were determined using single degree of freedom contrast statements.

Results and Discussion

There were no treatment × gender interactions ($P > 0.21$) for any of the criteria evaluated. Overall gender differences in growth performance were as expected, with barrows having greater ($P < 0.05$) ADG and ADFI but poorer ($P < 0.05$) F/G than gilts (Table 2). From d 0 to 42, when all pigs were fed 30% DDGS diets with the exception of the control pigs, there were no differences ($P > 0.31$) among treatments. However, ADG, ADFI, and F/G of pigs fed 0% DDGS were numerically improved by 6.3%, 3.6% and 2.9%, respectively, compared with pigs fed 30% DDGS.

From d 42 to 69, pigs in all treatment groups had similar ($P > 0.47$) growth performance. However, when the amount of DDGS was lowered to 0% or 15% of the diet (6 wk vs. 3 wk withdrawal; Treatments 2 and 4 vs. 3 and 5), reducing DDGS earlier tended ($P < 0.10$) to lead to a greater ADG but poorer F/G.

From d 69 to 89, ADFI decreased (linear; $P < 0.01$) but F/G tended to improve (linear; $P < 0.10$) as the duration of complete DDGS withdrawal from the diet (Treatments

[4] AOCS. 1998. Official Methods and Recommended Practices of the AOCS. 5th ed. Am. Oil. Chem. Soc., Champaign, IL.

1, 2, 3, and 6) increased. When DDGS level during the last 3 wk (0%, 15%, and 30%; Treatments 3, 5, and 6) was compared, F/G tended ($P < 0.10$) to improve as less DDGS was withdrawn from the diet. Complete withdrawal or reduction to 15% DDGS in the diet 6 wk before pigs were marketed improved ($P < 0.05$) F/G compared with a 3-wk complete DDGS withdrawal or reduction to 15% (Treatments 2 and 4 vs. 3 and 5). From d 42 to 89, there were no differences ($P > 0.42$) in ADFI or F/G among the 6 treatments. However, increasing the duration of DDGS withdrawal increased ADG (quadratic; $P < 0.05$; Treatments 1, 2, 3, and 6).

Overall, there were no differences in growth performance among treatments ($P > 0.35$). However, when comparing the effect of amount of DDGS withdrawn from the diet during the last 6 wk before market (100%, 50%, and 0% DDGS withdrawn; Treatments 2, 4, and 6), F/G became worse (quadratic; $P = 0.05$). The effect of DDGS withdrawal observed in this experiment agrees with the findings from a previous study that evaluated the effects of feeding diets with 30% DDGS and a withdrawal (0% DDGS) duration of 0, 3, or 6 wk before marketing on growth performance (Gaines et al., 2007[5]). Gaines et al. (2007) reported that pigs continuously fed 30% DDGS had poorer F/G than pigs that were fed diets with 0% DDGS. Possible explanations for the differences in results between our study and that of Gaines et al. (2007) include the quality of DDGS used and method of diet formulation. We used higher levels of synthetic amino acids to minimize excess CP. Because of the similar growth performance exhibited by all the treatment groups in our study, no significant differences in final weights were observed. However, feeding DDGS for longer durations numerically reduced market weight.

Feeding DDGS continuously or withdrawing it from the diet, regardless of the amount, had no significant effect ($P > 0.39$) on any of the carcass characteristics measured (Table 3). This is in contrast to results of Gaines et al. (2007), who observed an improvement in carcass yield and weight when DDGS was withdrawn from the diet several weeks before market.

As expected, fat quality was negatively affected in pigs fed diets containing DDGS. Fat firmness is less desirable when it contains high amounts of polyunsaturated fatty acids (PUFA), which are correlated to a high IV. All DDGS-fed pigs had increased ($P < 0.01$) PUFA in all fat depots compared with the non-DDGS-fed pigs (Table 4). When the duration of DDGS withdrawal decreased (Treatments 1, 2, 3, and 6), PUFA increased in backfat (quadratic; $P < 0.01$), belly fat (linear; $P < 0.01$), and jowl fat (linear; $P < 0.01$). Thus, feeding DDGS increased ($P < 0.01$) the IV of all 3 fat depots compared with the controls. Complete withdrawal of DDGS from the diet did not reduce IV to levels similar or close to the controls, which is not consistent with other studies that showed a reduction in IV when DDGS was withdrawn from the diet for as little as 3 wk (Xu et al., 2008[6]). Results of our study indicate that a 6-wk withdrawal or reduction of DDGS in the diets is not enough to totally alleviate the negative effect of feeding

[5] Gaines, A. M., J. D. Spencer, G. I. Petersen, N. R. Augspurger, and S. J. Kitt. 2007. Effect of corn distillers dried grains with solubles (DDGS) withdrawal program on growth performance and carcass yield in grow-finish pigs. J. Anim. Sci. 85(Suppl. 1):438. (Abstr.)

[6] Xu, G., S. K. Baidoo, L. J. Johnston, J. E. Cannon, D. Bibus, and G. C. Shurson. 2008. Effects of dietary corn dried distillers grains with solubles (DDGS) and DDGS withdrawal intervals, on pig growth performance, carcass traits, and fat quality. J. Anim. Sci. 86(Suppl. 2):52. (Abstr.)

DDGS on carcass fat. However, this may depend on the quality or crude fat content of the DDGS. As the duration of complete DDGS withdrawal increased (Treatments 6, 3, 2, and 1), IV for all fat depots decreased (linear; $P < 0.01$). The rate of IV decrease in backfat, belly fat, and jowl fat was 0.02, 0.02, and 0.08 g/100g, respectively, for every week that DDGS was reduced to 15% (Figures 1, 2, and 3). When DDGS was completely withdrawn from the diet, IV of backfat, belly fat, and jowl fat decreased by 0.18, 0.31, and 0.34 g/100g per wk, respectively. The change in IV for the 3 fat depots appears to be more variable between the 3 and 6 wk data when DDGS was reduced to only 15% compared with complete withdrawal.

Feed cost per pig was highest ($P < 0.05$) when 0% DDGS was fed in the diets or withdrawn 6 wk before marketing (Treatments 1 and 2; Table 5) and lower when DDGS was added in the diets until at least 3 wk before marketing (Treatments 3, 4, 5, and 6). As the number of days that DDGS was withdrawn from the diet decreased (Treatments 1, 2, 3, and 6), feed cost per pig also decreased (linear; $P < 0.01$). Feed cost per pig was also reduced (linear; $P < 0.05$) as the level of DDGS withdrawn from the diet was reduced from 100% to 0% during the last 6 wk prior to market (Treatments 2, 4, and 6). However, the reduction in feed cost did not result ($P > 0.57$) in any significant improvement in revenue or income over feed cost (IOFC), although IOFC was numerically highest in pigs that were fed 30% DDGS continuously.

In summary, feeding 30% DDGS in finishing pigs did not affect growth performance but resulted in softer fat as indicated by increased carcass fat IV. Diet cost was reduced when DDGS was fed continuously in finishing pigs, which resulted in a numeric increase in IOFC. Reducing or completely withdrawing DDGS from diets 3 or 6 wk before pigs were marketed did not totally alleviate the negative effect of DDGS on carcass fat IV but numerically reduced the IV compared with continuously feeding DDGS until marketing.

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

	Phase 1		Phase 2		Phase 3			Phase 4		
DDGS, %[2]:	0	30	0	30	0	15	30	0	15	30
Ingredient, %										
Corn	72.2	49.1	73.7	53.0	78.9	69.4	57.0	69.6	59.0	47.8
Soybean meal (46.5% CP)	22.6	15.6	21.4	12.0	16.2	10.9	8.1	25.4	21.3	17.2
DDGS	---	30.0	---	30.0	---	15.0	30.0	---	15.0	30.0
Choice white grease	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Monocalcium P (21% P)	0.5	0.3	0.4	---	0.3	---	---	0.3	---	---
Limestone	0.9	1.1	0.9	1.1	1.0	0.9	1.1	1.0	1.0	1.2
Salt	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
L-lysine HCl	0.3	0.5	0.2	0.5	0.2	0.4	0.4	0.2	0.3	0.4
L-threonine	0.03	---	---	---	---	---	---	0.04	---	---
DL-methionine	0.02	---	---	---	---	---	---	0.035	---	---
Ractopamine HCl, 9 g/lb[3]	---	---	---	---	---	---	---	0.025	0.025	0.025
Vitamin-trace mineral premix	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Phytase[4]	0.013	---	0.013	0.005	0.013	0.013	0.005	0.010	0.010	0.005
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis:										
SID[5] amino acids, %										
Lysine	0.94	0.94	0.85	0.85	0.72	0.72	0.72	0.95	0.95	0.95
Isoleucine:lysine	65	69	69	69	70	68	72	69	70	71
Leucine:lysine	148	186	161	196	173	192	219	154	171	188
Methionine:lysine	28	33	29	34	30	33	38	31	30	33
Met & Cys:lysine	56	66	59	69	63	68	77	60	62	67
Threonine:lysine	60	63	61	64	62	63	68	65	63	65
Tryptophan:lysine	18	17	19	17	19	17	17	19	19	18
Valine:lysine	74	83	80	85	82	84	91	78	82	85
Total lysine, %	1.05	1.10	0.96	1.00	0.81	0.84	0.87	1.07	1.09	1.12
ME, kcal/lb	1,580	1,582	1,582	1,587	1,583	1,589	1,587	1,581	1,587	1,585
SID Lysine:ME, g/Mcal	2.70	2.70	2.44	2.43	2.06	2.05	2.06	2.73	2.72	2.72
CP, %	16.7	19.6	16.2	18.3	14.2	15.0	16.7	17.7	19.0	20.2
Ca, %	0.54	0.54	0.52	0.48	0.50	0.41	0.48	0.54	0.46	0.52
P, %	0.46	0.52	0.43	0.44	0.40	0.38	0.43	0.44	0.42	0.47
Available P, %	0.27	0.27	0.24	0.26	0.23	0.23	0.25	0.23	0.23	0.26
Cost, $/ton[6]	189.3	175.9	183.4	165.6	169.7	159.1	154.7	212.0	202.0	195.0

[1] Phases 1, 2, 3, and 4 were fed from approximately 80 to 130, 130 to 185, 185 to 230, and 230 to 270 lb BW, respectively.
[2] Dried distillers grains with solubles.
[3] Paylean; Elanco Animal Health, Greenfield, IN.
[4] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN) provided per pound of diet: 227 and 0 FTU in the 0% and 30% DDGS diets, respectively, in Phase 1; 227 and 91 FTU in the 0% and 30% DDGS diets, respectively, in Phase 2; 227 FTU in the 0% and 15% DDGS diets and 91 FTU in the 30% DDGS diet in Phase 3; and 181 FTU in the 0% and 15% DDGS diets and 91 FTU in the 30% DDGS diet in Phase 4.
[5] Standardized ileal digestible.
[6] Diet cost was based on corn at $3.05/bu and 46.5% soybean meal at $370/ton.

Table 2. Effect of dried distillers grains with solubles (DDGS) step-down or withdrawal regimen on growth performance of growing-finishing pigs[1]

	DDGS, %									
Treatment:	1	2	3	4	5	6				
d 0 to 48:	0	30	30	30	30	30				
d 48 to 69:	0	0	30	15	30	30		Gender		
d 69 to 89:	0	0	0	15	15	30	SEM	Barrow	Gilt	SEM
Weight, lb										
d 0	85.9	85.7	85.9	87.1	86.6	85.1	2.11	86.6	85.6	1.22
d 42	171.6	166.9	167.3	166.6	166.6	167.4	3.61	169.5	166.0	2.08
d 69	225.4	221.1	221.3	218.5	218.5	219.1	3.99	223.3	218.0	2.30
d 76	241.5	237.4	236.7	235.4	233.2	235.0	3.98	239.8	233.3	2.30
d 89[a]	267.8	266.4	267.0	263.2	261.7	261.4	4.06	268.1	261.1	2.34
d 0 to 42										
ADG, lb	2.02	1.91	1.91	1.88	1.88	1.92	0.051	1.95	1.89	0.030
ADFI, lb[a]	4.84	4.66	4.71	4.80	4.69	4.57	0.135	4.86	4.56	0.078
F/G[e]	2.40	2.44	2.47	2.57	2.49	2.38	0.063	2.50	2.42	0.036
d 42 to 69										
ADG, lb[a,h]	5.74	5.82	5.73	5.85	5.54	5.71	0.111	5.95	5.51	0.064
ADFI, lb	1.92	1.96	1.97	1.89	1.90	1.91	0.050	1.96	1.89	0.029
F/G[a,h]	3.00	2.97	2.91	3.09	2.93	2.99	0.063	3.04	2.92	0.037
d 69 to 89										
ADG, lb	2.29	2.50	2.25	2.38	2.39	2.41	0.072	2.39	2.34	0.042
ADFI, lb[a,b]	5.84	6.30	6.32	6.15	6.34	6.38	0.126	6.48	5.97	0.073
F/G[a,c,f,g]	2.55	2.54	2.82	2.59	2.67	2.65	0.068	2.72	2.56	0.040
d 42 to 89										
ADG, lb[d]	2.06	2.17	2.15	2.09	2.09	2.08	0.041	2.13	2.08	0.024
ADFI, lb[a]	5.78	6.02	5.97	5.97	5.86	5.98	0.105	6.16	5.70	0.061
F/G[a]	2.81	2.78	2.79	2.86	2.81	2.88	0.051	2.90	2.74	0.029
d 0 to 89										
ADG, lb[a]	2.04	2.04	2.03	1.98	1.98	2.00	0.031	2.04	1.99	0.018
ADFI, lb[a]	5.32	5.35	5.36	5.40	5.29	5.29	0.096	5.53	5.14	0.056
F/G[a,e]	2.61	2.62	2.64	2.72	2.66	2.64	0.037	2.71	2.59	0.022

[1] A total of 962 pigs (PIC L337 × 1050, initial BW = 86.1 lb) were used with 27 pigs per pen and 6 pens per treatment.
[a] Gender effect: $P < 0.05$.
[b] Linear effect of decreasing duration of DDGS withdrawal (Treatments 1, 2, 3, and 6); $P < 0.05$.
[c] Linear effect of decreasing duration of DDGS withdrawal (Treatments 1, 2, 3, and 6); $P < 0.10$.
[d] Quadratic effect of decreasing duration of DDGS withdrawal (Treatments 1, 2, 3, and 6); $P < 0.05$.
[e] Quadratic effect of DDGS level (100%, 50%, and 0%) withdrawn from the diet 41 d before market (Treatments 2, 4, and 6); $P < 0.05$.
[f] Linear effect of DDGS level (100%, 50%, and 0%) withdrawn from the diet 20 d before market (Treatments 3, 5, and 6); $P < 0.10$.
[g] Effect of 20 d vs. 41 d step-down program regardless of DDGS level withdrawn from the diet (Treatments 2 and 4 vs. 3 and 5); $P < 0.05$.
[h] Effect of 20 d vs. 41 d step-down program regardless of DDGS level withdrawn from the diet (Treatments 2 and 4 vs. 3 and 5); $P < 0.10$.

Table 3. Effect of dried distillers grains with solubles (DDGS) step-down or withdrawal regimen on carcass characteristics of growing-finishing pigs[1]

	DDGS, %							
Treatment:	1	2	3	4	5	6		
d 0 to 48:	0	30	30	30	30	30		
d 48 to 69:	0	0	30	15	30	30		
d 69 to 89:	0	0	0	15	15	30	SEM	Probability, $P <$
Carcass weight, lb	201.0	200.3	198.8	198.9	198.0	198.5	3.09	0.98
Yield, %	75.11	75.72	75.85	75.09	75.24	75.71	0.422	0.59
Backfat[2], in.	0.71	0.71	0.70	0.68	0.74	0.68	0.040	0.88
Lean, %[2]	55.16	55.43	54.73	55.68	54.29	55.63	0.731	0.70
Loin depth[2], in.	2.39	2.34	2.32	2.40	2.26	2.37	0.051	0.39
Fat-free lean index[2]	49.81	49.86	49.92	50.19	49.43	50.14	0.494	0.89

[1] A total of 962 pigs (PIC L337 × 1050, initial BW = 86.1 lb) were used with 27 pigs per pen and 6 pens per treatment.
[2] Values are adjusted to a common carcass weight.

Table 4. Effect of dried distillers grains with solubles (DDGS) step-down or withdrawal regimen on carcass fat composition[1]

	DDGS[2], %									
Treatment:	1	2	3	4	5	6				
d 0 to 48:	0	30	30	30	30	30				
d 48 to 69:	0	0	30	15	30	30		Gender[3]		
d 69 to 89:	0	0	0	15	15	30	SEM	Barrow	Gilt	SEM
Total SFA[4], %										
Backfat[a,b]	36.96	34.99	34.77	34.80	34.42	34.39	0.601	35.93	34.19	0.322
Belly fat[a,b]	35.11	33.64	33.26	33.09	32.70	32.69	0.524	34.11	32.72	0.281
Jowl fat[a,b]	33.71	32.45	31.97	31.67	31.79	31.56	0.454	32.95	31.44	0.247
Total MUFA[5], %										
Backfat[c,d]	45.68	42.19	43.16	42.72	41.46	42.26	0.522	43.17	42.66	0.279
Belly[c]	48.12	44.23	44.65	44.66	43.44	44.02	0.569	45.12	44.59	0.305
Jowl[b]	50.03	47.66	47.74	47.38	46.79	47.17	0.545	47.64	47.96	0.297
Total PUFA[6], %										
Backfat[a,c]	16.31	21.86	21.04	21.43	23.17	22.37	0.798	19.89	22.17	0.427
Belly[a,b]	15.70	21.05	21.07	21.23	22.81	22.23	0.749	19.71	21.66	0.402
Jowl[a,b]	15.20	18.79	19.15	19.73	20.32	20.14	0.670	18.28	19.50	0.365
Iodine value, g/100 g										
Backfat[a,b]	66.89	73.19	72.77	73.07	74.89	74.24	1.111	70.77	74.24	0.595
Belly[a,b]	67.82	73.53	73.90	74.21	75.88	75.40	0.993	72.00	74.91	0.532
Jowl[a,b]	68.60	72.59	73.34	74.15	74.57	74.65	0.852	71.81	74.16	0.464

[1] A total of 962 pigs (PIC L337 × 1050, initial BW = 86.1 lb) were used with 27 pigs per pen and 6 pens per treatment.
[2] Values are means of 12 observations per treatment.
[3] Values are means of 36 observations per treatment.
[4] Saturated fatty acids.
[5] Monounstaurated fatty acids.
[6] Polyunsaturated fatty acids.
[a] Gender effect; $P < 0.05$.
[b] Linear effect of decreasing duration of DDGS withdrawal (Treatments 1, 2, 3, and 6); $P < 0.01$.
[c] Quadratic effect of decreasing duration of DDGS withdrawal (Treatments 1, 2, 3, and 6); $P < 0.05$.
[d] Quadratic effect of DDGS level (100%, 50%, and 0%) withdrawn from the diet 20 d before market (Treatments 3, 5, and 6); $P < 0.05$.

Table 5. Effect of dried distillers grains with solubles (DDGS) step-down or withdrawal program on economics[1]

	DDGS, %									
Treatment:	1	2	3	4	5	6				
d 0 to 48:	0	30	30	30	30	30				
d 48 to 69:	0	0	30	15	30	30		Gender		
d 69 to 89:	0	0	0	15	15	30	SEM	Barrow	Gilt	SEM
Feed cost, $/pig[2,a,b]	44.81	43.45	42.65	42.46	41.56	40.99	0.755	44.24	41.06	0.436
Revenue, $/pig	119.61	120.77	119.53	121.10	117.73	119.94	2.265	120.35	119.21	1.264
Discount, $/pig	2.18	2.02	1.82	1.57	1.93	2.17	0.550	1.68	2.21	0.307
Income over feed cost, $/pig	74.30	77.32	76.88	78.65	76.02	78.86	1.969	75.92	78.09	1.098

[1] A total of 962 pigs (PIC L337 × 1050, initial BW = 86.1 lb) were used with 27 pigs per pen and 6 pens per treatment.
[2] Feed cost was based on corn at $3.05/bu and 46.5% soybean meal at $370/ton.
[a] Linear effect of decreasing duration of DDGS withdrawal (Treatments 1, 2, 3, and 6); $P < 0.01$.
[b] Linear effect of DDGS level (100%, 50%, and 0%) withdrawn from the diet 41 d before market (Treatments 2, 4, and 6); $P < 0.05$.

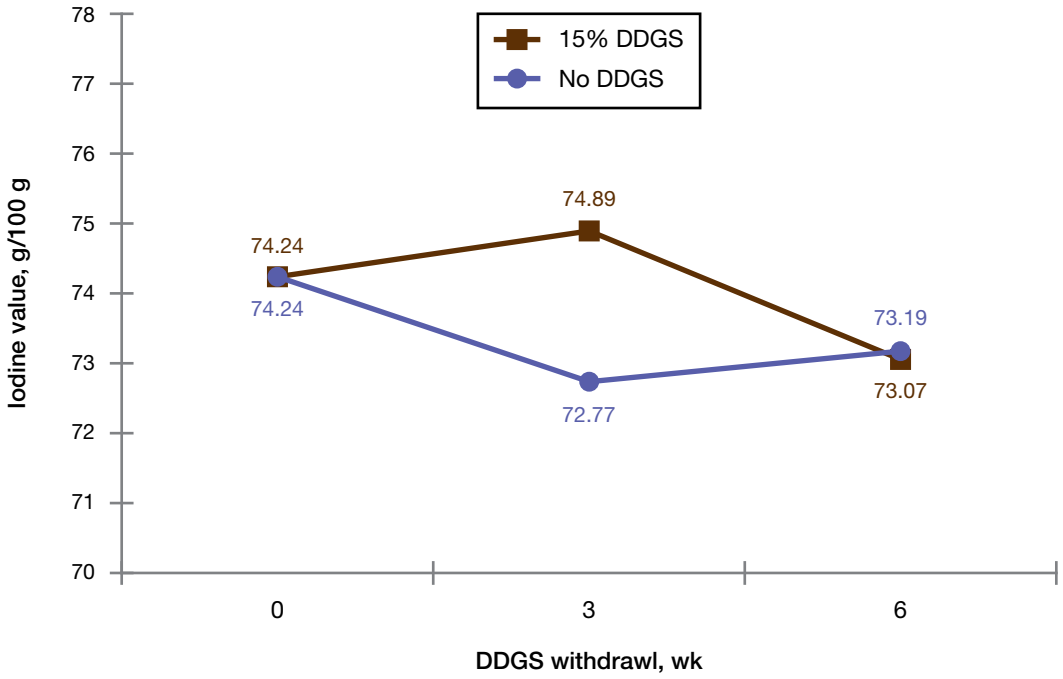

Figure 1. Effect of duration and level of DDGS withdrawal on backfat iodine value.

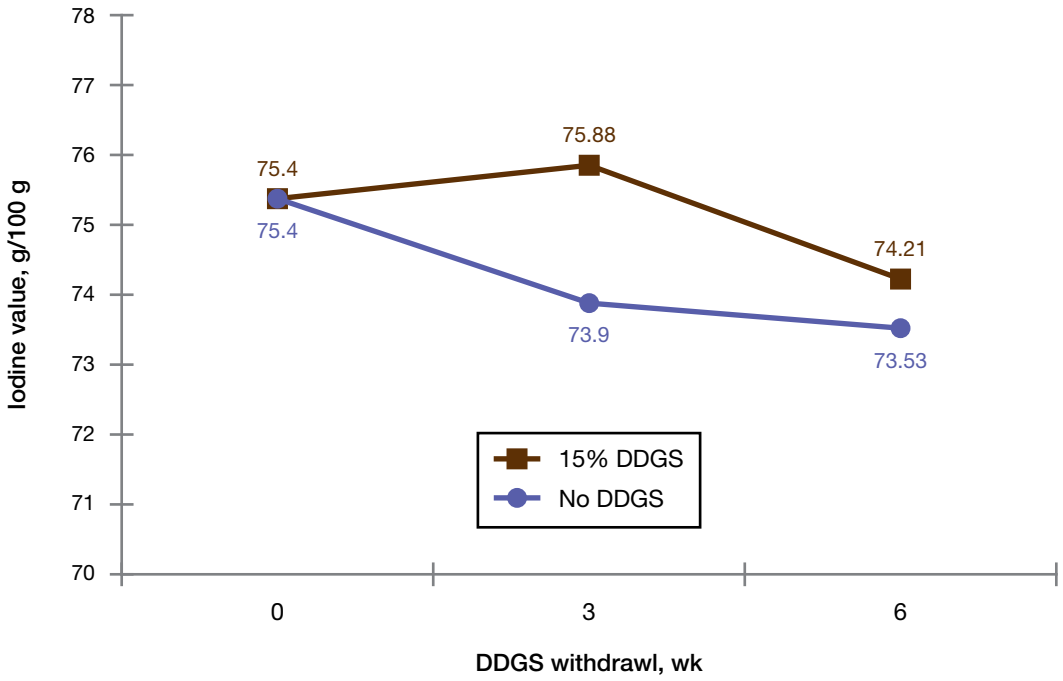

Figure 2. Effect of duration and level of DDGS withdrawal on belly fat iodine value.

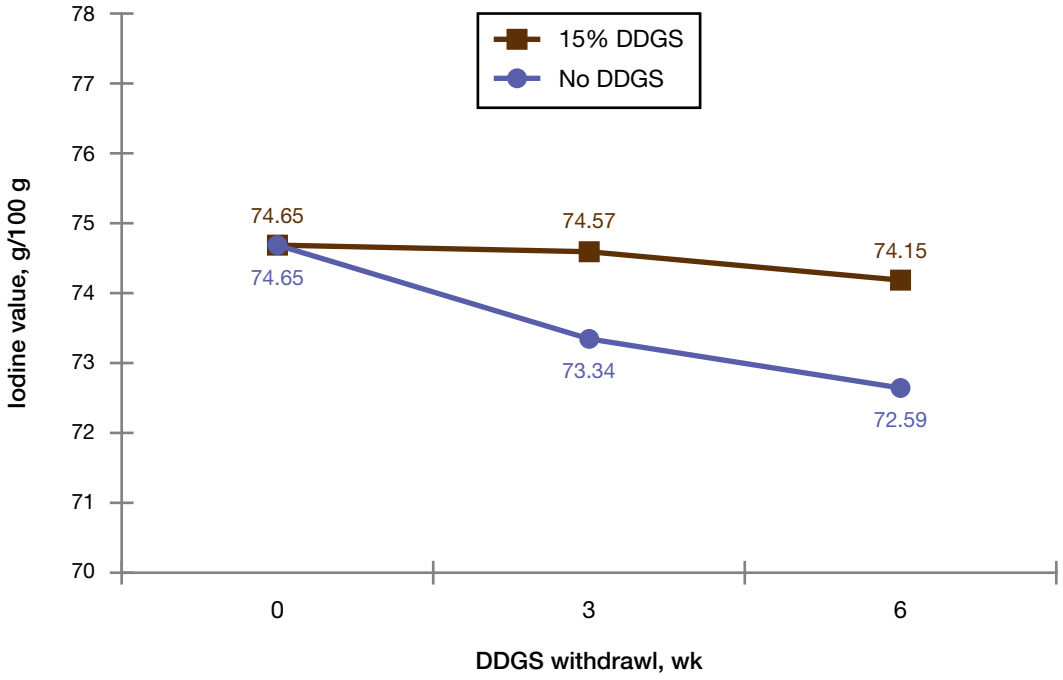

Figure 3. Effect of duration and level of DDGS withdrawal on jowl fat iodine value.

Effects of Adding Enzymes to Diets Containing High Levels of Dried Distillers Grains with Solubles on Growth Performance of Finishing Pigs[1]

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Summary

A total of 1,032 pigs (BW = 101.5 lb) were used in a 90-d experiment to determine the effects of adding enzymes to diets containing high levels of dried distillers grains with solubles (DDGS) on growth performance and carcass characteristics of finishing pigs. Pigs were blocked by BW and randomly allotted to 1 of 7 dietary treatments with 6 pens per treatment. The control diet contained 30% DDGS. The remaining treatments were arranged in a 2 × 3 factorial design based on DDGS (45 or 60%) and enzyme inclusion (none, product A, or product B). Enzyme products were commercially available and designed for use in swine diets containing DDGS. Pigs allotted to the 60% DDGS treatment were fed 45% DDGS during the first 2 wk of the experiment to acclimate the pigs to DDGS. The 4 heaviest pigs from each pen were sold at d 78, and DDGS levels for all treatments were decreased to 20% until the end of the trial. Overall (d 0 to 90), enzyme supplementation did not affect ADG ($P > 0.24$), ADFI ($P > 0.30$), or F/G ($P > 0.52$). From d 0 to 78, regardless of enzyme treatment, ADG decreased (linear; $P < 0.05$) as DDGS increased because of a reduction (quadratic; $P < 0.04$) in ADFI. After topping and adding Paylean to the diets at d 78, ADFI tended to increase (linear; $P < 0.06$) in pigs previously fed 45 and 60% DDGS. However, the decrease in ADFI from d 0 to 78 still resulted in an overall reduction (linear; $P < 0.04$) with increasing DDGS. Increasing DDGS did not affect ($P > 0.17$) overall ADG, F/G, or final weight. There were no differences in carcass weight and yield ($P > 0.65$) or in backfat, loin depth, percentage lean, and fat-free lean index ($P > 0.38$) after adjusting to a common carcass weight. Increasing dietary DDGS increased (linear; $P < 0.01$) iodine value of belly fat (77.2, 83.7, and 87.3 g/100 g, respectively). This study indicates that up to 60% DDGS may be added to pig diets without negatively affecting growth performance or carcass traits compared to 30% DDGS when levels are reduced to 20% for 12 d before market; however, fat iodine values will be significantly increased. Neither commercially available enzyme product had any effect on pig growth performance.

Key words: enzyme, dried distillers grains with solubles

Introduction

Prices of major feed ingredients used in swine diets, such as corn, have risen tremendously in recent years. This has resulted in increased use of alternative feed ingredients

[1] Appreciation is expressed to New Horizon Farms for use of pigs and facilities, to Richard Brobjorg and Marty Heintz for technical assistance, and to Cargill Animal Nutrition for diet formulation.

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like dried distillers grains with solubles (DDGS) to reduce diets costs. Studies have shown that up to 20% DDGS can be effectively used in nursery and grow-finish diets without decreasing performance. However, the continued increase in prices of major feed ingredients in the summer of 2008 and lower pig prices had producers opting to use higher levels of DDGS to further reduce diet costs.

Several factors limit the use of higher levels of DDGS in swine diets. Compared with corn, DDGS has a relatively high CP content but lower digestibility of lysine. This could mean that additional synthetic lysine and other amino acids are needed to achieve the ideal balance of amino acids when high levels of DDGS are used in the diets. Palatability appears to be negatively affected by higher levels of DDGS, as previous studies have shown reductions in feed intake with increasing DDGS level in pig diets. Carcass quality and value also diminish at high DDGS levels. Because DDGS contains high amounts of corn oil, which contains a high percentage of unsaturated fatty acids, pigs fed DDGS tend to have softer fat in their carcasses as measured by increased iodine value (IV).

High amounts of non-starch polysaccharides are also present in DDGS, which can affect its nutritional value. Use of added dietary enzymes is one approach that may aid in non-starch polysaccharide digestion and improve the utilization of fibrous materials in DDGS. In recent studies at Kansas State University (K-State), pigs fed DDGS-containing diets with enzyme supplementation did not show significant improvements in growth performance compared with pigs fed non-enzyme-supplemented diets. However, those studies used relatively low levels of DDGS (15 to 30%). This study was conducted to determine the effects of enzyme supplementation of diets containing high levels of DDGS on the growth performance and carcass characteristics of growing-finishing pigs.

Procedures

This study was approved by and conducted in accordance with the guidelines of the K-State Institutional Animal Care and Use Committee. The trial was conducted in a commercial research finishing barn in southwestern Minnesota. The barns were naturally ventilated and double curtain sided. Pens were 18 × 10 ft with completely slatted flooring and deep pits for manure storage. Each pen contained 1 self-feeder and a cup waterer. The barn was equipped with a robotic feeding system capable of providing and measuring feed amounts on an individual pen basis.

A total of 1,032 pigs (PIC 337 × C22, initially 101.5 lb) were blocked on the basis of BW and allotted to 1 of 7 dietary treatments with 6 pens per treatment. The control treatment was a corn-soybean meal-based diet containing 30% DDGS. The remaining treatments were arranged in a 2 × 3 factorial design based on the level of DDGS (45 or 60%) and enzyme inclusion (none, product A, or product B). Enzymes used were commercial enzymes designed for use in DDGS-containing diets. Diets were fed in 4 phases. During the first 2 wk of the experiment (Phase 1), the 60% DDGS treatments contained only 45% DDGS. Phase 1 was fed from approximately 100 to 128 lb BW. Phase 2 was fed from 128 to 185 lb BW, Phase 3 from 185 to 230 lb BW, and Phase 4 from 230 to 270 lb BW (Table 1). Pigs were weighed every 2 wk from d 0 to 90 to determine ADG. On d 78, 4 of the heaviest pigs from each pen were sold in accordance

with the normal marketing procedure of the farm and DDGS levels were decreased to 20% in all dietary treatments. This adjustment was done to help alleviate the decreased carcass yield impact when pigs are fed high levels of DDGS prior to market. Ractopamine HCL (Paylean; Elanco Animal Health, Greenfield, IN) was added in all dietary treatments from d 78 to 90. Average daily feed intake and F/G were calculated from the feed delivery data generated through the automated feeding system every weigh day.

Pigs were individually tattooed at the end of the trial and transported to JBS Swift and Company (Worthington, MN) for processing and carcass data collection. Standard carcass criteria of loin and backfat depth, HCW, percentage lean, and yield were collected. Fat-free lean index (FFLI) was determined with the following equation: 50.767 + (0.035 × HCW) - (8.979 × backfat). Belly fat samples were collected in 18 randomly selected pigs (6 pigs per treatment) from each of the groups that received dietary treatments without enzyme to determine fat IV. Iodine value analyses were conducted at Barrow-Agee Laboratories, LLC (Memphis, TN) using the cyclohexane-acetic acid method.[4]

Statistical analysis was performed by analysis of variance with the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). Data were analyzed as randomized complete block design with pen as the experimental unit. Backfat, loin depth, percentage lean, and FFLI were adjusted to a common carcass weight. Linear and polynomial contrasts were used to determine the main effects of increasing DDGS. The main effects of enzyme addition and DDGS addition were determined using single degree of freedom contrast and estimate statements.

Results and Discussion

From d 0 to 78, regardless of enzyme treatment, ADG decreased (linear; $P < 0.05$) as DDGS increased because of a reduction (quadratic; $P < 0.04$) in ADFI (Table 2). The greatest reduction in ADFI occurred when DDGS was increased from 30 to 45%, and there was a modest reduction when DDGS was increased from 45 to 60%. There were no differences in weight between treatments before and after topping on d 78. After pens were topped and ractopamine HCl was added to the diets at d 78, ADFI tended to increase (linear; $P < 0.06$) in pigs previously fed 45 and 60% DDGS. The decrease in ADFI from d 0 to 78 resulted in an overall ADFI reduction (linear; $P < 0.04$) with increasing DDGS but did not affect ($P > 0.17$) overall ADG, F/G, or final weight. Pigs fed 30% DDGS had a numerically lower mortality rate than pigs fed the 45 and 60% DDGS, but the difference was not statistically significant. Numerically, the group that was fed 30% DDGS had the highest percentage of pigs sold at full value.

There were no differences in carcass weight and percentage yield ($P > 0.65$) regardless of enzyme treatment or DDGS level (Tables 3 and 4). Although previous research has shown a reduction in carcass yield when DDGS increased in the diets, the reduction of DDGS to 20% during the last 12 d in this study possibly eliminated the negative effect of high DDGS levels on carcass yield. After adjusting to a common carcass weight, there were no differences between treatments for backfat, loin depth, percentage lean, and FFLI ($P > 0.38$). Iodine value of belly fat increased (77.2, 83.7, and 87.3 g/100 g,

[4] AOCS. 1998. Official methods and recommended practices of the AOCS. 5th ed. Am. Oil. Chem. Soc., Champaign, IL. Method Cd 1d-92.

respectively) with increasing dietary DDGS (linear; $P < 0.01$). Overall (d 0 to 90), enzyme supplementation did not affect ADG ($P > 0.24$), ADFI ($P > 0.30$), F/G ($P > 0.53$), or any of the carcass parameters measured ($P > 0.29$) (Table 4).

In this study, added dietary enzymes did not result in any improvements in pig growth performance or carcass characteristics. This is similar to the results of previous studies at K-State in which DDGS-containing diets were supplemented with enzymes. The previous studies had lower levels of DDGS, which might have been insufficient to detect a significant response to enzyme in terms of growth. In this study, however, added dietary enzymes did not improve growth or feed efficiency, even in diets containing 60% DDGS. It is possible that the products used in this study may not have the optimal balance of enzyme activities specific for the substrates present in the DDGS used in the experimental diets. Other factors can also affect the efficacy of the enzyme products, such as the amount of enzyme used, age of the animal, overall nutrient density of the diet, and particle size. All of these could have played a role in limiting or preventing a response to the enzyme from a growth performance standpoint.

Previous studies at K-State indicated that up to 30% DDGS can be added to nursery and grow-finish diets without affecting performance. In this study, reductions in ADFI and ADG were observed as DDGS was increased from 30 to 60% from d 0 to 78. However, no further reductions in ADG and ADFI occurred when DDGS levels were decreased to 20% in all treatments and ractopamine HCl was added to the diets after d 78. These results suggest that decreasing DDGS levels in the diets to 20% for at least 12 d prior to market can help alleviate the negative effects of high levels of DDGS on ADG and ADFI.

The linear increase in IV seen in this experiment was expected. Previous studies conducted at K-State and by other universities have consistently shown a positive correlation between dietary DDGS and IV. This is due to the higher amounts of corn oil, which is high in unsaturated fat (high IV), present in DDGS. Iodine value increased by 10.1 g/100 g in pigs fed 60% DDGS compared to those fed 30%. This is equivalent to a 3.4 g/100 g increase in IV for every 10% increase (from 30 to 60%) in DDGS.

In conclusion, up to 60% DDGS can replace corn in diets for growing-finishing pigs as an option to reduce feed costs. The addition of enzymes, however, had no significant impact on growth and did not improve feed efficiency in growing-finishing pigs. High DDGS levels may slightly inhibit growth, but if finishing spaces are available to accommodate pigs for several more days to meet target weights and as long as the potential savings are greater than the extra space costs, using high levels of DDGS in a grow-finish diet is highly feasible. This study indicates that up to 60% DDGS may be added to pig diets without negatively affecting growth or carcass yield compared to 30% DDGS when levels are reduced to 20% for 12 d before market. However, belly fat IV will be increased and may affect carcass value depending on the market in which the pigs are sold.

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

	Phase 1			Phase 2			Phase 3			Phase 4[3]		
Ingredient[2], %	30% DDGS	45% DDGS	60% DDGS	30% DDGS	45% DDGS	60% DDGS	30% DDGS	45% DDGS	60% DDGS	30% DDGS	45% DDGS	60% DDGS
Corn	46.23	29.50	29.50	49.03	32.43	17.61	52.14	37.66	22.85	60.10	60.10	60.10
Soybean meal (46.5% CP)	16.61	15.40	15.40	14.12	12.84	11.69	10.85	9.68	8.53	11.63	11.63	11.63
Bakery product	6.90	6.90	6.90	6.83	6.83	6.83	5.00	5.00	5.00	6.83	6.83	6.83
Choice white grease	0.24	1.19	1.19	0.00	0.95	1.80	0.00	0.74	1.59	---	---	---
Limestone	0.91	1.07	1.07	0.91	1.07	1.21	1.10	1.06	1.21	0.82	0.82	0.82
Salt	0.21	0.16	0.16	0.21	0.17	0.13	0.28	0.20	0.16	0.24	0.24	0.24
L-threonine	0.03	---	---	0.01	---	---	---	---	---	0.025	0.025	0.025
Stafac	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	---	---	---
L-lysine HCl	0.61	0.61	0.61	0.56	0.57	0.58	0.50	0.51	0.51	0.27	0.27	0.27
DDGS[4]	28.10	45.00	45.00	28.17	45.00	60.00	30.00	45.00	60.00	20.00	20.00	20.00
OptiPhos	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Vitamin-trace mineral premix	0.09	0.09	0.09	0.09	0.09	0.09	0.08	0.08	0.08	0.08	0.08	0.08
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis												
Standardized ileal digestible amino acids												
Lysine, %	1.06	1.08	1.08	0.97	0.99	1.01	0.86	0.87	0.89	0.71	0.71	0.71
Methionine:lysine ratio, %	29	33	33	31	34	38	34	37	41	37	37	37
Met & Cys:lysine ratio, %	60	66	66	63	70	76	69	76	83	76	76	76
Threonine:lysine ratio, %	60	62	62	60	65	69	63	68	74	70	70	70
Tryptophan:lysine ratio, %	16	16	16	16	16	17	16	17	17	19	19	19
Total lysine, %	1.22	1.28	1.28	1.13	1.18	1.23	1.01	1.06	1.11	0.84	0.84	0.84
CP, %	20.1	22.7	22.7	19.1	21.7	24.0	18.2	20.5	22.8	16.7	16.7	16.7
SID Lys:calorie ratio, g/Mcal ME	3.14	3.16	3.16	2.89	2.91	2.92	2.55	2.57	2.59	2.10	2.10	2.10
ME, kcal/lb	1,533	1,551	1,551	1,529	1,547	1,563	1,524	1,541	1,557	1,535	1,535	1,535
Ca, %	0.43	0.49	0.49	0.42	0.48	0.53	0.48	0.47	0.52	0.38	0.38	0.38
P, %	0.46	0.53	0.53	0.45	0.52	0.57	0.45	0.50	0.56	0.41	0.41	0.41
Available P, %	0.30	0.38	0.38	0.30	0.38	0.46	0.30	0.38	0.45	0.25	0.25	0.25

[1] Phases 1, 2, 3, and 4 fed from approximately 100 to 128 lb BW, 128 to 185 lb BW, 185 to 230 lb BW, and 230 to 270 lb BW, respectively.

[2] A commercial enzyme blend containing protease, amylase, xylanase, β-glucanase, pectinase, cellulose, and phytase (Product A) or an experimental proprietary blend of enzymes selected to have maximum activity for the non-starch polysaccharides in DDGS (Product B) was added in diets containing 45 and 60% DDGS in place of corn.

[3] Ractopamine HCl (Paylean, Elanco Animal Health, Greenfield, IN) at 4.5 g/ton was added at the expense of corn.

[4] Diets in the 60% DDGS treatment contained only 45% DDGS during Phase 1 (d 0 to 14).

Table 2. Effects of enzyme supplementation in diets containing high levels of DDGS on growth performance and carcass characteristics of grow-finish pigs[1]

	Treatment								
	30% DDGS	45% DDGS			60% DDGS				
	No enzyme	No enzyme	Product A	Product B	No enzyme	Product A	Product B	SE	Probability, $P <$
Weight, lb									
d 0	101.6	101.6	101.7	101.2	101.5	101.4	101.3	2.8	1.00
d 78 (before topping)	249.8	248.5	247.7	244.6	243.7	247.2	247.3	4.2	0.95
d 78 (after topping)	244.5	243.3	242.7	238.1	238.9	241.5	241.9	4.3	0.94
Tops[2]	274.8	272.9	272.2	277.0	267.5	274.9	272.5	5.0	0.81
d 90[3]	270.9	270.4	270.8	265.3	266.9	269.6	269.7	4.4	0.96
d 0 to 78[4]									
ADG, lb	1.89	1.84	1.85	1.81	1.79	1.84	1.83	0.03	0.33
ADFI, lb	5.12	4.91	4.90	4.76	4.78	4.94	4.83	0.07	0.03
F/G	2.71	2.66	2.65	2.64	2.66	2.68	2.65	0.03	0.70
d 78 to 90[3,5]									
ADG, lb	2.15	2.22	2.29	2.24	2.30	2.30	2.26	0.08	0.83
ADFI, lb	6.11	6.61	6.70	6.40	6.51	6.63	6.57	0.21	0.47
F/G	2.86	3.00	2.93	2.86	2.82	2.87	2.92	0.10	0.83
d 0 to 90[3,5]									
ADG, lb	1.92	1.88	1.90	1.86	1.85	1.89	1.87	0.03	0.64
ADFI, lb	5.24	5.10	5.11	4.95	4.98	5.13	5.03	0.08	0.18
F/G	2.73	2.71	2.68	2.68	2.69	2.71	2.68	0.03	0.88
Pigs removed and marketed, %									
Mortality[6]	2.07	4.13	3.33	3.65	2.14	2.79	4.18	1.71	0.95
Marginal value[7]	0.95	3.08	2.21	2.70	3.62	1.10	2.12	1.52	0.81
Full value[8]	97.05	92.94	94.92	93.07	94.08	96.35	93.75	2.00	0.63

continued

Table 2. Effects of enzyme supplementation in diets containing high levels of DDGS on growth performance and carcass characteristics of grow-finish pigs[1]

	Treatment								
	30% DDGS	45% DDGS			60% DDGS				
	No enzyme	No enzyme	Product A	Product B	No enzyme	Product A	Product B	SE	Probability, $P <$
Carcass characteristics									
Slaughter wt, lb	266.8	266.1	266.6	261.5	263.3	264.0	264.9	4.1	0.97
Carcass wt, lb	201.5	199.1	200.3	198.8	197.8	198.8	198.8	3.3	0.99
Yield, %	75.6	75.0	75.5	75.6	75.2	75.5	74.9	0.4	0.65
Backfat, in.[9]	0.67	0.67	0.67	0.68	0.68	0.70	0.65	0.01	0.44
Loin depth, in.[9]	2.42	2.44	2.44	2.45	2.42	2.40	2.45	0.03	0.93
Lean, %[9]	55.42	55.90	55.92	55.85	55.70	55.36	56.25	0.31	0.40
FFLI[9,10]	50.22	50.28	50.30	50.23	50.17	49.96	50.54	0.17	0.43

[1] A total of 1,032 pigs (PIC 337 × C22), initially 101.5 lb, were used with 24 pigs per pen and 6 replications per treatment.
[2] Removed after weighing on d 78.
[3] Only pigs that were on test up to d 90 (excluding tops) were included in the data analysis.
[4] All pigs that were on test up to d 78 (including tops) were used in the data analysis.
[5] Paylean was added to all dietary treatments from d 78 to 90, and all diets contained 20% DDGS during this 12-d period.
[6] Includes pigs that died, were culled, and were pulled off test during the experiment.
[7] Lightweight pigs sold at the end of the experiment.
[8] Top pigs and pigs that were sold at the end of the experiment excluding lightweight pigs.
[9] Data analyzed using carcass weight as a covariate.
[10] Fat-free lean index.

Table 3. Effects of diets containing high levels of DDGS on growth performance and carcass characteristics of grow-finish pigs[1]

	DDGS, %				Probability, $P <$				
	30	45	60	SE	30 vs. 45	30 vs. 60	45 vs. 60	Linear	Quad
Weight, lb									
d 0	101.6	101.5	101.4	1.6	0.98	0.95	0.97	0.95	1.00
d 78 (before topping)	249.8	247.0	246.1	2.4	0.55	0.43	0.79	0.43	0.77
d 78 (after topping)	244.5	241.3	240.7	2.5	0.53	0.46	0.87	0.46	0.72
Top[2]	274.8	274.0	271.6	3.0	0.89	0.55	0.50	0.55	0.83
d 90[3]	270.9	268.8	268.7	2.5	0.69	0.68	0.98	0.68	0.79
d 0 to 78[4]									
ADG, lb	1.89	1.84	1.82	0.02	0.14	0.05	0.47	0.05	0.45
ADFI, lb	5.12	4.86	4.85	0.04	0.004	0.003	0.87	0.003	0.04
F/G	2.71	2.65	2.66	0.02	0.11	0.18	0.65	0.18	0.17
d 78 to 90[3,5]									
ADG, lb	2.15	2.25	2.29	0.05	0.30	0.15	0.57	0.15	0.64
ADFI, lb	6.11	6.57	6.57	0.12	0.06	0.06	0.99	0.06	0.17
F/G	2.86	2.93	2.87	0.06	0.54	0.94	0.41	0.94	0.41
d 0 to 90[4,6]									
ADG, lb	1.92	1.88	1.87	0.02	0.31	0.17	0.62	0.17	0.61
ADFI, lb	5.24	5.05	5.05	0.05	0.05	0.04	0.92	0.04	0.17
F/G	2.73	2.69	2.69	0.02	0.28	0.31	0.91	0.31	0.41
Pigs removed and marketed, %									
Mortality[6]	2.07	3.70	3.04	0.99	0.41	0.62	0.63	0.62	0.42
Marginal value[7]	0.95	2.66	2.28	0.90	0.33	0.43	0.74	0.43	0.39
Full value[8]	97.05	93.64	94.73	1.17	0.14	0.29	0.47	0.29	0.16

continued

Table 3. Effects of diets containing high levels of DDGS on growth performance and carcass characteristics of grow-finish pigs[1]

	DDGS, %				Probability, $P <$				
	30	45	60	SE	30 vs. 45	30 vs. 60	45 vs. 60	Linear	Quad
Carcass characteristics									
Slaughter wt, lb	266.8	264.7	264.1	2.5	0.67	0.57	0.85	0.57	0.84
Carcass wt, lb	201.5	199.4	198.5	2.0	0.58	0.42	0.72	0.42	0.82
Yield, %	75.6	75.4	75.2	0.2	0.63	0.37	0.55	0.37	0.96
Backfat, in	0.67	0.67	0.68	0.01	0.95	0.83	0.71	0.83	0.82
Loin depth, in	2.42	2.44	2.42	0.02	0.57	0.97	0.46	0.97	0.44
Lean, %	55.42	55.9	55.8	0.2	0.20	0.33	0.65	0.33	0.26
FFLI[9]	50.22	50.3	50.2	0.1	0.81	0.98	0.76	0.98	0.75
Belly fat iodine value, g/100 g[10]	77.2	83.7	87.3	1.8	---	---	---	0.002	0.54

[1] A total of 1,032 pigs (PIC 337 × C22), initially 101.5 lb, were used with 24 pigs per pen and 6 replications per treatment.
[2] Removed after weighing on d 78.
[3] Only pigs that were on test up to d 90 (excluding tops) were included in the data analysis.
[4] All pigs that were on test up to d 78 (including tops) were used in the data analysis.
[5] Paylean was added to all dietary treatments from d 78 to 90, and all diets contained 20% DDGS during this 12-d period.
[6] Includes pigs that died, were culled, and were pulled off test during the experiment.
[7] Lightweight pigs sold at the end of the experiment.
[8] Top pigs and pigs that were sold at the end of the experiment excluding lightweight pigs.
[9] Fat-free lean index.
[10] Values are means of 6 observations per treatment taken from each level of the non-enzyme-supplemented DDGS treatment.

Table 4. Effects of enzyme supplementation on growth performance and carcass characteristics of grow-finish pigs (main effects)[1]

	Enzyme[2]				Probability, *P* <		
	No	Product A	Product B	SE	No vs. Enzyme	No vs. Product A	No vs. Product B
Weight, lb							
d 0	101.5	101.5	101.2	2.0	0.94	1.00	0.91
d 78 (before topping)	246.1	247.4	246.0	3.0	0.87	0.75	0.97
d 78 (after topping)	241.1	242.1	240.0	3.0	0.99	0.82	0.80
Top[3]	270.2	273.5	274.7	3.7	0.29	0.45	0.31
d 90[4]	268.6	270.2	267.5	3.1	0.95	0.72	0.81
d 0 to 78[5]							
ADG, lb	1.82	1.85	1.82	0.02	0.48	0.28	0.93
ADFI, lb	4.85	4.92	4.80	0.05	0.84	0.30	0.49
F/G	2.66	2.66	2.64	0.02	0.73	0.98	0.53
d 78 to 90[4,6]							
ADG, lb	2.26	2.30	2.25	0.06	0.83	0.64	0.92
ADFI, lb	6.56	6.67	6.48	0.15	0.95	0.60	0.68
F/G	2.91	2.90	2.89	0.07	0.80	0.88	0.77
d 0 to 90[4,6]							
ADG, lb	1.87	1.90	1.87	0.02	0.45	0.24	0.92
ADFI, lb	5.04	5.12	4.99	0.06	0.84	0.30	0.49
F/G	2.70	2.69	2.68	0.02	0.69	0.95	0.53
Pigs removed and marketed, %							
Mortality[7]	3.14	3.06	3.92	1.22	0.81	0.96	0.65
Marginal value[8]	3.35	1.65	2.41	1.11	0.27	0.23	0.51
Full value[9]	93.51	95.64	93.41	1.45	0.52	0.25	0.96
Carcass characteristics							
Slaughter wt, lb	264.7	265.3	263.2	3.2	0.91	0.89	0.73
Carcass wt, lb	198.5	199.5	198.8	2.5	0.80	0.74	0.92
Yield, %	75.1	75.5	75.3	0.3	0.41	0.29	0.70
Backfat, in.	0.68	0.69	0.66	0.01	0.79	0.60	0.33
Loin depth, in.	2.43	2.42	2.44	0.02	0.92	0.74	0.61
Lean, %	55.8	55.6	56.1	0.2	0.88	0.62	0.45
FFLI[10]	50.2	50.1	50.4	0.1	0.84	0.59	0.38

[1] A total of 1,032 pigs (PIC 337 × C22), initially 101.5 lb, were used with 24 pigs per pen and 6 replications per treatment.
[2] No = means of 45% DDGS and 60% DDGS treatments without enzyme; A = means of 45% DDGS + Product A and 60% DDGS + Product A; B = means of 45% DDGS + Product B and 60% DDGS + Product B.
[3] Removed after weighing on d 78.
[4] Only pigs that were on test up to d 90 (excluding tops) were included in the data analysis.
[5] All pigs that were on test up to d 78 (including tops) were used in the data analysis.
[6] Paylean was added to all dietary treatments from d 78 to 90, and all diets contained 20% DDGS during this 12-d period.
[7] Includes pigs that died, were culled, and were pulled off test during the experiment.
[8] Lightweight pigs sold at the end of the experiment.
[9] Top pigs and pigs that were sold at the end of the experiment excluding lightweight pigs.
[10] Fat-free lean index.

Effects of Mycotoxin Binders and a Liquid Immunity Enhancer on the Growth Performance of Wean-to-Finish Pigs[1]

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Summary

A total of 1,120 pigs (PIC 337 × C22, initial BW = 16.0 lb) were used in a study to evaluate the effects of 2 commercial mycotoxin binders and a liquid immunity enhancer product on growth performance of wean-to-finish pigs. Pigs were randomly assigned to 1 of 4 treatments balanced by initial average BW within gender with 10 replicate pens per treatment. Treatments were: (1) control standard phase-fed diets based on corn and soybean meal with DDGS (20 to 35%) fed for 132 d, (2) a control diet with mycotoxin binders Biomannan fed from d 0 to 55 and T-BIND fed from d 0 to 132, (3) a control diet with Biomannan and T-BIND fed from d 0 to 132, and (4) Treatment 3 with a liquid immunity enhancer product administered through the water lines of pens continuously for 7 d every 3 wk. Both mycotoxin binders and the liquid immunity enhancer product were provided by Biotech Development Company, Inc. (Dexter, MO). The mycotoxin binder products were added in the diets at the expense of corn. Pigs from each pen were weighed as a group and feed disappearance was determined every 2 wk to determine ADG, ADFI, and F/G. Results of laboratory analysis showed that all mycotoxins tested in diet samples were below the practical quantitation limit. Overall, there were no treatment × sex interactions ($P > 0.50$). As expected, gender differences were noted as barrows had greater ($P < 0.01$) ADG and ADFI but poorer ($P < 0.05$) F/G than gilts. The addition of mycotoxin binders and liquid immunity enhancer product did not affect growth performance ($P > 0.73$) as all treatment groups had similar performance during the nursery ($P > 0.28$) and growing-finishing stages ($P > 0.61$). Under the conditions of the present study, the products tested had no effect on growth performance of wean-to-finish pigs.

Key words: growth, mycotoxin binder

Introduction

Grains such as corn are susceptible to mold growth, particularly when exposed to high moisture coupled with poor handling and storage procedures. Although molds do not necessarily affect pigs' health, molds can produce mycotoxins that can have negative effects. Mycotoxins are substances that can cause a variety of problems in growing-finishing pigs including decreased feed intake, weight loss, and poor performance. They also can suppress the pig's immune system, which predisposes them to infectious diseases. Thus, keeping pig diets free of mycotoxins or within tolerable levels requires good production practices to avoid problems that may arise from consumption of

[1] Appreciation is expressed to Biotech Development Company, Inc., Dexter, MO, for supplying the test products, New Horizon Farms for use of pigs and facilities, and Richard Brobjorg and Marty Heintz for technical assistance.

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contaminated grains. Mycotoxins are not visible to the naked eye, and detection in grains or feeds requires specific equipment, making on-farm detection difficult. Also, only small levels (measured in ppm or ppb) are required for mycotoxins to exert a negative effect on pigs.

Mycotoxin binders are substances that have the ability to bind mycotoxins and prevent their absorption in the gut when added in the diet. The most common substances used as mycotoxin binders are adsorbent clays such as bentonite. Yeast cell wall polysaccharides, such as β-glucans, also have been shown to adsorb various mycotoxins in addition to their known stimulatory effect on mucosal immunity. The use of mycotoxin binders in swine diets has received more attention as the use of dried distillers grains with solubles (DDGS) has become more widespread. Concerns have been raised recently regarding the possibility of DDGS having more concentrated mycotoxins (as much as 3 times) than the main grain source it originated from.

Also, with more emphasis on production efficiency, tools that can aid in disease prevention without compromising consumer health and the environment are receiving more attention. Thus, a wide array of natural products, such as organic acids and other phytogenic feed additives, that may help protect pigs from infectious agents are becoming more available. One such product is ARNAp (Biotech Development Co., Inc., Dexter, MO), which is a natural multi-use product that contains dried citrus pulp extract, vitamin C, and organic acids. It is marketed for use in pigs as an aid to strengthen the immune system and protect the pig from common infectious agents.

We conducted this study to determine the effect of two commercial mycotoxin binders and a liquid immunity enhancer product added to drinking water on growth performance of growing-finishing pigs fed diets containing DDGS.

Procedures

This study was approved by and conducted in accordance with the guidelines of the Kansas State University Institutional Animal Care and Use Committee. The experiment was conducted in a commercial research finishing barn in southwestern Minnesota. The barns were naturally ventilated and double curtain sided. Pens had completely slatted flooring and deep pits for manure storage. Each pen was equipped with a 5-hole stainless steel dry self-feeder and a cup waterer for ad libitum access to feed and water. Daily feed additions to each pen were accomplished through a robotic feeding system capable of providing and measuring feed amounts on an individual pen basis.

A total of 1,120 pigs (PIC 337 × C22, initial BW = 16.0 lb) were randomly assigned to 1 of 4 treatments balanced by average BW within gender. There were 10 single-gender pens (5 pens of barrows and 5 pens of gilts) per treatment with 28 pigs per pen. Treatments were: (1) control standard phase-fed diets based on corn and soybean meal with DDGS (20 to 35%) fed for 132 d, (2) a control diet with mycotoxin binders Biomannan fed from d 0 to 55 and T-BIND fed from d 0 to 132, (3) a control diet with T-BIND and Biomannan fed from d 0 to 132, and (4) Treatment 3 with ARNAp, a liquid immunity enhancer product, administered at 500 ppm through the water lines of pens continuously for 7 d every 3 wk. The mycotoxin binder products were added in the diets at the expense of corn. T-BIND is a blend of hydrated sodium calcium alumi-

nosilicates, and Biomannan is a natural mannan-based oligosaccharide and glucose fermentation product. ARNAp is a natural multi-use product that contains dried citrus pulp extract, vitamin C, and organic acids. It is being marketed for use in swine to help the immune system fight against common infectious agents. Both mycotoxin binders and the liquid immunity enhancer product were provided by a single manufacturer (Biotech Development Company, Inc., Dexter, MO). Pigs from each pen were weighed as a group and feed disappearance was determined every 2 wk to determine ADG, ADFI, and F/G. Control nursery and finishing diet samples were submitted for a complete mycotoxin analysis at the Veterinary Diagnostic Laboratory at North Dakota State University, Fargo.

Statistical analysis was performed by analysis of variance using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). Data were analyzed as a completely randomized design with pen as the experimental unit. The main effects of the different treatment regimens, gender, and their interaction were tested.

Results and Discussion

Results of the laboratory analysis showed that all mycotoxins tested in both diet samples were below the practical quantitation limit (Table 1). Overall, there were no treatment × sex interactions ($P > 0.50$; Table 2). Growth performance of barrows and gilts was similar ($P > 0.59$) during the nursery stage. However, barrows exhibited greater ($P < 0.01$) ADG and ADFI with poorer ($P < 0.02$) F/G during the finishing stage than gilts. Overall, barrows had greater ($P < 0.01$) ADG and ADFI but poorer ($P < 0.02$) F/G than gilts. The addition of the mycotoxin binders or the liquid immunity enhancer product did not affect growth performance of the pigs in the nursery stage (d 0 to 55; $P > 0.28$), growing-finishing stage (d 55 to 132; $P > 0.61$), or overall (d 0 to 132; $P > 0.73$).

In this experiment, the mycotoxin binders and liquid immunity enhancer product used had no effect on growth performance of wean-to-finish pigs. However, it should be noted that the pigs used in this study had good health status during the entire course of the experiment. Also, all mycotoxins tested from feed samples were found to be well below the suggested cautionary levels. Therefore, in the absence of mycotoxin contamination and disease challenge, no beneficial effects were realized from the use of the products evaluated.

Table 1. Analyzed mycotoxin content (ppm) in diet samples (as-fed)[1]

Mycotoxin	Nursery diet[2]	Finishing diet[3]
Aflatoxin B1	<0.02	<0.02
Fumonisin B1	<2.0	<2.0
T-2 toxin	<0.5	<0.5
Vomitoxin	<0.5	<0.5
Zearalenone	<0.5	<0.5

[1] Major mycotoxins affecting feedstuffs commonly used in swine diets. Diet samples were submitted for a complete mycotoxin analysis at the Veterinary Diagnostic Laboratory at North Dakota State University, Fargo.
[2] The nursery diet was sampled 3 times during this portion of the study, and a composite sample was sent for analysis.
[3] The finishing diet was sampled 4 times during this portion of the study, and a composite sample was sent for analysis.

Table 2. Effect of mycotoxin binders and a liquid immunity enhancer on growth performance of wean-to-finish pigs[1]

	Treatment					Sex			Probability, *P* <		
	1	2	3	4							
T-BIND[2,3]:	-	+	+	+							
Biomannan (d 0 to 55)[2,4]:	-	+	+	+							
Biomannan (d 55 to 132)[2,5]:	-	-	+	+							
ARNAp[6]:	-	-	-	+	SEM	Barrow	Gilt	SEM	Treatment × sex	Treatment	Sex
Weight, lb											
d 0	15.9	16.0	16.1	15.9	0.26	16.0	15.9	0.18	0.95	0.94	0.57
d 55	85.7	87.1	87.1	88.4	1.21	86.9	87.2	0.86	0.62	0.50	0.81
d 132	233.0	234.0	234.6	235.3	1.44	237.3	231.1	1.02	0.77	0.73	0.0001
d 0 to 55											
ADG, lb	1.26	1.29	1.29	1.32	0.019	1.29	1.29	0.013	0.58	0.28	0.73
ADFI, lb	2.10	2.09	2.11	2.13	0.043	2.10	2.12	0.030	0.98	0.94	0.59
F/G	1.66	1.62	1.64	1.61	0.024	1.63	1.64	0.017	0.87	0.56	0.71
d 55 to 132											
ADG, lb	1.91	1.89	1.91	1.90	0.020	1.94	1.86	0.014	0.50	0.93	0.0004
ADFI, lb	4.93	4.93	4.98	4.97	0.046	5.11	4.80	0.032	0.61	0.76	<.0001
F/G	2.58	2.60	2.61	2.62	0.022	2.63	2.58	0.015	0.98	0.61	0.02
d 0 to 132											
ADG, lb	1.64	1.64	1.65	1.65	0.011	1.67	1.62	0.008	0.73	0.73	0.0004
ADFI, lb	3.74	3.74	3.78	3.78	0.037	3.84	3.67	0.026	0.81	0.77	<.0001
F/G	2.28	2.28	2.29	2.28	0.019	2.31	2.26	0.013	0.95	0.96	0.02

[1] A total of 1,120 pigs (PIC 337 × C22, initial BW = 16.0 lb) were used with 28 pigs per and 10 replications per treatment.
[2] Biotech Development Company, Inc., Dexter, MO.
[3] Added in all dietary phases at 4 lb/ton in place of corn.
[4] Added in the diet at 4 lb/ton in place of corn and fed during the nursery stage.
[5] Added in the diet at 1 lb/ton in place of corn and fed during the finishing stage.
[6] A liquid immune system enhancer product added to drinking water continuously for 7 days at 3-wk intervals starting at d 21.

Effect of a Commercial Enzyme (Nutrase) on Growth Performance of Growing Pigs Fed Diets Containing Dried Distillers Grains with Solubles[1]

J. Y. Jacela[2], S. S. Dritz[2], J. M. DeRouchey, M. D. Tokach, R. D. Goodband, and J. L. Nelssen

Summary

A total of 1,076 pigs (PIC 337 × C22, initially 87.4 lb) were used to determine the effect of a commercial enzyme product on the growth performance of pig fed diets containing dried distillers grains with solubles (DDGS). Pigs were randomly allotted to 1 of 3 treatments balanced by average initial BW within gender. There were 13 replicate pens (7 barrow and 6 gilt pens) per treatment. Treatments included: (1) diet with 3% added fat (control); (2) diet supplemented with enzyme with only 2% added fat but formulated to have an energy content equal to that of the control diet on the basis of calculated increased ME from the enzyme (Nutrase; Nutrex, Lille, Belgium); and (3) diet with 2% added fat without enzyme formulated using the same energy values for the control diet (low energy). Diets were corn-soybean meal-based, contained DDGS, and were fed in 3 phases (87 to 130 lb, 130 to 185 lb, and 185 to 210 lb BW for Phases 1, 2, and 3, respectively). Thirty percent DDGS was included in diets from 87 to 185 lb, and 15% DDGS was included in the last phase from 187 to 210 lb. The control and Nutrase dietary treatments were balanced to a constant lysine:calorie ratio at 2.69, 2.29, and 1.97 g/Mcal ME for Phases 1, 2, and 3, respectively, whereas the low energy dietary treatment had calculated lysine:calorie ratios of 2.73, 2.32, and 2.00 g/Mcal ME for Phases 1, 2, and 3, respectively. There were no treatment × gender interactions ($P > 0.25$) observed for any response criteria evaluated. The expected differences ($P > 0.03$) in growth performance between barrows and gilts were observed in all periods and overall. Barrows had greater ADG, ADFI, and final weight but poorer F/G compared with gilts. Except for the poorer F/G ($P < 0.01$) of pigs fed the enzyme treatment compared with pigs fed diets without enzyme from d 0 to 28, there were no differences among treatments for ADG ($P > 0.70$), ADFI ($P > 0.77$), and F/G ($P > 0.66$) at any of the periods or for the overall study. In conclusion, under the conditions of the present experiment, the commercial enzyme used at the manufacturer's recommended level did not affect growth performance of growing pigs fed diets containing DDGS.

Key words: dried distillers grains with solubles, enzyme

Introduction

A considerable number of studies have shown that dried distillers grains with solubles (DDGS) can be a suitable replacement for a portion of the corn and soybean meal commonly used in swine diets. Adding up to 30% DDGS in nursery and grow-finish

[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] Food Animal Health and Management Center, College of Veterinary Medicine, Kansas State University.

diets can result in growth performance similar to that of pigs fed corn-soybean meal-based diets. However, DDGS inclusion levels greater than 30% can have negative effects on both performance and carcass quality[3]. One factor that limits the use of DDGS in swine diets is its high fiber content. High-fiber feedstuffs such as DDGS contain non-starch polysaccharides (NSP), which are referred to as anti-nutritional factors because of their negative effects on the digestibility of energy and other nutrients such as amino acids.

Because pigs lack the enzymes to break down NSP, the use of exogenous enzymes to maximize nutrient utilization from high-fiber feedstuffs has been evaluated in numerous studies, mostly in diets containing wheat or barley, with mixed results. The inconsistent results obtained from these trials may be due to a number of factors including the substrate present in the ingredient and the use of appropriate enzymes. Enzymes are known to act on specific substrates. In theory, there should be enough substrate for the specific enzyme used to achieve a measurable response. Corn DDGS, for example, has been found to contain appreciable amounts of arabinoxylans, a major NSP found in most grains. Thus, an enzyme containing xylanase activity that can break down arabinoxylans may aid in improving the digestibility of nutrients in corn DDGS. Available energy also can be potentially increased with enzyme supplementation. Thus, energy source ingredients such as added fat can be reduced in the diets and still meet the targeted energy level of the diet because of the expected uplift in energy value resulting from the addition of enzyme. This also can have a significant impact on economics by reducing the overall diet cost. Therefore, we conducted this study to determine the energy replacement value and effect of a commercial enzyme product containing bacterial endo-1,4-beta-xylanase on the growth performance of growing pigs fed diets containing DDGS.

Procedures

Procedures used in this experiment were approved by the Kansas State University Institutional Animal Care and Use Committee. The trial was conducted in a commercial swine research facility in southwestern Minnesota. The barns were naturally ventilated and double curtain sided. Pens were 18 × 10 ft with completely slatted flooring and deep pits for manure storage. Each pen was equipped with a self-feeder and a cup waterer. The barn had an automated feeding system (FeedPro; Feedlogic Corp., Willmar, MN) capable of delivering and recording feed amounts on an individual pen basis.

A total of 1,076 pigs (PIC 337 × C22), initially 87.4 lb, were randomly allotted to 1 of the 3 treatments balanced by average BW within gender. There were 27 pigs per pen and 13 replicate pens (7 barrow and 6 gilt pens) per treatment. A diet with 3% added fat (control) was formulated using NRC (1998[4]) values for ME of corn and soybean meal (1,551 and 1,533 kcal ME/lb, respectively; Tables 1 and 2). Note that for DDGS, we did not use NRC (1998) ME values to formulate the diets but rather an ME value equal to that of corn. As directed by the manufacturer of the enzyme product tested in this study, an increased ME value was calculated for corn, soybean meal, and DDGS to account for the expected increase in ME with the addition of enzyme (Table 1). This

[3] Stein, H. H., and G. C. Shurson. 2009. Board-invited review: The use and application of distillers dried grains with solubles in swine diets. J. Anim. Sci. 87(4):1292-1303.
[4] NRC. 1998. Nutrient Requirements of Swine. 10th rev. ed. Natl. Acad. Press, Washington, DC.

was based on the assumption that the addition of enzyme will increase the energy value of the ingredients. Using the calculated increased ME values, dietary fat was removed proportionately in the second dietary treatment with added enzyme (Nutrase) so that the dietary energy value was similar to the control diet. The enzyme evaluated in the experiment was a commercial product containing bacterial endo-1,4-beta-xylanase (Nutrase; Nutrex, Lille, Belgium) added at the expense of corn. A third diet similar to the Nutrase diet with 2% added fat but without added enzyme (low energy) was formulated on the basis of the ME values used in the control diets. Thus, the calculated dietary energy content was lower than that of the control and Nutrase diets (Table 2). Diets were corn-soybean meal-based, contained DDGS, and were fed in 3 phases (87 to 130 lb, 130 to 185 lb, and 185 to 210 lb BW for Phases 1, 2, and 3, respectively). Thirty percent DDGS was included in diets from 87 to 185 lb, and 15% DDGS was included in the last phase from 187 to 210 lb. The control and Nutrase dietary treatments were balanced to a constant lysine:calorie ratio at 2.69, 2.29, and 1.97 g/Mcal ME for Phases 1, 2, and 3, respectively, whereas the low energy dietary treatment had calculated lysine:calorie ratios of 2.73, 2.32, and 2.00 g/Mcal ME for Phases 1, 2, and 3, respectively.

Pigs from each pen were weighed as a group every 2 wk to determine ADG. Feed delivery data generated through the automated feeding system every weigh day were used to calculate feed consumption per pen and determine ADFI and F/G.

Statistical analysis was performed by analysis of variance with the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). Data were analyzed as a completely randomized design with pen as the experimental unit. The main effects of dietary treatment and gender as well as their interactions were tested.

Results and Discussion

There were no treatment × gender interactions ($P > 0.25$) observed for any criteria evaluated at any time during the experiment. The expected differences ($P > 0.03$) between genders were observed in all periods and overall as barrows exhibited greater ADG, ADFI, and final weight but poorer F/G than gilts (Table 3).

With the exception of poorer F/G ($P < 0.01$) from d 0 to 28 of pigs fed the enzyme treatment compared with pigs fed diets without enzyme, there were no differences for ADG ($P > 0.70$), ADFI ($P > 0.77$), and F/G ($P > 0.66$) in all periods or the overall study. It is not clear what contributed to the poor F/G of pigs fed the enzyme treatment during the first period. We believe this may have been due to random variability. We were also unable to detect a significant improvement in F/G in pigs fed the 3% added fat diets compared with pigs fed 2% added fat. Thus, even though pigs fed diets with enzyme performed similarly to pigs fed the basal diets, we were unable to conclude that the addition of enzyme was able to increase the energy value of the diets because pigs fed the low energy diets also performed similarly to the control pigs.

The absence of an enzyme effect on growth performance of growing pigs relative to pigs fed the low energy diets in this experiment is similar to results we observed in our previous studies with different enzyme products. In the past, we performed several experiments that used combinations of enzymes in an attempt to improve the nutritional

value of corn-soybean meal-based diets with added DDGS. We did not observe a positive response in pig performance in these previous studies. A number of other researchers have suggested that other factors can contribute to the effect of enzymes, such as enzyme dose and amount of substrate in the actual diet. It is worth mentioning that before conducting the trial, corn DDGS samples used in diets from a previous enzyme experiment were analyzed to quantify the arabinoxylan content. These samples were obtained from the same source as the DDGS used for the present trial. Results of the analysis showed that corn DDGS contains a considerable amount of total arabinoxylans (11.1% of DM). Theoretically, because an enzyme product with xylanase activity was used, an improvement in the nutrient value of the DDGS used in this trial and, consequently, an improvement in growth performance should be possible. However, this was not the case in the present study, even at the manufacturer's recommended usage level of the enzyme product. Therefore, under the conditions of the present experiment, we conclude that the enzyme product used did not affect growth performance of growing pigs fed diets containing DDGS.

Table 1. Metabolizeable energy values used for diet formulation

Ingredient	Control[1]	Nutrase[2]
Corn	1,551	1,576
Soybean meal	1,533	1,546
Dried distillers grains with solubles	1,551	1,576

[1] Based on NRC (1998) values, except for DDGS, which was assigned an ME value equal to corn NRC (1998) value.
[2] Calculated uplift values for ME when enzyme was added as recommended by the manufacturer based on arabinoxylan content.

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

	Phase 1		Phase 2		Phase 3	
Ingredient, %	Control	Low energy	Control	Low energy	Control	Low energy
Corn	49.42	50.60	53.82	55.00	70.47	71.60
Soybean meal (46.5% CP)	15.60	15.50	11.22	11.15	9.72	9.65
Dried distillers grains with solubles	30.00	30.00	30.00	30.00	15.00	15.00
Choice white grease	3.00	1.92	3.00	1.92	3.00	1.92
Limestone	1.08	1.08	1.10	1.10	1.00	1.00
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin and trace mineral premix	0.10	0.10	0.10	0.10	0.10	0.10
Phytase[3]	0.0075	0.0075	0.006	0.006	0.0125	0.0125
L-lysine HCl	0.45	0.45	0.40	0.40	0.35	0.35
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis						
Standardized ileal digestible (SID) amino acids, %						
Lysine	0.94	0.94	0.80	0.80	0.69	0.69
Isoleucine:lysine ratio	69	69	72	72	68	69
Leucine:lysine ratio	186	187	206	207	196	198
Methionine:lysine ratio	33	33	36	36	34	34
Met & Cys:lysine ratio	66	66	73	73	70	70
Threonine:lysine ratio	63	63	67	67	63	63
Tryptophan:lysine ratio	17	17	17	17	17	17
Valine:lysine ratio	83	83	89	89	85	85
Total lysine, %	1.10	1.10	0.95	0.95	0.80	0.80
MD, kcal/lb	1,586	1,564	1,587	1,565	1,589	1,566
SID lysine:ME ratio, g/Mcal	2.69	2.73	2.29	2.32	1.97	2.00
Ca, %	0.49	0.49	0.48	0.48	0.44	0.44
P, %	0.46	0.46	0.44	0.44	0.37	0.37
Available P, %	0.29	0.29	0.27	0.27	0.23	0.23

[1] Phases 1, 2, and 3 fed from approximately 87 to 130 lb, 130 to 185 lb, and 185 to 210 lb BW, respectively.
[2] A commercial enzyme product containing bacterial endo-1,4-beta-xylanase (Nutrase) replaced corn in the low energy diet at 0.25 lb/ton to make the third dietary treatment.
[3] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN); provided 136, 109, and 227 phytase units per pound of diet in Phases 1, 2, and 3, respectively.

Table 3. Effect of a commercial enzyme product and gender on performance of growing pigs[1,2]

	Treatment				Gender			Probability, $P <$ [3]	
Item	Low control	High control	Enzyme	SEM	Barrows	Gilts	SEM	Treatment	Gender
Weight									
d 0	87.2	87.6	87.3	2.08	87.8	86.9	1.76	0.99	0.71
d 28	138.0	138.6	137.6	2.65	139.6	136.5	2.25	0.97	0.33
d 66	209.8	210.2	208.0	3.25	213.9	204.8	2.75	0.88	0.02
d 0 to 28									
ADG, lb	1.81	1.82	1.79	0.031	1.85	1.77	0.026	0.80	0.03
ADFI, lb	3.89	3.88	3.96	0.081	4.05	3.77	0.069	0.77	0.01
F/G	2.15[a]	2.13[a]	2.21[b]	0.017	2.19	2.13	0.014	0.01	0.003
d 28 to 66									
ADG, lb	1.83	1.79	1.81	0.032	1.87	1.75	0.027	0.70	0.001
ADFI, lb	5.25	5.19	5.18	0.084	5.50	4.91	0.072	0.82	<0.0001
F/G	2.87	2.90	2.86	0.037	2.94	2.81	0.031	0.66	0.01
d 0 to 66									
ADG, lb	1.82	1.80	1.80	0.026	1.86	1.76	0.022	0.86	0.001
ADFI, lb	4.66	4.62	4.65	0.075	4.87	4.42	0.064	0.93	<0.0001
F/G	2.56	2.56	2.58	0.021	2.62	2.52	0.018	0.88	0.0003

[1] A total of 1,076 pigs (PIC 337 × C22, initially 87.4 lb) were used with 27 pigs per pen and 13 replications per treatment.
[2] Bacterial endo-1,4-beta-xylanase (Nutrase; Nutrex, Lille, Belgium).
[3] Treatment × gender interactions for all criteria were not significant ($P > 0.05$).
[ab] Within a row, means without a common superscript differ ($P < 0.05$).

Effects of an Enzyme Blend (Livestock Answer) in Diets Containing Dried Distillers Grains with Solubles on Growth Performance of Nursery and Finishing Pigs

J. M. Benz, J. L. Nelssen, J. M. DeRouchey, M. D. Tokach, R.D. Goodband, and S. S. Dritz[1]

Summary

Two trials were conducted to determine the effects of an enzyme blend (Livestock Answer; Environmental Care and Share, Golden, CO) on growth performance of nursery and wean-to-finish pigs. Livestock Answer contains amylases, cellulases, proteases, lipases, and phytases. In Exp. 1, a total of 180 pigs (PIC TR4 × 1050, initially 12.3 lb and 21 d old) were used in a 28-d trial. Pigs were blocked by weight and allotted at weaning to 1 of 3 enzyme levels (0%, 0.125%, and 0.175%). There were 6 pigs per pen and 10 replications per treatment. Diets were corn-soybean meal based and contained 15% dried distillers grains with solubles (DDGS) during Phase 1 (d 0 to 14) and 25% DDGS during Phase 2 (d 14 to 28). From d 0 to 14, increasing enzyme level improved ADG (quadratic; $P = 0.04$) and F/G (linear; $P = 0.05$) and tended to improve ($P < 0.07$) ADFI and pig weight on d 14. From d 14 to 28, enzyme level had no effect ($P > 0.20$) on ADG or ADFI but worsened F/G (quadratic; $P = 0.04$). Pigs fed an enzyme blend for the first 14 d after weaning had improved growth performance. However, over the entire 28-d nursery period, enzyme level had no effect ($P > 0.22$) on pig performance. In Exp. 2, a total of 224 nursery pigs (PIC TR4 ×1050, initially 13.4 lb and 21 d of age) were blocked by weight and allotted to 1 of 4 treatments. There were 8 pigs per pen and 7 pens per treatment. Livestock Answer was added at 0.125% to either the nursery or finisher stage or both in a 2 × 2 factorial arrangement (with and without in nursery and with and without in finisher). Diets were corn-soybean meal based and contained 15% DDGS from d 0 to 14, 25% DDGS from d 14 to 35, and 30% DDGS from d 35 to d 126. On d 126, pigs were harvested and carcass data were collected. Adding the enzyme to nursery, finishing, and nursery and finishing combined diets containing DDGS did not influence ($P > 0.20$) ADG, ADFI, F/G, or any of the carcass criteria measured in Exp 2.

Key words: dried distillers grains with solubles, enzyme

Introduction

With recent feed price volatility, greater emphasis has been placed on improving feed efficiency. Enzymes have been used extensively in European swine diets, which contain more fibrous feedstuffs than traditional corn-based diets in the United States. Dried distillers grains with solubles (DDGS) have been incorporated into swine diets to reduce cost. Because DDGS are more fibrous than corn, feeding enzymes in DDGS-containing diets may be beneficial. Livestock Answer (Environmental Care and Share, Golden, CO) is a blend of 17 enzymes including amylases, lipases, proteases, cellulases,

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and phytases. Because limited data are available on the impact of this enzyme blend on pig performance, we conducted 2 experiments to determine the effect of Livestock Answer on growth performance of nursery and wean-to-finish pigs.

Procedures

Experiment 1

A total of 180 nursery pigs (12.3 lb and 21 d of age) were blocked by weight at weaning and allotted to 1 of 3 dietary treatments. There were 6 pigs per pen and 10 pens per treatment. The 3 dietary treatments were a control diet without enzyme and the control diet with 0.125% or 0.25% Livestock Answer. Corn-soybean meal-based diets were fed in 2 phases; Phase 1 diets contained 15% DDGS, and Phase 2 diets contained 25% DDGS (Table 1). Phases 1 and 2 were from d 0 to 14 and d 14 to 28, respectively. Diets did not contain an antibiotic and were fed in meal form.

Each pen contained 1 self-feeder and 1 nipple waterer to provide ad libitum access to feed and water. Pens were 5 × 5 ft. Pigs were weighed and feed disappearance was determined on d 0, 7, 14, 21, and 28 to calculate ADG, ADFI, and F/G.

Experiment 2

A total of 224 nursery pigs (13.4 lb and 21 d of age) were blocked by weight and allotted to 1 of 4 dietary treatments. There were 8 pigs per pen and 7 pens per treatment. Livestock Answer (0.125%) was added to the diets in either the nursery or finisher stage or both to complete the 2 × 2 factorial arrangement of treatments (with and without in nursery and with and without in finisher).

Diets were corn-soybean meal based and contained 15% DDGS from d 0 to 14, 25% DDGS from d 14 to 35, and 30% DDGS from d 35 to d 145 (end of the trial; Table 2). Diets did not contain an antibiotic and were fed in meal form.

Pigs were housed in a nursery in 5- × 5-ft pens from d 0 to 35. On d 35, pigs were moved to a finishing facility, where they were housed in 8- × 10-ft pens for the remainder of the trial. Feed delivery to each pen was measured daily. Pigs and feeders were weighed on d 7, 14, 21, 28, and 35 in the nursery and every 2 wk in the finisher to calculate ADG, ADFI, and F/G. On d 126, the heaviest 2 pigs from each pen were removed and marketed. Remaining pigs were marketed on d 145 after weaning. Carcass data including HCW, yield, backfat, loin depth, and percentage lean were collected.

Data were analyzed using the PROC MIXED procedure of SAS (SAS Institute Inc., Cary, NC) with pen as the experimental unit for all analysis. In Exp. 1, the linear and quadratic effect of Livestock Answer was tested. In Exp. 2, there were 14 replications of the 2 dietary treatments being fed during the nursery portion of the trial (d 0 to 35) and 7 replications during the finishing phase.

Results

Experiment 1

From d 0 to 14, increasing the level of enzyme improved ADG (quadratic; $P = 0.04$) and F/G (linear; $P = 0.05$) and tended to improve ADFI (quadratic; $P = 0.06$) and d 14 BW (quadratic; $P = 0.07$; Table 3). From d 14 to 28, enzyme level had no effect

($P > 0.31$) on ADG or ADFI but worsened F/G (quadratic; $P < 0.05$). Overall (d 0 to 28), the enzyme had no effect ($P > 0.24$) on ADG, ADFI, F/G, or d-28 BW; however, the tendency for improved BW at d 14 was maintained at d 28, resulting in a 1.5 lb heavier pig.

Experiment 2

Adding the enzyme to nursery, finishing, and nursery and finishing combined diets containing DDGS did not influence ADG, ADFI, F/G, or any of the carcass criteria measured in the study (Table 4).

Similar to results from previous research at Kansas State University, adding the enzyme blend to corn-soybean meal based diets containing DDGS did not result in improvements in overall pig performance. Additional trials are needed in commercial facilities to understand the variable growth response related to feeding this enzyme blend.

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

Ingredient, %	Phase 1	Phase 2
Corn	40.86	47.36
Soybean meal (46.5% CP)	23.02	23.94
Corn DDGS[3]	15.00	25.00
Select menhaden fish meal	3.00	---
Spray-dried whey	15.00	---
Monocalcium P (21% P)	0.70	1.00
Limestone	0.75	1.20
Salt	0.30	0.35
Zinc oxide	0.38	---
Vitamin premix	0.25	0.25
Trace mineral premix	0.15	0.15
Lysine-HCl	0.40	0.55
DL-methionine	0.10	0.08
L-threonine	0.10	0.13
Total	100.00	100.00
Calculated analysis		
SID[4] amino acids, %		
Lysine, %	1.35	1.30
Isoleucine:lysine	61	62
Leucine:lysine	129	139
Methionine:lysine	33	31
Met & Cys:lysine	57	58
Threonine:lysine	62	63
Tryptophan:lysine	17	17
Valine:lysine	68	71
SID lysine:ME, g/Mcal	4.10	3.92
Total lysine, %	1.49	1.43
CP, %	22.5	22.7
ME, kcal/lb	1,546	1536
Ca, %	0.80	0.79
P, %	0.73	0.70
Available P, %	0.48	0.41

[1] Phase 1 diets were fed from d 0 to 14 in both experiments. Phase 2 diets were fed from d 14 to 28 in Exp. 1 and d 14 to 35 in Exp. 2.
[2] Livestock Answer was substituted for corn.
[3] Dried distillers grains with solubles.
[4] Standardized ileal digestible.

Table 2. Composition of finishing diets in Exp. 2 (as-fed basis)[1]

	Weight range, lb				
Ingredient	40 to 80	80 to 120	120 to 165	165 to 215	> 215
Corn	48.12	54.51	59.84	63.87	65.91
Soybean meal (46.5% CP)	19.58	13.24	8.06	4.08	2.09
DDGS[2]	30.0	30.0	30.0	30.0	30.0
Monocalcium P (21% P)	0.40	0.30	0.20	0.15	0.15
Limestone	1.00	1.00	0.95	0.95	0.95
Salt	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.10	0.10	0.10	0.10	0.08
Trace mineral premix	0.10	0.10	0.10	0.10	0.08
Lysine HCl	0.35	0.40	0.40	0.40	0.40
Total	100.0	100.0	100.0	100.0	100.0
Calculated values					
SID[3] amino acids, %					
Lysine	1.05	0.93	0.80	0.70	0.65
Isoleucine:lysine	73	71	71	72	72
Methionine:lysine	31	32	34	37	38
Met & Cys:lysine	64	65	70	75	78
Threonine:lysine	63	62	63	64	65
Tryptophan:lysine	19	18	18	17	17
Valine:lysine	85	85	88	91	93
SID Lysine:ME, g/Mcal	3.14	2.77	2.38	2.08	1.93
Total lysine, %	1.18	1.04	0.90	0.79	0.73
Protein, %	21.8	19.5	17.5	16.0	15.3
ME, kcal/lb	1,519	1,522	1,525	1,527	1,528
Ca, %	0.60	0.56	0.50	0.48	0.48
P, %	0.58	0.54	0.50	0.47	0.46
Available P, %	0.28	0.25	0.22	0.21	0.21

[1] Livestock Answer was substituted for corn.
[2] Dried distillers grains with solubles.
[3] Standardized ileal digestible.

Table 3. Effect of Livestock Answer on growth performance (Exp. 1)[1]

	Dietary enzyme, %				*P* <	
Item	0	0.125	0.175	SEM	Linear	Quadratic
d 0 to14						
ADG, lb	0.40	0.50	0.45	0.02	0.04	0.04
ADFI, lb	0.51	0.59	0.54	0.02	0.16	0.06
F/G	1.28	1.19	1.20	0.03	0.04	0.05
d 14 to 28						
ADG, lb	0.79	0.76	0.80	0.03	0.87	0.31
ADFI, lb	1.20	1.23	1.24	0.04	0.36	0.99
F/G	1.53	1.61	1.55	0.03	0.21	0.05
d 0 to 28						
ADG, lb	0.59	0.63	0.63	0.02	0.24	0.61
ADFI, lb	0.85	0.91	0.89	0.03	0.25	0.44
F/G	1.44	1.44	1.42	0.02	0.50	0.33
Weight, lb						
d 14	17.8	19.2	18.6	0.61	0.07	0.07
d 28	28.6	30.4	29.8	0.90	0.22	0.31

[1] A total of 224 pigs (initial BW 12.3 lb) were used with 6 pigs per pen and 10 pens per treatment.

Table 4. Effects of Livestock Answer (LA) on growth performance and carcass criteria (Exp. 2)[1,2]

d 0 to 35:	Control	Control	0.125% LA	0.125% LA	
d 35 to 145:	Control	0.125% LA	Control	0.125% LA	SEM
d 0 to 35					
ADG, lb	0.90		0.86		0.01
ADFI, lb	1.27		1.23		0.01
F/G	1.41		1.43		0.01
d-35 wt, lb	44.9		43.4		0.64
d 35 to 126					
ADG, lb	2.18	2.18	2.20	2.16	0.05
ADFI, lb	5.65	5.61	5.64	5.60	0.19
F/G	2.60	2.58	2.56	2.59	0.04
d 126 to 145					
ADG, lb	2.17	2.31	2.36	2.35	0.17
ADFI, lb	7.42	7.19	7.64	7.63	0.43
F/G	3.43	3.16	3.24	3.26	0.19
d 35 to 145					
ADG, lb	2.18	2.19	2.22	2.18	0.05
ADFI, lb	5.89	5.83	5.91	5.87	0.21
F/G	2.71	2.66	2.66	2.69	0.05
Carcass characteristics					
Weight, lb	203.5	205.0	206.8	204.2	5.8
Yield, %	73.2	72.9	72.9	73.2	0.39
Backfat, mm	21.9	21.8	22.1	22.0	1.72
Loin depth, mm	59.7	58.4	59.8	58.5	1.18
Lean, %	51.8	51.6	51.7	51.6	0.8

[1] A total of 224 pigs (initial BW 13.4 lb) were used with 8 pigs per pen and 14 pens per treatment from d 0 to 35 and 6 pens per treatment from d 35 to 145.
[2] The 2 heaviest pigs in each pen were removed on d 126.

A Meta-Analysis of Supplemental Enzyme Studies in Growing-Finishing Pigs Fed Diets Containing Dried Distillers Grains with Solubles: Effects on Growth Performance[1]

J. Y. Jacela[2], S. S. Dritz[2], J. M. DeRouchey, M. D. Tokach, R. D. Goodband, and J. L. Nelssen

Summary

A meta-analysis of 4 experiments involving 4,506 pigs was conducted to determine the effects of several commercial enzymes on the growth performance of growing-finishing pigs fed various amounts of dried distillers grains with solubles (DDGS). Experiments 1 and 2 used corn-soybean meal-based diets with 15% DDGS. A β-mannanase enzyme (Hemicell; ChemGen Corp., Gaithersburg, MD) was used in enzyme treatments in Exp. 1, and a blend of enzymes that had β-glucanase, cellulase, and protease activities (Agri-king REAP; Agri-King, Inc., Fulton, IL) was used in Exp. 2. In Exp. 3, diets containing 45% and 60% DDGS were fed with or without 2 commercial enzyme products designed for use in diets containing DDGS. In Exp. 4, an enzyme product with bacterial endo-1,4-β-xylanase was evaluated in diets containing 30% DDGS. All enzyme treatments in each experiment were pooled in a meta-analysis to compare the responses to diets with or without enzyme addition regardless of the other factors tested in each trial. All experiments were conducted in the same commercial swine research facility. There were no differences in ADG ($P > 0.52$), ADFI ($P > 0.33$), F/G ($P > 0.35$), and final weight ($P > 0.60$) among pigs fed diets with added enzyme and pigs fed diets without enzyme in any of the 4 experiments or in the pooled data. In conclusion, on the basis of the combined results from the 4 experiments evaluated in this meta-analysis, adding these enzymes in diets containing various amounts of DDGS does not appear to be beneficial in pigs.

Key words: dried distillers grains with solubles, enzyme

Introduction

The use of carbohydrate- and protein-degrading enzymes in livestock diets as an aid to improve nutrient utilization from plant-based ingredients has received a great deal of attention over the past decade. Studies conducted in poultry have consistently shown favorable results with the use of exogenous enzymes, but this has not been the case in pigs. Some experiments have reported beneficial effects of enzyme supplementation of diets on pig performance, but overall, results have been inconsistent. This suggests that the use of currently available enzymes may be better suited for poultry than pigs. Nevertheless, given the potential benefits of improved feed efficiency and high cost of feed, there is renewed interest in adding exogenous enzymes in swine diets.

[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] Food Animal Health and Management Center, College of Veterinary Medicine, Kansas State University.

The increased interest in enzyme use also has been fueled by the increasing use of less expensive alternative feed ingredients, most notably dried distillers grains with solubles (DDGS). Dried distillers grains with solubles have a high fiber content that is less digestible to the pig. Thus, there is potential to increase the nutritional value of DDGS by using exogenous enzymes to aid in breaking down fiber components. Experimental results suggest that DDGS can be fed to pigs only up to 30% in the diets before a decrease in performance is observed. The use of fiber-degrading enzymes provides an opportunity to maximize the value of DDGS for swine by improving its nutrient digestibility and could also potentially allow for higher inclusion rates of DDGS in swine diets. Therefore, we conducted a meta-analysis of data from 4 different experiments using various commercial enzyme products currently available in the market to determine the effects of these enzymes on the growth performance of growing-finishing pigs fed various amounts of DDGS.

Procedures

Procedures used in the experiments were approved by the Kansas State University Institutional Animal Care and Use Committee. The meta-analysis involved 4 different experiments using a total of 4,506 pigs of the same genetics (PIC L337 × C22). The first trial (Exp. 1) started on October 24, 2007, and the last trial (Exp. 4) ended on April 30, 2009. All experiments were conducted in a commercial swine research facility located in southwestern Minnesota. The barns were naturally ventilated and double curtain sided. Pens were 18 × 10 ft with completely slatted flooring and deep pits for manure storage. Each pen was equipped with a self-feeder and a cup waterer. Each barn had an automated feeding system (FeedPro; Feedlogic Corp., Willmar, MN) capable of delivering and recording data on feed amounts added on an individual pen basis.

Information regarding the 4 trials is shown in Table 1. In Exp. 1, a total of 1,269 pigs were assigned to treatments in a 2 × 2 × 2 factorial arrangement. The factors were Porcine Circovirus Type 2 vaccine dose (half or full), enzyme (with or without), and gender (barrow or gilt). The enzyme used was a commercially available β-mannanase (Hemicell; ChemGen Corp., Gaithersburg, MD). In Exp. 2, a total of 1,129 pigs were assigned to treatments in a 2 × 3 factorial arrangement. The factors were enzyme (with or without) and added fat (0%, 2.5%, or 5.0%). The commercial enzyme used was a proprietary blend of enzymes that had β-glucanase, cellulase, and protease activities (Agri-king REAP; Agri-King, Inc., Fulton, IL). In Exp. 1 and 2, DDGS was added at 15% in all dietary phases. In Exp. 3, a total of 1,032 pigs were allotted to a control treatment (30% DDGS) and 6 additional treatments in a 2 × 3 factorial arrangement based on DDGS level (45% or 60%) and enzyme used (none, product A, or product B). Enzymes used were commercial enzymes designed for use in diets containing DDGS. Regardless of treatment, levels of DDGS were reduced to 20% in all diets during the last 12 d of the experiment. In Exp. 4, a total of 1,076 pigs were assigned to 3 treatments: diets with 30% DDGS and 2% added fat with or without enzyme and a diet with 30% DDGS and 3% added fat without enzyme. The enzyme product used contained a bacterial endo-1,4-β-xylanase (Nutrase; Nutrex, Lille, Belgium). Regardless of treatment, levels of DDGS were reduced to 15% in the last dietary phase.

With the exception of Exp. 3, which was blocked by initial BW, pigs in all experiments were randomly assigned to treatments balanced by initial BW. In each experiment, all

enzyme treatments were pooled into 1 treatment (yes) to compare the responses to treatments without enzyme (no). Pen was the experimental unit in all trials. Data from the 4 experiments were then pooled, and statistical analysis was performed by analysis of variance using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with the fixed effect of enzyme (yes vs. no) and the random effects of trial and sex.

Results and Discussion

There were no differences in ADG ($P > 0.52$), ADFI ($P > 0.33$), F/G ($P > 0.35$), and final weight ($P > 0.60$) among pigs fed diets with or without added enzyme in any of the 4 experiments or in the pooled data (Table 2). These results are similar to a number of other experiments that did not find any significant impact of enzyme supplementation on pig growth performance.

In the first experiment, a commercially available enzyme with β-mannanase activity was used in corn-soybean meal-based diets with 15% added DDGS. However, the mannose fraction in DDGS, unlike in soybean meal, is present in very small amounts compared to the other carbohydrate fractions, which could limit the potential response of pigs to the enzyme used. This may be a plausible explanation for the absence of any response seen in Exp. 1. Because DDGS varies in carbohydrate composition and enzymes act on specific substrates, a combination of several enzymes that can act on various substrates present in DDGS might be a more logical approach. Using the same level of DDGS as in Exp. 1, a commercial enzyme blend known to act on and break down various carbohydrate fractions was used in corn-soybean meal-based diets in Exp. 2. Similar to the results obtained in Exp. 1, no significant improvement in growth performance was observed with the addition of the commercial enzyme product.

There are several possible explanations as to why results from enzyme supplementation in DDGS-containing diets have been inconsistent, including age of animal and amount of substrate. It has been reported that enzyme supplementation of diets containing 30% DDGS improved growth and feed efficiency in nursery pigs. In the commercial research facility where these 4 experiments were conducted, diets containing 30% DDGS fed to growing-finishing pigs have resulted in growth performance similar to that from corn-soybean meal-based diets without DDGS. Thus, we tested the effect of feeding higher levels of DDGS (45% to 60%) and whether enzyme supplementation, using two commercial enzymes designed for use in DDGS-containing diets, would help alleviate the negative effects of high levels of DDGS on growth performance. In theory, this significantly increases the amount of possible substrates for the enzymes to act on. However, similar to observations in the first 2 experiments, there was no significant effect of enzyme supplementation on growth performance of growing-finishing pigs, even with very high levels of DDGS.

In DDGS, non-starch polysaccharide arabinoxylans are present in greater proportions. Thus, using a product with xylanase activity can potentially increase the energy value of DDGS. In Exp. 4, we investigated the effect of a bacterial endo-1,4-β-xylanase on growth performance of pigs fed diets containing 30% DDGS. However, similar to the first 3 experiments, we did not observe any significant impact of enzyme supplementation on the growth performance of growing-finishing pigs.

In conclusion, adding these enzymes in diets containing DDGS as a means to improve nutrient and energy utilization does not appear to be beneficial in pigs, as measured by growth performance based on combined results from the 4 experiments. Even when some factors that affect enzyme efficacy, such as substrate specificity and level of DDGS, were addressed in the 4 experiments, the enzyme products used did not exert any positive effect on growth performance. At this point, it appears that use of these exogenous enzymes in corn-soybean meal-based swine diets containing high-fiber ingredients such as DDGS as a means to improve pig performance is not justified.

Table 1. Details of individual experiments included in the meta-analysis[1]

Experiment	Duration, d	Experimental units, n	Start weight, lb	DDGS[2], %	Enzyme activity of product used	Reference
1	92	47	65.3	15	β-mannanase	
2	56	42	75.8	15	β-glucanase, cellulase, and protease	Jacela et al., 2008[3]
3	90	42	101.5	45 and 60	Proprietary blend of enzymes	Jacela et al., 2009[4]
4	66	39	87.4	30	Bacterial endo-1,4- β-xylanase	Jacela et al., 2009[5]

[1] Data from 4 experiments involving 4,506 pigs.
[2] Dried distillers grains with solubles.
[3] Jacela et al., Swine Day 2008, Report of Progress 1001, pp. 111-116.
[4] Jacela et al., Swine Day 2009, Report of Progress 1020, pp. 192-201.
[5] Jacela et al., Swine Day 2009, Report of Progress 1020, pp. 207-212.

Table 2. Effect of enzyme addition to diets containing DDGS on growth performance of growing-finishing pigs[1]

	Final wt, lb			ADG, lb			ADFI, lb			F/G		
Experiment	Control	Enzyme	SED[2]	Control	Enzyme	SED	Control	Enzyme	SED	Control	Enzyme	SED
1	266.6	266.9	1.78	2.21	2.22	0.016	5.42	5.47	0.054	2.45	2.46	0.016
2	192.7	192.2	1.99	2.08	2.07	0.016	4.93	4.94	0.066	2.37	2.38	0.031
3	269.4	268.9	3.20	1.89	1.88	0.021	5.11	5.05	0.062	2.71	2.69	0.021
4	210.4	208.3	4.08	1.82	1.81	0.035	4.66	4.66	0.118	2.57	2.58	0.030
avg.	234.8	234.2	1.34	2.00	2.00	0.010	5.03	5.03	0.033	2.52	2.52	0.012

[1] Data from 4 experiments involving 4,506 pigs. In each experiment, pigs fed enzyme-supplemented diets were compared with pigs fed diets without enzyme regardless of other factors being tested in the experiment. There was no significant difference ($P > 0.33$) between control and enzyme supplementation for any response criteria either within individual experiments or overall when data from all experiments were pooled together.
[2] Standard error of the difference.

Effects of Feeding Ractopamine HCl (Paylean) for Various Durations on Late-Finishing Pig Performance and Carcass Characteristics[1]

M. L. Potter[2], S. S. Dritz[2], M. D. Tokach, J. M. DeRouchey, R. D. Goodband, and J. L. Nelssen

Summary

A total of 627 pigs (241.5 lb) were used in a 21-d finishing trial to evaluate the effects of feeding ractopamine HCl (RAC; Paylean, Elanco Animal Health, Greenfield, IN) for different durations on growth performance and carcass characteristics. On d 0, pens of pigs containing both barrows and gilts in approximately equal numbers were blocked by average BW and randomly allotted to 1 of 3 dietary treatments (8 pens per treatment) with average initial weight balanced across treatments. Dietary treatments were feeding a control diet without RAC and feeding a diet containing 4.5 g/ton RAC for the last 14 or 21 d prior to marketing. Pens of pigs were weighed and feed intake was collected on d 0, 7, and 21 to calculate ADG, ADFI, and F/G. Carcass data were collected from the 4 heaviest pigs per pen marketed on d 7 and from all pigs marketed on d 21. Pigs fed RAC starting on d 0 gained faster ($P = 0.01$) and consumed less feed ($P = 0.01$) from d 0 to 7 than control pigs and pigs not yet fed RAC. From d 7 to 21, pigs started on RAC at d 7 had improved ($P \leq 0.04$) ADG and F/G compared with control pigs and pigs that remained on RAC. There was no difference ($P = 0.14$) in overall ADG between the treatment groups; however, ADFI was lower ($P < 0.01$) and F/G improved ($P < 0.01$) for pigs fed RAC, regardless of duration, compared with control pigs. There were no differences ($P \geq 0.32$) in overall live weight or HCW at market in this trial. Compared with control pigs, pigs fed RAC for 21 d had reduced ($P < 0.01$) backfat depth, increased ($P = 0.01$) loin depth, and improved ($P < 0.01$) percentage lean. Pigs fed RAC for 14 d had intermediate responses to these 2 treatments for loin and backfat depth but had a higher percentage lean than control pigs.

These data demonstrate that feeding RAC to pigs for 14 d reduced ADFI, improved F/G, and improved percentage lean compared with control pigs. Feeding RAC for an additional 7 d did not influence overall ADFI or F/G compared with feeding RAC for 14 d total but further improved percentage lean compared with feeding RAC for 14 d. Pigs fed RAC for 21 d had decreased backfat and increased loin depth compared with control pigs. This study demonstrates that for heavyweight pigs, F/G and ADFI responses are achieved with either duration of RAC feeding, but the magnitude of the carcass response to feeding RAC appears to be duration dependent.

Key words: carcass, growth, Paylean, ractopamine

[1] Appreciation is expressed to J-Six Enterprises, Seneca, KS, for their assistance and for providing the pigs and facilities used in this experiment.

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

Introduction

Use of ractopamine HCl (RAC; Paylean, Elanco Animal Health, Greenfield, IN) in finishing pigs prior to market has been demonstrated to improve growth rate and carcass characteristics. Although many research trials have demonstrated the efficacy of RAC, few of these trials have been done at heavy market weights (greater than 240 lb). Ractopamine HCl, a β-adrenergic agonist, is labeled for use in swine diets during the last 45 to 90 lb of gain. When fed, it promotes lean growth rather than fat deposition by directing nutrients away from the fat toward muscle development. Because fat tissue deposition requires more energy than lean growth, increasing lean deposition leads to improved feed efficiency prior to market and a leaner carcass. Because of the impact of RAC on lean and fat deposition and the changing lean to fat deposition ratio as BW increases, pigs marketed at heavier weights may have a different magnitude of response to RAC feeding than pigs at lighter weights. Therefore, the objective of this trial was to determine the effects of feeding RAC for different durations prior to market on late commercial finishing pig performance and carcass characteristics for pigs marketed at a heavy weight.

Procedures

Procedures used in this study were approved by the Kansas State University Institutional Animal Care and Use Committee. A total of 627 commercial finishing pigs (initially 241.5 lb) were used in a 21-d study performed in a commercial research finishing barn. The barn, located in northeastern Kansas, was naturally ventilated and double curtain sided with completely slatted flooring. Barrows and gilts were comingled in approximately equal numbers within each of 24 pens (10 × 18 ft), and pens initially contained 25 to 27 pigs. Each pen was equipped with a double swinging waterer and a 3-hole dry self-feeder, allowing for ad libitum access to water and feed. An automated feeding system (FeedPro; Feedlogic Corp., Willmar, MN) was used in the barn to deliver and measure feed amounts added to individual pen feeders. Pens of pigs were blocked by average initial pig BW and randomly allotted to 1 of 3 treatments, resulting in 8 pens per treatment. Initial weights were balanced across the 3 treatment groups. Treatments were feeding a control diet without RAC and feeding a diet containing 4.5 g/ton RAC for the last 14 or 21 d prior to marketing (Table 1).

Pens of pigs were weighed and feed intake was collected on d 0, 7, and 21 (marketing day). From these data, ADG, ADFI, and F/G were calculated. On d 7, the 4 heaviest pigs per pen were marketed from each pen, with the balance of the pigs remaining on test until d 21. On d 21 of the trial, all pigs were marketed except the lightest pig from each pen. This allowed all pigs to be greater than 215 lb to meet the minimum acceptable weight for the packing plant specifications. Data from these lightweight pigs were included in the growth and performance calculations; however, these 24 pigs are not represented in the carcass data. To facilitate carcass data collection, pigs were tattooed according to pen number, and carcass data were collected for pigs marketed on both d 7 and 21.

Data were analyzed as a randomized complete block design using the GLIMMIX procedure of SAS (SAS Institute Inc., Cary, NC) with pen as the experimental unit. Dietary treatment was a fixed effect, and weight block was a random effect. Backfat depth, loin depth, and percentage lean were adjusted to a common HCW. Percentage yield was

calculated by dividing the HCW total for each pen by the live weight obtained at the research barn prior to transport to the packing facility. Differences between treatments were determined by using least squares means ($P < 0.05$). In addition, for response criteria through d 7, comparisons between pigs not fed RAC (control and last 14-d RAC treatment) and pigs fed RAC (21-d RAC treatment) were made using contrast statements.

Results and Discussion

Within the first 7 d of the trial, pigs fed RAC starting on d 0 gained more ($P = 0.01$) and consumed less ($P = 0.01$) feed than control pigs and pigs not yet fed RAC (Table 2). This resulted in an improvement ($P < 0.01$) in F/G for d 0 to 7 and a trend ($P = 0.08$) toward heavier d-7 weights for pigs fed RAC compared with those not fed RAC.

From d 7 to 21, pigs started on RAC on d 7 had improved ($P < 0.04$) ADG and F/G compared with control pigs and pigs that remained on RAC. There was no difference ($P \geq 0.12$) in ADG or F/G between the control pigs and pigs that received RAC for 21 d; however, d 7 to 21 feed intake was similar ($P = 0.29$) for pigs consuming RAC and lower ($P < 0.01$) than intake of control pigs.

Because of the fluctuation in gain response and the excellent growth rates of pigs fed the control diet, there was no difference ($P = 0.14$) in overall ADG between the three treatment groups, although rate of gain was numerically better for RAC-fed pigs. Compared with control pigs, ADFI was lower ($P < 0.01$) and F/G improved ($P < 0.01$) for pigs fed RAC, regardless of duration. Therefore, the improvement in F/G found in this trial was largely driven by the reduced feed consumption when RAC was fed, as overall gain was similar across the 3 treatment groups.

Evaluation of carcass characteristics of the 4 heaviest pigs per pen marketed on d 7 and remaining pigs marketed on d 21 showed that there was no difference ($P \geq 0.23$) in live weight or HCW of pigs marketed, regardless of treatment (Table 3). By d 7, pigs fed diets containing RAC were leaner ($P < 0.01$) and had greater ($P < 0.01$) loin depth than pigs not fed RAC. On d 21, pigs fed RAC for the last 14 or 21 d prior to market had greater ($P < 0.01$) percentage lean than control pigs. Compared with control pigs, the pigs fed RAC for 21 d had lower ($P < 0.05$) backfat depth. Pigs fed RAC for the last 14 d had backfat depths that were intermediate between control pigs and pigs fed RAC for 21 d.

Overall, there were no differences ($P \geq 0.32$) in live weight or HCW at market. Pigs fed RAC for 21 d had greater ($P = 0.02$) yield than pigs fed RAC for 14 d, whereas the control pigs were intermediate. Pigs fed RAC for 21 d had reduced ($P < 0.01$) backfat depth, increased ($P = 0.01$) loin depth, and improved ($P < 0.01$) percentage lean of carcasses compared with control pigs. Pigs fed RAC for 14 d had intermediate responses to these 2 treatments for loin and backfat depth and had a greater ($P = 0.04$) percentage lean compared with control pigs.

These data demonstrate that feeding RAC to pigs reduced feed intake and improved F/G compared with not feeding RAC. In addition, it appears that the majority of the

benefit in F/G was captured within the first 7 to 14 d of feeding duration. In this trial, improvements in carcass composition were achieved by feeding RAC for a short duration of 7 d in heavyweight pigs. However, improvements to carcass characteristics in the 14-d RAC treatment were intermediate between those of the control and 21-d RAC treatment groups, suggesting that the magnitude of carcass improvement is increased with longer feeding durations. Therefore, these factors and the cost of the product should be evaluated before deciding upon use or duration of including RAC in swine diets prior to market.

Pigs in this study were in the final stages of growth, when ADG decreases and fat deposition is increasing relative to lean tissue growth. Energy requirements to produce fat and lean tissue are different, as lean tissue requires less energy to deposit than fat. When RAC is fed, more nutrients are used to produce lean tissue than fat tissue, which decreases energy requirements and drops feed intake. The maintained growth during this period was achieved with lower feed consumption; thus, F/G was improved. Also, findings from this study indicate that lean deposition was increased by RAC feeding, suggesting that carcass traits can be influenced at later stages of maturity.

Given the rising cost of feed, RAC still could be considered as a tool to help improve feed efficiency and carcass value. This study demonstrates that for heavyweight pigs, F/G and ADFI responses are achieved with either duration of RAC feeding, but the magnitude of the carcass response to feeding RAC appears to be duration dependent.

Table 1. Diet composition (as-fed basis)

Ingredient,%	Control[1]	Ractopamine HCl[2]
Corn	55.76	44.20
Soybean meal (46.5% CP)	4.44	15.97
Beef tallow	1.00	1.00
Limestone	0.70	0.70
Salt	0.30	0.30
Vitamin premix with phytase	0.06	0.06
Trace mineral premix	0.06	0.06
L-lysine HCl	0.18	0.18
Ractopamine HCl (9 g/lb)	---	0.03
Fortified hominy	37.50	37.50
Phytase 600	0.01	0.01
Total	100.00	100.00
Calculated analysis		
SID[3] amino acid, %		
Lysine	0.64	0.93
Isoleucine:lysine	73	71
Leucine:lysine	193	162
Methionine:lysine	38	32
Met & Cys:lysine	74	62
Threonine:lysine	66	62
Tryptophan:lysine	18	19
Valine:lysine	92	84
SID Lysine:ME, g/Mcal	1.91	2.79
ME, kcal/lb	1,517	1,514
Total lysine, %	0.74	1.06
CP, %	14.48	18.86
Ca, %	0.53	0.56
P, %	0.48	0.52
Available P, %	0.21	0.22

[1] Control diets formulated for average weight range of 240 to 280 lb.
[2] Diets contained ractopamine HCl at 4.5 g/ton.
[3] Standardized ileal digestible.

Table 2. Effect of ractopamine HCl (RAC) on growth performance of finishing pigs[1]

	Feeding period				Probability, $P <$	
Item	Control[2]	Last 14 d[3]	Last 21 d[4]	SEM	Treatment	Contrast
d 0 to 7						
Initial wt, lb	241.6	241.5	241.5	2.8	1.00	0.97
ADG, lb[5]	2.29[a]	2.40[ab]	2.78[b]	0.13	0.04	0.01
ADFI, lb[5]	7.90[a]	7.89[a]	7.49[b]	0.12	0.04	0.01
F/G[5]	3.52[a]	3.34[a]	2.73[b]	0.14	<0.01	<0.01
d 7 wt, lb	257.7	258.4	260.9	2.6	0.20	0.08
d 7 to 21[6]						
ADG, lb	2.08[a]	2.25[b]	1.95[a]	0.06	<0.01	---
ADFI, lb	7.69[a]	7.09[b]	6.91[b]	0.15	<0.01	---
F/G	3.70[a]	3.17[b]	3.56[a]	0.09	<0.01	---
d 0 to 21						
ADG, lb	2.16	2.31	2.26	0.07	0.14	---
ADFI, lb	7.77[a]	7.39[b]	7.12[b]	0.12	<0.01	---
F/G	3.62[a]	3.22[b]	3.17[b]	0.08	<0.01	---
Final wt, lb	279.6	283.4	281.1	3.0	0.37	---

[1] A total of 627 pigs (barrows and gilts) were used with 25 to 27 pigs per pen and 8 pens per treatment.
[2] Pigs in the control treatment group were fed a diet without RAC.
[3] Pigs were fed the control diet until d 7 and then fed a diet containing 4.5 g/ton RAC until d 21.
[4] Pigs were fed a diet containing 4.5 g/ton RAC for 21 d.
[5] Control and last 14 d vs. last 21 d ($P < 0.05$).
[6] On d 7, the 4 heaviest pigs per pen were removed and marketed.
[ab] Within a row, means without a common superscript differ ($P < 0.05$).

Table 3. Effect of ractopamine HCl (RAC) on carcass characteristics of finishing pigs[1]

	Feeding period				Probability, $P <$	
Item	Control[2]	Last 14 d[3]	Last 21 d[4]	SEM	Treatment	Contrast
d 7 marketing[5,6,7]						
Live wt, lb[8]	297.7	294.1	300.7	5.0	0.64	0.43
HCW, lb[8]	222.0	219.0	225.0	3.8	0.46	0.29
Yield, %[8]	74.6	74.5	74.8	0.3	0.30	0.15
Lean, %[8]	51.9[a]	51.6[a]	52.8[b]	0.2	<0.01	<0.01
Backfat depth, mm[8]	20.3	21.3	19.8	0.6	0.28	0.22
Loin depth, mm[8]	59.7[a]	59.6[a]	63.7[b]	0.9	<0.01	<0.01
d 21 marketing[6,7,9]						
Live wt, lb	282.8	287.3	284.1	3.0	0.23	---
HCW, lb	212.7	215.2	214.8	2.4	0.33	---
Yield, %	75.2[ab]	74.9[a]	75.6[b]	0.2	0.05	---
Lean, %	51.6[a]	52.3[b]	52.5[b]	0.2	<0.01	---
Backfat depth, mm	22.2[a]	21.1[ab]	20.3[b]	0.4	0.02	---
Loin depth, mm	60.1	61.5	61.6	0.7	0.14	---
Overall marketing[6,7,10]						
Live wt, lb	285.2	288.2	286.8	2.9	0.43	---
HCW, lb	214.2	215.8	216.4	2.3	0.32	---
Yield, %	75.1[ab]	74.9[a]	75.4[b]	0.2	0.05	---
Lean, %	51.6[a]	52.2[b]	52.6[b]	0.2	<0.01	---
Backfat depth, mm	22.0[a]	21.1[ab]	20.2[b]	0.4	0.03	---
Loin depth, mm	59.9[a]	61.2[ab]	62.0[b]	0.7	0.04	---

[1] A total of 602 pigs (barrows and gilts; 8 pens/treatment) are represented in this carcass data.
[2] Pigs in the control treatment group were fed a diet without RAC.
[3] Pigs were fed the control diet until d 7 and then fed a diet containing 4.5 g/ton RAC until d 21.
[4] Pigs were fed a diet containing 4.5 g/ton RAC for 21 d.
[5] On d 7, the 4 heaviest pigs per pen were removed and marketed.
[6] Percentage lean, backfat depth, and loin depth were adjusted to a common HCW.
[7] Percentage yield was calculated by dividing HCW by live weight obtained prior to transport to the packing plant.
[8] Control and last 14 d vs. last 21 d ($P < 0.05$).
[9] On d 21, all but the single lightest pig in the pen were marketed.
[10] Overall marketing data combines data from all pigs marketed on d 7 and 21.
[ab] Within a row, means without a common superscript differ ($P < 0.05$).

Effect of Constant or Step-Up Ractopamine HCl (Paylean) Feeding Programs on Growth Performance and Carcass Characteristics of Late-Finishing Pigs[1]

J. Y. Jacela[2], S. S. Dritz[2], M. D. Tokach, J. M. DeRouchey, R. D. Goodband, and J. L. Nelssen

Summary

A total of 1,099 pigs (PIC 337 × C22; initial BW = 208 lb) were used to evaluate the effect of ractopamine HCl (RAC) feeding programs on growth and carcass traits of late-finishing pigs. Pigs were randomly assigned to 1 of 3 treatments balanced by average BW within gender. There were 14 pens per treatment and 26 pigs per pen. Treatments were a basal diet with: (1) 0 g/ton RAC for 28 d (control), (2) 0 g/ton RAC from d 0 to 7 and 4.5 g/ton RAC from d 7 to 28 (constant), and (3) 4.5 g/ton from d 0 to 14 and 6.75 g/ton from d 14 to 28 (step-up). Pig ADG, ADFI, and F/G were determined weekly, and carcass data were collected at the end of experiment. From d 0 to 7, step-up pigs had improved ($P < 0.04$) ADG, ADFI, and F/G compared with pigs in all other treatments. From d 0 to 14, RAC-fed pigs, regardless of the feeding program, had greater ($P < 0.01$) ADG and better ($P < 0.01$) F/G than control pigs. From d 14 to 28, although pigs in both RAC-fed treatments had greater ($P < 0.01$) ADG than control pigs, the step-up pigs had lower ($P < 0.05$) ADG and ADFI than the constant-fed pigs. Regardless of the RAC feeding program, all RAC-fed pigs exhibited better ($P < 0.01$) F/G than control pigs. From d 7 to 28, pigs fed the constant and step-up treatments exhibited greater ($P < 0.01$) ADG and better ($P < 0.05$) F/G than control pigs. However, when pigs fed the RAC-fed treatments were compared, step-up pigs had lower ($P < 0.01$) ADG and ADFI but similar ($P > 0.27$) F/G. Overall (d 0 to 28), ADFI ($P = 0.15$) was similar between treatments, but RAC-fed pigs had greater ($P < 0.01$) ADG than control pigs, which led to improved ($P < 0.01$) F/G. Pigs fed either RAC feeding strategy had similar performance overall. RAC-fed pigs had heavier ($P < 0.05$) carcass weights and tended ($P < 0.10$) to have greater yield than control pigs. Among the 3 groups, step-up pigs had the greatest ($P < 0.05$) percentage lean, loin depth, and fat-free lean index as well as the lowest ($P < 0.01$) backfat depth. The pigs fed either RAC program had greater ($P < 0.05$) revenue than control pigs. Although feed cost was higher ($P < 0.01$) in the RAC-fed pigs than in the control, income over feed cost tended ($P < 0.07$) to be higher for RAC-fed pigs than for control pigs. In conclusion, feeding a constant level of 4.5 g/ton RAC for 21 d improved growth similarly to feeding the 28-d step-up program. However, the 28-d RAC step-up program resulted in additional improvement in carcass traits of late-finishing pigs.

Key words: growth, ractopamine HCl

[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.

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Introduction

Ractopamine HCl (RAC; Paylean; Elanco Animal Health, Greenfield, IN) is widely used in the swine industry to improve growth and carcass traits of finishing pigs. It is classified as a β-agonist and exerts beneficial effects on growth and carcass by diverting nutrients to favor lean rather than fat tissue growth. Ractopamine HCl is the only β-agonist approved by the U.S. Food and Drug Administration as a feed additive in pig diets. It is labeled to be added at levels of 4.5 to 9 g/ton and fed continuously for the last 45 to 90 lb of gain before market. Dietary inclusion has shown consistent improvement in pig growth performance and has led to its widespread use in the swine industry. When RAC is used at the recommended dosage, pigs fed RAC-supplemented diets have rapid improvement in growth performance. The maximum growth response to RAC occurs within the first 2 wk. However, the response progressively declines over the remaining days of the feeding period.[3,4,5] The observed decrease in growth response to RAC has been attributed to down-regulation or desensitization of β-receptors when RAC is fed at a constant level for longer periods.[6]

A step-up feeding program can be used to counteract the decline in growth improvement and optimize the use of RAC. Previous studies have shown that the growth performance benefit gained during the first 2 wk of RAC feeding can be extended by increasing the dosage of RAC added in the diet.[7,8] However, given the challenging economics and high diet costs associated with RAC use, it is necessary to determine if implementing a RAC step-up feeding program is economically feasible.

Therefore, we conducted a study to determine the effect on growth performance and economic impact of two different RAC-feeding programs.

Procedures

This study was approved by and conducted in accordance with the guidelines of the Kansas State University Institutional Animal Care and Use Committee. The experiment 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 was equipped with a 5-hole, stainless steel, dry self-feeder and a cup waterer for ad libitum access to feed and water. The barn had an automated feeding system (FeedPro; Feedlogic Corp., Willmar, MN) capable of delivering and measuring feed amounts added on an individual pen basis.

[3] Dunshea, F. R., R. H. King, R. G. Campbell, R. D. Sainz, and Y. S. Kim. 1993. Interrelationships between sex and ractopamine on protein and lipid deposition in rapidly growing pigs. J. Anim. Sci. 71(11): 2919-2930.

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[7] Armstrong, T. A., D. J. Ivers, J. R. Wagner, D. B. Anderson, W. C. Weldon, and E. P. Berg. 2004. The effect of dietary ractopamine concentration and duration of feeding on growth performance, carcass characteristics, and meat quality of finishing pigs. J. Anim. Sci. 82(11):3245-3253.

[8] See, M. T., T. A. Armstrong, and W. C. Weldon. 2004. Effect of a ractopamine feeding program on growth performance and carcass composition in finishing pigs. J. Anim. Sci. 82(8):2474-2480.

A total of 1,099 pigs (PIC 337 × C22; initial BW = 208 lb) were randomly assigned to 1 of 3 treatments balanced by average BW within gender. There were 14 pens per treatment with 26 pigs per pen (8 barrow pens and 6 gilt pens). Treatments were a basal diet with: (1) 0 g/ton RAC for 28 d (control), (2) 0 g/ton RAC from d 0 to 7 and 4.5 g/ton RAC from d 7 to 28 (constant), and (3) 4.5 g/ton from d 0 to 14 and 6.75 g/ton from d 14 to 28 (step-up). Composition of diets used in each of the treatments is shown in Table 1. Pigs from each pen were weighed as a group and feed disappearance was determined weekly to determine ADG, ADFI, and F/G.

On d 14 of the experiment, the 3 heaviest pigs from each pen (determined visually) were sold in accordance with the normal marketing procedure of the farm. At the end of the experiment, pigs were individually tattooed according to pen number to allow for carcass data collection at the packing plant and data retrieval by pen. Pigs were transported to JBS Swift and Company (Worthington, MN) for processing and carcass data collection. Standard carcass criteria of loin and backfat depth, HCW, percentage lean, and yield were collected. Fat-free lean index was calculated using the equation: 50.767 + (0.035 × HCW) - (8.979 × backfat).

Statistical analysis was performed by analysis of variance using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). Data were analyzed as a completely randomized design with pen as the experimental unit. The main effects of the different RAC feeding regimens and gender as well as their interactions were tested.

Results and Discussion

There were no treatment × gender interactions ($P > 0.15$) for any of the criteria evaluated. Although barrows and gilts had similar ($P > 0.92$) overall ADG, barrows had greater ($P < 0.01$) ADFI with poorer ($P < 0.01$) F/G than gilts. From d 0 to 7, step-up pigs (the only group fed RAC at this time) had improved ($P < 0.04$) ADG, ADFI, and F/G compared with pigs in all other treatments (Table 2). This shows that positive growth responses to RAC can be seen immediately during the first 7 d of feeding. Pigs fed the control and constant treatments had similar ADG and ADFI during the same period, which was expected because both groups were fed the same diet. However, the constant group exhibited better F/G than the control even though both groups were fed the same diets. It is not clear what contributed to the improved F/G in the constant-fed pigs during this period.

From d 0 to 14, RAC-fed pigs, regardless of the feeding program, had greater ($P < 0.01$) ADG and better ($P < 0.01$) F/G than control pigs. When pigs fed RAC treatments were compared, step-up pigs had better ($P < 0.05$) F/G than pigs fed the constant treatment. The greater improvement in F/G of the step-up pigs may be due to the pigs having been fed RAC-supplemented diets for 14 d compared to only 7 d for the constant-fed pigs. This is consistent with previous research indicating that the greatest improvement in performance occurs during the first 2 wk of feeding RAC-supplemented diets.[9] The improvements in F/G were 16% and 20% for the constant and step-up pigs, respectively, relative to pigs fed the control diet. During the second half of the experiment (d 14 to 28), although all RAC-fed pigs had greater ($P < 0.01$)

[9] Schinckel, A. P., B. T. Richert, and C. T. Herr. 2002. Variation in the response of multiple genetic populations of pigs to ractopamine. J. Anim. Sci. 80(E-Suppl_2):E85-E89.

ADG than the control pigs, step-up pigs had decreased ADG compared with pigs fed the constant treatment. This occurred because the step-up pigs had decreased ($P < 0.01$) ADFI compared with both control and constant-fed pigs but their F/G remained similar to that of pigs in the constant treatment. Regardless of the RAC feeding program, all RAC-fed pigs exhibited better ($P < 0.01$) F/G than control pigs. There was no difference ($P > 0.19$) in pig weight between treatments in any period of the experiment. However, it is worth noting that RAC-fed pigs numerically had the heaviest live weight (262.3 and 261.7 vs. 253.0 lb for constant and step-up vs. control pigs, respectively) at the end of the trial.

Because the constant-fed pigs were not fed RAC diets until d 7, we also evaluated the d 7 to 28 performance. During this period, pigs fed the constant and step-up treatments exhibited greater ($P < 0.01$) ADG and better ($P < 0.05$) F/G than control pigs. However, when RAC-fed treatments were compared, step-up pigs had decreased ($P < 0.01$) ADG and ADFI but similar ($P > 0.27$) F/G. Overall (d 0 to 28), ADFI ($P = 0.15$) was similar between treatments, but RAC-fed pigs had greater ($P < 0.01$) ADG than control pigs, which resulted in improved ($P < 0.01$) F/G. There were no differences in performance between the RAC-fed pigs. This indicates that the increased RAC dosage in the diets used in the step-up program did not result in additional improvement in growth performance.

In addition to improved growth performance, RAC is also known to improve carcass traits in pigs. In this study, both RAC feeding programs resulted in heavier ($P = 0.03$) carcass weight with no difference between RAC treatments (Table 3). Pigs fed the RAC treatments also tended ($P < 0.10$) to have greater carcass yield than control pigs. Interestingly, pigs fed the step-up feeding program had increased ($P < 0.01$) percentage lean, loin depth, and fat-free lean index as well as the lowest ($P < 0.01$) backfat compared with the control and constant-fed pigs. These results indicate that, although it will not result in additional improvement in growth performance, increasing the levels of RAC in the diets or feeding RAC for a longer duration will result in improvements in carcass quality. This has significant management implications because pigs tend to develop more fat than muscle at heavier weights. This observation suggests that a step-up program can be an effective tool in managing the carcass quality of pigs if they have to stay for an extended period during the finishing stage.

Pigs fed the control treatment numerically incurred the greatest weight discounts ($2.60 vs. $1.26 and $1.87/pig for control vs. constant-fed and step-up pigs, respectively; $P > 0.24$; Table 4). Both RAC-fed groups generated higher ($P < 0.03$) revenue than the control group. Feed consumption was similar ($P > 0.14$) between treatments, although pigs fed the step-up program numerically consumed the least feed (150.9 vs. 156.6 and 155.6 lb/pig for step-up vs. control and constant-fed pigs, respectively). Feed cost for both the constant and step-up programs was higher ($P < 0.01$) relative to the control diet. However, because of improved efficiency, income over feed cost tended ($P < 0.07$) to be higher in both the constant and step-up programs compared with the control treatment.

In conclusion, feeding diets supplemented with at least 4.5 g/ton RAC during the last 3 wk of the finishing stage will improve the growth performance of late-finishing pigs. Adding RAC in the diet at levels greater than 4.5 g/ton did not result in any additional improvement in growth. However, implementing a step-up RAC feeding program 4 wk before market improved carcass traits of late-finishing pigs. Thus, feeding RAC at a constant level of 4.5 g/ton continuously for 3 wk prior to market is ideal from a growth performance standpoint. However, if pigs cannot be marketed in a timely manner and must be kept in the finishing barn for additional days, increasing the level of RAC in the diets is recommended. There will be no additional benefit to growth performance, but carcass quality will be improved.

Table 1. Diet composition (as-fed basis)

Ingredient, %	0 g/ton RAC[1]	4.50 g/ton RAC	6.75 g/ton RAC
Corn	75.04	66.73	66.72
Soybean meal (46.5% CP)	11.19	19.36	19.36
Dried distillers grains with solubles	10.00	10.00	10.00
Choice white grease	2.00	2.00	2.00
Limestone	0.95	0.95	0.95
L-lysine-HCl	0.33	0.40	0.40
Salt	0.35	0.35	0.35
L-threonine	0.03	0.08	0.08
RAC, 9 g/lb	---	0.0250	0.0375
Vitamin and trace mineral premix	0.10	0.10	0.10
Phytase[2]	0.02	0.02	0.02
Total	100.00	100.00	100.00
Calculated analysis			
Standardized ileal digestible (SID) amino acids, %			
Lysine	0.70	0.95	0.95
Isoleucine:lysine	68	64	64
Leucine:lysine	187	158	158
Methionine:lysine	33	28	28
Met & Cys:lysine	67	57	57
Threonine:lysine	65	65	65
Tryptophan:lysine	17	17	17
Valine:lysine	83	75	75
Total lysine, %	0.81	1.08	1.08
ME, kcal/lb	1,568	1,567	1,566
SID lysine:ME ratio, g/Mcal	2.02	2.75	2.75
Ca, %	0.42	0.45	0.45
P, %	0.36	0.39	0.39
Available P, %	0.22	0.22	0.22

[1] Ractopamine HCl (Paylean; Elanco Animal Health, Greenfield, IN).
[2] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN) provided 363, 272, and 272 phytase units per pound of diet in diets with 0, 4.5, and 6.75 g/ton RAC, respectively.

Table 2. Effect of different feeding programs using diets containing ractopamine HCl (RAC) on growth performance of late-finishing pigs[1]

	Feeding program[2]			
Item	Control	Constant	Step-up	SEM
Weight, lb				
d 0	208.1	208.0	208.1	3.62
d 7	222.2	223.0	226.0	3.58
d 14 (before topping)	235.3	240.4	241.7	3.64
d 14 (top pigs)	265.7	270.9	272.0	2.89
d 14 (after topping)	231.3	236.3	237.8	3.83
d 21	242.9	251.2	251.5	3.74
d 28	253.0	262.3	261.7	3.99
d 0 to 7				
ADG, lb	2.00[a]	2.14[a]	2.50[b]	0.064
ADFI, lb	6.11[a]	6.04[a]	6.42[b]	0.104
F/G	3.06[a]	2.84[b]	2.60[c]	0.069
d 0 to 14				
ADG, lb	1.94[a]	2.31[b]	2.37[b]	0.036
ADFI, lb	6.13	6.13	6.02	0.091
F/G	3.17[a]	2.66[b]	2.55[c]	0.034
d 14 to 28				
ADG, lb	1.55[a]	1.85[b]	1.70[c]	0.045
ADFI, lb	5.72[a]	5.63[a]	5.38[b]	0.087
F/G	3.72[a]	3.05[b]	3.19[b]	0.065
d 7 to 28				
ADG, lb	1.66[a]	2.08[b]	1.89[c]	0.034
ADFI, lb	5.87[a]	5.85[a]	5.47[b]	0.085
F/G	3.54[a]	2.82[b]	2.90[b]	0.049
d 0 to 28				
ADG, lb	1.76[a]	2.09[b]	2.05[b]	0.034
ADFI, lb	5.94	5.90	5.72	0.081
F/G	3.39[a]	2.82[b]	2.79[b]	0.036

[1] A total of 1,099 pigs (PIC 337 × C22) were used with 26 pigs per pen and 14 pens per treatment.
[2] Control = 0 g/ton RAC for 28 d; Constant = 0 g/ton RAC on d 0 to 7 and 4.50 g/ton RAC on d 7 to 28; and Step-up = 4.50 g/ton RAC on d 0 to 14 and 6.75 g/ton RAC on d 14 to 28.
[abc] Within a row, means without a common superscript differ ($P < 0.05$).

Table 3. Effect of different feeding programs using diets containing ractopamine HCl (RAC) on carcass characteristics of late-finishing pigs[1]

	Feeding program[2]			
Item	Control	Constant	Step-up	SEM
Carcass weight, lb	191.7[a]	201.7[b]	199.3[b]	3.30
Yield, %	75.35	76.18	75.96	0.332
Lean, %[3]	55.21[a]	56.11[a]	57.04[b]	0.442
Loin[3], in.	2.38[a]	2.48[a]	2.56[b]	0.049
Backfat[3], in.	0.68[a]	0.66[a]	0.62[b]	0.023
Fat-free lean index[3]	50.02[a]	50.34[a]	50.84[b]	0.256

[1] A total of 1,099 (PIC 337 × C22; initial BW = 208 lb) pigs were used with 26 pigs per pen and 14 pens per treatment.
[2] Control = 0 g/ton RAC for 28 d; Constant = 0 g/ton RAC on d 0 to 7 and 4.50 g/ton RAC on d 7 to 28; and Step-up = 4.50 g/ton RAC on d 0 to 14 and 6.75 g/ton RAC on d 14 to 28.
[3] Values are adjusted to a common carcass weight.
[ab] Within a row, means without a common superscript differ ($P < 0.05$).

Table 4. Economic impact of different feeding programs using diets containing ractopamine HCl (RAC)[1]

	Feeding program[2]			
Item	Control	Constant	Step-up	SEM
Weight discount, $/pen	62.30	30.35	44.85	15.82
Weight discount, $/pig	2.60	1.26	1.87	0.66
Revenue, $/pen[3]	2,997[a]	3,264[b]	3,220[b]	87.3
Revenue, $/pig[3]	115.3[a]	125.6[b]	123.8[b]	3.36
Feed consumed, lb/pen	4,071	4,046	3,924	55.4
Feed consumed, lb/pig	156.6	155.6	150.9	2.13
Feed cost, $/pen[4]	366.4[a]	418.7[b]	393.0[c]	5.45
Feed cost, $/pig[4]	14.09[a]	16.10[b]	15.12[c]	0.21
Income over feed cost, $/pen	2,631	2,835	2,824	85.5
Income over feed cost, $/pig	101.18	109.03	108.61	3.287

[1] A total of 1,099 pigs (PIC 337 × C22; initial BW = 208 lb) were used with 26 pigs per pen and 14 pens per treatment.
[2] Control = 0 g/ton RAC for 28 d; Constant = 0 g/ton RAC on d 0 to 7 and 4.50 g/ton RAC on d 7 to 28; and Step-up = 4.50 g/ton RAC on d 0 to 14 and 6.75 g/ton RAC on d 14 to 28.
[3] Calculated based on $60.99/cwt carcass value.
[4] Calculated based on the following values: $180/ton for diets containing 0 g/ton RAC; $217/ton for diets containing 4.5 g/ton RAC; and $226/ton for diets containing 6.75 g/ton RAC.
[abc] Within a row, means without a common superscript differ ($P < 0.05$).

Effects of Dietary Astaxanthin on the Growth Performance and Carcass Characteristics of Finishing Pigs[1]

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Summary

A total of 48 barrows (initially 215 lb) were used to evaluate the effects of increasing dietary astaxanthin (0, 5, 10, and 20 ppm) on late-finishing pig performance and carcass characteristics. Pigs were blocked by weight and randomly allotted to 1 of 4 dietary treatments in a 26-d experiment. Pigs were fed simple corn-soybean meal-based diets. Treatments consisted of a control diet and the control diet with 5, 10, or 20 ppm added astaxanthin. For overall growth performance (d 0 to 26), ADG and F/G of pigs fed astaxanthin was not different from that of the control pigs. However, ADFI tended (linear; $P < 0.10$) to decrease with increasing astaxanthin. For the comparison of carcass characteristics, pigs fed increasing astaxanthin had decreased average ($P < 0.03$) and 10th rib ($P < 0.06$) backfat depth compared with control pigs. Pigs fed 5 or 10 ppm astaxanthin tended to have the lowest (quadratic; $P < 0.10$) 10th rib fat depth. Pigs fed increasing astaxanthin tended to have increased (quadratic; $P < 0.10$) standardized fat-free lean and percentage of fat-free lean, and pigs fed 5 or 10 ppm were the leanest. The loin muscle of pigs fed astaxanthin tended to have lower L* and b* ($P < 0.06$ and $P < 0.08$, respectively), indicating a darker color. The improved carcass characteristics of pigs fed astaxanthin resulted in a numeric increase in the net profit per pig for those fed 5 and 10 ppm astaxanthin. In conclusion, growth performance of pigs fed 5, 10, or 20 ppm astaxanthin was not different from that of pigs fed the control diet. However, the improved carcass characteristics could be economically beneficial to pork producers. Additionally, the improvements observed in loin color could result in improved consumer acceptance of fresh pork. These results warrant further research.

Key words: astaxanthin, carcass characteristics, pork color

Introduction

Astaxanthin is a carotenoid that has potent antioxidant properties and exists naturally in various plants, algae, and seafood. Astaxanthin is used extensively in the aquaculture feed industry for its pigmentation characteristics, but it is not currently approved for use in feed for food animals (other than farmed aquatic species) in the United States. Although it is used primarily for pigmentation, astaxanthin also has been found to be essential for the proper growth and survival of certain aquatic species.

Inclusion of astaxanthin in poultry diets has been reported to improve egg production and the general health of laying hens. It has also been found to improve hatching percentage and the shelf life of eggs. In addition, improvements in chick growth and

[1] Appreciation is expressed to IGENE – Astaxanthin Partners, Ltd. for providing the Aquasta astaxanthin and for partial funding of the trial.

[2] Food Animal Health and Management Center, College of Veterinary Medicine, Kansas State University.

feed utilization during the first 3 wk of life and resistance to *Salmonella* infection have also been observed with astaxanthin supplementation. Furthermore, chick mortality associated with yolk sac inflammation has been reduced. Other studies have reported changes in egg yolk color and poultry muscle color that could improve consumer acceptance.

Few studies have been performed to evaluate feeding astaxanthin to pigs. Researchers in Scandinavia (Smits et al., 2000[3]) reported increased semen volume and sperm count for boars fed 3 g/d astaxanthin, which resulted in an increased number of pigs born alive. In another experiment (Inborr et al., 1997[4]) using sows over 2 consecutive parities, mean litter weight at 21 d of age was increased for sows fed 5 ppm astaxanthin for 35 d pre-farrowing through lactation and 21 d after weaning. During the second parity, the wean-to-service interval was reduced for sows fed astaxanthin.

In a study performed in Korea by Yang et al. (2006[5]), feeding 1.5 and 3 ppm astaxanthin to finishing pigs for 14 d prior to slaughter linearly improved dressing percentage and loin muscle area and decreased backfat thickness. There were no differences in meat color score. However, few animals were used in this study, and the linear responses observed in carcass characteristics suggest that higher levels of astaxanthin need to be evaluated.

Therefore, our objective was to evaluate the effects of feeding astaxanthin to finishing pigs for 26 d prior to slaughter on growth performance, carcass characteristics, and loin color.

Procedures

Procedures used in this experiment were approved by the Kansas State University (K-State) Institutional Animal Care and Use Committee. The project was conducted at the K-State Swine Teaching and Research Farm. Pigs were housed in an environmentally regulated finishing building with pens over a totally slatted floor that provided approximately 8 ft^2/pig. Each pen was equipped with a dry self-feeder and a nipple waterer to provide ad libitum access to feed and water. The facility was a mechanically ventilated room with a pull-plug manure storage pit.

Forty-eight barrows (PIC TR4 × C22) averaging 215 lb were used in this study. Pigs were blocked by weight and randomly allotted to 1 of the 4 dietary treatments; there were 2 pigs per pen and 6 pens per treatment. Experimental diets were fed in meal form, and astaxanthin (0, 5, 10, and 20 ppm) was added to the control diet at the expense of cornstarch to achieve the dietary treatments (Table 1). Pigs and feeders were weighed on d 0, 7, 14, 21, and 26 to determine ADG, ADFI, and F/G.

[3] Smits, R. J., P. R. Smith, and J. Inborr. 2000. Nutritional supplementation of astaxanthin to breeding boars affects semen characteristics and increases litter size. 14th Intl. Congress on Anim. Reprod. Stockholm, July 2-6. Poster abstract 10:35.
[4] Inborr, J., R. Campbell, B. Luxford, D. Harrison, and Å. Lignell. 1997. Improving sow and litter performance by feeding astaxanthin-rich algae meal. Proceedings of the VII International Symposium on Digestive Physiology in Pigs. Saint Malo, France. EAAP No. 88:479-482.
[5] Yang, Y. X., Y. J. Kim, Z. Jin, J. D. Lohakare, C. H. Kim, S. H. Ohh, S. H. Lee, J. Y. Choi, and B. J. Chae. 2006. Effects of dietary supplementation of astaxanthin on production performance, egg quality in layers and meat quality in finishing pigs. Asian-Aust. J. Anim. Sci. 19(7):1019-1025.

On d 27, one pig per pen was transported to the K-State meats lab for humane slaughter and collection of carcass data. Hot carcass weights were collected immediately after evisceration. First-rib, 10th rib, last-rib, and last-lumbar backfat depth as well as loin eye area at the 10th rib were collected from the right half of each carcass 24 h postmortem. Additionally, each carcass was evaluated for loin muscle color at the 10th rib with a HunterLab Miniscan XE Plus spectrophotometer (Model 45/0 LAV, 2.54-cm-diameter aperture, 10° standard observer, Illuminant D65, Hunter Associates Laboratory, Inc., Reston, VA) to measure CIE L*, a*, and b*. This was performed after 30 min of bloom time for each loin muscle surface.

Data were analyzed as a randomized complete block design using the PROC MIXED procedure of SAS (SAS Institute Inc., Cary, NC) with pen as the experimental unit. Linear and quadratic polynomial contrasts were used to determine the effects of increasing astaxanthin.

Results and Discussion

The analyzed astaxanthin levels for the experimental diets were 0.8, 4.8, 9.5, and 19.8 ppm, similar to the targeted values of 0, 5, 10, and 20 ppm used in diet formulation.

For overall growth performance (d 0 to 26), ADG and F/G of pigs fed astaxanthin were not different than those of control pigs (Table 2). However, ADFI tended (linear; $P < 0.10$) to decrease with increasing astaxanthin.

Increasing astaxanthin decreased average ($P < 0.03$) and 10th rib ($P < 0.06$) fat depth. The reduction in 10th rib fat depth tended to be greatest (quadratic; $P < 0.10$) at the 5 or 10 ppm level of astaxanthin.

The amount of standardized fat-free lean in the carcasses tended (quadratic; $P < 0.09$) to be improved with increasing astaxanthin, and this resulted in a trend ($P < 0.09$) for an increased percentage of fat-free lean for pigs fed astaxanthin. Pigs fed 5 or 10 ppm astaxanthin tended (quadratic; $P < 0.10$) to have the greatest percentage of fat-free lean.

Loin color measurements of CIE L* and b* tended ($P < 0.06$ and $P < 0.08$, respectively) to be lower for pigs fed astaxanthin. The L* measurement indicates the degree of lightness (0 = black, 100 = white). The b* is a measure of yellowness (positive value) vs. blueness (negative value). The CIE a* and b* measurements were lowest (quadratic; $P < 0.02$ and $P < 0.06$, respectively) at the 10 ppm level of astaxanthin; however, the CIE a* of pigs fed 5 and 20 ppm astaxanthin was numerically greater than that of the controls. The a* is a measure of redness (positive value) vs. greenness (negative value).

In this study, the improved carcass characteristics associated with feeding astaxanthin resulted in numeric improvements in the net profit per pig for those fed 5 and 10 ppm. However, because there was not any further improvement in carcass characteristics for pigs fed 20 ppm astaxanthin, feeding this level was of no economic benefit (based on a price of $9.07/lb for the 10,000 ppm astaxanthin product). The improvements in carcass characteristics are similar to those observed by Yang et al. (2006), who evaluated feeding 1.5 and 3 ppm astaxanthin for 14 d preslaughter. However, Yang et al. (2006) did not observe differences in loin muscle color at the 10th rib.

Although packers do not generally provide producers with premiums or discounts based on muscle color characteristics, consumer acceptance studies for pork have determined that lower CIE L* values are more desirable. Results of the current study indicate that feeding higher concentrations of astaxanthin over a longer period may improve pork color characteristics.

In conclusion, growth performance of pigs receiving 5, 10, or 20 ppm astaxanthin was not different from that of pigs fed the control diet. However, the improvements in carcass characteristics could be economically beneficial to pork producers. Additionally, the improvements in loin color could result in improved consumer acceptance of fresh pork. However, astaxanthin is not yet approved for food animals other than farmed aquatic species in the United States. These results warrant further research.

Table 1. Composition of the experimental control diet[1, 2]

Ingredient	%
Corn	85.40
Soybean meal (46.5% CP)	12.44
Monocalcium P (21% P)	0.45
Limestone	0.85
Salt	0.35
L-lysine HCl	0.15
Vitamin premix	0.08
Trace mineral premix	0.08
Cornstarch[3]	0.20
Total	100.00
Calculated analysis	
Total lysine, %	0.72
SID[4] amino acids	
Lysine, %	0.63
Isoleucine:lysine ratio, %	71
Leucine:lysine ratio, %	188
Methionine:lysine ratio, %	33
Met & Cys:lysine ratio, %	68
Threonine:lysine ratio, %	64
Tryptophan:lysine ratio, %	18
Valine:lysine ratio, %	85
Protein, %	13.2
ME, kcal/lb	1,522
SID lysine:ME ratio, g/Mcal	1.88
Ca, %	0.47
P, %	0.42
Available P, %	0.15

[1] Experimental diets were fed for 26 d before slaughter.
[2] Ingredient prices used to determine the diet cost were: corn, $118/ton; soybean meal, $207/ton; Monocalcium P, $332/ton; Limestone, $30/ton; Salt, $53/ton; L-lysine HCl, $1,800/ton; Processing and delivery, $12/ton; and Astaxanthin (10,000 ppm), $9.07/lb.
[3] Astaxanthin replaced cornstarch in the control diet to achieve the 5, 10, and 20 ppm astaxanthin treatments.
[4] Standardized ileal digestible.

Table 2. Growth performance and carcass characteristics of pigs fed increasing astaxanthin[1]

	Astaxanthin, ppm					Probability, $P <$		
Item	0	5	10	20	SEM	Control vs. Astaxanthin	Linear	Quadratic
Growth performance, d 0 to 26								
Initial wt, lb	215	215	215	215	2.90	---[2]	---	---
ADG, lb	2.11	2.23	2.03	1.99	0.12	---	---	---
ADFI, lb	6.67	6.76	6.24	6.20	0.24	---	0.10	---
F/G	3.22	3.05	3.08	3.16	0.15	---	---	---
Final wt, lb	270	273	268	267	3.81	---	---	---
Feed, $/lb gain	0.23	0.23	0.25	0.29	0.01	---	0.01	---
Feed, $/pig	12.57	13.55	13.23	14.59	0.51	0.06	0.02	---
Carcass characteristics								
Live wt, lb	271	273	271	270	3.95	---	---	---
HCW, lb	192	192	191	189	3.38	---	---	---
Yield, %	71.0	70.6	70.6	70.3	0.64	---	---	---
Average backfat thickness, in.	1.00	0.89	0.85	0.87	0.05	0.03	---	---
10th rib fat depth, in.	0.82	0.65	0.65	0.70	0.07	0.06	---	0.10
Loin eye area, sq. in.	7.33	7.72	7.58	7.28	0.30	---	---	---
Loin eye color[3]								
CIE L*	60.3	55.3	58.9	56.2	1.42	0.06	---	---
CIE a*	9.4	10.1	8.2	10.3	0.31	---	---	0.02
CIE b*	15.8	14.8	14.4	15.1	0.47	0.08	---	0.06
Standardized fat-free lean, lb	102	107	106	103	2.37	---	---	0.09
Fat-free lean, %	53.2	55.6	55.5	54.5	1.04	0.09	---	0.10
Economic implications								
Estimated carcass value, $/100 lb[4]	68.76	70.13	70.08	69.41	0.65	---	---	---
Estimated total carcass value, $	128.37	131.79	130.98	130.41	2.40	---	---	---
Estimated net profit/loss per pig relative to control, $	-	2.44	1.95	0.02	3.31	---	---	---

[1] A total of 48 barrows (PIC TR4 × C22) were used with 2 pigs per pen and 6 pens per treatment. Data were obtained from 1 pig per pen for the determination of carcass characteristics.
[2] Probability, $P > 0.10$.
[3] The range for CIE L* is 0 to 100 (0 = black, 100 = white). A positive CIE a* indicates the degree of redness. A positive CIE b* indicates the degree of yellowness.
[4] From the Sept. 13, 2007, USDA National Daily Direct Negotiated Hog Purchase Matrix with adjustments for carcass weight differentials.

Effects of Meal or Pellet Diet Form on Finishing Pig Performance and Carcass Characteristics[1]

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Summary

Two experiments were performed to determine the effects of feeding diets in meal or pellet form on finishing pig performance. A corn-soybean meal-based diet was fed in Exp. 1, and a diet containing alternative ingredients was used in Exp. 2. All pelleted diets were processed through a CPM pellet mill (California Pellet Mill Co., Crawfordsville, IN) equipped with a 3⁄16 in. die.

In Exp. 1, a total of 1,072 pigs (60.7 lb) were used in a 112-d trial. Treatments were arranged in 2 × 2 factorial design (10 pens per treatment) with main effects of diet form (meal or pellet) and gender (barrows or gilts). Diet formulation and particle size (approximately 660 microns) was identical among the treatments. From d 0 to 112, pigs fed pelleted diets had increased ADG (2.04 vs. 1.92 lb, $P < 0.01$) compared with pigs fed diets in meal form. There was no difference ($P = 0.69$) in ADFI, but pigs fed pelleted diets had a 5.3% improvement (2.68 vs. 2.83, $P < 0.01$) in F/G compared with pigs fed meal diets. With the improvements in F/G driving the growth response, pigs fed pellets were 13.6 lb heavier ($P < 0.01$) at off test than pigs fed meal diets.

In Exp. 2, a total of 1,214 pigs (58.3 lb) were used in a 42-d trial to evaluate diets containing alternative ingredients in pellet or meal form. Barrow and gilt pens were randomly allotted to a meal or pellet treatment group (11 pens per treatment). Like Exp. 1, diet particle size (approximately 660 microns) and formulation were identical among the treatments. Pigs fed a by-product-based diet in pellet form had greater (2.05 vs. 1.95 lb, $P < 0.01$) ADG than pigs fed the identical diet in meal form. There were no differences ($P \geq 0.15$) in overall (d 0 to 42) ADFI or F/G between pigs fed meal and pelleted diets. Pigs fed pelleted diets had a numerical ($P = 0.14$) weight advantage of 4.1 lb on d 42 compared with pigs fed meal diets.

These data demonstrate that feeding a pelleted diet improved ADG compared with feeding a meal diet; however, the magnitude of the response was inconsistent between trials. In addition, F/G was improved by pelleting in the first trial, with no effect found in the second trial. One explanation for this difference might be the quality of the pellets. Samples of the pelleted diets collected in Exp. 1 contained approximately 25% fines, whereas samples of the pelleted diets in Exp. 2 were composed of approximately 35% fines. Diets formulation (corn-soybean vs. corn-alternative ingredients) can influence pellet quality, which may explain differences between the experiments.

Key words: carcass, growth, pellet

[1] Appreciation is expressed to J-Six Enterprises, Seneca, KS, for their assistance and for providing the pigs and facilities used in this experiment.

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

Introduction

Feeding pelleted diets to pigs has been shown to increase nutrient digestibility and improve F/G from 5% to 8% in finishing pigs fed a corn-soybean meal-based diet under university research conditions. Other advantages to pelleted diets include the ability to grind grain to a smaller micron size and use high percentages of alternative ingredients in the diets and still maintain feed flowability. However, the improvement in F/G may not be as large under field conditions because of poor pellet quality. Increased fine buildup in feed pans and feed wastage are outcomes of a poor quality pellet. Besides the cost of pelleting, another disadvantage to feeding pelleted diets is a mortality increase as a result of gastric ulcers. This susceptibility to ulcers also appears to be dependent on genotype. The recent increase in feed costs has led producers to reevaluate the economics of feeding pelleted finishing pig diets. Therefore, the objective of this study was to determine the effects of feeding a pelleted milo or corn-soybean meal-based diet (Exp. 1) or a diet containing a large proportion of alternative ingredients (Exp. 2) on performance of commercial finishing pigs.

Procedures

Procedures used in these studies were approved by the Kansas State University Institutional Animal Care and Use Committee. Both experiments were performed in commercial research finishing barns located in northeastern Kansas. The barns were naturally ventilated and double curtain sided with completely slatted flooring. Each pen (10 × 18 ft) was equipped with a double swinging waterer and a 3-hole dry self-feeder, allowing for ad libitum access to water and feed. An automated feeding system (FeedPro; Feedlogic Corp., Willmar, MN) was used in each barn to deliver and measure feed amounts added to individual pen feeders.

In Exp. 1, a total of 1,072 pigs (60.7 lb) were used in a 112-d finishing trial. Pigs were sorted by gender (barrow or gilt) and placed in pens with 26 to 28 pigs per pen. Pens of pigs were randomly allotted to a diet form treatment (meal or pellet) with average pig weight balanced across treatments. Treatments were arranged in 2 × 2 factorial design with main effects of gender and diet form in a completely randomized design. Diets were pelleted at a commercial mill with a CPM pellet mill (California Pellet Mill Co., Crawfordsville, IN) with a 3⁄16 in. die. There were 10 pens per diet form × gender treatment. The same dietary formulation was used for both diet forms. Diets were corn-soybean meal based, except the diet used for the initial batch of feed contained 30% milo to replace a portion of the corn in the diet. Particle size was kept constant so that only the processing form varied among treatment groups. Samples of the pelleted diets were collected at the barn during each phase, and pellet durability index (PDI) was determined on the corn-soybean meal-based diet by using the standard tumbling-box technique. Before testing pellets for durability, fines were removed and quantified. A modified PDI was also conducted by adding 5 hexagon nuts into the tumbling box.

Pens of pigs were weighed and feed intake was recorded on d 0, 14, 28, 41, 56, 70, 90, and 112. From these data, ADG, ADFI, and F/G were calculated. At the conclusion of the study, pigs were individually tattooed with a number corresponding to their pen to facilitate collection of carcass data at harvest. On d 90, the 4 heaviest pigs ("tops") in each pen were removed and marketed. At the end of the trial, pigs were sold over 2 consecutive days in a balanced fashion, with the last pigs weighed off test on d 112.

In accordance with allowable weight guidelines from the packing plant, pigs weighing more than 215 lb were marketed and carcass data were collected. Lightweight pigs weighing less than 215 lb were held back to allow for additional weight gain. Data from these lightweight pigs are included in all growth and performance data but not in the carcass data.

Finisher growth and feed performance data were analyzed as a completely randomized design using the GLIMMIX procedure of SAS (SAS Institute Inc., Cary, NC) and pen as the experimental unit. Diet form and gender were the main effects. For analysis of carcass characteristics, percentage yield was calculated by dividing HCW by live weight determined at the site prior to transport to the processing plant. For comparisons among treatments for backfat depth, loin depth and percentage lean, HCW was used to adjust responses to a common HCW. Differences among treatments were determined by using least squares means ($P < 0.05$).

In Exp. 2, a total of 1,214 pigs (58.3 lb) were used in a 42-d trial to determine the effects of diet form (meal or pellet) on performance. There were 27 to 28 pigs per single-sex pen, with 11 pens per diet form × gender treatment. Although there were 22 replication pens per gender treatment, gender was confounded with genotype because gilt pens were comprised of progeny from terminal sire-line matings and barrow pens were progeny of maternal or terminal sire-line matings. A common diet containing 32.5% fortified hominy mixture was used for both diet form treatments. Particle size was identical among the treatments. To minimize sources of variation between diet forms, meal diets were made and mixed at a common commercial feed mill, and then 24 tons of complete diet were trucked to an alternate location for pelleting. Diets were pelleted using a 3⁄16 in. die. Because of this transport schedule, the pelleted diets were fed based on a budget of 24 tons per phase, and diets were fed in 2 phases. Meal diet phases matched the phase changes in the pellet treatment. The standard and modified PDI values were determined by using the same procedures as in Exp. 1.

Pens of pigs were weighed and feed intake was recorded on d 0, 14, 28, and 42. From these data, ADG, ADFI, and F/G were calculated.

Performance data were analyzed as a completely randomized design using the GLIMMIX procedure of SAS and pen as the experimental unit. Diet form was analyzed as a fixed effect, and because of the confounding with genotype, gender was considered a random effect. Differences among treatments were determined by using least squares means ($P < 0.05$).

Results and Discussion

In Exp. 1, a gender × diet form interaction ($P \leq 0.03$) was observed for ADG from d 0 to 90 and d 90 to 112 (Table 1). From d 0 to 90, within both barrows and gilts, pigs fed pelleted diets had greater ($P < 0.01$) ADG; barrows fed pelleted diets gained 0.19 lb/d more than barrows fed meal diets, and gilts fed pelleted diets gained 0.12 lb/d more than gilts fed meal diets. The magnitude of the response to consuming pelleted diets on ADG from d 0 to 90 was greater in barrows than in gilts; however, from d 90 to 112, barrows fed pelleted diets had decreased ($P < 0.01$) ADG compared with barrows fed meal diets, and there was no difference ($P = 0.74$) in ADG attributable to diet form for

gilts. Because of the variability in these data, there was no gender × diet form interaction ($P = 0.22$) observed for overall (d 0 to 112) ADG. From d 0 to 112, there was no difference ($P = 0.69$) in feed intake among pigs fed meal and pelleted diets (Table 2). Therefore, the greater ($P < 0.01$) overall growth rate in pigs fed pelleted diets compared with pigs fed meal diets is attributable to the difference in F/G between these treatment groups. Pigs fed pelleted diets had a 5.3% improvement (2.68 vs. 2.83, $P < 0.01$) in overall F/G compared with pigs fed meal diets. These data support findings previously reported in the literature for improvements in feed efficiency achievable with feeding corn-soybean meal-based pelleted diets. With the improvements in F/G driving the increased gain for pellet-fed pigs, pigs consuming pellets were 13.6 lb heavier ($P < 0.01$) at off test than meal-fed pigs. From d 0 to 112, barrows had greater ($P < 0.01$) ADG and ADFI and poorer ($P < 0.01$) F/G than gilts.

Similar to live weight results, pigs fed pellets had heavier ($P < 0.01$) carcasses than pigs fed meal diets (Table 3). Though backfat depth was unaffected ($P = 0.19$) by diet form, there was a trend for pigs fed pelleted diets to be less ($P = 0.07$) lean and have decreased ($P = 0.09$) loin depth.

For other carcass characteristics, there was a gender × diet form interaction ($P = 0.03$) for percentage yield. Barrows fed meal diets had lower (73.4%, $P \leq 0.02$) percentage yield than barrows fed pelleted diets or gilts fed either diet form. There was no difference ($P \geq 0.08$) among barrows fed pellets (74.7%), gilts fed meal diets (74.1%), and gilts fed pellets (74.4%). Overall, barrow carcasses were heavier (214.0 vs. 203.9 lb, $P < 0.01$) and less lean (51.9% vs. 54.1%, $P < 0.01$) with increased (21.8 vs. 17.0 mm, $P < 0.01$) backfat depth and decreased (60.3 vs. 62.7 mm, $P < 0.01$) loin depth.

In summary, pigs fed a pelleted corn-soybean meal-based diet had increased ADG compared with pigs fed the same diets in meal form, but the magnitude of the response was gender dependent. Regardless of gender, pigs fed pelleted diets had improved F/G and heavier market and carcass weights than pigs fed meal diets.

In Exp. 2, pigs fed a fortified hominy-based diet in pellet form from d 0 to 42 had greater ($P < 0.01$) ADG than pigs fed the same diet formulation in meal form (Table 4). Feeding pelleted diets improved ($P < 0.05$) F/G from d 14 to 28 and d 28 to 42 but not for the overall trial ($P \geq 0.15$). The F/G improvements were 3.3% from d 14 to 28 and 5.1% from d 28 to 42. The overall response from d 0 to 42 was 2.4%. The growth performance differences resulted in pigs fed pelleted diets having a numerical weight advantage of 4.1 lb at off test compared with pigs fed meal diets.

Differences in pellet quality may have contributed to the lower response in Exp. 2 compared with Exp. 1. It was unknown what pellet quality would be achievable with the diet containing alternative ingredients. Although it was possible to produce a pelleted diet with this base diet, the quality of the pellet was poorer than that of the corn-soybean meal-based pellet used in Exp. 1. Samples of the pelleted diets collected in Exp. 1 contained approximately 25% fines, whereas samples of the pelleted diets in Exp. 2 were composed of approximately 35% fines. Standard and modified PDI average values were 87% and 80%, respectively, for both experiments. The PDI analysis was conducted after fines were removed from the samples.

Additional research needs to be completed with fortified hominy-based diets to help further explain the variability in the responses found in these experiments. These trials indicate that the magnitude of expected response appears to be affected by diet composition and pellet quality.

Table 1. Effect of gender and diet form on growth performance of finishing pigs (Exp. 1)[1]

	Barrow		Gilt			Gender × Form
Diet form[2]:	Meal	Pellet	Meal	Pellet	SEM	*P* <
d 0 to 90						
Initial wt, lb	60.6	60.8	60.8	60.6	0.9	0.81
ADG, lb	1.96[a]	2.15[b]	1.85[c]	1.97[a]	0.02	0.03
ADFI, lb	5.39	5.57	4.87	4.92	0.06	0.26
F/G	2.75	2.59	2.63	2.50	0.02	0.41
d-90 wt, lb	238.2[a]	257.4[b]	229.2[c]	239.8[b]	2.0	0.04
d 90 to 112[3]						
ADG, lb	2.12[a]	1.98[b]	1.83[c]	1.85[c]	0.04	0.03
ADFI, lb	7.55	6.96	6.45	6.17	0.09	0.11
F/G	3.57	3.52	3.54	3.34	0.06	0.27
d 0 to 112						
ADG, lb	1.99	2.12	1.85	1.95	0.02	0.22
ADFI, lb	5.74	5.80	5.13	5.12	0.06	0.60
F/G	2.89	2.73	2.77	2.63	0.02	0.70
Final wt, lb	276.8	293.0	261.3	272.3	2.4	0.30

[1] A total of 1,072 pigs with 26 to 28 pigs per pen were used in a 112-d trial. There were 10 replication pens per gender × diet form treatment.

[2] A common corn-soybean meal-based diet was fed in either meal or pellet form (3/16 in.).

[3] On d 90, the 4 heaviest pigs per pen were removed and marketed.

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

Table 2. Main effects of diet form on growth performance of finishing pigs (Exp. 1)[1]

	Diet form[2]			Probability, $P <$
Item	Meal	Pellet	SEM	Diet
d 0 to 90				
Initial wt, lb	60.7	60.7	0.7	0.99
ADG, lb	1.91	2.06	0.01	<0.01
ADFI, lb	5.13	5.25	0.04	0.05
F/G	2.69	2.54	0.01	<0.01
d-90 wt, lb	233.7	248.6	1.4	<0.01
d 90 to 112[3]				
ADG, lb	1.98	1.91	0.03	0.09
ADFI, lb	7.00	6.57	0.07	<0.01
F/G	3.55	3.43	0.04	0.06
d 0 to 112				
ADG, lb	1.92	2.04	0.01	<0.01
ADFI, lb	5.44	5.46	0.04	0.69
F/G	2.83	2.68	0.01	<0.01
Final wt, lb	269.0	282.6	1.7	<0.01

[1] A total of 1,072 pigs with 26 to 28 pigs per pen were used in a 112-d trial. There were 20 replication pens per diet form treatment.
[2] A common corn-soybean meal-based diet was fed in either meal or pellet form (3⁄16 in.).
[3] On d 90, the 4 heaviest pigs per pen were removed and marketed.

Table 3. Effect of diet form on carcass characteristics of finishing pigs (Exp. 1)[1]

	Diet form[2]			Probability, $P <$	
Item	Meal	Pellet	SEM	Diet	Gender × Diet form
no. of pigs (> 215 lb) marketed	473	480	---	---	---
no. of pigs (< 215 lb) held back	45	29	---	---	---
Overall marketing[3,4,5]					
Live wt, lb	275.6	287.7	1.5	<0.01	0.69
HCW, lb	203.4	214.5	1.3	<0.01	0.30
Yield, %[6]	73.8	74.5	0.1	<0.01	0.03
Lean, %[7]	53.2	52.8	0.1	0.07	0.56
Backfat depth, mm[7]	19.1	19.7	0.3	0.19	0.40
Loin depth, mm[7]	62.0	61.0	0.4	0.09	0.22

[1] A total of 953 pigs (d 90: 160 pigs; d 111 and 112: 793 pigs) are represented in the carcass data from 20 replication pens per diet form treatment.
[2] A common corn-soybean meal-based diet was fed in either meal or pellet form.
[3] On d 90, the 4 heaviest pigs per pen were removed and marketed.
[4] On d 111 and 112, pigs greater than 215 lb were marketed for carcass data collection.
[5] Overall marketing data combines data from all pigs marketed on d 90 and 112.
[6] Percentage yield was calculated by dividing HCW by live weight obtained prior to transport to the packing plant.
[7] Percentage lean, backfat depth, and loin depth were adjusted to a common HCW.

Table 4. Effect of diet form on growth performance of finishing pigs (Exp. 2)[1]

	Diet form[2]			
Item	Meal	Pellet	SEM	Probability, $P <$
d 0 to 14				
ADG, lb	1.87	1.83	0.06	0.39
ADFI, lb	3.56	3.58	0.12	0.85
F/G	1.90	1.95	0.02	0.12
d 14 to 28				
ADG, lb	1.72	1.97	0.07	<0.01
ADFI, lb	3.76	4.17	0.17	<0.01
F/G	2.19	2.12	0.03	0.05
d 28 to 42				
ADG, lb	2.27	2.34	0.10	0.03
ADFI, lb	5.11	5.01	0.32	0.23
F/G	2.25	2.14	0.05	0.01
d 0 to 42				
ADG, lb	1.95	2.05	0.08	<0.01
ADFI, lb	4.14	4.25	0.20	0.24
F/G	2.12	2.07	0.03	0.15
Weight, lb				
d 0	58.2	58.3	1.8	0.98
d 42	140.4	144.5	4.8	0.14

[1] A total of 1,214 pigs (27 to 28 pigs per pen) were used in a 42-d trial. There were 22 replication pens per diet form treatment.

[2] A common diet consisting of 32.5% fortified hominy mixture was fed in either meal or pellet form.

Effects of Feeder Design, Gender, and Dietary Concentration of Dried Distillers Grains with Solubles on the Growth Performance and Carcass Characteristics of Growing-Finishing Pigs[1]

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Summary

A 2 × 2 × 2 factorial experiment was conducted to evaluate the interactive effects of feeder design (conventional dry vs. wet-dry feeder), gender (barrow vs. gilt), and dietary concentration of dried distillers grains with solubles (DDGS; 20% vs. 60%) on finishing pig performance. A total of 1,080 pigs (PIC 337 × 1050) were used in the 99-d experiment. Pigs were sorted by gender (barrows and gilts) into groups of 27, weighed (77.4 lb initial BW), allotted to pens containing 1 of the 2 feeder types, and assigned to a corn-soybean meal-DDGS-based feeding program of either 20% or 60% DDGS. A completely randomized design was used to evaluate the 8 treatment combinations, with 5 pens per treatment. This provided 20 pens per treatment for each of the three main effects (feeder type, gender, and DDGS concentration). All pigs were fed their assigned level of DDGS in 3 dietary phases (d 0 to 28, 28 to 56, and 56 to 78). On d 78, 2 pigs per pen were weighed and harvested. Jowl fat samples were collected from these pigs for fatty acid analysis and iodine value (IV). All remaining pigs were fed a common diet from d 78 to 99 that contained 20% DDGS and 4.5 g/ton of ractopamine HCl (Paylean; Elanco Animal Health, Indianapolis, IN). On d 99, all remaining pigs were harvested and carcass data were obtained from 885 pigs. Jowl fat samples were collected from 2 pigs per pen for fatty acid analysis and IV. Overall (d 0 to 99), pigs using the wet-dry feeder had greater ($P < 0.001$) ADG, ADFI, F/G, final BW, feed cost per pig, HCW, and backfat depth but decreased ($P < 0.05$) fat-free lean, jowl fat IV, premium per pig, value per cwt live, and net income per pig. Feeding 60% DDGS from d 0 to 78 resulted in decreased ($P < 0.02$) ADG, final BW, feed cost per pig, HCW, and backfat depth but increased ($P < 0.05$) F/G, fat-free lean, jowl fat IV, and net income per pig. Barrows had greater ($P < 0.01$) ADG, ADFI, F/G, final BW, feed cost per pig, HCW, and backfat depth but reduced fat-free lean, jowl fat IV, premium per pig, value per cwt live, and net income per pig. In conclusion, the greatest net income per pig resulted from feeding gilts 60% DDGS from d 0 to 78 and 20% DDGS with Paylean from d 78 to 99 using a conventional dry feeder. However, using wet-dry feeders improved ADG and ADFI of growing-finishing pigs and may improve the performance of slower growing populations within a group (e.g., gilts). Wet-dry feeders may also restore the growth rates of pigs fed adverse levels of DDGS. More research with wet-dry feeders is needed to resolve concerns with F/G, carcass leanness, and economic returns.

Key words: dried distillers grains with solubles, feeders

[1] Appreciation is expressed to New Horizon Farms for use of pigs and facilities and to Richard Brobjorg, Scott Heidebrink, and Mary Heintz for technical assistance.

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Introduction

Because finishing feed costs represent a significant proportion of the cost of production, swine producers are continually evaluating technologies that may improve the growth performance of finishing pigs and income over feed cost. Considerable improvements in growth and efficiency have been made in the areas of genetics and nutrition. However, studies that improve our understanding of various feeder types and their effects on performance, feeding behavior, and efficiency are scarce.

Currently, commercial growing-finishing barns are equipped with various types of feeders and waterers designed to provide pigs with ad libitum access to feed and water while attempting to minimize waste. Feed is often presented to pigs in its original, dry form with water provided separately in a nipple waterer, cup waterer, or water trough located in close proximity. However, some barns are equipped with wet-dry feeders, and these types of feeders are becoming increasingly common.

With a wet-dry feeder, the water source is located in the feed pan, giving pigs access to dry feed and water in the same location and the opportunity to consume wet feed. Previous research at Kansas State University (Rantanen et al., 1998[3]; Amornthewaphat et al., 2000[4]; Bergstrom et al., 2008[5]) has consistently demonstrated that using a wet-dry feeder improves the growth rate of finishing pigs. These previous studies evaluated the differences between a wet-dry feeder and a dry feeder with water provided separately. However, more studies comparing the effects of various feeder designs on the growth performance and carcass characteristics of finishing pigs in commercial facilities are needed.

The increasing costs of traditional feed ingredients coupled with the increased availability of dried distillers grains with solubles (DDGS) and other coproducts of the ethanol industry has resulted in an increase in the use of alternative feed ingredients. Research in recent years indicates that up to 20% DDGS may be included in diets for growing-finishing without reducing performance. Feeding more than 20% DDGS may result in reduced feed intake and growth performance, and pork fat quality may become unacceptable for some market outlets. Feeding pigs with a wet-dry feeder could overcome some of the negative aspects of feeding higher levels of alternative ingredients, giving swine producers more flexibility with ingredient selection.

Variation in the growth rates of individual pigs within a group reduces the efficiency of facility utilization in pork production. Normal biological variation results from individual differences in gender, genetics, health, birth weight, BW at placement, social status within the group, and nutritional status and requirements. Typically, gilts and barrows are fed a different feed budget during the growing and finishing period because gilts generally have lower ADG, ADFI, and F/G; are leaner; and therefore have different nutrient requirements. Using a wet-dry feeder for gilts could be more beneficial than for barrows and may improve the ability to manage within-group variation to achieve greater economic benefit.

[3] Rantanen et al., Swine Day 1995, Report of Progress 746, pp. 119-120.
[4] Amornthewaphat et al., Swine Day 2000, Report of Progress 858, pp. 123-131.
[5] Bergstrom et al., Swine Day 2008, Report of Progress 1001, pp. 196-203.

Therefore, the objective of this research was to determine if wet-dry feeders would improve the performance and profitability of barrows and gilts housed in commercial conditions and fed diets containing 20% or 60% DDGS.

Procedures

Procedures used in the experiment were approved by the Kansas State University Institutional Animal Care and Use Committee. The experiment was conducted in a commercial research finishing facility in southwestern Minnesota. The facility was double curtain sided with pit fans for minimum ventilation and completely slatted flooring over a deep pit for manure storage. Individual pens were 10 × 18 ft. Half of the pens were equipped with a single 60-in.-wide 5-hole conventional dry feeder (STACO, Inc., Schaefferstown, PA) and a single cup waterer in each pen (Figure 1). The remaining pens were each equipped with a double-sided wet-dry feeder (Crystal Springs, GroMaster, Inc., Omaha, NE) with a 15-in. feeder opening on both sides that provided access to feed and water (Figure 2). All pens that were equipped with a wet-dry feeder contained a cup waterer; however, these waterers were shut off during the experiment. Therefore, the only source of water for pigs in these pens was through the wet-dry feeder.

A total of 1,080 pigs (PIC 337 × 1050) were used in a 99-d experiment. A 2 × 2 × 2 factorial arrangement of treatments was used to evaluate the interactive effects of feeder design (conventional dry vs. wet-dry feeder), gender (barrow vs. gilt), and dietary concentration of DDGS (20% vs. 60%) on finishing pig performance. Pigs were sorted by gender (barrows and gilts) into groups of 27, weighed (77.4 lb initial BW), allotted to pens containing 1 of the 2 feeder types, and assigned to a corn-soybean meal-DDGS-based feeding program of either 20% or 60% DDGS (Table 1). A completely randomized design was used to evaluate the 8 treatment combinations, with 5 pens per treatment. This provided 20 pens per treatment for each of the 3 main effects (feeder type, gender, and DDGS concentration). All pigs were fed their assigned level of DDGS in 3 dietary phases (d 0 to 28, 28 to 56, and 56 to 78). On d 78, the 2 largest pigs in each pen were weighed and removed for harvest. Jowl fat samples were collected from these pigs for fatty acid analysis and iodine value (IV). All remaining pigs were fed a common diet from d 78 to 99 that contained 20% DDGS and 4.5 g/ton of ractopamine HCl (Paylean; Elanco Animal Health, Indianapolis, IN). On d 99, all remaining pigs were harvested and carcass data were obtained from 885 pigs. Jowl fat samples were collected from the carcasses of 2 average-sized pigs within each pen for fatty acid analysis and IV. This experiment was conducted from Aug. 8 to Nov. 12, 2008.

Data were analyzed as 2 × 2 × 2 factorial arrangement in a completely randomized design using the PROC MIXED procedure of SAS (SAS Institute Inc., Cary, NC). Pen was the experimental unit. Because there were differences in the initial BW of barrows and gilts, the initial BW was used as a covariate in data analysis.

Results

From d 0 to 78 (Table 2), feeder design × DDGS ($P < 0.05$) and feeder design × gender ($P < 0.04$) interactions were observed for ADG and d-78 BW. The reductions in ADG and d-78 BW that were associated with feeding 60% DDGS were much greater for pigs using the wet-dry feeder. Additionally, the ADG and d-78 BW of barrows and gilts

using the wet-dry feeder were similar; however, with the conventional dry feeder, the ADG and d-78 BW of barrows were greater than those of gilts. Despite the interactions, ADG, ADFI, and d-78 BW were greater and F/G was poorer for pigs using the wet-dry feeder ($P < 0.001$). Pigs fed 20% DDGS had greater ($P < 0.001$) ADG and d-78 BW but better ($P < 0.001$) F/G than those fed 60% DDGS. Barrows had greater ($P < 0.02$) ADG, ADFI, and d-78 BW but poorer F/G than gilts.

From d 78 to 99, when all pigs received a common diet containing 20% DDGS and 4.5 g/ton Paylean, a trend ($P < 0.06$) for a feeder design × gender interaction was observed for ADFI. This occurred because the difference in ADFI between barrows and gilts was greater with the wet-dry feeder. Despite the interaction, ADG and ADFI were greater ($P < 0.02$) for pigs using the wet-dry feeder compared with the dry feeder and for pigs fed 60% DDGS compared with 20% DDGS in the previous period. Barrows also had greater ($P < 0.01$) ADFI and poorer F/G than gilts.

Overall (d 0 to 99, Tables 2 and 3), there were trends ($P < 0.10$) for a feeder design × gender interaction for F/G and net income per pig. These occurred because the differences in F/G and net income per pig between pigs using the wet-dry feeder and conventional dry feeder were less for gilts than barrows. No other significant interactions were observed. Pigs using the wet-dry feeder had greater ($P < 0.001$) ADG, ADFI, final BW, feed cost per pig, HCW, and backfat depth; poorer ($P < 0.05$) F/G; and decreased fat-free lean, jowl fat IV, premium per pig, value per cwt live, and net income per pig. There was also a trend ($P < 0.09$) for pigs using the wet-dry feeder to have greater total revenue per pig because of their heavier final BW. Feeding 60% DDGS from d 0 to 78 resulted in decreased ($P < 0.02$) ADG, final BW, feed cost per pig, HCW, and backfat depth; poorer ($P < 0.05$) F/G; and decreased fat-free lean, jowl fat IV, and net income per pig. There was also a trend ($P < 0.08$) for pigs fed 60% DDGS from d 0 to 78 to have greater value per cwt live. This was primarily due to a marginal improvement in fat-free lean but also to the absence of a reduction in yield that is commonly associated with feeding increasing levels of DDGS. The absence of a reduction in yield is likely because the level of DDGS was reduced from 60% to 20% for the last 21 d. Barrows had greater ($P < 0.01$) ADG, ADFI, final BW, feed cost per pig, HCW, and backfat depth; poorer F/G; and decreased fat-free lean, jowl fat IV, premium per pig, value per cwt live, and net income per pig.

Discussion

Feeding gilts with a conventional dry feeder and a diet containing 60% DDGS to d 78 followed by 20% DDGS and 4.5 g/ton Paylean for the last 21 d resulted in the greatest net income in this experiment. The net income per pig was $25.23 greater for these gilts compared with barrows fed 20% DDGS with the wet-dry feeder. Although these gilts grew slower, they were leaner and more efficient and had a greater net income than these barrows.

In this experiment, the ADG, ADFI, and final weight of barrows and gilts were increased with a wet-dry feeder. Although ADG, ADFI, and final weight were greater for barrows than for gilts, the differences in ADG and final weight between barrows and gilts using the wet-dry feeder were less than those of barrows and gilts using the conventional dry feeder. Also, in spite of the expected overall differences in growth between

barrows and gilts, the ADG of gilts using the wet-dry feeder was nearly 5% greater than that of barrows using the conventional dry feeder, and the final weight of gilts using the wet-dry feeder was nearly 3% greater than that of barrows using the conventional dry feeder. These data suggest that swine producers could use wet-dry feeders to manage variation in growth rates within a population of pigs and potentially improve facility utilization. Although the difference in net income per pig between gilts fed with wet-dry feeders and barrows fed with conventional feeders was $3.73/pig better for gilts compared with barrows, our economic analysis indicates that the net income per pig was still lower by $8.09/pig for gilts fed with the wet-dry feeder compared with gilts fed with the conventional feeder. The greater feed cost per pig, greater backfat depth, and poorer F/G resulted in a lower net income ($9.96) for pigs fed with a wet-dry feeder.

Despite the reductions in ADG and final weight that were associated with increasing DDGS from 20% to 60% during d 0 to 78, the ADG of pigs fed 60% DDGS with the wet-dry feeder was 5% greater than that of pigs fed 20% DDGS with a conventional dry feeder, and the final weight of pigs fed 60% DDGS with the wet-dry feeder was nearly 4% greater than that of pigs fed 20% DDGS with a conventional dry feeder. Clearly, wet-dry feeders could be used to overcome the negative effect of increasing levels of DDGS on ADG. Despite their reduced ADG and poorer F/G, pigs fed 60% DDGS from d 0 to 78 had a lower feed cost per pig and greater net income ($6.16) than pigs fed 20% DDGS from d 0 to 99. Switching pigs fed 60% DDGS to 20% DDGS for the last 21 d resulted in improvements in their ADG and ADFI and likely improved their final weight and carcass yield. However, the jowl fat IV values of these pigs remained considerably higher than the levels deemed acceptable by various packers.

Unlike previous experiments comparing wet-dry and conventional feeders (Rantanen et al., 1995; Amornthewaphat et al., 2000; Bergstrom et al., 2008), F/G was considerably poorer for pigs using the wet-dry feeder in this experiment, particularly in the early period for pigs fed 60% DDGS. Also, F/G was considerably poorer for pigs fed 60% DDGS in the later periods. An explanation for this may be that there was more feed wastage associated with the type of diets used in the current experiment than for diets in other experiments. Initially, all of the conventional dry feeders were set to a common feeder gap opening of approximately 1 in., which was determined to be optimal in previous experiments (Duttlinger et al., 2008[6]). The wet-dry feeders were initially adjusted to a common feeder gap opening of approximately 1.25 in., which was used in previous experiments as suggested by a representative of the feeder manufacturer. This setting appeared to be acceptable for a short period just prior to the initiation of the experiment. However, once the experiment began, the feed pans in most of the pens receiving the 60% DDGS diet became covered (or filled) with feed very quickly, and this was observed to be much worse for the wet-dry feeders.

In our previous experiments (Bergstrom et al., 2008), the diets were formulated using 5% bakery by-product, contained various amounts of choice white grease, and contained from 9% to 30% DDGS. Few experiments have evaluated diets containing 60% DDGS. Differences in the flowability characteristics of the feeds may account for some of the differences in ADFI (or feed disappearance) and F/G observed within and

[6] Duttlinger et al., Swine Day 2008, Report of Progress 1001, pp. 204-214.

between experiments. Because of the flowability characteristics encountered in this experiment, individual feeders were adjusted daily as needed to obtain a targeted pan coverage of just greater than 50%, as suggested by Duttlinger et al. (2008) in previous experiments. This was difficult to achieve initially but became easier as pigs grew larger. Experiments to identify the optimal adjustment for wet-dry feeders have not been reported, and further experiments are needed to determine the optimum feeder adjustment for various feeders, diets (e.g., pellet vs. meal, high oil vs. low oil ingredients, angle of repose), feeder stocking densities, and BW.

In conclusion, using wet-dry feeders improved ADG and ADFI of growing-finishing pigs and may improve the performance of slower growing populations within a group (e.g., gilts). Wet-dry feeders may also restore the growth rates of pigs fed adverse levels of DDGS. However, more research is needed to resolve concerns with F/G, carcass leanness, and economic returns. Future research may improve our understanding of the dynamics of feeder design, water source and location relative to the feeder, feeder adjustment, feed intake, feed wastage, feeder space, feeding behavior, and diet composition and the related consequences for growing-finishing pigs.

Figure 1. Conventional dry feeder with cup waterer.

Figure 2. Wet-dry feeder.
Note that the cup waterer was shut off so the only source of water was through the feeder.

Table 1. Diet composition[1]

	Dietary phase						
	d 0 to 28		d 28 to 56		d 56 to 78		d 78 to 99
DDGS,%[2]:	20	60	20	60	20	60	20
Ingredient, %							
Corn	60.07	26.45	63.00	29.90	66.84	33.55	58.36
Soybean meal (46.5% CP)	18.06	11.20	15.25	7.83	11.49	4.24	19.85
DDGS	20.00	60.00	20.00	60.00	20.00	60.00	20.00
Limestone	1.00	1.40	0.95	1.35	0.90	1.35	1.00
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Liquid lysine (60%)	0.40	0.50	0.35	0.48	0.33	0.43	0.33
VTM + OptiPhos 2000[3]	0.12	0.10	0.10	0.09	0.09	0.08	0.08
Paylean	---	---	---	---	---	---	0.025
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Cost, $/lb[4]	0.110	0.098	0.107	0.096	0.104	0.093	0.117
Calculated analysis							
SID[5] amino acids, %							
Lysine, %	0.95	0.95	0.85	0.85	0.74	0.74	0.95
Isoleucine:lysine, %	68	77	70	80	72	85	71
Leucine:lysine, %	175	231	188	249	204	278	180
Methionine:lysine, %	31	40	33	43	35	48	32
Met & Cys:lysine, %	63	81	67	86	72	96	65
Threonine:lysine, %	61	73	64	76	67	82	64
Tryptophan:lysine, %	17	18	18	18	18	18	18
Valine:lysine, %	81	97	85	101	89	110	84
CP, %	18.9	23.8	17.9	22.5	16.5	21.1	19.6
Total lysine, %	1.10	1.18	0.99	1.07	0.87	0.94	1.10
ME, kcal/lb	1,526	1,521	1,527	1,522	1,529	1,523	1,526
SID lysine:ME ratio, g/Mcal	2.82	2.83	2.52	2.53	2.20	2.17	2.82
Ca, %	0.47	0.60	0.44	0.57	0.41	0.56	0.47
P, %	0.43	0.58	0.42	0.56	0.41	0.55	0.44
Available P, %	0.27	0.32	0.25	0.32	0.23	0.31	0.22

[1] Each dietary phase was fed to both feeder types during the periods described in the table.
[2] Dried distillers grains with solubles.
[3] VTM = Vitamin and trace mineral premix. OptiPhos 2000 (Enzyvia LLC, Sheridan, IN) provided 0.07% to 0.12% available P.
[4] Ingredient prices used were: corn, $195/ton; soybean meal, $325/ton; DDGS, $160/ton; limestone, $50/ton; salt, $60/ton; liquid lysine, $1,600/ton; VTM, $3,200/ton; phytase, $5,300/ton; Paylean, $57,000/ton; and $12/ton processing and delivery fee.
[5] Standardized ileal digestible.

Table 2. Effects of feeder design, gender, and dietary concentration of dried distillers grains with solubles (DDGS) on the growth performance of growing-finishing pigs[1,2]

	Feeder type													
	Wet-Dry				Conventional dry					Probability, P <				
	20% DDGS		60% DDGS		20% DDGS		60% DDGS							
Item	Barrow	Gilt	Barrow	Gilt	Barrow	Gilt	Barrow	Gilt	SEM	Feeder type	DDGS	Feeder × DDGS	Gender	Feeder × Gender
d 0 to 78														
ADG, lb	2.04	2.01	1.90	1.91	1.88	1.81	1.81	1.75	0.02	0.001	0.001	0.05	0.02	0.04
ADFI, lb	5.58	5.23	5.50	5.20	4.86	4.54	4.84	4.47	0.06	0.001	---[3]	---	0.001	---
F/G	2.75	2.60	2.90	2.72	2.59	2.51	2.67	2.56	0.04	0.001	0.001	---	0.001	---
d 78 BW, lb	239.5	234.8	226.6	227.5	227.3	218.8	220.2	214.9	1.8	0.001	0.001	0.05	0.01	0.04
d 78 to 99	20% DDGS													
ADG, lb	2.45	2.35	2.66	2.50	2.34	2.25	2.42	2.43	0.08	0.02	0.01	---	---	---
ADFI, lb	7.51	6.64	7.74	6.80	6.62	6.17	7.03	6.64	0.17	0.001	0.02	---	0.001	0.06
F/G	3.07	2.83	2.93	2.72	2.83	2.74	2.92	2.73	0.08	---	---	---	0.01	---
d 0 to 99														
ADG, lb	2.11	2.07	2.05	2.02	1.97	1.89	1.93	1.88	0.02	0.001	0.01	---	0.01	---
ADFI, lb	5.94	5.50	5.93	5.51	5.19	4.86	5.27	4.89	0.06	0.001	---	---	0.001	---
F/G	2.82	2.65	2.90	2.72	2.64	2.56	2.73	2.60	0.03	0.001	0.01	---	0.001	0.10
d 99 BW, lb	288.0	282.0	282.0	278.2	275.4	264.9	269.7	264.3	2.7	0.001	0.02	---	0.001	---

[1] A total of 1,080 pigs (PIC 337 × 1050) with an initial BW of 77.4 lb were placed in 40 pens containing 27 pigs each and were used in a 99-d experiment to compare the growth performance of barrows and gilts fed diets containing 20% or 60% DDGS with either a conventional dry feeder with a cup waterer or a wet-dry feeder.

[2] There were no feeder × DDGS × gender or DDGS × gender interactions observed for these criteria.

[3] Not significant ($P > 0.10$).

Table 3. Effects of feeder design, gender, and dietary concentration of dried distillers grains with solubles (DDGS) on the carcass characteristics and profitability of growing-finishing pigs[1,2]

	Feeder type												
	Wet-Dry				Conventional dry								
	20% DDGS		60% DDGS		20% DDGS		60% DDGS			Probability, P <			
Item	Barrow	Gilt	Barrow	Gilt	Barrow	Gilt	Barrow	Gilt	SEM	Feeder type	DDGS	Gender	Feeder × Gender
Live BW, lb	289.5	279.1	277.9	271.2	273.7	262.1	267.1	259.9	3.8	0.001	0.01	0.001	---[3]
HCW, lb	216.0	209.7	209.2	203.1	204.5	196.5	200.1	196.0	3.0	0.001	0.01	0.001	---
Yield, %	74.6	75.1	75.3	74.9	74.7	75.0	75.0	75.4	0.3	---	---	---	---
Backfat depth, in.	0.84	0.69	0.78	0.65	0.72	0.58	0.70	0.57	0.02	0.001	0.01	0.001	---
Loin depth, in.	2.33	2.38	2.32	2.32	2.36	2.45	2.33	2.37	0.05	---	---	---	---
Fat-free lean index	48.8	50.4	49.3	50.7	49.9	51.2	50.0	51.5	0.2	0.001	0.05	0.001	---
Jowl IV[4]													
d 78 (n = 72)	68.7	70.8	80.2	81.3	71.0	74.1	81.2	86.2	1.5	0.001	0.001	0.001	---
d 99 (n = 72)	70.3	73.8	79.3	81.4	72.0	75.0	81.0	82.9	1.2	0.05	0.001	0.001	---
Live bid, $/cwt	40.50												
Premium/pig, $	-2.07	4.61	2.13	4.73	4.14	7.35	4.69	7.31	1.09	0.001	---	0.001	---
Value live, $/cwt	39.91	42.25	41.38	42.34	42.13	43.40	42.36	43.39	0.40	0.001	0.08	0.001	---
Revenue/pig, $	115.52	117.95	114.95	114.86	115.27	113.77	113.14	112.82	1.98	0.09	---	---	---
Feed cost/pig, $	103.67	93.68	92.94	86.17	89.04	81.71	81.86	75.74	1.27	0.001	0.001	0.001	---
Facility cost/pig, $	10.40												
Pig cost at entry, $	50.00												
Net income/pig, $	-48.56	-36.14	-38.39	-31.71	-34.16	-28.34	-28.95	-23.33	1.69	0.001	0.001	0.001	0.09

[1] A total of 885 pigs (PIC 337 × 1050) were used to compare carcass characteristics and profitability of barrows and gilts fed 20% or 60% DDGS with either a conventional dry feeder with a cup waterer or a wet-dry feeder.

[2] There were no feeder × DDGS × gender, feeder × DDGS, or DDGS × gender interactions observed for these criteria.

[3] Not significant ($P > 0.10$).

[4] A DDGS × day interaction (P < 0.02) was observed for jowl iodine value (IV). Jowl IV was greater on d 99 for pigs that were fed 20% DDGS throughout the experiment but was greater on d 78 for pigs fed 60% DDGS from d 0 to 78.

Economic Impact of Removing Pigs Before Marketing on the Remaining Pigs' Growth Performance[1]

J. Y. Jacela[2], S. S. Dritz[2], M. D. Tokach, J. M. DeRouchey, R. D. Goodband, and J. L. Nelssen

Summary

The economic impact of removing the heaviest pigs (topping) before marketing a finishing group and the effect of topping on performance of the remaining pigs were determined in 2 studies. In Exp. 1, a total of 1,126 pigs (BW = 241 lb; 25 pigs/pen) were randomly assigned to 1 of 3 treatments: topping 0, 2, or 4 pigs/pen 15 d before marketing the remaining pigs in the group. After topping, floor space per pig was 7.2, 7.8, and 8.6 ft^2 for pens with 0, 2, and 4 pigs topped per pen, respectively. Overall (d 0 to 15), increasing the number of pigs topped per pen improved ADG ($P < 0.02$), ADFI (linear; $P < 0.03$), and F/G (quadratic; $P < 0.04$). Revenues were similar ($P > 0.76$) between treatments, but feed usage and cost was reduced (quadratic; $P < 0.01$) as more pigs were topped per pen. However, there was no impact on income over feed cost (IOFC). In Exp. 2, a total of 1,084 pigs (BW = 234 lb; 27 pigs/pen) were assigned to 1 of 5 treatments. On d 0 (20 d before closeout), 2 pigs were topped from each pen excluding the control pens (0 top). Pens that were topped at d 0 had an additional 0, 2, 4, or 6 pigs per pen topped on d 10. Floor space per pig was 6.7 ft^2 in control pens and 7.2 ft^2 for the remaining pens from d 0 to 10. After topping on d 10, floor space per pig was 7.8, 8.6, and 9.5 ft^2 for pens with 2, 4, or 6 more pigs topped, respectively. From d 10 to 20, the remaining pigs had increased (linear; $P < 0.01$) ADFI, which led to a linear increase ($P < 0.01$) in ADG. Overall, ADG and ADFI increased (linear; $P < 0.05$) with increasing number of pigs topped, and F/G improved ($P < 0.01$) in topped pens relative to intact pens. Weight discounts were highest in intact pens ($P < 0.02$) compared to topped pens. Revenue decreased ($P < 0.05$) as additional pigs were topped after d 10 in pens topped at d 0. Feed usage was highest ($P < 0.01$) in intact pens. As more pigs were topped on d 10, IOFC tended to decrease ($P = 0.07$). Topping, regardless of number of pigs, did not affect ($P > 0.23$) any of the carcass traits measured. Topping improves growth performance of the remaining pigs. Based on IOFC, topping 2 pigs once is the most optimal. Improvements in performance from topping more than 2 pigs were not great enough to overcome the reduction in total weight produced by the pen.

Key words: growth, marketing

Introduction

Natural variability exists in pig body weight within a given group. Sources of variability may be classified as intrinsic, which means related to the pig itself (e.g., genetics), or extrinsic, which refers to environmental factors that affect the pig (e.g., stocking density). Variability in weights at market has become increasingly important with the

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

[2] Food Animal Health and Management Center, College of Veterinary Medicine, Kansas State University.

adoption of all-in-all-out practices. Pigs that fall outside the specified weight ranges of processing plants can have significant economic discounts. Although it may be impossible to eliminate all sources of variation, several approaches can be implemented to effectively manage variation including increasing the growth rate of the whole group during the grow-finish period and sorting finishing pigs at market to fit weight requirements of processing plants.

In the United States, marketing the heaviest pigs several weeks before the expected barn closeout (topping) is a common practice. Previous studies have shown that this kind of marketing strategy can also lead to improved growth performance of the remaining pigs in the pen. The result is that more pigs are marketed within the weight window of a particular processing plant and premiums may be maximized. Topping, however, also can add to overall production costs if topped pigs are not the appropriate market weight and because of the increased labor requirements. Thus, it is necessary to evaluate the economics of removing pigs before barn closeout and determine the economically feasible number of pigs to top. These studies were conducted to evaluate the economic impact of removing the heaviest pigs prior to marketing the whole finishing group and determine the effect of topping on growth performance of the remaining pigs.

Procedures

This study was approved by and conducted in accordance with the guidelines of the Kansas State University Institutional Animal Care and Use Committee. The experiment was conducted in a commercial research finishing barn in southwestern Minnesota. The barns were naturally ventilated and double curtain sided. Pens were 18 × 10 ft with completely slatted flooring and deep pits for manure storage. Each pen was equipped with a 5-hole STACO (Schaefferstown, PA) stainless steel dry self-feeder with a feed pan dimension of 60 × 7 × 5.75 in. (length × width × height). Water was provided ad libitum through a cup waterer installed in each pen. Daily feed additions to each pen were accomplished through a robotic feeding system capable of providing and measuring feed amounts on an individual pen basis.

Two separate experiments were conducted in this study. In Exp. 1, a total of 1,126 pigs (PIC 337 × C22, initial BW = 241 lb) were randomly assigned to 1 of 3 treatments balanced by average BW within gender. There were 25 pigs per pen and 15 pens per treatment (7 pens of barrows and 8 pens of gilts). Treatments were topping 0, 2, or 4 pigs per pen at d 0 (15 d before barn closeout). Pigs selected for topping were visually selected as the heaviest pigs in the pen. The resulting floor space per pig was 7.2, 7.8, and 8.6 ft^2 for pens with 0, 2, and 4 pigs topped per pen, respectively.

In Exp. 2, a total of 1,084 pigs (PIC 337 × C22, initial BW = 234 lb) were randomly assigned to 1 of 5 treatments balanced by average BW. There were 27 pigs per pen and 8 pens per treatment. On d 0 (20 d prior to closeout), all pens had 2 pigs topped per pen with the exception of the control pens (0 topped per pen). All pens initially topped on d 0 were then topped on d 10 with 0, 2, 4, or 6 pigs removed per pen to complete the 5 treatments. As in Exp. 1, pigs selected for topping were visually selected as the heaviest pigs in the pen. Floor space per pig was 6.7 ft^2 in control pens and 7.2 ft^2 for all remaining pens during the first 10 d. After topping on d 10, the resulting floor space per pig was 7.8, 8.6, and 9.5 ft^2 for pens with an additional 2, 4, or 6 pigs topped per pen, respectively.

Immediately after topping, pens were weighed again (d 0) to determine the average pig weight in Exp. 1 and 2. All treatment groups were fed similar diets based on corn and soybean meal. Diets contained 5 ppm ractopamine HCl (Paylean; Elanco Animal Health, Greenfield, IN). Pigs from each pen were weighed as a group and feed consumption was determined on d 8 and 15 (off test) in Exp. 1 and on d 10 and 20 in Exp. 2 to measure ADG, ADFI, and F/G. Economic criteria including total revenue (adjusted to 25 and 27 pigs per pen in Exp. 1 and 2, respectively), feed cost, and income over feed cost (IOFC) were calculated on a pen and pig basis. At the end of Exp. 2, pigs were individually tattooed by pen before being transported to JBS Swift and Company (Worthington, MN) for processing and carcass data collection. Standard carcass criteria of loin and backfat depth, HCW, percentage lean, and yield were collected. Fat-free lean index (FFLI) was determined with the following equation: 50.767 + (0.035 × HCW) - (8.979 × backfat).

Statistical analysis was performed by analysis of variance with the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) to test for the main effects and interactions between number of pigs topped and gender. Data were analyzed as a completely randomized design with pen as the experimental unit. Linear and polynomial contrasts were used to determine the main effects of increasing number of pigs topped per pen. In Exp. 2, controls were excluded when analyzing the linear and quadratic effects of topping. Means for percentage lean, loin depth, backfat, and FFLI were adjusted to a common HCW, which was used as a covariate in the model.

Results and Discussion

In Exp. 1, there was no topping × sex interaction ($P > 0.33$) for any of the criteria measured (Table 1). Average BW was similar ($P > 0.50$) between treatments after topping. From d 0 to 8, ADG and F/G of the remaining pigs improved (quadratic; $P < 0.04$) as more pigs were topped per pen. From d 8 to 15, ADFI increased (linear; $P < 0.01$) with increasing number of pigs topped per pen. Overall (d 0 to 15), increasing the number of pigs topped per pen from 0 to 2 or 4 increased ADG ($P < 0.02$), ADFI (linear; $P < 0.03$), and F/G (quadratic; $P < 0.04$). There were no differences ($P > 0.76$) in revenue between treatments, but feed usage and feed cost on a pen or pig basis was reduced (quadratic; $P < 0.01$) as more pigs were topped per pen (Table 2). The reduction in feed usage and cost did not affect IOFC.

In Exp. 2, there was no difference ($P > 0.24$) in ADG and ADFI from d 0 to 10 (Table 3). There was a linear increase ($P < 0.02$) in F/G that may have been due to random variability. From d 10 to 20, increasing the number of pigs topped linearly increased ($P < 0.01$) ADFI of pigs remaining in the pen, which led to a linear increase ($P < 0.01$) in ADG. This resulted in overall improvements in ADG and ADFI (linear; $P < 0.05$) with increasing number of pigs topped. Overall, F/G improved ($P < 0.01$) in all pens that were topped relative to pens that were not topped. However, topping more than 2 pigs per pen did not result ($P > 0.24$) in further improvement in F/G. This suggests that the linear increase in ADG with increasing number of pigs topped per pen was mainly due to the linear increase in ADFI. At the end of the trial, average BW did not differ ($P > 0.91$) between treatments. Pens that were not topped had the highest weight discounts ($P < 0.02$) compared to pens that were topped (Table 4). However, there were no differences in weight discounts among pens with different numbers of pigs

topped. Revenue, either on a pen or pig basis, decreased ($P < 0.05$) as additional pigs were topped after d 10 in pens that were topped at d 0. Similar to Exp. 1, feed usage was highest ($P < 0.01$) in intact pens. As more pigs were topped on d 10, IOFC tended to decrease ($P > 0.07$). Topping, regardless of number of pigs, had no effect ($P > 0.23$) on any of the carcass parameters measured (Table 5).

Removing the heaviest market-ready pigs prior to marketing all pigs in a group provides an opportunity for producers to potentially maximize revenues. Pigs that have already reached market weight can be sold earlier, providing additional days for the rest of the group to reach target weights. As shown in this experiment, the remaining pigs in the pen have increased floor space and, consequently, increased access to feed and water. This could explain the resulting post-topping increase in growth performance of the remaining pigs in both experiments. As expected, total feed usage was reduced as a result of a lower number of pigs on feed. However, the removal of additional pigs after d 10 led to a decreasing revenue and IOFC as a result of decreasing total weight of pigs sold per pen as more pigs were removed. Thus, it was most economical to top 2 pigs once prior to the final marketing of all pigs. It should be noted, however, that Exp. 2 was conducted during the winter months when floor space could possibly have less impact on growth. Therefore, the effects of marketing strategies used in Exp. 2 should also be investigated during the summer months.

Another advantage of topping appears to be a reduction in variability as indicated by less weight discounts from pigs that came from topped pens than from pigs from non-topped pens. This supports the results from previous research that suggest topping is an effective tool to manage variability in finishing systems.

In conclusion, removing the heaviest pigs before marketing the entire group improved growth performance of the remaining pigs compared to pigs from pens that were left intact. Producers should evaluate topping procedures on an IOFC basis for optimal economic returns. Topping at least 2 pigs twice before marketing improved growth performance the most, but topping 2 pigs only once was optimal based on IOFC. Topping more than 2 pigs provided continual improvements in performance; however, the benefits were not great enough to overcome the reduction in total weight produced by the pen.

Table 1. Effect of sex and marketing strategy on growth performance (Exp. 1)[1]

	Treatment[2]				Probability, $P <$	
Item	None	2 pigs	4 pigs	SEM	Linear	Quadratic
Weight, lb						
d 0 (before topping)	240.6	241.5	241.6	2.29	0.81	0.82
d 0 (after topping)	240.6	238.8	236.6	2.38	0.58	0.29
Tops	---	271.9	267.0	2.79	---	---
d 8	260.0	259.9	259.5	2.39	0.99	0.90
d 15	275.0	276.9	275.6	2.26	0.56	0.95
d 0 to 8						
ADG, lb	2.41	2.62	2.83	0.120	0.19	0.04
ADFI, lb	5.89	6.31	5.93	0.168	0.10	0.39
F/G	2.60	2.47	2.11	0.131	0.43	0.01
d 8 to 15						
ADG, lb	2.10	2.40	2.30	0.127	0.12	0.70
ADFI, lb	6.62	7.14	7.11	0.131	0.01	0.19
F/G	3.52	3.08	3.14	0.239	0.22	0.57
d 0 to 15						
ADG, lb	2.26	2.52	2.58	0.068	0.01	0.02
ADFI, lb	6.23	6.70	6.48	0.138	0.03	0.97
F/G	2.81	2.67	2.52	0.085	0.24	0.03

[1] A total of 1,126 pigs, initially 241 lb, were used with 22 to 27 pigs per pen and 15 replications per treatment.
[2] None = topped 0 pigs/pen, 2 pigs = topped 2 pigs/pen, 4 pigs = topped 4 pigs/pen on d 0.

Table 2. Economic impact of gender and marketing strategy (Exp. 1)[1]

	Treatment[2]				Probability, $P <$	
Item	None	2 pigs	4 pigs	SEM	Linear	Quadratic
Total pig weight produced, lb/pen	6,865	6,905	6,850	53.9	0.60	0.65
Revenue[3]						
Low, $/pen[4]	3,089	3,107	3,082	24.3	0.60	0.65
High, $/pen[4]	4,119	4,143	4,110	32.4	0.60	0.65
Low, $/pig[5]	123.57	124.29	123.30	0.972	0.60	0.65
High, $/pig[5]	164.76	165.72	164.40	1.295	0.60	0.65
Total feed consumption						
Feed usage, lb/pen	2,336	2,310	2,040	47.6	0.66	<0.0001
Feed usage, lb/pig	93.4	92.4	81.6	1.90	0.66	<0.0001
Feed cost[6]						
Low, $/pen	233.6	231.0	204.0	4.76	0.66	<0.0001
High, $/pen	303.6	300.4	265.2	6.19	0.66	<0.0001
Low, $/pig[7]	9.34	9.24	8.16	0.190	0.66	<0.0001
High, $/pig[7]	12.15	12.01	10.61	0.247	0.66	<0.0001
IOFC, $/pen[8]						
LowRev-LowFeed	2,856	2,876	2,878	22.0	0.50	0.57
HighRev-HighFeed	3,815	3,843	3,845	29.4	0.50	0.59
LowRev-HighFeed	2,786	2,807	2,817	21.4	0.47	0.37
HighRev-LowFeed	3,885	3,912	3,906	30.0	0.52	0.77
IOFC, $/pig[8]						
LowRev-LowFeed	114.23	115.05	115.14	0.879	0.50	0.57
HighRev-HighFeed	152.61	153.71	153.79	1.175	0.50	0.59
LowRev-HighFeed	111.42	112.28	112.69	0.858	0.47	0.37
HighRev-LowFeed	155.42	156.48	156.24	1.199	0.52	0.77

[1] A total of 1,126 pigs, initially 241 lb, were used with 22 to 27 pigs per pen and 15 replications per treatment.
[2] None = topped 0 pigs/pen, 2 pigs = topped 2 pigs/pen, 4 pigs = topped 4 pigs/pen on d 0.
[3] Based on $45/cwt for Low and $60/cwt for High.
[4] Adjusted to 25 pigs/pen and calculated as:
None = [(avg. wt at d 0 × 25) + (ADF × 15 × 25)] × 0.45 or 0.60.
2 Pigs = Total top wt + [(avg. wt after Top × 23) + (ADF × 15 × 23)] × 0.45 or 0.60.
4 Pigs = Total top wt + [(avg. wt after Top × 21) + (ADF × 15 × 21)] × 0.45 or 0.60.
[5] Revenue/pen divided by 25 pigs/pen for all treatments.
[6] Based on diet costs of $200/ton for Low and $260/ton for High.
[7] Feed cost per pen divided by 25 pigs/pen for all treatments.
[8] Income over feed cost; calculated as revenue - feed cost.

Table 3. Effect of different marketing strategies on growth performance of remaining pigs (Exp. 2)[1]

	No. of pigs topped per pen							
d 0:	0	2	2	2	2		Probability, $P <$	
d 10:	0	0	2	4	6	SEM	Linear	Quadratic
Weight, lb								
d 0 (before top)	234.0	234.0	234.0	234.1	234.0	1.83	0.99	0.96
d 0 (after top)	234.0	231.5	231.2	231.4	231.5	1.92	1.00	0.92
d 0 (top pigs)	---	264.0	270.0	268.6	265.1	3.12	---	---
d 10 (before top)	259.9	257.9	257.5	258.7	258.3	2.17	0.83	1.00
d 10 (after top)	259.9	257.9	255.3	253.9	250.8	2.39	0.07	0.93
d 10 (top pigs)	---	---	283.4	283.0	281.1	2.77	---	---
d 20	275.8	277.7	275.5	274.8	274.3	2.65	0.39	0.76
d 0 to 10								
ADG, lb	2.45	2.57	2.60	2.53	2.52	0.053	0.32	0.75
ADFI, lb	5.99	5.96	6.28	6.39	6.28	0.121	0.24	0.29
F/G	2.45	2.32	2.41	2.53	2.49	0.043	0.02	0.29
d 10 to 20								
ADG, lb	1.59	1.91	2.02	2.08	2.28	0.093	0.01	0.63
ADFI, lb	5.65	5.86	6.31	6.69	6.72	0.098	<0.0001	0.13
F/G	3.65	3.20	3.14	3.32	2.95	0.163	0.53	0.42
d 0 to 20								
ADG, lb	2.02	2.24	2.32	2.32	2.42	0.052	0.03	0.88
ADFI, lb	5.82	5.91	6.30	6.52	6.47	0.085	0.01	0.17
F/G	2.90[a]	2.66[b]	2.71[bc]	2.82[c]	2.67[bc]	0.052	0.68	0.24

[1] A total of 1,084 pigs, initially 234 lb, were used with 27 pigs per pen and 8 replications per treatment.
[abc] Within a row, means without a common superscript differ ($P < 0.05$).

Table 4. Effect of different marketing strategies on various economic parameters (Exp. 2)[1]

	No. of pigs topped per pen							
d 0:	0	2	2	2	2		Probability, $P <$	
d 10:	0	0	2	4	6	SEM	Linear	Quadratic
Total pig weight produced, lb/pen	7,448	7,471	7,443	7,440	7,429	64.1	0.67	0.90
Weight discount, $/pen	68.8[a]	37.0[b]	32.6[b]	38.2[b]	28.7[b]	8.46	0.61	0.76
Revenue, $/100 lb	55.8	56.6	56.5	56.4	56.3	0.43	0.59	1.00
Revenue, $/pen	3,115	3,178	3,146	3,094	3,095	33.2	0.05	0.61
Revenue, $/pig	115.37	117.71	116.54	114.58	114.64	1.228	0.05	0.61
Feed usage, lb/pen	3,141[a]	2,954[bc]	3,022[c]	3,002[c]	2,849[b]	41.8	0.32	0.14
Feed usage, lb/pig	116.3[a]	109.4[bc]	111.9[c]	111.2[c]	105.5[b]	1.55	0.32	0.14
Feed cost[2]								
Low, $/pen	314.1[a]	295.4[bc]	302.2[c]	300.2[c]	284.9[b]	4.18	0.32	0.14
High, $/pen	408.4[a]	384.0[bc]	392.9[c]	390.3[c]	370.3[b]	5.43	0.32	0.14
Low, $/pig	11.63[a]	10.94[bc]	11.19[c]	11.12[c]	10.55[b]	0.155	0.32	0.14
High, $/pig	15.13[a]	14.22[bc]	14.55[c]	14.45[c]	13.72[b]	0.201	0.32	0.14
IOFC[3]								
At low feed cost, $/pen	2,801	2,883	2,844	2,794	2,811	31.1	0.07	0.39
At high feed cost, $/pen	2,707	2,794	2,754	2,703	2,725	30.6	0.08	0.34
At low feed cost, $/pig	103.73	106.77	105.34	103.46	104.10	1.153	0.07	0.39
At high feed cost, $/pig	100.24	103.49	102.98	100.12	100.93	1.134	0.08	0.34

[1] A total of 1,084 pigs, initially 234 lb, were used with 27 pigs per pen and 8 replications per treatment.
[2] Used standard values of $0.10/lb for Low and $0.13/lb for High feed cost scenarios.
[3] Income over feed cost.
[abc] Within a row, means without a common superscript differ ($P < 0.05$).

Table 5. Effect of different marketing strategies on carcass characteristics (Exp. 2)[1]

	Number of pigs topped per pen								
d 0:	0	2	2	2	2		Probability, $P <$		
d 10:	0	0	2	4	6	SEM	Treatment	Linear	Quadratic
Carcass weight, lb	206.4	208.8	208.1	205.6	205.8	2.40	0.78	0.23	0.70
Yield, %	76.6	76.4	76.3	75.5	75.8	0.41	0.23	0.13	0.66
Lean[2], %	56.4	56.1	57.5	56.4	56.6	0.62	0.54	0.97	0.50
Loin depth[2], in.	2.48	2.48	2.61	2.53	2.54	0.051	0.36	0.60	0.35
Backfat[2], in.	0.61	0.60	0.60	0.62	0.64	0.018	0.29	0.19	0.84
Fat-free lean index[2]	51.3	51.3	51.4	51.1	50.9	0.20	0.32	0.25	0.78

[1] A total of 1,084 pigs, initially 234 lb, were used with 27 pigs per pen and 8 replications per treatment.
[2] Values adjusted to a common carcass weight.

Incidence and Severity of *Arcanobacterium pyogenes* Injection Site Abscesses with Needle or Needle-Free Injection Methods[1]

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Summary

A total of 198 nursery age pigs were used to evaluate the difference in the occurrence of injection site abscesses between needle-free jet injection and conventional needle-and-syringe injection systems. Pigs were fed for 21 d prior to treatment administration to acclimate the pigs to the environment of the Kansas State University Segregated Early Weaning Unit. On d 21, each pig received 4 injections of aluminum hydroxide adjuvant, 1 in the neck and 1 in the ham by needle-free jet injection (Pulse Needle-Free Systems, Lenexa, KS) on 1 side and 1 in the neck and 1 in the ham on the opposite side by conventional needle-and-syringe injection. Immediately prior to injection, the external surface of the injection sites was contaminated with an inoculum of *Arcanobacterium pyogenes*. The pigs were then fed for a period of 27 and 28 d. On d 27 and 28, the pigs were humanely euthanized and sent to the Kansas State University Veterinary Diagnostics Laboratory, where necropsies were performed and the injection sites underwent histopathological evaluation. The needle-free jet injection system was associated with more injection site abscesses than the conventional needle-and-syringe injection method for both the neck ($P = 0.06$) and ham ($P = 0.03$) injection sites. Twelve abscesses were found at needle-free injection sites, whereas only 1 abscess was found where a conventional needle injection method was used. Five abscesses were found at the neck injection sites, and 8 abscesses were observed at the ham injection sites. Of the 13 abscesses found, 10 developed on the left side of the animal, and only 3 were on the right side. In summary, the implementation of needle-free jet injection systems in market hog production will be beneficial by eliminating the potential for needles and needle fragments in meat products, but it may increase the occurrence of injection site abscesses in pork carcasses that will need to be trimmed in pork processing plants.

Key words: abscess, *Arcanobacterium pyogenes*, needle-free injection

Introduction

According to the 1994 Pork Chain Quality Audit (NPPC, 1994[4]), 8% of pork carcasses have abscesses present. As a result, abscesses are a very costly problem for commercial pork harvesting plants in the United States because carcasses exhibiting abscesses require trimming and may even be condemned. The presence of abscesses contributes to carcass trimming on 7.4% of all pork carcasses (NPPC, 1994).

[1] Appreciation is expressed to the National Pork Board for funding this project.
[2] Veterinary Diagnostics Laboratory, Kansas State University.
[3] Department of Statistics, Kansas State University.
[4] NPPC (1994). Pork Chain Quality Audit (Progress Report – April 6, 1994). National Pork Producers Council, Des Moines, Iowa.

Another dilemma facing the pork packing industry is the potential for broken needles or needle fragments in pork products. This is of great concern to the industry because it presents a significant safety hazard to consumers. Even though metal detection systems are commonplace in packing plants, the alloys that these needles are made of and the size of the needle fragments can allow these metal pieces to go undetected (Sundberg, 2000[5]).

Needle-free air-powered vaccine injection systems are currently being used in the commercial swine industry. These injection systems are capable of serological responses similar to those of conventional needle injection devices with the added benefit of no broken needles (Houser et al., 2004[6]). Additionally, needle-free injection methods have shown potential for reducing lateral transmission of diseases when large numbers of animals are vaccinated (Reinbold et al., in press[7]). However, there has been no research investigating the relationship between injection types and abscess occurrence. Thus, the objective of this study was to investigate whether different injection types have different effects on the development of injection site abscesses when pigs are inoculated with *Arcanobacterium pyogenes*.

Procedures

The Kansas State University (K-State) Institutional Animal Care and Use Committee approved protocols used in this experiment. Pigs were housed at the K-State Segregated Early Weaning Unit.

A total of 198 nursery-age pigs were used in this 49-d study. The pigs were allowed a 21-d conditioning period to become acclimated with their environment before treatments were administered. On d 0 of the trial, each pig received a total of 4 intramuscular injections of a 2 mL dose of aluminum hydroxide vaccine adjuvant. On one side of the animal, a conventional needle-and-syringe injection method using a disposable 18 gauge × ¾ in. needle was used to administer an injection in the neck and ham, and needles were changed after every 25 animals. On the opposite side of the animal, a Pulse 250 needle-free jet injector (Pulse Needle-Free Systems, Lenexa, KS) set at 45 psi was used to administer injections in the neck and ham. A random number generator was used to randomize which side of the animal received each type of injection. Immediately prior to injection, the skin over the injection site was contaminated with an inoculum of *A. pyogenes*, a bacterium commonly associated with abscesses in swine, which was prepared by the K-State Veterinary Diagnostic Laboratory. The injection devices were not decontaminated or disinfected between injections.

After injections were administered, the pigs were housed in their originally assigned pens for 27 and 28 d and monitored daily with feed additions weighed and recorded.

[5] Sundberg, P. (2000). Detectability of needle fragments in pork under packing plant conditions. Pages 317-320 in Proceedings of the American Association of Veterinary Practitioners Preconference Workshops.

[6] Houser, T. A., J. G. Sebranek, B. J. Thacker, T. J. Baas, D. Nilubol, E. L. Thacker, and F. Kruse. 2004. Effectiveness of transdermal, needle-free injections for reducing pork carcass defects. Meat Sci. 68:329-332.

[7] Reinbold, J. B., J. F. Coetzee, L. C. Hollis, J. S. Nickell, C. Reigel, J. Huff, and R. R. Ganta. Comparison of *Anaplasma marginale* disease transmission with needle-free versus needle injection. Accepted for publication (Aug. 31). American J. of Veterinary Research – 09-07-0279.

On d 27 and 28, the pigs were humanely euthanized via jugular injection of 6 mL of Fatal Plus, 390 mg/mL pentobarbital. The euthanized pigs were then sent to the K-State Veterinary Diagnostic Laboratory, where externally palpable lesions were measured through the skin with calipers. Necropsies were then performed on all animals, and abscessed areas were harvested, measured, and weighed. Representative portions of the reactive tissue surrounding the injection sites were placed in 10% neutral buffered formalin for histopathological evaluation. A score of "0" was given to tissue from injections sites that were normal when viewed under a microscope. A score of "1" was given to tissue that contained groups of swollen macrophages with some granulation surrounding them that were due to a reaction to the adjuvant. A score of "2" was given to tissue that had abscesses and granulation visible microscopically.

The FREQ procedure of SAS (SAS Institute Inc., Cary, NC) was used, and injection site served as the experimental unit. The paired binary data were then analyzed using McNemar's test.

Results and Discussion

Of a total of 792 injection sites, only 13 abscesses were found by gross and histological evaluation. There were 11 individual pigs that had injection site abscesses, with 1 individual having 3 abscesses. There was a greater amount of abscesses from the use of the needle-free jet injection system than from the conventional needle-and-syringe injection system for both the neck ($P = 0.0625$) and the ham ($P = 0.0313$) injection locations (Table 1). Of the 13 observed abscesses, 12 occurred at needle-free injection sites, and only 1 developed at a conventional needle-and-syringe injection site. Additionally, no statistical difference ($P > 0.05$) was observed when comparing abscess occurrence and injection site; neck injection sites had 5 abscesses, whereas 8 abscesses were observed at ham injection sites. There was not a significant difference in occurrence of abscesses between right and left sides. Of the 13 abscesses found, 10 developed on the left side of the animal, and 3 were on the right side.

Our findings contradict results by Houser et al. (2004), who found no difference in abscess formation between needle-free and conventional needle injection. This difference might be caused by the inoculum used in this study because no inoculum was used in their study.

Previous audit data has shown that abscesses occur at a relatively low rate in the commercial slaughter hog population (NPPC, 1994). This is in agreement with our data because only 5.6% of the pigs used in the present trial were positive for abscess formation. This is somewhat surprising because we purposely contaminated the exterior of the skin with a pathogen known to be found in abscesses on pork carcasses.

There is no question that the use of needle-free jet injection systems will benefit the pork industry by eliminating the potential for needles and needle fragments in meat products. However, these results suggest that implementing needle-free jet injection systems into commercial swine production may increase the amount of injection site abscesses as a result of *A. pyogenes* contamination. Additional research is needed to further understand the relationship between the occurrences of abscesses with different injection types.

Table 1. Pigs with histological injection site abscesses after vaccination[1]

Item	Needle-and-Syringe	Needle-Free[2]	*P*-value
Neck			
Total	198	198	----
Positive	0	5	0.06
Negative	198	193	----
Ham			
Total	198	198	----
Positive	1	7	0.0313
Negative	197	191	----

[1] A total of 198 pigs were injected twice by needle-free injection on 1 side (neck and ham) and twice by needle-and-syringe injection on the opposite side (neck and ham). Pigs were euthanized 27 or 28 d later, and injections sites were evaluated for abscess formation.

[2] Pulse Needle-Free Systems, Lenexa, KS.

Sensory Characteristics of Loins from Pigs Fed Glycerol and Ractopamine HCl During the Last 28 Days of Finishing[1,2]

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Summary

Sensory characteristics were evaluated on a total of 80 loins from pigs fed diets containing glycerol, ractopamine HCl (RAC), and a combination of glycerol and RAC during the last 28 d prior to harvest. A total of 1,054 pigs were blocked by weight and randomly allotted to 1 of 4 dietary treatments with 10 replications per treatment. Pigs were fed corn-soybean meal-based diets. Dietary treatments were arranged in a 2 × 2 factorial design with main effects of glycerol (0% or 5%) and RAC (0 or 6.75 g/ton). Pork loins from 1 randomly selected barrow and gilt from each pen were used for sensory analysis. There were no glycerol × RAC interactions or main treatment effects for cooking loss or Warner-Bratzler shear force (WBSF). Additionally, there were no glycerol × RAC interactions or main treatment effects for the sensory traits including myofibrillar tenderness, overall tenderness, pork flavor intensity, or off-flavor intensity. There was a glycerol × RAC interaction ($P < 0.01$) for the sensory trait of connective tissue amount. The interaction was a result of increased connective tissue amounts when glycerol was added to the diet without RAC but numerically decreased amounts when glycerol was fed in combination with RAC. In conclusion, feeding dietary glycerol or RAC singularly or in combination for 28 d prior to slaughter did not influence sensory characteristics of center-cut pork loin chops.

Key words: glycerol, ractopamine HCl, sensory analysis

Introduction

Ractopamine HCl (RAC; Paylean, Elanco Animal Health, Indianapolis, IN) is a widely used feed additive fed to finishing pigs prior to marketing to improve growth rate, F/G, yield, loin depth, and fat-free lean index. However, pigs fed RAC have been shown to have increased levels of polyunsaturated fatty acids and increased iodine value in carcass fat. Increased concentrations of polyunsaturated fatty acids lower fat stability, which can result in development of off-flavors.

Legislation and energy mandates have supported rapid expansion of renewable biofuel production in the United States. The Energy Independence and Security Act of 2007 increased the minimum level of renewable fuels, previously set by the Renewable

[1] Appreciation is expressed to Elanco Animal Health, Indianapolis, IN, for partial funding of this trial.
[2] Appreciation is expressed to New Horizon Farms for use of pigs and facilities and Richard Brobjorg, Scott Heidebrink, and Marty Heintz for technical assistance.
[3] Food Animal Health and Management Center. College of Veterinary Medicine, Kansas State University.
[4] Department of Food Science and Human Nutrition, Iowa State University.
[5] JBS Swift & Company, Greeley, CO.

Fuels Standard of 2005, to be produced and consumed by the United States to 136 billion liters by 2022. Crude glycerol is the primary coproduct from biodiesel production. There are currently 176 biodiesel production facilities operating in the United States producing more than 9.88 billion liters of biodiesel. This level of production will produce approximately 7.81×10^8 kg of crude glycerol. Crude glycerol has been shown to have a minimal impact on growth performance and carcass characteristics, but Mourot et al. (1994[6]) reported an increase in the saturation of carcass fat from pigs fed crude glycerol. Little is known about the effect of crude glycerol on loin sensory characteristics.

The potential increase in availability of glycerol as a feedstuff for swine along with the common practice of feeding RAC to finishing pigs warrants evaluation of these ingredients in combination and their effect on loin sensory characteristics. Therefore, the objective of this trial was to evaluate the effect of dietary glycerol and RAC on cooking loss, Warner-Bratzler Shear Force (WBSF), and sensory traits.

Procedures

Procedures used in these experiments were approved by the Kansas State University Institutional Animal Care and Use Committee and Institutional Review Board. The experiment was conducted at a commercial research facility in southwestern Minnesota. The facility had a totally slatted floor, and each pen was equipped with a 4-hole dry self-feeder and a cup waterer. The facility was a double-curtain-sided deep-pit barn. The experiment was conducted in the winter of 2008.

A total of 1,054 barrows and gilts (PIC 337 × 1050, initially 207.8 lb) were used in the 28-d study. Pigs were randomly allotted and blocked to 1 of 4 dietary treatments with 10 pens per treatment. Each pen contained 25 to 27 barrows and gilts.

Pigs were fed corn-soybean meal-based experimental diets (Table 1) in meal form. Dietary treatments were arranged in a 2 × 2 factorial design with main effects of glycerol (0% or 5%) and RAC (0 or 6.75 g/ton). Glycerol from a soybean biodiesel production facility (Minnesota Soybean Processors, Brewster, MN) was used in the trial. All experimental diets were formulated to maintain a constant standardized ileal digestible lysine:ME ratio within treatments that included or did not include RAC. For glycerol, the NRC (1998[7]) ME value of corn (1,551 kcal/lb) was used in diet formulation.

The pigs in this study were marketed in 2 different groups. First, on d 14, the barn was "topped" similar to normal marketing procedures in most commercial production operations. The 4 heaviest pigs from all pens were visually selected, removed, and marketed. The remaining pigs in the barn were marketed at the conclusion of the study (d 28).

At the end of the experiment, pigs from each pen were individually tattooed with pen number and shipped to the JBS Swift & Company processing plant (Worthington, MN). After harvest, chilling, and fabrication, whole loins were collected from 1 barrow and 1 gilt randomly chosen from each pen from the d-28 marketing group for loin

[6] Mourot, J., A. Aumaitre, A. Mounier, P. Peiniau, and A. C. Fracois. 1994. Nutritional and physiological effects of dietary glycerol in the growing pig: Consequences on fatty tissues and post mortem muscular parameters. Livest. Prod. Sci. 38:237-244.
[7] NRC. 1998. Nutrient Requirements of Swine. 10th ed. Natl. Acad. Press, Washington, DC.

quality evaluation. After the loins were identified and packaged, they were transported to the Kansas State University Meat Laboratory and stored at 32°F to 38°F. Loins were fabricated into 1-in. chops 10 d postmortem. Five center-cut loin chops were individually vacuum packaged and frozen (-40°F) for determination of cooking loss, WBSF, and sensory characteristics. Chops were removed from the freezer and thawed in a refrigerator (32°F to 38°F) overnight. To determine cooking loss, the chops were first weighed to determine initial weight and then cooked to an internal temperature of 104°F, turned, and cooked to a final internal temperature of 158°F in a dual-airflow convection gas oven (Blodgett, model DFC-102 CH3, G.S. Blodgett Co., Burlington, VT). Chops were monitored with copper-constantan thermocouples placed in the approximate geometric center of each chop and attached to a Doric temperature recorder (Model 205, Vas Engineering, San Francisco, CA). Following a 30-min cooling period, chops were re-weighed to determine cooking loss percentages. The chops were then chilled at 32°F to 38°F overnight, and six 0.5-in. cores were removed parallel to the muscle fiber direction. Each core was sheared once perpendicular to the direction of the muscle fibers with the Warner-Bratzler V-shaped blunt blade (G-R Manufacturing Co., Manhattan, KS) attached to an Instron Universal Testing Machine (model 4201, Instron Corp., Canton, MA) with a 50-kg compression load cell and a crosshead speed of 250 mm/min. Peak shear force values were recorded.

To determine sensory characteristics, the chops were removed from the package, cooked to an internal temperature of 104°F, turned, and cooked to a final internal temperature of 158°F in a dual-airflow convection gas oven. Cooked chops were then cut into 1-in. × 0.5-in. × 0.5-in. samples. Samples were kept warm in blue enamel double boiler pans with warm water in the bottom portion. Eight trained panelists were given 2 cubes of each chop to evaluate sensory characteristics. Each panelist conducted sensory analysis on a warm-up chop and a chop from each treatment during each session. Sensory characteristics evaluated include myofibrillar tenderness, juiciness, pork flavor intensity, connective tissue, overall tenderness, and off-flavor intensity.

Data were analyzed as a randomized complete block design by using the PROC MIXED procedure of SAS (SAS Inst., Inc., Cary, NC) with pen as the experimental unit. Main effects and interactions between pigs fed crude glycerol and RAC were tested. Statistical significance was set at $P < 0.05$ for all statistical tests.

Results and Discussion

The control and treatment means for cooking loss, WBSF, myofibrillar tenderness, connective tissue amount, overall tenderness, juiciness, pork flavor intensity, and off-flavor intensity are reported in Table 2. For cooking loss and WBSF, there were no glycerol × RAC interactions or main treatment effects. Additionally, there were no glycerol × RAC interactions or treatment differences for the sensory traits of myofibrillar tenderness, overall tenderness, pork flavor intensity, or off-flavor intensity. However, there was a glycerol × RAC interaction ($P < 0.01$) for connective tissue level. The interaction was a result of increased connective tissue amounts when glycerol was added to the diet without RAC but numerically decreased amounts when glycerol was fed in combination with RAC. We have no explanation for this unexpected interaction because we would not expect an increase in connective tissue without a decrease in tenderness, which was not observed.

In other research evaluating RAC and loin quality, Fernández-Dueñas et al. (2008[8]) reported that inclusion of RAC did not affect the loin quality traits of cooking loss, tenderness, juiciness, and flavor. However, Carr et al. (2005a[9], 2005b[10]) reported an increase in WBSF and a decrease in sensory tenderness scores for loins from pigs fed RAC.

In conclusion, our results indicate that feeding pigs crude glycerol or RAC did not influence loin sensory characteristics.

[8] Fernández-Dueñas, D. M., A. J. Myers, S. M. Scramlin, C. W. Parks, S. N. Carr, J. Killefer, and F. K. McKeith. 2008. Carcass, meat quality, and sensory characteristics of heavy body weight pigs fed ractopamine hydrochloride (Paylean). J. Anim. Sci. 86:3544-3550.
[9] Carr, S. N., D. J. Ivers, D. B. Anderson, D. J. Jones, D. H. Mowrey, M. B. England, J. Killefer, P. J. Rincker, and F. K. McKeith. 2005a. The effects of ractopamine hydrochloride on lean carcass yields and pork quality characteristics. J. Anim. Sci. 83:2886-2893.
[10] Carr, S. N., P. J. Rincker, J. Killefer, D. H. Baker, M. Ellis, and F. K. McKeith. 2005b. Effects of different cereal grains and ractopamine hydrochloride on performance, carcass characteristics, and fat quality in late-finishing pigs. J. Anim. Sci. 83:223-230.

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

	Ractopamine HCl, g/ton			
	0		6.75	
Ingredient, %	0% glycerol	5% glycerol	0% glycerol	5% glycerol
Corn	82.77	77.36	74.81	69.41
Soybean meal (46.5% CP)	15.24	15.64	23.19	23.59
Glycerol	---	5.00	---	5.00
Ractopamine HCl (9 g/lb)	---	---	0.04	0.04
Monocalcium P (21% P)	0.48	0.48	0.43	0.45
Limestone	0.90	0.90	0.88	0.85
Salt	0.35	0.35	0.35	0.35
Vitamin premix	0.04	0.04	0.04	0.04
Trace mineral premix	0.05	0.05	0.05	0.05
Phytase[2]	0.03	0.03	0.03	0.03
L-Lysine HCl	0.15	0.15	0.15	0.15
DL-methionine	---	---	0.02	0.02
L-threonine	0.01	0.01	0.03	0.03
Total	100.00	100.00	100.00	100.00
Calculated analysis				
SID[3] amino acids, %				
Lysine	0.70	0.70	0.90	0.90
Methionine:lysine	31	31	30	30
Met & Cys:lysine	65	63	61	59
Threonine:lysine	64	64	64	64
Tryptophan:lysine	19	19	19	19
SID lysine:ME, g/Mcal	2.09	2.09	2.69	2.69
ME, kcal/lb	1,521	1,521	1,520	1,520
Total lysine, %	0.79	0.79	1.01	1.01
CP, %	14.3	14.0	17.3	17.1
Ca, %	0.51	0.51	0.51	0.51
P, %	0.44	0.42	0.46	0.45
Available P, %[4]	0.22	0.22	0.22	0.22

[1] Fed from 208 to 259 lb.
[2] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN) provided 227 phytase units of phytase per pound of diet.
[3] Standardized ileal digestible.
[4] Includes expected P release of .07% from added phytase.

Table 2. Influence of crude glycerol and ractopamine HCl on loin characteristics[1]

	Ractopamine HCl, g/ton							
	0		6.75			Probability, $P <$		
Item	0% glycerol	5% glycerol	0% glycerol	5% glycerol	SE	Ractopamine HCl × Glycerol	Ractopamine HCl	Glycerol
Cooking loss, %	25.63	24.65	25.20	24.13	0.66	0.95	0.47	0.13
Warner-Bratzler shear force, lb	8.71	8.40	8.09	8.64	0.24	0.41	0.74	0.81
Sensory traits								
Myofibrillar tenderness[2]	5.6	5.8	5.7	5.6	0.16	0.23	0.94	0.74
Connective tissue amount[3]	7.2	7.4	7.5	7.3	0.08	0.01	0.37	0.76
Overall tenderness[2]	5.8	6.1	6.1	5.9	0.15	0.15	0.89	0.73
Juiciness[4]	5.1	5.0	5.0	5.2	0.13	0.21	0.62	0.83
Pork flavor intensity[5]	5.4	5.3	5.3	5.4	0.09	0.09	0.64	0.86
Off-flavor intensity[3]	7.4	7.5	7.5	7.6	0.09	0.89	0.16	0.20

[1] A total of 80 loins were used in the experiment with 2 loins per pen and 10 pens per treatment. Values are the mean of 1 gilt and 1 barrow per pen (10 barrows and 10 gilts per treatment).
[2] 1 = extremely tough, 2 = very tough, 3 = moderately tough, 4 = slightly tough, 5 = slightly tender, 6 = moderately tender, 7 = very tender, 8 = extremely tender.
[3] 1 = abundant, 2 = moderately abundant, 3 = slightly abundant, 4 = moderate, 5 = slight, 6 = traces, 7 = practically none, 8 = none.
[4] 1 = extremely dry, 2 = very dry, 3 = moderately dry, 4 = slightly dry, 5 = slightly juicy, 6 = moderately juicy, 7 = very juicy, 8 = extremely juicy.
[5] 1 = extremely bland, 2 = very bland, 3 = moderately bland, 4 = slightly bland, 5 = slightly intense, 6 = moderately intense, 7 = very intense, 8 = extremely intense.

Index of Key Words

Page numbers in parentheses

Acknowledgments

Appreciation is expressed to these organizations for assisting with swine research at Kansas State University.

Abilene Animal Hospital, Abilene, KS
ADM, Decatur, IL
Agri-King, Inc., Fulton, IL
Ajinomoto Heartland LLC, Chicago, IL
Cargill Animal Nutrition, Minneapolis, MN
DSM Nutritional Products, Parsippany, NJ
Elanco Animal Health, Indianapolis, IN
Engrain, LLC, Salina, KS
Environmental Care and Share, Golden, CO
Enzyvia LLC, Sheridan, IN
Evonik Degussa Hanau, Germany
Feedlogic Corporation, Willmar, MN
Form-A-Feed, Inc., Stewart, MN
Henry's LTD, Longford, KS
Hill's Pet Nutrition Inc., Topeka, KS
Hubbard Feeds, Mankato, MN
IGENE – Astaxanthin Partners, Ltd., Columbia, MO
JBS-United, Sheridan, IN
J-Six Farms, Seneca, KS
Kansas Pork Association, Manhattan, KS
Kansas Swine Alliance, Abilene, KS
Keesecker Agri Business, Washington, KS
Key Milling, Clay Center, KS
Kyodo Shiryo, Yokohama, Kanagawa, Japan
Livestock and Meat Industry Council, Manhattan, KS
Lonza, Inc., Allendale, NJ
N & N Farms, St. George, KS
National Pork Board, Des Moines, IA
New Horizon Farms, Pipestone, MN
Novartis Animal Health, Greensboro, NC
Nutra-Flo, Sioux City, IA
Pfizer Animal Health, New York, NY
PIC USA, Franklin, KY
Protein Resources LLC, West Bend, IA
Purco, Pipestone, MN
Swine Nutrition Services, Inc., Anchor, IL
Triumph Foods, St. Joseph, MO
Zenith Project, Geneseo, KS
Zephyr Project, Geneseo, KS
Zoltenko Farms Inc., Hardy, NE

We especially appreciate the assistance and dedication of Kansas State University employees Jon Bergstrom, Lyle Figgy, Frank Jennings, Mark Nelson, and Theresa Rathbun. We also wish to thank J-Six farms, Seneca, KS; Joe, Jim, Jeff, Janie, and John Kramer; Dan and Jenny Gerety; Kirk Sturbota; Scott Holthaus; Jannie Binneman; and Bob Boden for their technical assistance. Appreciation is also expressed to Richard Brobjorg, Scott Heidebrink, Marty Heintz, and Bob Taubert, New Horizon Farms, Pipestone, MN, for their dedicated support.

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