FOREWORD

It is with great pleasure that we present the 2008 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.

2008 Swine Day Report of Progress Editors

Bob Goodband Mike Tokach Steve Dritz Joel DeRouchey

STANDARD ABBREVIATIONS

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

NRC. 1998. Nutrient requirements of swine, 10th ed. National Academy Press, Washington, DC.

KSU 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.

CONTENTS

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.

GENETIC BACKGROUND INFLUENCES PIG GROWTH RATE RESPONSES TO PORCINE CIRCOVIRUS TYPE 2 (PCV2) VACCINES[1]

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Summary

A total of 454 pigs (21 d of age, 13.4 lb) were used in a 130-d field study to investigate porcine circovirus type 2 (PCV2) vaccine effects on growth performance of boars and gilts of 4 different genetic backgrounds: A×A (Duroc-based sire and dam), B×B (synthetic line sire and dam lines derived from Duroc, Pietrain, and Large White), A×B, and B×A.

Pigs were identified as potential test pigs at birth and ear tagged for identification. Characteristics including litter, genetic background, gender, and birth weight were recorded and used in allotting PCV2 vaccine treatment groups. Pigs were vaccinated according to label dose with a 2-dose commercial PCV2 vaccine (Circumvent PCV, Intervet Inc., Millsboro, DE) at weaning (d 0) and again 14 d later. Vaccinated and control pigs were comingled within the same pen for the duration of the study. Pigs were individually weighed on d 0, 40, and 130 to measure growth rate. Backfat and loin depth were measured on d 130 by using real-time ultrasound. Blood was collected on d 0, 40, and 130 for indirect fluorescent antibody measurement of PCV2 antibodies and polymerase chain reaction (PCR) analysis for determination of PCV2 virus load.

By d 130, vaccinates were heavier ($P < 0.01$) than controls. However, the magnitude of the weight difference between control and vaccinates was almost 4 times greater in the A×A pigs than in the B×B pigs ($P < 0.05$). On the basis of growth performance, the different genetic backgrounds responded differently to the PCV2 vaccination even though they were comingled in the same pen. In the 2 pure-line populations, even the best performing portion of the population appeared to benefit from vaccination, suggesting that growth performance of most pigs is being affected by PCV2 infection.

Control pigs exhibited a late increase in PCV2 antibody levels, a consequence of natural infection. In contrast, vaccinated pigs did not exhibit a late-finisher antibody rise. Vaccinated pigs possessed a decreased viral load (as quantified by PCR PCV2 viral DNA) at both d 40 and 130. The data demonstrate that genetic background affects either the expression of porcine circoviral disease or the response to the PCV2 vaccine.

Key words: circovirus, genetics, growth, PCV2, swine, vaccination

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[1] Appreciation is expressed to PIC, Hendersonville, TN, for partial financial support of this study.
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Introduction

The primary agent of porcine circoviral disease (PCVD) is porcine circovirus type 2 (PCV2). The approved case definition for PCVD defines a PCVD herd as one which demonstrates one or more of the following clinical manifestations: wasting, respiratory or enteric signs, high mortality, porcine dermatitis and nephropathy syndrome, or reproductive disorders. Porcine circoviral disease is confirmed by finding microscopic lesions consistent with the disease in affected pigs as well as the presence of viral antigen in tissues.

Reported risk factors associated with PCVD include litter of origin, management factors, and gender as well as genetics. Only limited, controlled research has been completed to define the role of these risk factors in the development and expression of PCVD and response to vaccination. The focus of this study was to further elucidate the contribution of genetic background to PCVD by comparing the response of different genetic lines of pigs to PCV2 vaccination in a high-health herd with naturally circulating PCV2.

Procedures

A 1,700-sow multiplier farm in Kansas was used for this field study. This single-site farm maintains a high-health status; it is porcine reproductive and respiratory syndrome virus negative and without evidence of *Mycoplasma hyopneumoniae* infection since its stocking in 2000. Despite the high-health status, the presence of PCV2b virus had been documented in this herd. However, the primary concern was an increase in morbidity characterized by ill-thrift and slow growing pigs as mortality was within the expected historic range on this farm.

For this 130-d study, a total of 454 pigs from 4 genetic backgrounds were ranked by birth weight within litter and gender (boar or gilt) and randomly assigned to PCV2 vaccine treatment group (vaccinated or nonvaccinated control). Birth weight was balanced across vaccine treatment. Genetic background included pure lines of A×A (Duroc-based sire and dam) and B×B (synthetic line for the sire and dam primarily derived from Duroc, Pietrain, and Large White) and crossbreds A×B and B×A.

Vaccine treatment pigs were vaccinated intramuscularly with a 2-dose commercial PCV2 vaccine (Circumvent PCV, Intervet Inc, Millsboro, DE) according to label dose at 21 and 35 d of age. Vaccinated pigs were comingled with nonvaccinated control pigs for the duration of the trial.

Pigs were individually weighed and bled at birth, weaning (d 0), end of nursery (d 40), and off test (d 130). Loin depth and backfat measurements were collected by using real-time ultrasound on d 130.

Removals and deaths were recorded during all phases. There were 6 deaths in the nursery phase, 25 deaths in the finisher phase, and 6 other records removed because of data entry errors or unrelated physical defects. Data analysis was performed on the 417 pigs that had complete growth records.

Comparisons between vaccinates and nonvaccinated controls, genetic background, and gender were made in a 2 × 4 × 2 factorial treatment design. Litter of origin was managed as a random effect. Statistical analysis was performed by using the Proc GLIMMIX procedure of SAS to obtain least square means and standard errors for the response criteria.

Results

Despite active PCV2 infection, there was no discernable pattern of mortality among the genetic backgrounds, and overall mortality was similar between vaccinates (6.8%) and controls (7.0%). There were no 3-way gender × genetic background × vaccine interactions found for the response criteria in this study with the exception of backfat depth after

weight adjustment. The significant interaction ($P = 0.02$) was the result of control A×B crossbred boars having a higher weight-adjusted backfat depth than vaccinated A×B crossbred boars (11.9 ± 0.4 mm for controls vs. 10.9 ± 0.4 mm for vaccinates). Within all other gender by genetic background combinations, backfat depth was similar between controls and vaccinates.

Weaning age and weight and off-test age were not different for the vaccine × genetic background least squares means (Table 1). A vaccine × genetic background interaction was noted for nursery ADG, finisher ADG, and overall wean-to-finish ADG ($P = 0.05$, $P = 0.05$, and $P = 0.04$, respectively). In the nursery phase, this interaction was due to the A×B vaccinates having lower ($P = 0.04$) ADG than A×B controls. In contrast, B×A and B×B vaccinates had numerically higher ADG than controls. For the A×A pigs, controls and vaccinates had similar ADG. Therefore, in the nursery period of this study, genetic background did affect how vaccinates performed compared with controls; controls demonstrated higher nursery ADG in a single genetic background, whereas in the other lines, there was little to no performance difference between vaccinates and controls. Although the interaction was statistically significant, we are unsure of the biologic significance. In the finisher phase of production, ADG was lower ($P < 0.01$) for the A×A controls than for the control pigs of A×B, B×A, and B×B. In contrast, A×A vaccinates had similar ADG to all groups except A×B ($P = 0.04$). Thus, the magnitude of the difference between control and vaccinate groups was greater for the A×A pigs than for B×B and crossbred pigs. Wean-to-finish ADG followed a pattern similar to that of finisher ADG.

At d 130, A×A control pigs weighed less ($P < 0.01$) than controls from the other 3 genetic backgrounds, whereas A×A vaccinates weighed less ($P = 0.04$) than B×A vaccinates.

Prior to adjusting backfat and loin depths to a common off-test weight, it appeared there were significant differences in loin depth and numerical differences in backfat measurement between vaccine treatment groups. After adjustment, there was a genetic background effect ($P < 0.01$) for loin depth as well as a 3-way gender × genetic background × vaccine interaction ($P = 0.02$) for backfat measurement. Despite the 3-way interaction for backfat depth, there was no significant effect of vaccination on backfat ($P = 0.62$) or loin depth ($P = 0.29$) after adjustment to a common off-test weight.

Indirect fluorescent antibody analysis demonstrated antibody responses to both vaccine and natural PCV2 exposure (Figure 1). In response to vaccination, vaccinates had increased ($P < 0.01$) antibody production by d 40 compared with controls, but as a result of natural PCV2 exposure, controls demonstrated a rise ($P < 0.01$) in antibody levels compared with vaccinates by d 130. PCV2 DNA template copies per reaction provided an estimate of viral load (Figure 2). PCV2 vaccination reduced mean viral load in vaccinates compared with controls at both d 40 ($P < 0.01$) and 130 ($P < 0.01$)

Discussion

The results from this study demonstrate that genetic background affects response to PCV2 vaccination or PCVD expression as measured by growth rate. The findings in this study are unique because this herd did not fit the accepted case definition for PCVD; yet, this study clearly demonstrates that PCV2 vaccination improved the growth performance of vaccinated pigs compared with controls.

The difference in magnitude of the finisher ADG and wean-to-finish ADG was 3 and 5 times greater, respectively, in A×A pigs than in B×B pigs. In addition, within each crossbred genetic background, vaccinated pigs consistently had numerically increased ADG compared with controls. Vaccinated pigs were

19.7, 6.2, 10.2, and 5.0 lb heavier compared with nonvaccinated controls for A×A, A×B, B×A, and B×B genetic backgrounds, respectively. Similar to other studies we have conducted, PCV2-vaccinated pigs demonstrated increased growth rate during the finisher phase. However, the magnitude of the weight difference was almost 4 times greater in the A×A pigs than in the B×B pigs. Although the B×B pigs grew faster than the A×A pigs, they had a similar overall pattern of weight distribution about their means. There is a right shift in the off-test weights of vaccinates compared with controls in each population (Figures 3 and 4). This indicates that within each of these genetic backgrounds, all the vaccinated pigs had increased growth rate. Even in apparently clinically unaffected pigs, the PCV2 virus appears to affect growth rate.

Carcass composition was not affected by vaccination in this study after adjusting for off-test weight. Genetic background, however, did affect carcass traits. Pigs from the Duroc-based lines had decreased loin depth and increased backfat compared with pigs from the Duroc-, Pietrain-, and Large White-based lines.

There was a clear rise in antibody production by d 40 due to vaccination as indicated by the higher PCV2 antibody titers in the vaccinates compared with controls. A rise in antibody titer in the control pigs from d 40 to 130 indicated active PCV2 infection due to field virus exposure during the trial period. In contrast, vaccinates had a decrease in PCV2 antibody titer from d 40 to 130, which suggests that vaccinates have increased resistance to infection. The results of this study support previous research findings that PCV2 vaccination effectively decreases viral load, even under comingled conditions. Controls had a larger quantity of viral templates per reaction compared with vaccinates at d 40. By d 130, the difference between the treatment groups remained; however, mean template copies per reaction were reduced to 3.8 for controls compared with 1.3 for vaccinates. The biologic significance of these viral load quantities remains to be determined; however, the potential for the PCV2 vaccine to aid in the reduction of viremia and viral shedding is apparent.

The data in this study demonstrate that genetic background affects either the expression of PCVD or the response to the PCV2 vaccine, as measured by growth performance. Therefore, genetic background should be considered a risk factor for expression of PCVD or a factor that affects response to PCV2 vaccine.

Table 1. Effect of PCV2 vaccine treatment and genetic background on ages, weights, growth rates, and carcass characteristics[1]

	Genetic background[2]									
	A × A		A × B		B × A		B × B			Vaccine × Genetic
Item	Control[3]	Vacc.	Control	Vacc.	Control	Vacc.	Control	Vacc.	SE[4]	Probability, $P <$
no. of pigs	62	55	60	65	34	32	55	54		
Age, d										
Weaning	21.2	21.1	20.3	20.3	21.3	21.3	19.7	19.6	0.6	0.71
Off test	151.5	151.4	150.6	150.6	151.7	151.7	150.0	150.0	0.7	0.41
Weaning weight, lb	12.8	13.5	13.8	13.9	14.5	14.2	12.8	13.2	0.7	0.51
ADG[4], lb										
Nursery phase	0.84^{a}	0.85^{abc}	0.96^{bd}	0.90^{ace}	0.96^{bcde}	1.02^{de}	0.92^{abcde}	0.88^{abc}	0.05	0.05
Finisher phase	1.70^{a}	1.91^{b}	1.93^{b}	2.02^{c}	1.91^{bc}	2.00^{bc}	1.88^{b}	1.95^{bc}	0.05	0.05
Wean-to-finish	1.44^{a}	1.59^{b}	1.63^{bc}	1.68^{bc}	1.63^{b}	1.71^{c}	1.60^{bc}	1.60^{bc}	0.05	0.04
Off-test weight, lb	200.9^{a}	220.6^{b}	226.7^{bc}	232.9^{bc}	226.7^{bc}	236.9^{c}	220.7^{b}	225.7^{bc}	6.5	0.05
Carcass characteristics, mm										
Backfat depth	11.4	12.0	12.1	12.0	11.2	11.7	10.6	10.8	0.5	0.46
Loin depth	59.2	62.2	65.7	66.9	66.3	69.0	68.8	69.6	1.3	0.32
Backfat depth (weight adjusted)	12.2	12.1	11.9	11.6	11.1	11.2	10.7	10.7	0.5	0.79
Loin depth (weight adjusted)	62.3	62.6	65.1	65.4	65.8	67.1	69.2	69.2	0.9	0.82

Note. Results reported as least squares means.

^{abcde} Within a row, means without a common superscript letter differ ($P < 0.05$).

[1] A total of 454 pigs from 4 genetic backgrounds were assigned to vaccine treatment by ranking them by weight within litter and gender and randomly assigning each pig to either vaccine or nonvaccinate control, balanced by birth weight across vaccine treatment. Pigs were individually weighed at birth, weaning (d 0), end of nursery (d 40), and off test (d 130). Backfat and loin depth were measured at d 130.

[2] Genetic backgrounds used were A×A (Duroc-based sire and dam), A×B, B×A, and B×B (synthetic line for the sire and dam primarily derived from Duroc, Pietrain, and Large White).

[3] Vaccine treatments included vaccinates (2 cc Circumvent PCV, Intervet Inc., Millsboro, Delaware) and nonvaccinated controls. Vaccine was administered intramuscularly at 21 and 35 d of age.

[4] SE among treatment groups differed because of unbalanced design. In this table, the highest SE among the treatment groups was reported.

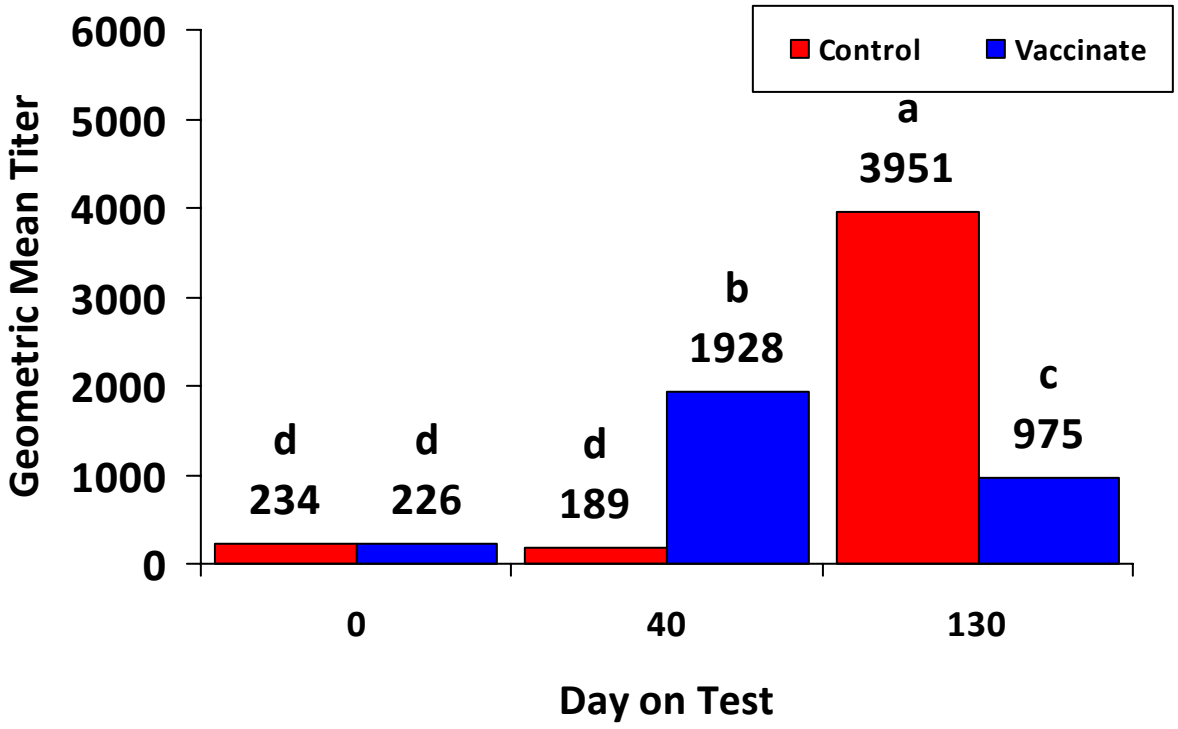

Figure 1. Effect of PCV2 vaccination and time on indirect fluorescent antibody geometric mean titer (vaccine × time $P < 0.01$; a,b,c,d $P < 0.01$).

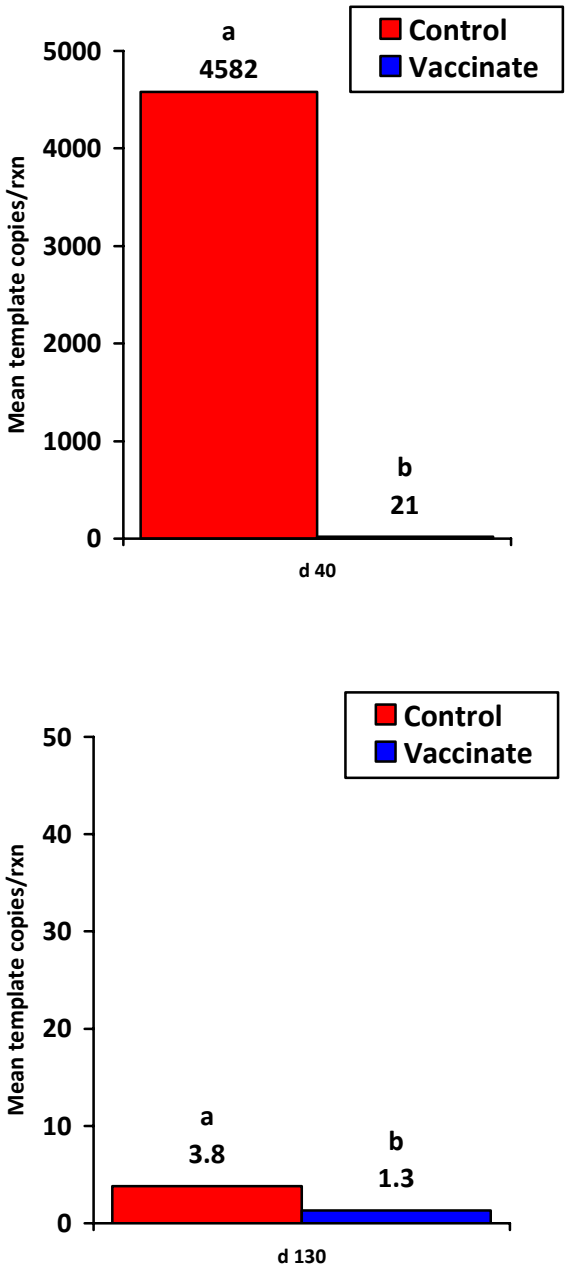

Figure 2. Effect of PCV2 vaccination and time on PCV2 viral template quantity (a,b $P < 0.01$ within day).

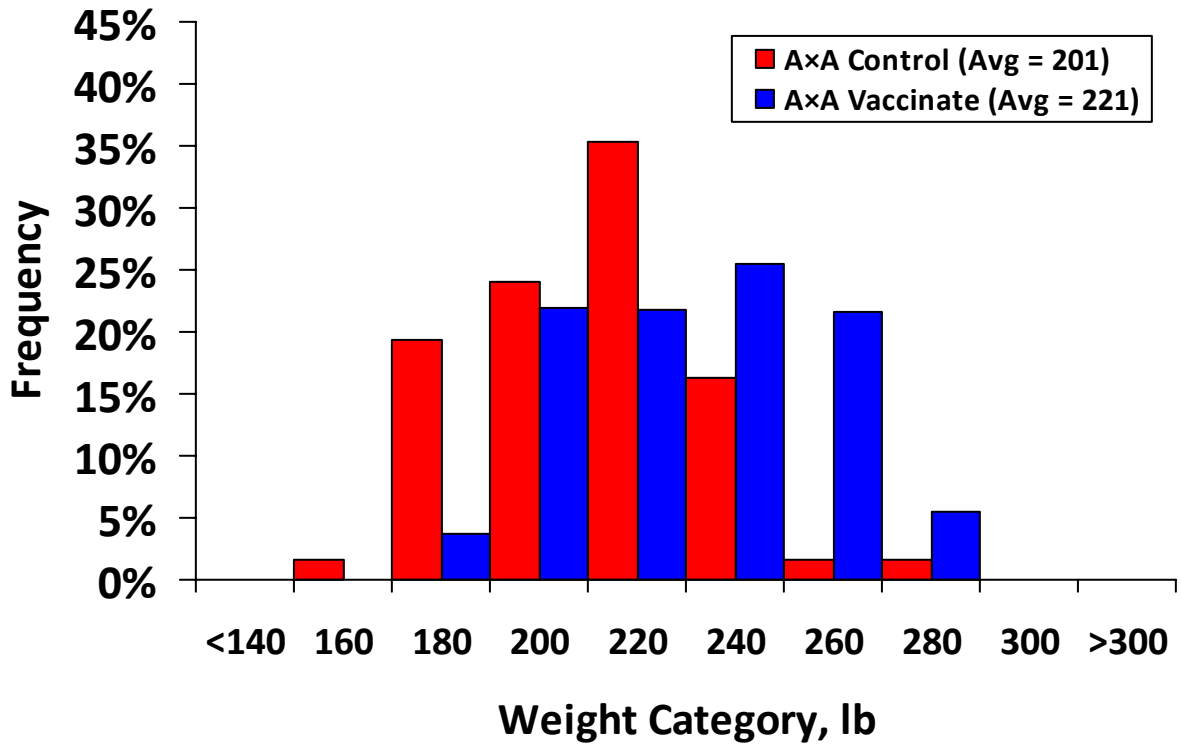

Figure 3. Distribution of off-test pig weights for control vs. vaccinated pigs of genetic background A×A.

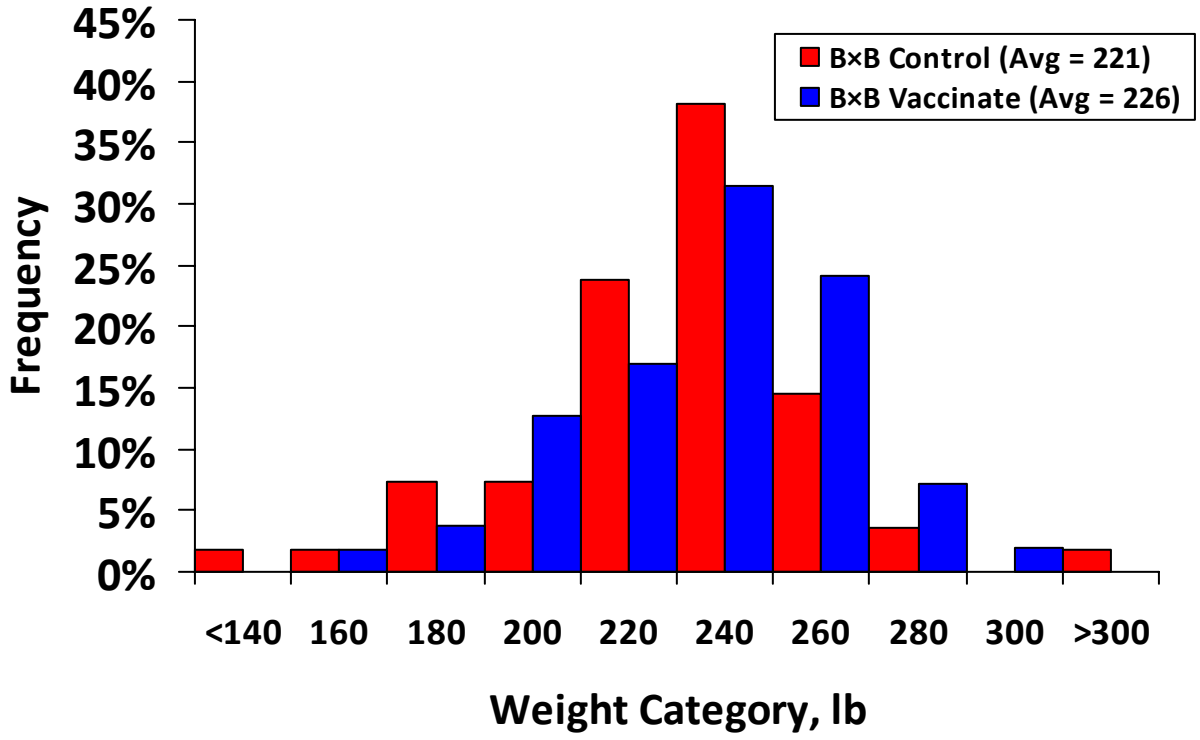

Figure 4. Distribution of off-test pig weights for control vs. vaccinated pigs of genetic background B×B.

EFFECTS OF PORCINE CIRCOVIRUS TYPE 2 AND *Mycoplasma hyopneumoniae* VACCINATION TIMING AND STARTER DIET SOURCE ON GROWTH PERFORMANCE OF NURSERY PIGS

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Summary

A total of 400 nursery pigs (initially 12.5 lb) were used in a 20-d study to evaluate the effects of varying porcine circovirus type 2 (PCV2) and *Mycoplasma hyopneumoniae* vaccination timing on growth performance of pigs fed commercial segregated early weaning (SEW) and transition diets from 4 different sources. At weaning (d 0), pigs were blocked by weight and randomly allotted to 1 of 8 treatments. Treatments were arranged in a 2 × 4 factorial on the basis of vaccination timing (0 or 8 d after weaning) and diet source (A, B, C, or D). There were 5 pigs per pen and 10 pens per treatment. Initially, SEW and transition diets were budgeted at 1 and 5 lb/pig, respectively. The SEW and transition diets were formulated to similar Kansas State University specifications but made by different manufacturers. Feeders were emptied on d 8, and a common phase 2 diet was fed for the remainder of the trial. On d 0, 4, 8, and 20, pigs were weighed and feed disappearance was measured to determine ADG, ADFI, and F/G. Diet source influenced ($P < 0.001$) ADG during the first 4 d of the trial. Pigs fed diet B had increased ($P < 0.001$) BW (d 4) and ADG (d 0 to 4) compared with pigs fed all other diets, and diet D pigs exhibited increased ADG compared with pigs fed diet C. On d 8, diet source effects remained significant ($P \leq 0.02$) for pig weights (d 8) as well as ADG and ADFI (d 4 to 8 and 0 to 8). Pigs fed diet A had increased ($P < 0.01$) ADG (d 4 to 8) compared with pigs fed the other 3 diet sources. Pigs fed diets A and B had similar ADFI, but their ADFI (d 4 to 8) was greater ($P \leq 0.02$) than that of pigs fed diets C and D. There were no effects of diet source from d 8 to 20. Pigs vaccinated on d 0 had lower ($P < 0.01$) BW (d 8) and ADG and ADFI (d 4 to 8 and d 0 to 8) than pigs vaccinated on d 8. From d 8 to 20, pigs vaccinated on d 8 had lower ($P = 0.05$) ADG. Overall (d 0 to 20), diet source and vaccine timing did not influence growth performance, although pigs fed diet C had a numeric decrease ($P = 0.06$) in ADFI. Nursery pigs in this trial were initially affected by both SEW/transition diet source and vaccination timing, but the influence of these factors lessened with time. Despite the transient nature of these effects, however, data obtained during this trial indicate that nursery pig growth performance is affected by diet source and vaccine timing immediately postweaning, and these factors should be taken into consideration when managing weaning groups.

Key words: PCV2, segregated early weaning, swine, vaccination

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Introduction

Positive growth performance of nursery pigs is an essential component of successful swine production. However, recent reports from field observations indicate that some producers have experienced difficulty in starting or maintaining weaned pigs on feed, which results in decreased performance and production. These reports seem to coincide with widespread adoption of porcine circovirus type 2 (PCV2) vaccination in growing pigs. Many weaned pigs receive PCV2 and other vaccinations at or near the time of weaning, though vaccination timing is not consistent in the swine industry. Other management factors affect pig performance and have been well characterized in research reports. For instance, it is well known that different diet formulations affect pig performance in the nursery. However, there is limited data on the potential effect of diet source. It has been suggested that nursery diet sources and vaccination timing may be important factors influencing this postweaning problem. The objective of this study was to investigate the effects of diet source as well as PCV2 and *Mycoplasma hyopneumoniae* (Mpp) vaccination timing on pig growth performance.

Procedures

A total of 400 weaned pigs (31 gilts and 369 barrows) were used in a 20-d growth trial. Pigs were blocked by weaning weights (12.5 lb average) and randomly allotted to 1 of 8 treatments. Because of the uneven number of gilts, 7 of the 8 treatments groups within 1 block contained 4 gilts each, and the remaining group contained 3 gilts. Initially, each pen contained 5 pigs, and there were 10 pens per treatment. Treatments included segregated early weaning (SEW)/transition diet source (A, B, C, or D) and vaccination timing (0 or 8 d after weaning). The SEW and transition diets were obtained from 4 commercial sources, and each diet was formulated to similar specifications (Table 1). At weaning (d 0), each pen received 1 lb/pig of SEW diet, and SEW diets were placed in the feeders at allotment. Transition diets were added to the feeders on top of the SEW diet and fed until d 8 (approximately 3 lb/pig). On d 8, feeders were emptied and refilled with a common phase 2 diet, which was fed for the duration of the trial. Pigs were vaccinated intramuscularly with commercially available PCV2 (Circumvent, Intervet) and Mpp (Respisure 1; Pfizer) vaccines on d 0 or 8 after weaning. The vaccines were administered according to label instructions. Pigs were weighed on d 0, 4, 8, and 20, and feeders were weighed on d 4, 8, and 20 to determine feed disappearance. From this data, ADG, ADFI, and F/G were calculated.

Data were analyzed as a randomized complete block design by using the PROC GLIMMIX procedure of SAS. 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 significant ($P < 0.05$) interactions observed between diet source and vaccine timing during this trial (Table 2). However, there was a trend ($P = 0.07$) toward a diet source and vaccine timing interaction effect on F/G between d 0 and 8. For pigs fed diet B, the d 0 vaccinates had improved F/G compared with pigs that were not vaccinated until d 8. In contrast, d 0 vaccinates fed diets A and C demonstrated poorer F/G during the first 8 d of the trial compared with their counterparts that were vaccinated on day 8. This interaction trend disappeared after d 8, and no additional trends or significant interactions were observed during the remainder of the trial.

From d 0 to 4, pigs fed diet B had greater ($P < 0.001$) ADG than pigs fed the other 3 diet

sources (Table 3). Pigs fed diet D also had greater ($P < 0.05$) ADG than pigs fed diet C, with pigs fed diet A being intermediate. The improved gain resulted in pigs fed diet B having heavier ($P < 0.001$) average weights on d 4 than pigs fed the other diets. From d 4 to 8, pigs fed diet A had greater ADG ($P < 0.002$) than pigs fed the other 4 diets. Pigs fed diets A and C had greater ($P < 0.02$) ADFI than pigs fed diets B and D. For the overall period when SEW and transition diets were fed (d 0 to 8), pigs fed diet C had lower ($P < 0.001$) ADG and ADFI than pigs fed diets A and B, with pigs fed diet D being intermediate. As a result of the differences in ADG, pigs fed diets A and B were heavier ($P < 0.001$) on d 8 than pigs fed diet C. Diet sources fed from d 0 to 8 did not influence pig performance from d 8 to 20, when all pigs were fed a common diet. Although a trend ($P = 0.06$) was observed for a diet effect from d 0 to 20 for ADFI (indicating increased intake for pigs fed diet A and B compared with pigs fed diet C), the differences between diets sources from d 0 to 8 were not substantial enough to cause a lasting effect on pig performance in the second phase of the trial or overall. Because SEW and transition diets were formulated to similar specifications, the transient effects of diet source seen in the first phase of the trial may be due to diet ingredient quality and source as well as manufacturing differences between the commercial suppliers.

Vaccinating pigs with PCV2 and Mpp vaccines on d 0 decreased ($P \leq 0.01$) ADG and ADFI from d 4 to 8 and 0 to 8 and pig weights (d 8; Table 4). From d 8 to 20 after weaning, the pigs vaccinated on d 8 grew slower ($P = 0.05$) than those vaccinated at weaning (d 0). According to this data, vaccination caused a temporary reduction in the growth performance of both d 0 and 8 vaccinates. Because of the stresses of vaccination, this transient decrease in performance is expected, but because the pigs were not weighed as often during phase 2 (day 8 to 20) as during phase 1 (day 0 to 8), it is not possible to determine whether one vaccine timing treatment group was more severely affected immediately postvaccination. However, because previous research has indicated that growth performance in the first week after weaning is a risk factor for subsequent nursery performance, we speculate that the decrease in performance around the time of weaning may have a greater potential for longer term effects than a decrease in performance in subsequent phases of the nursery period.

Overall (d 0 to 20), diet source and vaccination timing did not significantly affect growth performance of nursery pigs. However, performance was significantly affected by both of these factors throughout the first phase of the trial, indicating that diet source and vaccination do play a role in growth of nursery pigs during certain periods. Because pig weight and feed disappearance data were not collected as often during phase 2 as during phase 1, further studies investigating diet source and vaccine timing should be conducted to gain a better understanding of their effects on growth performance. It is evident that these factors do influence nursery pig growth performance to some extent; thus, vaccine timing and diet source should be considered when making health and management decisions for weaning groups.

Table 1. Composition of segregated early weaning (SEW) and transition diets

	Diet type				
Ingredient, %	SEW (diet sources A, B, and C)	SEW (diet Source D)[1]	Permeate transition[2] (diet sources A, B, and C)	Whey transition[2] (diet sources A, B, and C)	Transition (diet source D)[1]
Corn	33.70	25.60	37.70	37.25	26.35
Soybean meal (46.5%)	12.55	12.70	20.00	20.00	21.55
Spray-dried animal plasma	6.70	6.70	2.50	2.50	2.50
Select menhaden fish meal	6.00	6.00	5.80	5.00	6.00
Spray-dried blood cells	1.65	1.65	1.25	1.25	1.25
Spray-dried whey	25.00	---	12.50	25.00	---
DairyLac 80 or deproteinized whey	6.00	25.00	11.25	---	20.00
Pulverized oat grouts	---	15.00	---	---	15.00
Choice white grease	5.00	3.00	5.00	5.00	3.00
Monocalcium phosphate (21% P)	0.30	0.50	0.60	0.70	0.60
Limestone	0.45	0.60	0.45	0.45	0.60
Salt	0.25	0.25	0.30	0.30	0.30
Zinc oxide	0.36	0.36	0.36	0.36	0.36
Vitamin premix with phytase	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	0.30	0.26	0.30
DL-Methionine	0.15	0.23	0.20	0.18	0.19
L-Threonine	0.08	0.14	0.15	0.13	0.16
L-Isoleucine	---	0.15	---	---	0.05
Antibiotic 1	1.00	1.00	1.00	1.00	1.00
Acidifier	0.20	0.35	0.20	0.20	0.35
Vitamin E, 20,000 IU	0.05	0.05	0.05	0.05	0.05
Total	100.00	100.00	100.00	100.00	100.00
Calculated analysis					
Standardized ileal digestible amino acids					
Lysine, %	1.57	1.57	1.50	1.51	1.50
Methionine:lysine ratio, %	30	34	35	33	35
Met & Cys:lysine ratio, %	55	57	56	55	56
Threonine:lysine ratio, %	64	62	62	63	62
Tryptophan:lysine ratio, %	17	18	17	17	18
Total lysine, %	1.71	1.69	1.63	1.65	1.63
ME, kcal/lb	1,587	1,556	1,583	1,575	1,548
Protein, %	22.8	22.5	21.8	22.2	22.7
Ca, %	0.82	0.84	0.82	0.83	0.85
P, %	0.76	0.79	0.75	0.77	0.77
Available P, %	0.59	0.58	0.54	0.55	0.52

[1] Source D SEW and transition diets were formulated differently from diets supplied by other sources because of higher costs of whey at the time of formulation.
[2] Diet sources A, B, and C supplied identically formulated SEW diets but had the option of using either the permeate or whey formula for their transition diets.

Table 2. Interactions between diet source and vaccine timing and their effect on nursery pig growth performance[1]

	Diet source									Source × Timing
	A		B		C		D			
Vaccine timing, d	0	8	0	8	0	8	0	8	SE	*P*
Item										
d 0 to 4										
ADG, lb	0.38	0.42	0.48	0.48	0.36	0.36	0.40	0.45	0.03	0.67
ADFI, lb	0.24	0.24	0.26	0.29	0.23	0.22	0.30	0.26	0.03	0.71
F/G	0.64	0.59	0.56	0.61	0.63	0.65	0.82	0.58	0.14	0.44
d 4 to 8										
ADG, lb	0.51	0.57	0.47	0.48	0.38	0.47	0.39	0.49	0.04	0.54
ADFI, lb	0.55	0.56	0.54	0.60	0.45	0.50	0.38	0.55	0.06	0.25
F/G	1.08	1.00	1.17	1.25	1.25	1.10	1.47	1.13	0.27	0.76
d 0 to 8										
ADG, lb	0.44	0.49	0.47	0.48	0.37	0.41	0.39	0.47	0.03	0.43
ADFI, lb	0.39	0.40	0.40	0.45	0.34	0.36	0.34	0.40	0.03	0.51
F/G	0.88	0.82	0.85	0.93	0.92	0.88	0.87	0.86	0.04	0.07
d 8 to 20										
ADG, lb	0.69	0.68	0.69	0.67	0.74	0.65	0.72	0.71	0.03	0.25
ADFI, lb	0.93	0.95	0.94	0.92	0.93	0.88	0.95	0.95	0.03	0.50
F/G	1.35	1.40	1.37	1.36	1.27	1.37	1.32	1.35	0.05	0.48
d 0 to 20										
ADG, lb	0.59	0.60	0.60	0.60	0.59	0.55	0.59	0.61	0.02	0.30
ADFI, lb	0.71	0.73	0.72	0.73	0.69	0.67	0.70	0.73	0.03	0.57
F/G	1.21	1.21	1.20	1.22	1.18	1.22	1.20	1.20	0.03	0.72
Weight, lb										
d 0	12.5	12.5	12.5	12.6	12.5	12.6	12.5	12.5	0.6	0.82
d 4	14.0	14.2	14.5	14.5	13.9	14.0	14.1	14.3	0.7	0.87
d 8	16.1	16.5	16.3	16.4	15.5	15.9	15.7	16.3	0.7	0.52
d 20	24.3	24.6	24.3	24.5	24.1	23.7	24.3	24.5	1.0	0.79

[1] A total of 400 weaned pigs, initially 12.5 lb, were used in a 20-d growth trial. Each value is the mean of 5 pigs per pen and 10 pens per treatment.

Table 3. Effects of diet source on growth performance of nursery pigs

Item	Diet source[1]				SE	*P* <
	A	B	C	D		
d 0 to 4						
ADG, lb	0.40^{bc}	0.48^{a}	0.36^{c}	0.42^{b}	0.02	< 0.001
ADFI, lb	0.24	0.28	0.22	0.28	0.02	0.22
F/G	0.61	0.58	0.64	0.70	0.07	0.67
d 4 to 8						
ADG, lb	0.54^{a}	0.48^{b}	0.42^{b}	0.44^{b}	0.03	0.002
ADFI, lb	0.56^{a}	0.57^{a}	0.47^{b}	0.46^{b}	0.03	0.02
F/G	1.04	1.21	1.18	1.30	0.15	0.60
d 0 to 8						
ADG, lb	0.47^{ab}	0.48^{a}	0.39^{c}	0.43^{bc}	0.02	< 0.001
ADFI, lb	0.40^{ab}	0.42^{a}	0.35^{c}	0.37^{bc}	0.02	0.001
F/G	0.85	0.89	0.90	0.87	0.02	0.27
d 8 to 20						
ADG, lb	0.68	0.68	0.69	0.71	0.02	0.52
ADFI, lb	0.94	0.93	0.90	0.95	0.03	0.29
F/G	1.37	1.37	1.32	1.33	0.03	0.29
d 0 to 20						
ADG, lb	0.60	0.60	0.57	0.60	0.02	0.26
ADFI, lb	0.72	0.73	0.68	0.72	0.03	0.06
F/G	1.21	1.21	1.20	1.20	0.02	0.88
Weight, lb						
d 0	12.5	12.5	12.6	12.5	0.6	0.80
d 4	14.1^{b}	14.5^{a}	14.0^{b}	14.2^{b}	0.7	< 0.001
d 8	16.3^{ab}	16.4^{a}	15.7^{c}	16.0^{bc}	0.7	< 0.001
d 20	24.5	24.4	23.9	24.4	0.9	0.35

[1] Diet source refers to the commercial SEW/transition diet source. Initially, each pig received 1 lb SEW and was then fed transition diet until d 8 post weaning. Feeders were emptied on d 8, and a common phase 2 diet was fed for the duration of the trial.

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

Table 4. Effects of vaccine timing on growth performance of nursery pigs

	Vaccine timing[1]			
Item	0	8	SE	*P*
d 0 to 4				
ADG, lb	0.40	0.43	0.02	0.20
ADFI, lb	0.26	0.26	0.02	0.94
F/G	0.66	0.61	0.05	0.44
d 4 to 8				
ADG, lb	0.44[b]	0.50[a]	0.02	< 0.01
ADFI, lb	0.48[b]	0.55[a]	0.03	0.01
F/G	1.24	1.12	0.11	0.37
d 0 to 8				
ADG, lb	0.42[b]	0.46[a]	0.02	< 0.01
ADFI, lb	0.37[b]	0.40[a]	0.02	< 0.01
F/G	0.88	0.87	0.02	0.67
d 8 to 20				
ADG, lb	0.71[a]	0.68[b]	0.02	0.05
ADFI, lb	0.94	0.92	0.03	0.44
F/G	1.33	1.37	0.03	0.09
d 0 to 20				
ADG, lb	0.59	0.59	0.02	0.88
ADFI, lb	0.71	0.71	0.02	0.60
F/G	1.20	1.21	0.02	0.34
Weight, lb				
d 0	12.5	12.5	0.6	0.46
d 4	14.1	14.3	0.7	0.15
d 8	15.9[b]	16.3[a]	0.7	< 0.01
d 20	24.3	24.3	0.9	0.78

[1] Vaccine timing refers to the vaccination day (0 or 8 postweaning). Each pig was injected with 2 cc PCV2 and 2 cc Mpp vaccine.

EFFECTS OF DIFFERENT FEEDING REGIMENS ON GROWTH, LONGEVITY, AND SEMEN CHARACTERISTICS OF WORKING BOARS IN A COMMERCIAL AI STUD[1]

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Summary

The objective of the study was to determine the effects of 2 different feeding regimens on growth performance, semen production and quality, and longevity of boars in a commercial AI stud. A total of 30 replacement boars (PIC TR4, 375 lb and 14.2 mo of age) were randomly selected and allotted to 1 of 2 treatments. The control feeding program was the normal feeding program of the stud; boars were fed 6.7 lb/d for the first 8 wk, and then feeding was adjusted according to body condition of the individual boar. For the treatment feeding program, boars were fed 5.8 lb/d in the first 4 wk until boars reached 400 lb; afterward, boars were fed 6.0 lb/d for the duration of the study. Boars were weighed periodically to determine periodic and overall ADG. Semen was collected from each boar once a week for a total duration of 16 mo. Semen production and quality was determined for each ejaculate. Overall, treatment boars were consistently heavier than the control boars throughout the duration of the study because of their higher periodic and overall daily gains. At the end of the test, treatment boars were 32 lb heavier ($P < 0.15$) than the control boars. A higher proportion of treatment boars (73 vs. 42%) were active at the end of the study, which numerically increased ($P > 0.35$) average days in the stud (345 vs. 279 d), semen collections (58 vs. 49), and doses produced (1,238 vs. 1,077). There were no differences ($P > 0.28$) in the volume, sperm cell concentration, sperm cell count, and doses produced per ejaculate between boars fed the two feeding programs. Likewise, motility rates and proportion of normal cells in ejaculates were similar ($P > 0.33$) between boars fed the control and treatment feeding program. In conclusion, AI boars can be fed to a set feeding level to achieve targeted weight gains to influence longevity without affecting semen production and quality.

Key words: boars, growth rate, longevity, semen characteristics

Introduction

Despite the potential relationship between growth rate and reproductive performance, there is a lack of information on ideal growth rates of adult working boars. In previous studies, slow-growing boars fed at maintenance have shown significantly lower libido, semen volume, and sperm output. On the other hand, providing boars with high levels of feed to achieve fast growth is thought to induce leg

[1] The authors thank Zoltenko Farms, Inc., Hardy, NE, for animals and facilities used in this experiment.
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and libido problems. Rate of weight gain may also affect longevity and, therefore, lifetime semen production. Different feeding programs can lead to varying rates of growth; however, different feeding regimens for AI boars have never been evaluated. Therefore, the objective of this study was to determine the effect of 2 different feeding regimens on growth performance, semen production and quality, and longevity of boars in a commercial AI stud.

Procedures

A total of 30 replacement boars (PIC TR4, 375 lb and 14.2 mo of age) were randomly selected for this study conducted at the AI stud facilities of Zoltenko Farms, Inc., in Hardy, NE. Boars were allotted to 2 treatments in a completely randomized design; there were 15 boars (replicates) per treatment. The 2 experimental treatments were (1) control and (2) treatment feeding programs. The control feeding program was the existing feeding program of the stud. Upon entry to the stud, feed drops were set to 6.7 lb/d for the first 8 wk. After this initial period, feed box settings were adjusted periodically according to a subjective assessment of body condition of each boar throughout its lifetime in the stud. For the treatment feeding program, boars were fed 5.8 lb/d for the first 4 wk until boars reached 400 lb. Afterward, boars were offered 6.0 lb/d throughout the duration of the study. In a previous study, it was determined that a 12% overage was the average difference between feed box setting and the actual amount of feed dispensed in this specific stud. To provide the desired feeding levels for the treatment boars, feed boxes were set at 5.2 lb/d in weeks 0 to 4 and 5.4 lb/d throughout the rest of the study. The feed boxes for the control boars initially were set at 6.0 lb/d; however, because of the overage, the actual amount of feed presented to control boars was 6.7 lb/d in weeks 0 to 8 and between 4.5 to 11.2 lb/d during the period when boars were fed according to body condition. All boars were fed a corn-soybean meal-based diet with 10% soy hulls, 5% dehydrated alfalfa, and a boar base mix formulated to contain 0.79% standardized ileal digesible lysine and 1,340 kcal ME/lb (Table 1). Boars were fed twice a day, and water was provided ad libitum. Boars were weighed periodically by using a platform scale to determine periodic and cumulative daily gains. Any adjustments of the feeder box settings during the study were also recorded. Total duration of the study was 16 mo.

Table 1. Composition of the boar diet (as-fed basis)[1]

Ingredient	%
Corn	57.50
Soybean meal (46.5% CP)	21.25
Soybean hulls	10.00
Alfalfa meal, dehydrated	5.00
Boar base mix	6.25
Total	100.00
Calculated analysis	
CP, %	17.4
Standardized ileal digestible lysine, %	0.79
ME, kcal/lb	1,343
Ca, %	1.14
Available P, %	0.54

[1] Fed in meal form.

Semen was collected from each boar once a week on a dummy by using the hand glove technique with an average rest period of 5.3 d. The first collection was performed a week prior to the start of the experiment. For semen production, the volume of each ejaculate was measured immediately after collection. The concentration and number of sperm cells and the number of doses per ejaculate were also determined. Semen quality was assessed on the basis of sperm motility and the rate of normal cells per ejaculate. Each ejaculate was also evaluated for morphological defects such as distal and proximal droplets, loose heads, acrosome defects, pouch formations, and abnormal midpieces. Semen collections were trashed for the presence of morphological

defects, poor motility, bloody semen, or sterility. Trashed collections (due to morphological defects) were recorded with the date and reason for trashing. Boars were removed according to the culling standards of the stud. The date and reason for culling were recorded. Because 3 of the boars in the control feeding program were culled early because they were untrainable for semen collections, only 12 control boars were included in the analysis.

Data were analyzed by using the GLM procedure of SAS for a completely randomized design with boar as the experimental unit. Treatments were separated by using the LSMEANS statement and the PDIFF option of SAS. An alpha level of 0.05 was used to assess the significance between least square means.

Results and Discussion

The effect of the 2 feeding programs on live weight of boars in a commercial AI stud is shown in Figure 1. Boars on the control feeding program were 2.1% heavier (446 vs. 437 lb) than the boars on the treatment feeding program after the initial 8-wk period. This was expected because control boars were provided 0.7 to 0.9 lb more feed and had greater daily gains (weeks 0 to 8: 1.14 vs. 0.97 lb/d) during this period. However, control boars became lighter (wk 14: 452 vs. 464 lb) than the treatment boars immediately after the initial period. This change in the weight trend reflects the adjustment in the feeding program when control boars were fed according to body condition. After wk 14, boars on the treatment feeding program were consistently heavier than the boars on the control feeding program throughout the duration of the study. Treatment boars were significantly heavier ($P < 0.06$) at wk 18, 34, and 54. At the end of the test, treatment boars were 32 lb heavier ($P < 0.15$) than the control boars.

Except from wk 0 to 4 (Figure 2), boars on the treatment feeding program achieved higher periodic daily gains as boars increased in weight from 400 to 500 lb (wk 4 to 24: 0.67 vs. 0.55 lb/d) and 500 to 600 lb (wk 24 to 64: 0.33 vs. 0.28 lb/d), though differences were not significant ($P > 0.32$). Overall daily gains of treatment boars were numerically higher ($P < 0.39$; 0.51 vs. 0.46 lb/d) than those of boars on the control feeding program. With the treatment feeding program, boars showed a steady decline in daily gains from 0.84 lb/d in wk 4 to 0.33 lb/d at wk 64 (Figure 3). The variation in weight gains of individual treatment boars is shown in Figure 4. At a constant feed box setting, weight gains varied from boar to boar in each period. This may reflect animal differences or daily variations in the actual amount of feed dispensed from each feed box. However, all of the treatment boars were on a positive plane of growth throughout the study.

Boars on the control feeding program showed a more erratic pattern of growth rates with wide swings in daily gains throughout the study (Figure 3). Boars on the control feeding program had greater ($P < 0.14$) ADG than the treatment boars from wk 0 to 4 (1.04 vs. 0.84 lb/d) and from wk 54 to 64 (0.70 vs. 0.33 lb/d). In contrast, control boars had lower ($P < 0.14$) daily gains than the treatment boars from wk 8 to 14 (0.31 vs. 0.75 lb/d) and 28 to 34 (0.15 vs. 0.46 lb/d). These big changes in growth rates among the control boars suggest a cyclic pattern of increasing and decreasing feed allocation of individual boars to either reduce or compensate body condition (Figure 5). Boars were fed as much as 11.2 lb/d when they were below the farm's acceptable body condition and as little as 4.5 lb/d when individual boars were believed to need to lose condition. At this low level of feeding, boars were potentially being fed close to or below their maintenance requirements. This also highlights another problem—the boar stud failed to account for the differences between the feed box settings and the actual amount of feed dispensed.

It is important to check and account for these differences to accurately develop feeding programs.

Using the factorial approach, we determined the predicted weight gains of the treatment boars on the basis of their actual feed allocation (Table 1). The estimated total energy intake of the boars was 7.8 Mcal ME/d in wk 0 to 4 and 8.1 Mcal ME/d from wk 4 until the end of the study. The total energy requirement of the treatment boars for maintenance, mating activity, and sperm production increased from 5.86 Mcal ME at 376 lb to 8.03 Mcal ME at 607 lb BW. Therefore, the estimated ME difference for weight gain declined from 1.94 to 0.07 Mcal ME/d. This shows that with the constant feed allocation at 5.4 lb/d, the total energy intake of the boars approached maintenance as BW increased from 376 to 607 lb. The predicted weight gains of the treatment boars declined linearly from 0.88 to 0.03 lb/d for the entire duration of the study. The predicted weight gains of the treatment boars were plotted against their actual weight gains (Figure 6). The slope of the line for the actual weight gains (-0.0878) was 92.2% of the slope of the predicted weight gains (-0.0952), which indicates close agreement. The actual weight gains of the treatment boars were slightly greater than the predicted weight gains, which may be due to (1) differences in the energy value of some of the ingredients (i.e., soybean hulls) accounted in the feed formulation, (2) variations in the actual amount of feed dispensed from the boxes, or (3) differences between the predicted and actual animal efficiencies.

At the end of the 16-mo study, a higher proportion of active boars (73 vs. 42%) were maintained in boars fed the treatment feeding program (Figure 7). For the 10 control boars, 5 were culled because of poor semen quality, 3 were untrainable, 1 had a leg injury, and 1 died (identified as a twisted gut). All 4 boars culled from the treatment group were culled because of poor semen quality. Because there was a higher number of active boars maintained until the end of the test, boars under the treatment feeding program had greater total production days (+55%; 5,173 vs. 3,345 d), semen collections (+47%; 874 vs. 593), and doses produced (+47%; 18,569 vs. 12,619) than the control group (Table 3). However, the average production days (345 vs. 279 d/boar), number of semen collections (58 vs. 49 collections/boar), and number of doses produced (1,238 vs. 1,077 doses/boar) were only numerically improved ($P > 0.35$) in boars fed the treatment feeding program. There were no differences between the two treatments in the total and average number of semen collections trashed; however, the percentage of trashed collections was higher in the control group than in the treatment group (8.3 vs. 4.6%). The rate of morphological defects in trashed collections from the control and treatment groups was the same, with distal and proximal droplets making up more than half of the trashed collections. In terms of semen characteristics, there were no differences ($P > 0.28$) in the volume, sperm cell concentration, sperm cell count, and doses produced per ejaculate between boars fed the 2 feeding programs (Table 4). In other studies, plane of nutrition was found to significantly affect semen volume, especially in young boars. However, these differences were obtained when comparisons were made between boars fed above and below their nutrient requirements, which is not the case in the present study. Likewise, motility rates and proportion of normal cells in ejaculates were similar ($P > 0.33$) between boars fed the control and treatment feeding program. These results are consistent with previous studies in which varying levels of feed or energy intake of boars did not influence any semen quality variable.

In conclusion, AI boars can be fed to a set feeding level to achieve targeted weight gains to influence longevity without affecting semen production and quality. Because many of the

reasons for culling may not have been entirely due to feeding regimen, more research is required to validate that feeding regimen influences longevity of boars in the stud.

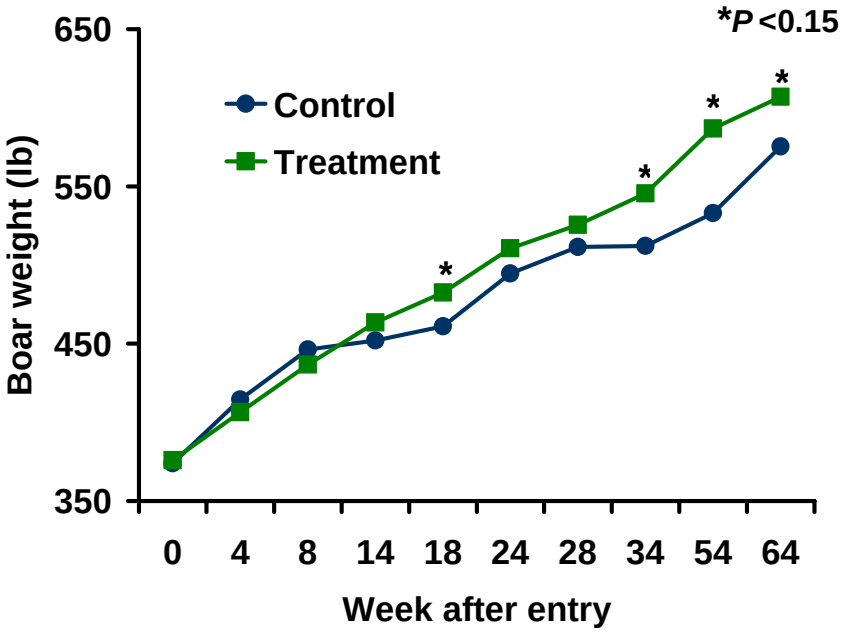

Figure 1. Effect of different feeding regimens on live weight of boars in a commercial AI stud.
(Control = 6.7 lb/d for wk 0 to 8 and then fed according to body condition, Treatment = 5.8 lb/d for wk 0 to 4 and then 6.0 lb/d until end of the study).

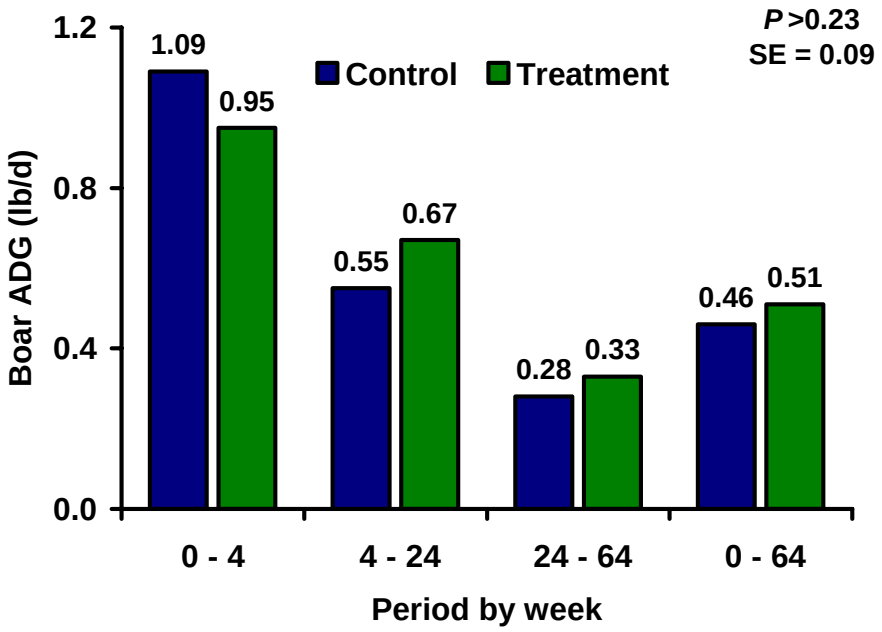

Figure 2. Effect of different feeding regimens on periodic and overall daily gains of boars in a commercial AI stud.
(Control = 6.7 lb/d for wk 0 to 8 then fed according to body condition, Treatment = 5.8 lb/d for wk 0 to 4 and then 6.0 lb/d until end of the study).

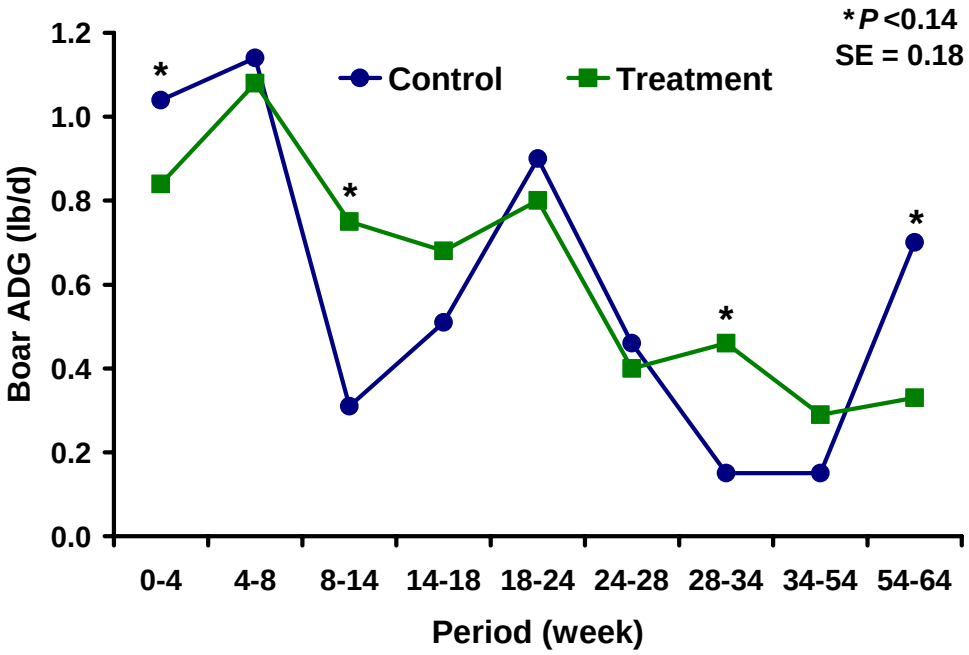

Figure 3. Effect of different feeding regimens on the pattern of growth rates of boars in a commercial AI stud.
(Control = 6.7 lb/d for wk 0 to 8 then fed according to body condition, Treatment = 5.8 lb/d for wk 0 to 4 and then 6.0 lb/d until end of the study).

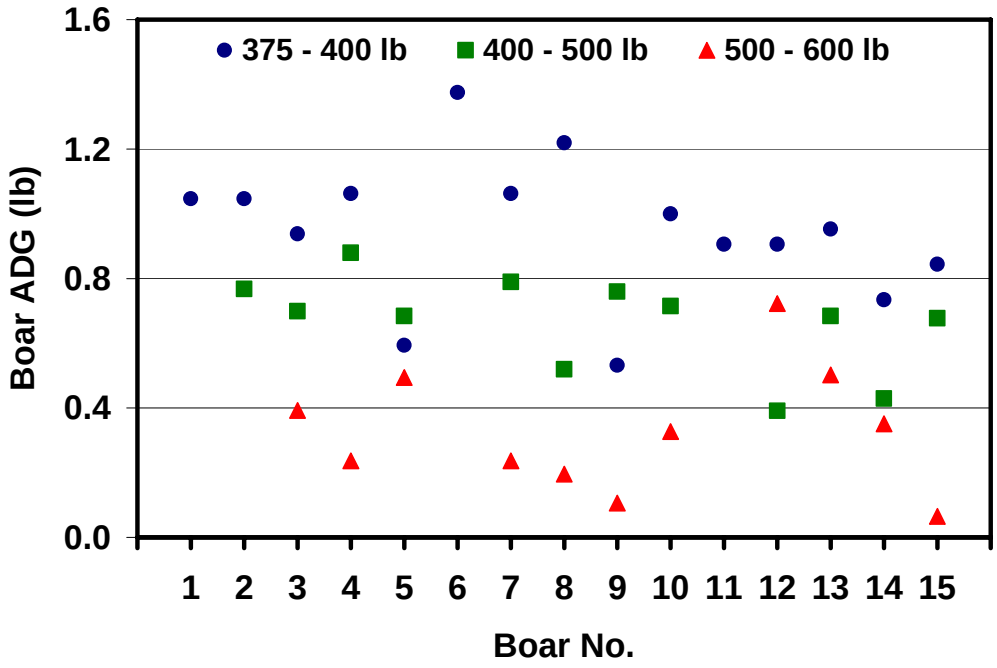

Figure 4. Variation in daily weight gains of treatment boars fed at constant feed box settings (5.8 lb/day at 375 to 400 lb and 6.0 lb/day at 400 to 600 lb BW).

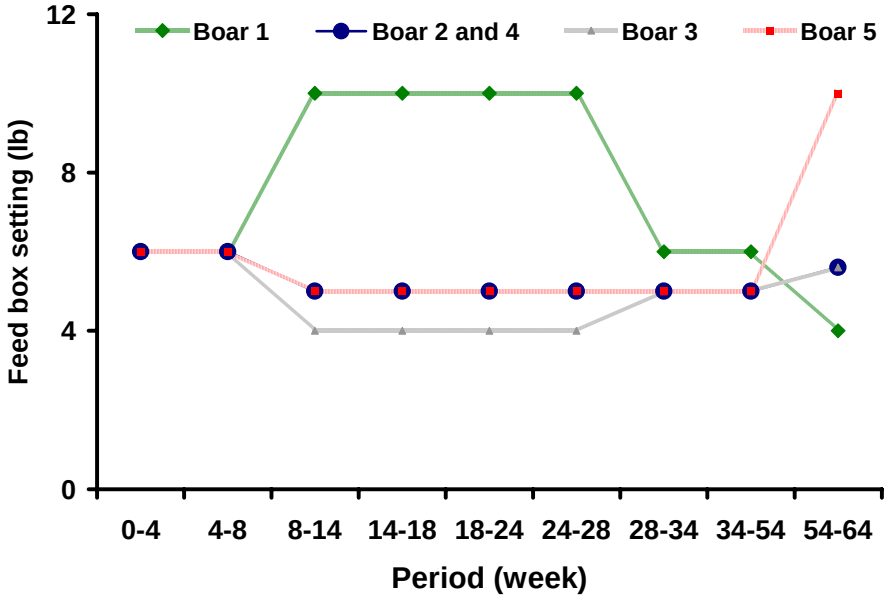

Figure 5. Feed box adjustments of individual boars in the control feeding program.

Table 2. Predicted daily weight gain of treatment boars

	Actual BW	Daily feed allocation		Estimated energy intake[2]	ME requirement			Total ME at wt gain = 0[6]	Difference[7]	Predicted wt gain[8]
		Box setting	+12% overage[1]		Maintenance[3]	Mating activity[4]	Sperm production[5]			
wk	lb	lb/d	lb/d	Mcal ME/d	Mcal ME	Mcal ME	Mcal ME	Mcal ME	Mcal ME/d	lb/d
0	376	5.2	5.8	7.80	5.56	0.20	0.10	5.86	1.94	0.88
4	406	5.4	6.0	8.10	5.85	0.22	0.10	6.17	1.94	0.87
8	437	5.4	6.0	8.10	6.14	0.23	0.10	6.47	1.64	0.74
14	464	5.4	6.0	8.10	6.39	0.24	0.10	6.73	1.38	0.62
18	483	5.4	6.0	8.10	6.56	0.24	0.10	6.91	1.20	0.54
24	511	5.4	6.0	8.10	6.81	0.26	0.10	7.17	0.94	0.42
28	526	5.4	6.0	8.10	6.94	0.26	0.10	7.31	0.80	0.36
34	546	5.4	6.0	8.10	7.12	0.27	0.10	7.49	0.62	0.28
54	587	5.4	6.0	8.10	7.47	0.28	0.10	7.86	0.25	0.11
64	607	5.4	6.0	8.10	7.64	0.29	0.10	8.03	0.07	0.03

[1] Average difference between feed box setting and actual amount of feed dispensed was +12%.
[2] Daily feed allocation, lb/d ×1.34 Mcal ME/lb of boar diet.
[3] 0.1823 Mcal ME/kg $BW^{0.665}$.
[4] 4.3 kcal/kg $BW^{0.75}$.
[5] 0.1 Mcal ME/d.
[6] Sum of ME requirements for maintenance, mating activity, and sperm production.
[7] Estimated energy intake - (Maintenance + Mating activity + Sperm production).
[8] Difference, Mcal ME/d ÷ 2.22 Mcal ME/lb.

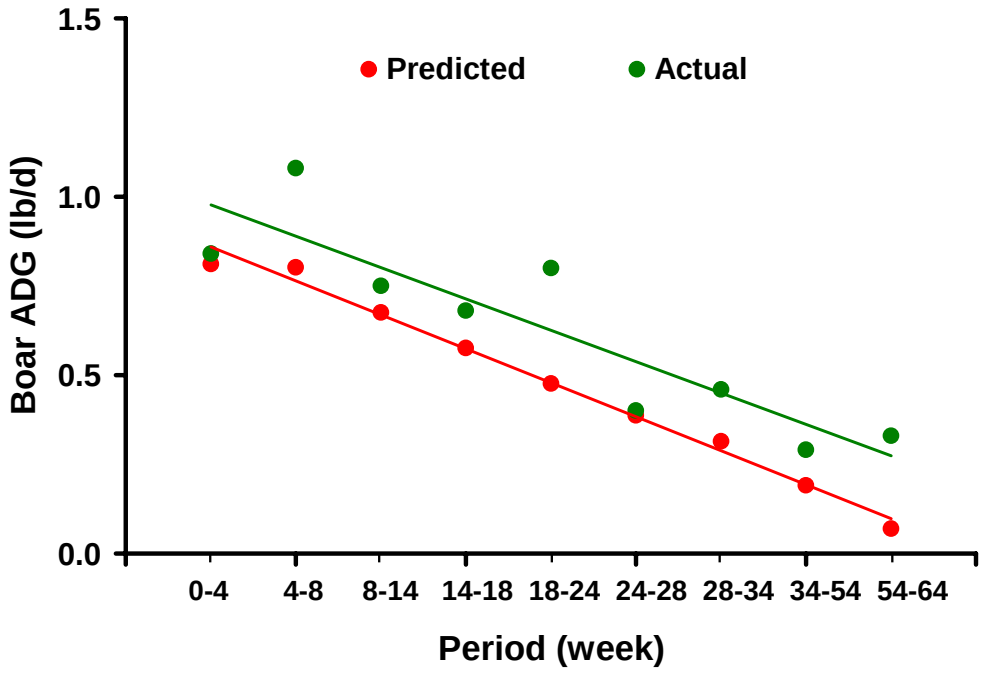

Figure 6. Predicted and actual daily weight gains (lb/d) of treatment boars.

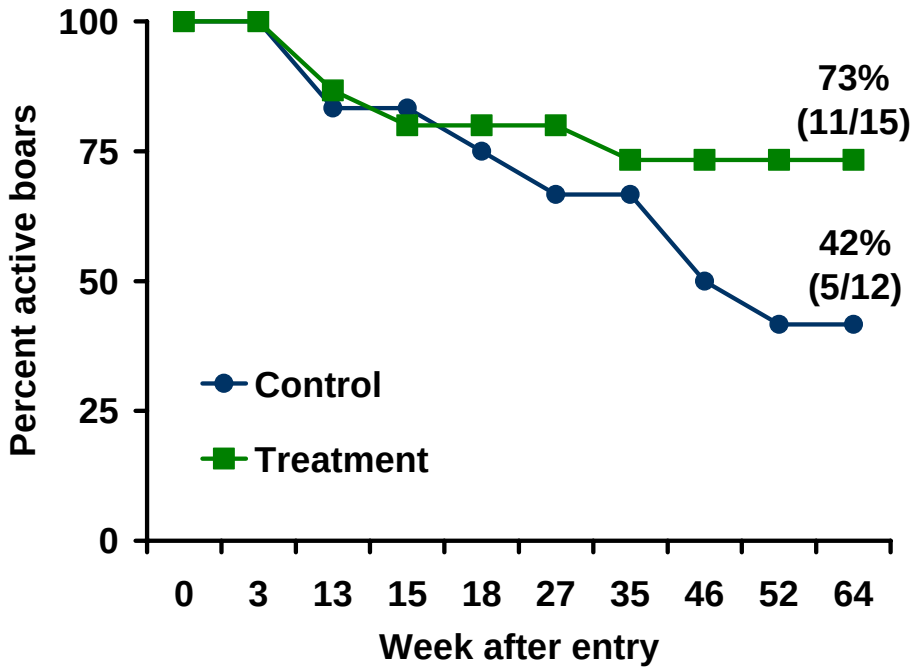

Figure 7. Effect of different feeding regimens on percentage of active boars in a commercial AI stud.
(Control = 6.7 lb/d for wk 0 to 8, then fed according to body condition, Treatment = 5.8 lb/d for wk 0 to 4 and then 6.0 lb/d until end of the study).

Table 3. Effect of different feeding regimens on semen production and longevity of adult working boars in a commercial AI stud[1]

Item	Feeding program[2]		SE	Probability, $P <$
	Control	Treatment		
No. of active boars				
Start of test	12	15	---	---
End of test	5	11	---	---
No. culled	7	4	---	---
Days in AI stud				
Total	3,345	5,173	---	---
Average	279	345	52.3	0.35
Semen collections				
Total	593	874	---	---
Average	49	58	7.9	0.41
Trashed collections				
Total	41	40	---	---
Average	3.4	2.7	1.0	0.59
% of Total	8.3	4.6	---	---
Doses produced				
Total	12,919	18,569	---	---
Average	1,077	1,238	226.0	0.60

[1] A total of 30 boars (initially 375 lb and 14.2 mo of age, PIC TR4) with 15 boars (replicates) per treatment; Control based on 12 boars because 3 early culls were untrainable for semen collections.

[2] Control feeding program = 6.7 lb/d for initial 8 wk then fed individual boars according to body condition; Treatment feeding program = 5.8 lb/d for initial 4 wk then fed all boars 6.0 lb/d for duration of the study.

Table 4. Effect of different feeding regimens on semen characteristics collected from adult working boars in a commercial AI stud[1]

Semen characteristics (average per ejaculate)	Feeding program[2]		SE	Probability, $P <$
	Control	Treatment		
Volume, mL	223	204	16.0	0.37
Doses produced	23	21	1.3	0.28
Sperm cells concentration, 1,000/mm^3	366	367	20.0	0.97
No. of sperm cells, $\times 10^9$	80	74	4.7	0.28
Motility, %	87.0	86.5	0.3	0.33
Normal cells, %	85.6	85.3	0.6	0.72

[1] A total of 30 boars (initially 375 lb and 14.2 mo of age, PIC TR4) with 15 boars (replicates) per treatment; Control based on 12 boars because 3 early culls were untrainable for semen collections.

[2] Control feeding program = 6.7 lb/d for initial 8 wk, then fed individual boars according to body condition; Treatment feeding program = 5.8 lb/d for initial 4 wk, then fed all boars 6.0 lb/d for duration of the study.

INFLUENCE OF ORGANOLEPTIC PROPERTIES OF THE FEED AND NURSERY DIET COMPLEXITY ON PREWEANING AND NURSERY PERFORMANCE[1]

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Summary

Two experiments were performed to determine the effects of adding an enhanced feed flavor to the creep feed on the proportion of piglets consuming creep feed within litters and preweaning performance (Exp. 1) and the interactive effects of preweaning exposure to the flavor, nursery diet complexity, and flavor addition to nursery diets on postweaning performance (Exp. 2).

In Exp. 1, 50 sows (PIC 1050) were blocked according to parity and date of farrowing and allotted to 2 experimental treatments in a randomized complete block design. Treatment 1 was a creep diet with no flavor (negative control), and treatment 2 was the negative control diet with the enhanced milky flavor (Luctarom) included at 1,500 ppm (3 lb/ton). Both creep diets contained 1.0% chromic oxide and were offered ad libitum from d 18 until weaning on d 21. In Exp. 2, 480 weanling pigs (PIC, 14.5 lb and 20 ± 2 d) from Exp. 1 were blocked by initial weight and allotted to 1 of 8 treatments in a randomized complete block design with preweaning exposure to the flavor (exposed vs. unexposed), nursery diet complexity (complex vs. simple), and flavor addition to the nursery diets (with vs. without flavor) as treatment factors.

In Exp. 1, no differences in weaning weight ($P > 0.53$), total gain ($P > 0.77$), and ADG ($P > 0.77$) were observed between litters or pigs fed creep with and without the flavor. Flavor added to the creep feed did not influence total ($P > 0.66$) or daily ($P > 0.66$) creep feed intake of litters or the proportion of creep feed eaters ($P > 0.41$) in whole litters. In Exp. 2, a tendency for a 3-way interaction for ADG from d 5 to 10 ($P < 0.11$), d 10 to 28 ($P < 0.09$), and d 0 to 28 ($P < 0.06$) was observed. Postweaning ADG of pigs exposed to the flavor in creep feed and pigs fed flavored complex diets was greater than that of pigs in any other treatment combination. Increasing diet complexity improved ($P < 0.01$) ADG and ADFI during both phases. Adding flavor in the creep feed had no effect on F/G ($P > 0.34$) and pig BW ($P > 0.45$) in both periods postweaning. Adding Luctarom to starter diets tended to improve ADFI ($P < 0.06$) during d 0 to 5.

In conclusion, adding Luctarom to the creep feed did not affect litter creep feed intake, proportion of piglets consuming creep feed, and preweaning performance when creep was provided for 3 d before weaning. Preweaning exposure to Luctarom improved postweaning daily gain of pigs fed complex diets supplemented with the same flavor but did not influence performance of pigs fed simple diets.

[1] The authors thank Lucta USA, Inc., Northbrook, IL, for partial financial support.

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Key words: feed intake, flavor, piglet

Introduction

Maximizing pig performance immediately postweaning is essential in improving lifetime growth efficiency and productivity. The weaning event, however, is usually characterized by a period of low feed intake caused by physical, physiological, and behavioral challenges that typically affect postweaning growth rates. Recent studies on creep feeding have shown that "eaters," which are piglets in a litter positively consuming creep feed, have better initial postweaning feed intake and growth performance than piglets that do not consume creep feed. Increasing creep feed consumption and the proportion of piglets consuming creep feed in whole litters may elicit positive effects on nursery performance. Nondietary factors, such as creep feeding duration and creep feeder type, have been shown to affect the proportion of creep feed eaters within a litter. Dietary factors can be investigated by using this model.

Organoleptic properties of feed may be a factor in improving the proportion of piglets consuming creep feed. Feed flavors are commonly used in piglet diets to improve diet acceptance and stimulate intake; however, the proportion of the litter actually consuming creep feed with the flavor or whether there is a difference in the proportion of creep feed eaters created compared with an unflavored creep diet have not been determined. Preweaning exposure to the flavor may also enhance postweaning responses when the same flavor is added to the nursery diets; however, evidence of this in piglets is limited. Some studies have shown an innate preference for flavored diets during changes in dietary regimes, especially at weaning or during the starter period. Reducing differences in performance between pigs fed complex and simple nursery diets through the use of feed flavors may have potential economic benefits.

Therefore, the objectives of this study were to determine (1) the effects of organoleptic properties of feed with an enhanced flavor (Luctarom) on the proportion of creep feed eaters within a litter and preweaning performance (Exp. 1), (2) the effects of diet complexity (complex vs. simple) on response to the inclusion of an enhanced flavor in nursery pig performance (Exp. 2), and (3) the effects of preweaning exposure to the enhanced flavor and flavor addition to nursery diets on postweaning performance (Exp. 2).

Procedures

Experiment 1. A total of 50 sows (PIC 1050) and their litters were used in this study conducted at the Kansas State University Swine Research and Teaching Center farrowing facility. Sows used in this experiment were from 2 batches of sows farrowed in November and December 2007; 25 experimental sows from each batch were included in the study. Sows were blocked according to parity and date of farrowing and allotted to 2 experimental treatments in a randomized complete block design. Cross-fostering was performed within 48 hours postfarrowing to standardize litter weights and litter size (> 10 pigs). The sow or litter was the experimental unit; there were 25 replicates per treatment group.

There were 2 experimental diets in this study. Treatment 1 was a creep diet with no flavor (negative control), and treatment 2 was the negative control diet with the enhanced milky flavor (Luctarom) included at 1,500 ppm (3 lb/ton). Both creep diets were formulated to contain 1,586 kcal ME/lb and 1.56% standardized ileal digestible (SID) lysine (Table 1). Chromium oxide was added to both diets at 1.0% to serve as a fecal marker. The creep diets were in pellet form (2-mm pellets) and offered ad libitum from d 18 until weaning on d 21. A single lactation diet (1,585 kcal ME/lb, 0.97% SID lysine) was used in the experiment. Sows were allowed free access to feed throughout lactation. Water was made available at all times for sows and their litters through nipple drinkers and bowls, respectively.

Table 1. Composition (as-fed basis) of creep diet for Exp. 1[1]

Ingredient	%
Corn	6.05
Soybean meal (46.5% CP)	2.32
Spray-dried animal plasma	6.00
Select menhaden fish meal	6.00
Spray-dried whey	25.00
Lactose	5.00
Extruded soy protein concentrate	10.00
Pulverized oat groats	30.00
Choice white grease	5.00
Monocalcium phosphate (21% P)	0.35
Limestone	0.45
Salt	0.30
Zinc oxide	0.38
Vitamin premix	0.25
Trace mineral premix	0.15
L-Lysine HCl	0.15
DL-Methionine	0.15
Antibiotic	1.00
Acidifier	0.20
Vitamin E, 20,000 IU	0.05
Chromium oxide	1.00
Total	100.00
Calculated analysis	
SID[2] Lysine, %	1.56
SID Lysine:ME ratio, g/Mcal	4.47
SID Isoleucine:lysine ratio, %	0.59
SID Methionine:lysine ratio, %	0.31
SID Met & Cys:lysine ratio, %	0.57
SID Threonine:lysine ratio, %	0.62
SID Tryptophan:lysine ratio, %	0.19
SID Valine:lysine ratio, %	0.71
ME, kcal/lb	1,585
Protein, %	23.88
Total lysine, %	1.69
Ca, %	0.81
Available P, %	0.55
Lactose, %	23.00

[1] Supplemented without (Control) and with Luctarom at 1,500 ppm (3 lb/ton)
[2] Standardized ileal digestible.

Piglets were weighed individually at d 0 (birth), 18, and 21 (weaning). The amount of creep feed offered was weighed daily. Creep feed that was not consumed at the time of weighing was collected and weighed back. Fecal samples from all piglets were taken using sterile swabs twice between 3 and 12 h before weaning for all treatments. The color of each fecal sample was visually determined. Piglets were categorized as "eaters" when the fecal sample was colored green at least once on any of the two samplings. Piglets that tested negative on the first fecal sampling were resampled 9 to 12 h after the first sampling.

Sows were weighed postfarrowing and at weaning. Weekly feed intake of the sows was recorded to calculate total feed intake and ADFI. In this study, 1 sow from treatment 2 was removed from the test because of very low feed intake. General health of the 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 by using heat lamps when needed.

Periodic and cumulative ADG and creep feed intake were calculated for each treatment group. Data were analyzed as a randomized complete block design by using the PROC MIXED procedure of SAS. The effect of the enhanced milky flavor on percentage of eaters was analyzed by using the chi-square test in SAS.

Experiment 2. A total of 480 weanling piglets (PIC, initially 14.5 lb and 20 ± 2 d) from Exp. 1 were allotted and blocked by initial weight to 1 of 8 treatments as a 2 × 2 × 2 factorial using a randomized complete block design. Treatment factors were preweaning exposure to the flavor (exposed vs. unexposed to the flavor), nursery diet complexity (complex vs. simple diet phase feeding), and flavor addition to the nursery diets (with vs. without flavor). Each treatment had 6 pigs per pen and 10 replications (pens). Each pen contained 1 self-feeder and 1 nipple drinker to provide ad libitum access to feed and water. Pigs were housed in the Kansas State University Swine Teaching and Research Center nursery facilities.

Experimental diets were the combinations of either complex or simple and with or without the flavor for both phases (Table 2). For

phase 1, simple diets were mainly composed of cornmeal and soybean meal with 2.5% fish meal and 10% dried whey. The complex diets contained 30% pulverized oat groats, 25% dried whey, 6% spray-dried porcine plasma, 6% fish meal, and lower levels of cornmeal and soybean meal. Lactose content was 7.2 and 18% for the simple and complex diet, respectively. For phase 2, the simple diet was mainly cornmeal and soybean meal. The complex diet was also composed of cornmeal and soybean meal but also contained 4.5% fish meal and 10% dried whey. The simple and complex diet contained 0 and 7.2% lactose, respectively. For both phase 1 and 2 diets, the simple and complex diets were isocaloric and were formulated to the same essential amino acid specifications (NRC, 1998). Diets with the flavor were supplemented with Luctarom at 1,500 ppm (3 lb/ton) in phase 1 diets and 1,000 ppm (2 lb/ton) in phase 2 diets. Phase 1 diets were in pellet form and fed from d 0 to 10. Phase 2 diets were in meal form and fed from d 11 to 28. Pigs and feeders were weighed on d 5, 10, and 28 following weaning to calculate ADG, ADFI, and F/G. Results were analyzed as a randomized complete block design with a 3-way factorial treatment structure by using the PROC MIXED procedure of SAS with pen as the experimental unit. Least squares means were evaluated by using the PDIFF and STDERR options of SAS and adjusted using the Tukey test.

Results and Discussion

Experiment 1. Performance of lactating sows used in this study is shown in Table 3. Sows had an average parity of 2.3 ± 0.3 and lactation length of 20.5 ± 0.3 d. There were no differences in postfarrowing weight ($P > 0.88$), weaning weight ($P > 0.80$), and lactation weight loss ($P > 0.17$) between the treatments. Likewise, litter size after fostering, at d 18, and at weaning were similar ($P > 0.50$) between the two treatments. There were also no differences ($P > 0.68$) between treatments in total and ADFI of sows throughout lactation.

Overall, differences in litter weaning weights ($P > 0.94$), total gain ($P > 0.77$), and daily gain ($P > 0.77$) between litters fed creep with and without the enhanced milky flavor were not significant (Table 4). For individual pigs, differences in weaning weight ($P > 0.53$), total gain ($P > 0.89$), and ADG ($P > 0.89$) between the two treatments were also not significant. Likewise, addition of the enhanced milky flavor to the creep feed did not influence total ($P > 0.66$) or daily ($P > 0.66$) creep feed intake of litters (Figure 1) or the proportion of creep feed eaters ($P > 0.41$) in whole litters (Figure 2).

These results may be explained by (1) the duration of creep feeding, (2) the maximum proportion of creep feed eaters within litters, and (3) the role of feed flavors in diets of suckling pigs. The duration of creep feeding may be important, and a minimum period of exposure to the flavor is required to see appreciable effects. However, our previous study on varying creep feeding durations showed that creep feed intake is more related to the maturity of piglets than to the period of induction of creep feeding. More importantly, most U.S. pig producers provide supplemental feed for only 2 to 7 d prior to weaning; thus, any effect of flavor addition should be observed in a short feeding duration. It is still undetermined whether dietary changes can increase the proportion of piglets consuming creep feed over the rate determined in previous studies. The highest rate of creep feed eaters achieved in our previous studies was 70% when nondietary factors were manipulated. Any effect of dietary factors on the proportion of piglets consuming creep feed remains to be demonstrated.

Results may also be due to the role taste and olfactory cues play in stimulating higher intakes by suckling pigs. Few studies have evaluated the effect of feed flavors on stimulating creep feed consumption; most have evaluated flavor exposure prenatally or flavors through the lactation feed. Some of these studies suggest that creep feed consumption can be

stimulated when piglets are acquainted with specific flavors associated with the sow's milk or diet. When flavors are added to the creep feed, results have been consistent. In one study, the addition of 5 g/kg of monosodium L-glutamate (MSG) to the creep feed led to a significant increase in creep feed intake from d 18 postfarrowing; however, no differences in weaning weights were observed despite the increase in intake. Monosodium L-glutamate is the principal source of the umami taste, which increases the intensity and acceptability of inherent flavors of food. In a follow-up study, addition of MSG to an associated commercial flavor in the creep feed did not elicit any effect on creep feed intake or preweaning performance. Results of the current study agree with these previous findings.

The lack of effect in suckling pigs may suggest age-related differences or greater individual variation in palatability perception. In a previous creep feeding study, increased physiological need for nutrients driven by restricted feeding of lactating sows did not stimulate litters to consume more creep feed or increase the proportion of creep feed eaters. This suggests that changing the flavor properties of the creep feed may not be sufficient to positively affect preweaning feed intakes.

In conclusion, addition of the enhanced milky flavor to the creep feed did not affect litter creep feed intake, the proportion of piglets consuming creep feed, or preweaning performance. The benefits of flavor addition preweaning should be assessed on the basis of effects on postweaning intake and performance.

Experiment 2. The interactive and main effects of flavor in the creep diet, diet complexity, and flavor in the nursery diets on postweaning performance are shown in Tables 5 and 6, respectively. Results showed tendencies for a 3-way interaction for daily gains from d 5 to 10 ($P < 0.11$), d 10 to 28 ($P < 0.09$), and d 0 to 28 ($P < 0.06$). No 3-way interaction was observed for pig weights ($P > 0.13$), daily feed intake ($P > 0.27$), or F/G ($P > 0.13$) in any period. Generally, postweaning ADG of pigs exposed to the flavor in creep feed and fed flavored complex diets was greater than that of pigs fed any other treatment.

Increasing diet complexity improved ($P < 0.01$) ADG and ADFI during both phases (Table 6). Pigs fed starter diets with greater complexity were heavier ($P < 0.0001$) than pigs fed simple diets at d 5 (+0.8 lb), 10 (+1.5 lb) and 28 (+3.3 lb). Feed efficiency was also improved ($P < 0.0001$) in pigs fed complex diets from d 0 to 5 and d 0 to 10 but not from d 5 to 10 ($P > 0.58$). However, pigs fed complex diets were less (6.0%; $P < 0.0001$) efficient from d 10 to 28 than pigs fed the simple diets. Overall (d 0 to 28), pigs fed the diets with greater complexity had poorer (2.3%; $P < 0.0001$) F/G than pigs fed simple diets.

These results agree with previous studies evaluating the effects of diet complexity on weanling pigs. Most previous studies showed marked improvements in early postweaning ADG, ADFI, and F/G when pigs were fed diets with greater complexity. However, the effect of diet complexity on pig growth and efficiency decreases with increasing time postweaning, which may help explain the poorer feed efficiency from d 10 to 28 observed in this study for pigs fed the complex diets. Though some studies have demonstrated the ability of certain feed flavors to mask less palatable ingredients, the negative effect of feeding the simple diets seen in this study may be too great for the effect of flavor to overcome. However, the benefit of feeding starter diets with greater complexity on weanling pig performance should be weighed against the additional feed consumption and the higher unit cost of the feed.

Exposing pigs to Luctarom in the creep feed did not affect daily gains ($P > 0.27$), feed efficiency ($P > 0.40$), or pig weights ($P > 0.45$) in all periods postweaning. Daily feed intake was also unaffected ($P > 0.29$), except

for d 5 to 10 when pigs exposed to the flavor preweaning tended to have lower ($P < 0.07$) daily feed intake than unexposed pigs. Supplementing the starter diet with the enhanced flavor tended to improve daily feed intake (5.9%; $P < 0.06$) and numerical differences in daily gains (6.3%; $P < 0.15$) during d 0 to 5. However, no differences in daily gain ($P > 0.20$), daily feed intake ($P > 0.42$), or feed efficiency ($P > 0.35$) were observed between pigs fed starter diets with and without the flavor in all succeeding periods. Pig weights were also unaffected ($P > 0.35$) by flavor addition in all periods.

These results show that the addition of flavor in the nursery diet helped achieve modest gains in feed intake and weight gains early postweaning; however, the benefit of flavor addition was not seen throughout the rest of the starter period. In one recent study, addition of the enhanced milky flavor to the starter diet improved daily gains and feed intake numerically only in one trial; another study showed a significant improvement compared with pigs fed unflavored diets during d 0 to 14. Overall (d 0 to 28), both of the previous trials showed higher daily gains for weanling pigs when the enhanced milky flavor was added to nursery diets, which is in contrast to the result of the current study. This suggests that the effect of the enhanced milky flavor is variable and may depend on the composition of the diet

In conclusion, preweaning exposure to Luctarom improved postweaning daily gains and feed intake of pigs fed complex diets supplemented with the same flavor but did not influence performance of pigs fed simple diets.

Table 2. Composition (as-fed basis) of phase 1 and 2 diets for Exp. 2

	Phase 1 diets[1]		Phase 2 diets[2]	
Ingredient, %	Simple	Complex	Simple	Complex
Corn	42.40	11.60	57.75	54.40
Soybean meal (46.5% CP)	35.90	13.25	36.70	26.50
Spray-dried animal plasma	---	6.00	---	---
Select menhaden fish meal	2.50	6.00	---	4.50
Spray-dried whey	10.00	25.00	---	10.00
Pulverized oat groats	---	30.00	---	---
Soybean oil	5.00	5.00	1.00	1.00
Monocalcium P (21% P)	1.45	0.20	1.60	0.75
Limestone	0.60	0.58	0.95	0.65
Salt	0.30	0.25	0.35	0.30
Zinc oxide	---	0.38	---	0.25
Vitamin premix	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15
L-Lysine HCl	0.33	0.20	0.30	0.30
DL-Methionine	0.20	0.17	0.14	0.15
L-Threonine	0.15	0.05	0.11	0.13
Neo-terramycin	0.70	0.70	0.70	0.70
Acidifier	---	0.20	---	---
Choline chloride	0.05	0.05	---	---
Total	100.00	100.00	100.00	100.00
Calculated analysis				
SID[3] Lysine, %	1.51	1.51	1.35	1.35
SID Lysine:ME ratio, g/Mcal	4.29	4.25	4.06	4.05
SID Isoleucine:lysine ratio, %	60	55	63	59
SID Leucine:lysine ratio, %	116	112	127	122
SID Methionine:lysine ratio, %	36	33	33	36
SID Met & Cys:lysine ratio, %	58	58	58	58
SID Threonine:lysine ratio, %	62	62	62	62
SID Tryptophan:lysine ratio, %	17	18	18	17
SID Valine:lysine ratio, %	65	68	69	66
ME, kcal/lb	1,596	1,613	1,508	1,513
CP, %	23.6	23.1	22.4	21.4
Total lysine, %	1.66	1.66	1.49	1.48
Ca, %	0.84	0.84	0.80	0.80
Available P, %	0.52	0.52	0.42	0.42
Lactose, %	7.2	18.0	---	7.2

[1] Supplemented without (Control) and with Luctarom at 1,500 ppm (3 lb/ton); diets in pellet form.
[2] Supplemented without (Control) and with Luctarom at 1,000 ppm (2 lb/ton); diets in meal form.
[3] Standardized ileal digestible.

Table 3. Sow performance (Exp. 1)[1,2]

	Enhanced Flavor			
Treatment	No	Yes	SED[3]	Probability, *P* <
No. of litters	25	24	---	---
Average parity	2.3	2.3	0.3	0.94
Lactation length, d	20.7	20.4	0.3	0.35
Sow weight, lb				
Postfarrowing	525.7	528.6	19.2	0.88
Weaning	505.9	501.2	18.8	0.80
Change	-19.8	-27.7	5.6	0.17
No. of pigs/litter				
Postfostering	11.1	11.1	0.3	0.98
d 18 (start creep)	10.3	10.2	0.3	0.74
d 21 (weaning)	10.3	10.1	0.4	0.50
Lactation feed intake, lb				
Total	269	264	13.3	0.68
ADFI	13.0	13.0	0.7	0.94

[1] Two groups of sows (total = 50, PIC 1050) were blocked according to day of farrowing and parity and allotted to 2 treatments.
[2] Creep feed with 1.0% chromium oxide supplemented without (No) and with Luctarom (Yes) at 1,500 ppm (3 lb/ton); offered ad libitum from d 18 to weaning (d 20).
[3] Standard error of the difference.

Table 4. Effects of adding an enhanced flavor to the creep feed on pig and litter performance (Exp. 1)[1,2]

	Enhanced Flavor			Probability,
Treatment	No	Yes	SED[3]	*P* <
No. of litters	25	24	---	---
Pig weights, lb				
Postfostering	3.22	3.23	0.08	0.91
d 18 (start creep)	12.40	12.72	0.48	0.51
d 21 (weaning)	14.32	14.66	0.53	0.53
Total gain (d 18 to 21), lb	1.92	1.93	0.11	0.89
Daily gain (d 18 to 21), lb	0.64	0.64	0.04	0.89
Litter weights, lb				
Postfostering	33.8	33.2	1.4	0.65
d 18 (start creep)	127.6	127.4	6.4	0.97
d 21 (weaning)	147.2	146.7	7.1	0.94
Total gain (d 18 to 21), lb	19.6	19.3	1.1	0.77
Daily gain (d 18 to 21), lb	6.53	6.43	0.35	0.77

[1] Two groups of sows (total = 50, PIC 1050) were blocked according to day of farrowing and parity and allotted to 2 treatments.
[2] Creep feed with 1.0% chromium oxide supplemented without (No) and with Luctarom (Yes) at 1,500 ppm (3 lb/ton); offered ad libitum from d 18 to weaning (d 20).
[3] Standard error of the difference.

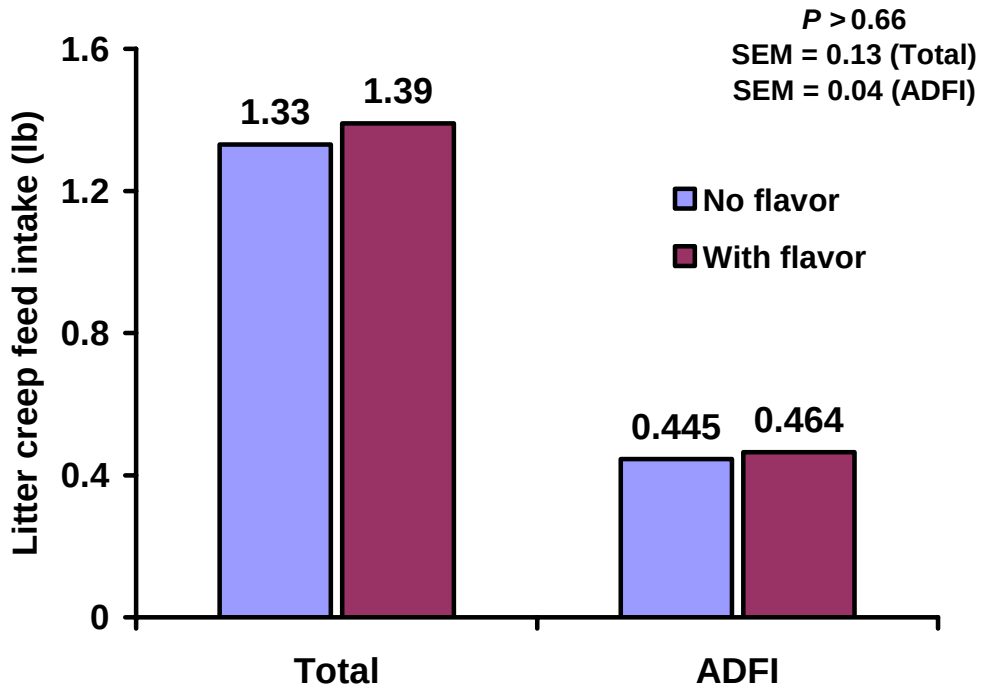

Figure 1. Total and daily creep feed intake of litters fed diets with and without an enhanced flavor.

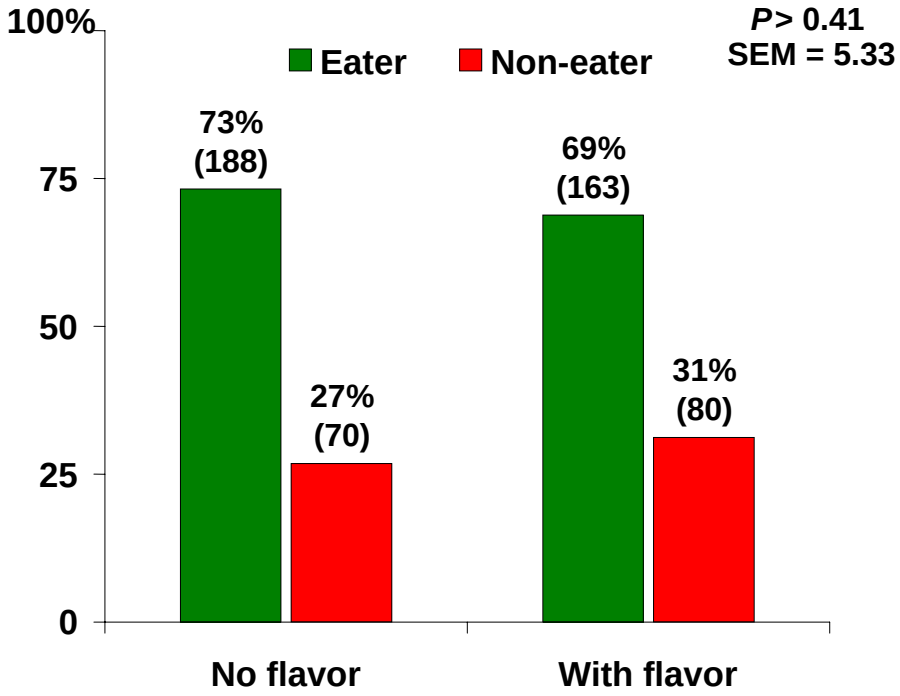

Figure 2. Effect of adding an enhanced flavor to the creep feed on the proportion of eaters in whole litters (no. of pigs in parentheses).

Table 5. Interactive effects of flavor in the creep diet, diet complexity, and flavor in the nursery diets on postweaning performance (Exp. 2)[1,2]

Flavor in creep	No				Yes					Probability, *P* <						
Diet complexity	Simple		Complex		Simple		Complex						Creep ×	Creep ×	Diet ×	Creep × Diet ×
Flavor in nursery	No	Yes	No	Yes	No	Yes	No	Yes	SED[3]	Creep	Diet	Nursery	Diet	Nursery	Nursery	Nursery
Pig weight, lb																
d 0	14.5	14.5	14.5	14.5	14.4	14.5	14.4	14.5	0.26	0.94	0.88	0.88	0.87	0.89	0.88	0.86
d 5	15.7	15.8	16.4	16.5	15.7	15.8	16.4	16.6	0.30	0.83	<0.0001	0.40	0.77	0.78	0.81	0.83
d 10	18.5	18.5	19.8	19.9	18.3	18.2	19.6	20.3	0.40	0.72	<0.0001	0.35	0.26	0.48	0.32	0.38
d 28	37.5	38.1	41.1	40.9	37.7	37.1	40.1	41.4	0.81	0.45	<0.0001	0.52	0.84	0.90	0.50	0.13
d 0 to 5																
ADG, lb	0.25	0.26	0.38	0.40	0.25	0.26	0.39	0.43	0.03	0.70	<0.0001	0.15	0.35	0.76	0.43	0.47
ADFI, lb	0.29	0.31	0.38	0.41	0.29	0.30	0.40	0.42	0.02	0.61	<0.0001	0.06	0.39	0.93	0.59	0.99
F/G	1.36	1.20	1.00	1.04	1.29	1.22	1.05	0.98	0.09	0.77	<0.0001	0.20	0.87	0.89	0.28	0.29
d 5 to 10																
ADG, lb	0.57	0.56	0.68	0.68	0.52	0.49	0.65	0.74	0.04	0.27	<0.0001	0.50	0.04	0.29	0.07	0.11
ADFI, lb	0.57	0.54	0.70	0.69	0.51	0.49	0.66	0.72	0.03	0.07	<0.0001	0.92	0.15	0.23	0.19	0.28
F/G	1.00	0.99	1.03	1.02	0.99	1.01	1.02	0.97	0.03	0.50	0.58	0.35	0.35	0.93	0.25	0.35
d 0 to 10																
ADG, lb	0.41	0.41	0.53	0.54	0.38	0.37	0.52	0.59	0.03	0.58	<0.0001	0.20	0.07	0.35	0.11	0.13
ADFI, lb	0.43	0.43	0.54	0.55	0.40	0.39	0.53	0.57	0.02	0.32	<0.0001	0.42	0.17	0.49	0.22	0.49
F/G	1.06	1.05	1.02	1.02	1.06	1.07	1.03	0.97	0.03	0.78	0.0008	0.35	0.27	0.49	0.23	0.13
d 10 to 28																
ADG, lb	1.06	1.09	1.18	1.16	1.08	1.05	1.14	1.17	0.03	0.57	<0.0001	0.96	0.80	0.90	0.99	0.09
ADFI, lb	1.42	1.43	1.66	1.62	1.41	1.40	1.58	1.63	0.05	0.32	<0.0001	0.88	0.81	0.50	0.94	0.27
F/G	1.34	1.32	1.40	1.40	1.30	1.34	1.38	1.40	0.03	0.44	<0.0001	0.65	0.87	0.14	0.90	0.48
d 0 to 28																
ADG, lb	0.82	0.84	0.95	0.94	0.83	0.81	0.92	0.96	0.03	0.48	<0.0001	0.63	0.68	0.74	0.57	0.06
ADFI, lb	1.07	1.07	1.26	1.25	1.05	1.05	1.21	1.26	0.04	0.29	<0.0001	0.72	0.90	0.43	0.80	0.27
F/G	1.29	1.27	1.32	1.32	1.26	1.29	1.31	1.30	0.02	0.40	0.004	0.93	0.53	0.30	0.77	0.24

[1] A total of 480 pigs (initial BW of 14.5 lb and 21 ± 2 d of age, PIC), with 6 pigs per pen and 10 replications per treatment.
[2] Diets provided without (No) and with (Yes) 1,500 and 1,000 ppm of Luctarom per ton of phase 1 (d 0 to 10) and phase 2 (d 10 to 28) diets, respectively.
[3] Standard error of the difference.

Table 6. Main effects of flavor in the creep diet, diet complexity, and flavor in the nursery diets on postweaning performance (Exp. 2)[1,2]

	Flavor in creep diet		Diet complexity		Flavor in nursery diets			Probability, $P <$						
	No	Yes	Simple	Complex	No	Yes	SED[3]	Creep	Diet	Nursery	Creep × Diet	Creep × Nursery	Diet × Nursery	Creep × Diet × Nursery
Pig weight, lb														
d 0	14.5	14.5	14.5	14.4	14.4	14.5	0.14	0.94	0.88	0.88	0.87	0.89	0.88	0.86
d 5	16.1	16.1	15.7	16.5	16.0	16.2	0.15	0.83	<0.0001	0.40	0.77	0.78	0.81	0.83
d 10	19.2	19.1	18.4	19.9	19.0	19.2	0.20	0.72	<0.0001	0.35	0.26	0.48	0.32	0.38
d 28	39.4	39.1	37.6	40.9	39.1	39.4	0.41	0.45	<0.0001	0.52	0.84	0.90	0.50	0.13
d 0 to 5														
ADG, lb	0.32	0.33	0.25	0.40	0.32	0.34	0.01	0.70	<0.0001	0.15	0.35	0.76	0.43	0.47
ADFI, lb	0.35	0.35	0.30	0.40	0.34	0.36	0.01	0.61	<0.0001	0.06	0.39	0.93	0.59	0.99
F/G	1.15	1.14	1.27	1.02	1.17	1.11	0.05	0.77	<0.0001	0.20	0.87	0.89	0.28	0.29
d 5 to 10														
ADG, lb	0.62	0.60	0.53	0.69	0.60	0.62	0.02	0.27	<0.0001	0.50	0.04	0.29	0.07	0.11
ADFI, lb	0.63	0.60	0.53	0.69	0.61	0.61	0.02	0.07	<0.0001	0.92	0.15	0.23	0.19	0.28
F/G	1.01	1.00	1.00	1.01	1.01	1.00	0.02	0.50	0.58	0.35	0.35	0.93	0.25	0.35
d 0 to 10														
ADG, lb	0.47	0.47	0.39	0.55	0.46	0.48	0.01	0.58	<0.0001	0.20	0.07	0.35	0.11	0.13
ADFI, lb	0.49	0.47	0.41	0.55	0.48	0.49	0.01	0.32	<0.0001	0.42	0.17	0.49	0.22	0.49
F/G	1.03	1.03	1.06	1.00	1.04	1.03	0.01	0.78	0.0008	0.35	0.27	0.49	0.23	0.13
d 10 to 28														
ADG, lb	1.12	1.11	1.07	1.16	1.11	1.11	0.02	0.57	<0.0001	0.96	0.80	0.90	0.99	0.09
ADFI, lb	1.53	1.51	1.41	1.62	1.52	1.52	0.03	0.32	<0.0001	0.88	0.81	0.50	0.94	0.27
F/G	1.37	1.35	1.32	1.40	1.36	1.36	0.01	0.44	<0.0001	0.65	0.87	0.14	0.90	0.48
d 0 to 28														
ADG, lb	0.89	0.88	0.83	0.94	0.88	0.89	0.01	0.48	<0.0001	0.63	0.68	0.74	0.57	0.06
ADFI, lb	1.16	1.14	1.06	1.24	1.15	1.15	0.02	0.29	<0.0001	0.72	0.90	0.43	0.80	0.27
F/G	1.30	1.29	1.28	1.31	1.30	1.29	0.01	0.40	0.004	0.93	0.53	0.30	0.77	0.24

[1] A total of 480 pigs (initial BW of 14.5 lb and 21 ± 2 d of age, PIC), with 6 pigs per pen and 10 replications per treatment.
[2] Diets provided without (No) and with (Yes) 1,500 and 1,000 ppm of Luctarom per ton of phase 1 (d 0 to 10) and phase 2 (d 10 to 28) diets, respectively.
[3] Standard error of the difference.

VALIDATION OF CONTROL DIETS FOR LACTOSE AND FISH MEAL REPLACEMENT STUDIES IN NURSERY PIGS

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Summary

The objective of this study was to develop and validate control test diets to be used for lactose and fish meal replacement studies in nursery pigs. A total of 180 nursery pigs (PIC, initially 16.6 lb and 28 ± 2 d of age) were blocked by initial weight and randomly allotted to 1 of the following 6 dietary treatments: (1) negative control (NC) diet based on corn-soybean meal, (2) NC + 10% food-grade whey, (3) NC + 10% feed-grade whey, (4) Diet 2 + 4.5% select menhaden fish meal, (5) Diet 2 + 2.25% select menhaden fish meal and 1.25% spray-dried blood cells, and (6) Diet 2 + synthetic amino acids. Diets 4 to 6 also contained 10% food-grade whey. Each treatment had 5 pigs per pen and 6 replications (pens). Diets were formulated to contain 1.37% standardized ileal digestible lysine and 1,495 kcal ME/lb and were fed in meal form. Newly-weaned pigs (21 ± 2 d of age) were fed a common segregated early weaning and transition diet for 7 days then fed the experimental phase 2 diets for 21 d. From d 0 to 7 and 0 to 14, pigs fed the diet containing 10% feed-grade whey tended to have greater ADG ($P < 0.07$) and heavier ($P < 0.08$) BW than pigs fed the negative control diet, with pigs fed the diet containing 10% food-grade whey being intermediate. Pigs fed the negative control diet with either added food- or feed-grade whey tended to have better ($P < 0.06$) F/G than pigs fed the phase 2 diet solely based on corn and soybean meal. Pigs fed phase 2 diets containing either 4.5% select menhaden fish meal or the combination of 2.25% select menhaden fish meal and 1.25% spray-dried blood cells tended to have greater ADG ($P < 0.07$) and BW ($P < 0.07$) than pigs fed the diet containing 10% food-grade whey. Pigs fed the diet with increased synthetic amino acids had similar ($P > 0.36$) ADG and BW compared with pigs fed the diet containing the same food-grade whey without specialty proteins but tended to have poorer ($P < 0.09$) F/G than pigs fed the diet containing food-grade whey during d 0 to 7. Overall (d 0 to 21), only numerical differences ($P > 0.15$) were observed in ADG, ADFI, F/G, and pig BW among the dietary treatments. More research is needed to evaluate the use of synthetic amino acids as a replacement for high quality protein ingredients in nursery diets. When reviewing data from previous studies, it is apparent that further development of the control diets for testing lactose and fish meal sources is needed so that the predicted response is consistent.

Key words: lactose, protein sources, synthetic amino acids, weanling pigs

Introduction

Success in feeding nursery pigs relies mainly on the proper selection and use of high

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quality feed ingredients. However, rising costs of typical feed ingredients used for starter diets has increased motivation to reduce cost, which many times can lead to using lower quality ingredients. Recent studies at Kansas State University (KSU) and observations in the field seem to indicate that lower quality feed ingredients are being utilized in nursery pig diets. Therefore, it is vital to assess potential protein and energy sources that can be used as effective substitutes for typical specialty feed ingredients without affecting nursery growth performance. However, to successfully determine potential alternatives, the formulation of the control diets for both lactose and fish meal replacement must be validated. Therefore, the objective of this study was to develop and validate control test diets to be used for studies investigating potential feed ingredients that can replace lactose and fish meal in nursery pig diets.

Procedures

A total of 180 nursery pigs (PIC, initially 16.6 lb and 28 ± 2 d of age) were used in a 21-d growth assay. Pigs were blocked by initial weight and randomly allotted to 1 of 6 experimental treatments in a randomized complete block design. Each treatment had 5 pigs per pen and 6 replications (pens). Each pen was 4 ft × 4 ft and contained a 4-hole self-feeder and 1 cup waterer to provide ad libitum access to feed and water. Pigs were housed at the KSU Segregated Early Weaning (SEW) Research Facility.

Initially, all pigs were fed a commercial SEW diet with a budget of 1 lb/pig followed by a commercial transition diet with a budget of 2.5 lb/pig for the first 7 d postweaning. Both diets were pelleted and based on KSU specifications. At d 7 postweaning (d 0 of the experiment), phase 2 diets (1 of the 6 experimental diets; Table 1) were fed to the pigs. The negative control diet was solely based on corn and soybean meal as the main energy and protein sources. For the lactose replacement controls, 10% feed-grade and food-grade whey from 2 different sources were added to the negative control diet at the expense of corn. Soybean meal content of these diets was maintained at the same level as in the negative control, with synthetic amino acids being altered to adjust diets to a constant lysine level. For the fish meal replacement controls, 4.5% select menhaden fish meal or a combination of 2.25% select menhaden fish meal and 1.25% spray-dried blood cells were added to the diet containing 10% food-grade whey to replace amino acids provided by soybean meal and corn. For the sixth dietary treatment, synthetic amino acids (L-lysine, DL-methionine, L-threonine, and L-valine) replaced the specialty protein sources in the fish meal replacement controls. All the experimental diets contained 1% soybean oil. Diets were formulated to contain 1.37% standardized ileal digestible (SID) lysine and 1,495 kcal ME/lb and were fed in meal form.

Pigs and feeders were weighed on d 0, 7, 14, and 21 to calculate ADG, ADFI, and F/G. Data were analyzed as a randomized complete block design by using the MIXED procedure of SAS with pen as experimental unit. Treatment means were separated by using the LSMEANS statement and the PDIFF option of SAS.

Results and Discussion

From d 0 to 7 of the study, pigs fed the diet containing 10% feed-grade whey tended to have greater ADG (17%; $P < 0.08$) and BW at d 7 (3.4%; $P < 0.07$) than pigs fed the negative control diet, with pigs fed the diet containing 10% food-grade whey being intermediate (Table 2). There were no differences ($P > 0.23$) in ADFI between pigs fed diets containing either of the 2 whey sources and the negative control diet. Pigs fed the negative control diet with either added food- or feed-grade whey had improved ($P < 0.04$) F/G compared with pigs fed the negative control diet solely based on corn and soybean meal. There were

no differences ($P > 0.40$) in F/G between the two whey sources.

For the fish meal replacement controls, pigs fed the diet containing 4.5% select menhaden fish meal tended to have greater ADG (16%; $P < 0.07$) and BW (3.3%; $P < 0.07$) at d 7 than pigs fed the diet containing 10% food-grade whey, with pigs fed the diet containing the combination of 2.25% select menhaden fish meal and 1.25% spray-dried blood cells being intermediate. The increase in ADG in pigs fed the diet containing select menhaden fish meal was due to a numerical improvement (8%; $P < 0.11$) in F/G. Pigs fed the diet with increased synthetic amino acids had similar ($P > 0.36$) ADG and BW but tended to have poorer ($P < 0.09$) F/G than pigs fed the diet containing food-grade whey. However, ADG, F/G, and BW at d 7 of pigs fed the diet with synthetic amino acids were lower ($P < 0.02$) than those of pigs fed the diets containing select menhaden fish meal and the fish meal-blood cells combination. There were no differences ($P > 0.53$) in ADFI across all the dietary treatments.

From d 7 to 14 and d 14 to 21, there were no differences ($P > 0.22$) in ADG, ADFI and F/G among the dietary treatments. Because of the improvements in performance from d 0 to 7, pigs fed the diet containing 10% feed-grade whey tended to have greater (15.4%; $P < 0.08$) ADG from d 0 to 14 and heavier (5.8%; $P < 0.08$) BW at d 14 than pigs fed the negative control diet, with pigs fed the diet containing 10% food-grade whey being intermediate. Pigs fed diets containing either of the 2 whey sources had a tendency for better (7 to 10%; $P < 0.06$) F/G than pigs fed the negative control diet. Likewise, feeding the diets containing 4.5% select menhaden fish meal or the combination of 2.25% select menhaden fish meal and 1.25% spray-dried blood cells to nursery pigs tended to have improved (16%; $P < 0.06$) ADG and increased (6.5%; $P < 0.06$) BW at d 14 compared with pigs fed the diet containing 10% food-grade whey. However, pigs fed the diet containing either of the specialty protein sources had similar ($P > 0.36$) F/G compared with pigs fed the diet containing food-grade whey. The difference in daily gains with pigs fed the diets containing either of the specialty protein sources was due to a slight increase (7 to 11%; $P > 0.13$) in ADFI. There were no differences ($P > 0.49$) in ADG, F/G, and BW at d 14 between pigs fed the diet containing select menhaden fish meal and those fed the fish meal-blood cells combination. Pigs fed the diet containing a high concentration of amino acids had similar ($P > 0.90$) ADG and BW at d 14 compared with pigs fed the diet containing food-grade whey; however, they were lower ($P < 0.05$) than pigs fed diets containing either of the specialty protein sources. Feed efficiency of pigs fed the diet containing synthetic amino acids was similar ($P > 0.26$) to that of pigs fed the diets containing food-grade whey or either of the specialty protein sources. No differences ($P > 0.25$) in ADFI were observed among dietary treatments.

Overall (d 0 to 21), pigs fed the diet containing 10% feed-grade whey had 8.4% greater ADG, 11.6% better F/G, and were 4.9% heavier at d 21 than pigs fed the negative control diet or the diet containing 10% food-grade whey; however, differences were not significant ($P > 0.15$). There were no differences ($P > 0.34$) in ADFI among the dietary treatments. The difference in performance between pigs fed diets containing food- and feed-grade whey, especially during the initial 2 weeks of the study, was in contrast with a previous trial in which pigs had a greater growth response with food-grade whey. This may be due to variations in the quality of whey regardless of the grade, not only between each type but also within sources. This also indicates that food-grade whey is not always higher quality than feed-grade whey. However, the improvements in growth rates and F/G are consistent with previous studies evaluating the effects of adding spray-dried whey in corn-soybean meal diets fed to nursery pigs.

Dried whey consistently improved growth performance in all of the studies in KSU Swine Day Reports of Progress from 1986 to 2008 in which the effects of spray-dried whey additions to phase 2 diets were measured (Table 3). Adding dried whey to the phase 2 diet numerically increased ADG in 24 of the 27 comparisons, and about 80% of these comparisons resulted in at least 5% improvement in daily gains. In the 15 comparisons in which 10% spray-dried whey was added to phase 2 diets, ADG improved by an average of 7.5% with smaller improvements in ADFI (2.7%) and F/G (-3.5%). However, the level of response to the addition of spray-dried whey also varied across and within studies. In a previous study in which 7 different sources of food-grade whey were compared, responses for ADG, ADFI, and F/G ranged from 4.6 to 18.5%, -1.2 to 11%, and -1.3 to -8.4%, respectively (Bergstrom et al., 2007). The variability in whey responses may be a result of differences in the type, source, or inherent variation in the quality of whey used in the diets. Whey is a by-product of the cheese industry, and the method of production and aggressiveness of drying may affect its biological value. Under high temperatures during the drying of whey, either lactose can form complexes with proteins or whey proteins become denatured. The aggressiveness of processing may also result in the loss of biologically active proteins such as immunoglobulins, which are the most heat sensitive.

For the fish meal replacement controls, pigs fed the diets containing 4.5% select menhaden fish meal or the combination of 2.25% select menhaden fish meal and 1.25% spray-dried blood cells had in numerical ($P > 0.15$) improvements in ADG (9.5%), and pig weights at d 21 (5.5%) compared with pigs fed the diet containing food-grade whey. Pigs fed the diet containing select menhaden fish meal also had slightly better (6%; $P > 0.19$) F/G. There were no differences ($P > 0.34$) in ADFI among the dietary treatments. Select menhaden fish meal is generally regarded as one of the highest quality animal protein sources used in the feed industry. However, responses to select menhaden fish meal in phase 2 diets have been inconsistent, which may reflect variations in quality (Table 4). Across 10 studies in which 4 to 5% select menhaden fish meal was added as a replacement for soybean meal, ADG, ADFI, and F/G were improved by an average of 3.9, 1.8, and 2.6%, respectively.

Spray-dried blood cells, a coproduct of animal plasma production, are another animal protein source commonly used in piglet diets. In 3 other studies, the addition of 2.5% spray-dried blood cells in phase 2 diets improved ADG and ADFI by an average of 10.8 and 4.1%, respectively (Table 5). The inclusion rate for spray-dried blood cells is limited because of low isoleucine content. Thus, a combination of select menhaden fish meal and spray-dried blood cells is often used in phase 2 diets.

Pigs fed the diet with increased synthetic amino acids had similar ($P > 0.80$) ADG, ADFI, and F/G compared with pigs fed the diet containing the same level of food-grade whey. This result is consistent with previous studies in which feeding high concentrations of synthetic amino acids to replace specialty protein sources in phase 2 diets containing dried whey failed to improve nursery growth performance (Table 6). It is speculated that either an essential amino acid other than those considered may be affecting amino acid balance or the required amino acid ratios for phase 2 pigs may have not been met. As reflected in the feed efficiency response, the addition of the specialty protein sources, such as select menhaden fish meal and spray-dried blood cells, to a diet based on soy and whey proteins may have met the animal's requirement more closely than the diet with increased synthetic amino acids. The use of high concentrations of synthetic amino acids to replace specialty protein sources in phase 2 diets did not improve nursery growth performance; therefore, more research is needed to evaluate

the use of synthetic amino acids as a replacement for high quality protein ingredients in nursery diets.

As evidenced by the differences in response between the feed- and food-grade whey exhibited in this study and the evaluation of responses in previous reports, it is important to use ingredients in the control test diets for both lactose and fish meal replacement that can result in a consistent response. It is apparent that further development of the control diets for testing alternative ingredients is needed so that consistency in the predicted response can be achieved.

Table 1. Diet composition (as-fed basis)

	Phase 2 diets[1,2]					
Ingredient, %	Negative Control	Food-grade whey	Feed-grade whey	SMFM + SDBC	SMFM	Synthetic amino acids
Corn	54.00	44.49	44.49	49.13	48.70	51.78
Soybean meal (46.5% CP)	40.02	40.01	40.01	32.21	32.13	32.17
Select menhaden fish meal	---	---	---	2.25	4.50	---
Spray-dried blood cells	---	---	---	1.25	---	---
Food-grade whey	---	10.00	---	10.00	10.00	10.00
Feed-grade whey	---	---	10.00	---	---	---
Soybean oil	1.00	1.00	1.00	1.00	1.00	1.00
Monocalcium phosphate (21% P)	1.90	1.55	1.55	1.30	1.03	1.60
Limestone	1.00	0.98	0.98	0.85	0.68	1.00
Salt	0.30	0.30	0.30	0.30	0.30	0.30
Zinc oxide	0.25	0.25	0.25	0.25	0.25	0.25
Vitamin premix with phytase	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
Neo-terramycin	0.70	0.70	0.70	0.70	0.70	0.70
L-lysine HCl	0.23	0.15	0.15	0.15	0.15	0.40
DL-methionine	0.12	0.12	0.12	0.14	0.11	0.20
L-threonine	0.09	0.05	0.05	0.08	0.06	0.16
L-valine	---	---	---	---	---	0.04
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis						
SID[3] amino acids						
Lysine, %	1.37	1.37	1.37	1.37	1.37	1.37
Lysine:ME, g/Mcal	4.16	4.17	4.17	4.16	4.14	4.17
Isoleucine:lysine, %	66	68	68	62	65	58
Leucine:lysine, %	131	131	131	133	129	117
Methionine:lysine, %	32	32	32	34	34	35
Met & Cys:lysine, %	58	58	58	58	58	58
Threonine:lysine, %	62	62	62	62	62	62
Tryptophan:lysine, %	19	20	20	19	18	17
Valine:lysine, %	71	72	72	74	71	65
Total Lysine, %	1.53	1.53	1.53	1.52	1.52	1.51
ME, kcal/lb	1,498	1,493	1,493	1,497	1,506	1,495
Protein, %	23.54	23.85	23.85	23.20	23.37	21.19
Ca, %	0.88	0.88	0.88	0.88	0.88	0.88
P, %	0.83	0.80	0.80	0.78	0.78	0.77
Available P, %	0.48	0.48	0.48	0.48	0.48	0.48

[1] Fed for 21 d with d 7 postweaning as d 0 of the experiment; diets were in meal form.
[2] SMFM = select menhaden fish meal, SDBC = spray-dried blood cells.
[3] Standardized ileal digestible.

Table 2. Effects of lactose and fish meal replacement control diets on growth performance of nursery pigs during Phase 2[1]

	Dietary treatment[2]							
Item	Negative control	Food-grade whey	Feed-grade whey	SMFM + SDBC	SMFM	Synthetic amino acids	SED	*P* <
no. of pens	6	6	6	6	6	6	---	---
d 0 to 7								
ADG, lb	0.60[a]	0.64[ab]	0.70[bc]	0.72[bc]	0.74[c]	0.59[a]	0.05	0.03
ADFI, lb	0.91	0.86	0.90	0.94	0.92	0.88	0.04	0.53
F/G	1.53[a]	1.37[b]	1.31[b]	1.32[b]	1.26[b]	1.50[a]	0.07	0.01
d 7 to 14								
ADG, lb	0.97	0.99	1.10	1.15	1.15	1.02	0.09	0.22
ADFI, lb	1.32	1.31	1.40	1.49	1.42	1.33	0.08	0.23
F/G	1.38	1.33	1.28	1.31	1.25	1.30	0.06	0.43
d 0 to 14								
ADG, lb	0.78[a]	0.81[ab]	0.90[bc]	0.94[c]	0.94[c]	0.81[ab]	0.06	0.05
ADFI, lb	1.12	1.09	1.15	1.21	1.17	1.10	0.06	0.25
F/G	1.43[a]	1.33[b]	1.29[b]	1.31[b]	1.29[b]	1.37[ab]	0.05	0.06
d 14 to 21								
ADG, lb	1.29	1.21	1.31	1.25	1.29	1.27	0.07	0.76
ADFI, lb	1.69	1.67	1.50	1.69	1.64	1.64	0.14	0.69
F/G	1.32	1.38	1.13	1.35	1.25	1.29	0.10	0.24
d 0 to 21								
ADG, lb	0.95	0.95	1.03	1.04	1.04	0.96	0.05	0.20
ADFI, lb	1.31	1.28	1.27	1.37	1.33	1.28	0.05	0.34
F/G	1.38	1.35	1.22	1.33	1.27	1.34	0.06	0.15
Pig weight, lb								
d 0	16.5	16.6	16.6	16.6	16.6	16.6	0.01	0.22
d 7	20.7[a]	21.0[ab]	21.4[bc]	21.6[bc]	21.7[c]	20.7[a]	0.37	0.03
d 14	27.5[a]	28.0[ab]	29.1[bc]	29.7[c]	29.8[c]	27.9[ab]	0.87	0.05
d 21	36.5	36.5	38.3	38.4	38.5	36.7	1.13	0.19

[1] A total of 180 pigs (PIC, initially 16.6 lb and 28 ± 2 d of age), with 5 pigs per pen and 6 replications per treatment; Experimental diets were fed for 21 d with d 7 postweaning as d 0 of the experiment.

[2] SMFM = Select menhaden fish meal, SDBC = Spray-dried blood cells.

[abc] Within a row, means without a common superscript letter differ ($P < 0.10$).

Table 3. Swine day studies (1985-2008) evaluating the effects of spray-dried whey in phase 2 diets on overall growth performance of nursery pigs[1,2]

		Response vs. pigs fed the control diet (%)			
Reference		BW	ADG	ADFI	F/G
Sulabo et al., 2008					
10% Feed-grade whey		4.9	8.4	-3.1	-11.6
10% Food-grade whey		0	0	-2.3	-2.2
Bergstrom et al., 2007; Exp. 1					
10% Feed-grade whey		-2.5	-7.6	-7.1	0
10% Food-grade whey		2.5	5.1	3.0	-3.2
Bergstrom et al., 2007; Exp. 2					
10% Whey source 1		6.1	18.5	6.0	-8.4
10% Whey source 2		1.5	4.6	-1.2	-3.1
10% Whey source 3		3.4	10.8	3.5	-4.6
10% Whey source 4		1.1	4.6	1.2	-1.3
10% Whey source 5		6.1	18.5	11.0	-3.8
10% Whey source 6		3.4	10.8	7.0	-2.3
10% Whey source 7		2.3	7.7	1.2	-3.8
DeRouchey et al., 2001					
12.5% Food-grade whey		---	1.9	-3.6	-5.7
25.0% Food-grade whey		---	19.2	18.2	-0.9
12.5% Granular whey		---	11.5	5.5	-5.7
25.0% Granular whey		---	7.7	9.1	0.9
Lee et al., 1998					
20%		---	9.3	3.7	-5.9
Goodband and Hines, 1986					
10%		---	7.1	8.1	1.3
20%		---	19.1	19.4	-1.3
Thaler et al., 1986; Exp. 1					
10% Food-grade whey		---	9.3	2.0	-4.8
20% Food-grade whey		---	11.6	6.1	-4.2
Thaler et al., 1986; Exp. 2					
5% Food-grade whey		---	9.3	7.6	-1.4
10% Food-grade whey		---	9.3	11.5	1.4
15% Food-grade whey		---	7.0	11.5	6.1
20% Food-grade whey		---	10.5	12.2	2.7
Stoner et al., 1985; Exp. 1					
20%		---	-2.5	-12.6	-3.8
Stoner et al., 1985; Exp. 2					
10%		---	5.8	0	-6.5
20%		---	8.1	8.3	-1.9
Level in the diet	n		Average response, %		
5.0%	1	---	9.3	7.6	-1.4
10.0%	15	2.6	7.5	2.7	-3.5
12.5%	2	---	6.7	1.0	-5.7
15.0%	1	---	7.0	11.5	6.1
20.0%	6	---	9.4	6.2	-2.4
25.0%	2	---	13.5	13.7	0

[1] Spray-dried whey was added at the expense of corn and soybean meal in the control diet. Control diet was a corn-soybean meal diet. Studies varied from 14- to 21-d growth assays.

[2] Response, % = (Treatment – Control)/Control. Average response = average of the responses across all studies at each inclusion level. n = number of comparisons.

Table 4. Swine day studies (1986-2008) evaluating the effects of select menhaden fish meal in phase 2 diets on overall growth performance of nursery pigs[1,2]

		Response vs. pigs fed the control diet (%)			
Reference		BW	ADG	ADFI	F/G
Sulabo et al., 2008					
4.5%		5.5	9.5	1.5	-11.0
Frantz et al., 2004					
4.5%		-1.1	-2.7	1.0	1.4
Keegan et al., 2003a					
2.5%		---	6.8	4.0	-3.5
5.0%		---	5.7	2.0	-3.5
Keegan et al., 2003b					
2.5%		---	6.0	0.9	-5.2
5.0%		---	6.6	2.7	-5.2
Lawrence et al., 2002					
4.5%		---	8.5	5.3	-4.4
Young et al., 2001					
2.5%		-0.2	-1.5	1.1	2.2
5.0%		3.8	7.6	9.0	1.5
Moser et al., 1998					
2.5%		---	-5.5	-2.3	3.1
5.0%		---	-10.1	-7.9	1.2
Lee et al., 1998					
4.0%		---	1.9	3.7	0
Woodworth et al., 1996					
4.0%		---	3.2	0	-3.9
Stoner et al., 1989					
8.0%		---	19.5	8.0	-9.7
Stoner et al., 1986					
4.0%		---	8.5	0.9	-2.2
8.0%		---	12.2	16.2	4.5
Level in the diet	n	Average response, %			
2.5%	4	-0.2	1.5	0.9	-0.9
4.0-5.0%	10	2.7	3.9	1.8	-2.6
8.0%	2	---	15.9	12.1	-2.6

[1] Select menhaden fish meal was added at the expense of soybean meal in the control diet. Treatment and control diets contained equal amounts of dried whey. Studies varied from 14- to 28-d growth assays.
[2] Response, % = (Treatment – Control)/Control. Average response = average of the responses across all studies at each inclusion level. n = number of comparisons.

Table 5. Swine day studies (1996-2002) evaluating the effects of spray-dried blood cells in phase 2 diets on overall growth performance of nursery pigs[1,2]

		Response vs. pigs fed the control diet (%)			
Reference		BW	ADG	ADFI	F/G
Lawrence et al., 2002					
2.5%		---	8.5	7.0	-1.5
DeRouchey et al., 2000					
2.5%		7.2	17.4	2.7	11.7
5.0%		5.1	13.0	-5.3	16.0
7.5%		6.8	19.6	-5.3	19.6
Lee et al., 1998					
2.0%		---	7.4	2.5	-4.6
Woodworth et al., 1996					
2.5%		---	6.5	2.5	-3.9
Level in the diet	n	Average response, %			
2.0%	1	---	7.4	2.5	-4.6
2.5%	3	7.2	10.8	4.1	2.1
5.0%	1	5.1	13.0	-5.3	16.0
7.5%	1	6.8	19.6	-5.3	19.6

[1] Spray-dried blood cells were added at the expense of soybean meal in the control diet. Treatment and control diets contained equal amounts of dried whey. All studies were 14-d growth assays.
[2] Response, % = (Treatment – Control)/Control. Average response = average of the responses across all studies at each inclusion level. n = number of comparisons.

Table 6. Swine day studies (1996-2008) evaluating the effects of adding synthetic amino acids in phase 2 diets on overall growth performance of nursery pigs[1,2]

	Response vs. pigs fed the control diet (%)			
Reference	BW	ADG	ADFI	F/G
Sulabo et al., 2008	0.5	1.1	-2.3	-2.9
Frantz et al., 2004	0.9	1.4	-1.0	2.1
Woodworth et al., 1996	-	-4.8	-3.8	1.6
Average response	0.7	-0.8	-2.4	0.3

[1] Synthetic amino acids were added to replace amino acids provided by specialty protein sources. Treatment and control diets contained equal amounts of dried whey. Studies varied from 10- to 21-d growth assays.
[2] Response, % = (Treatment – Control)/Control. Average response = average of the responses across all studies.

EFFECTS OF PEPSOYGEN AND DRIED PORCINE SOLUBLES 50 IN NURSERY PIG DIETS[1]

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Summary

Two experiments were conducted to evaluate the effects of dietary specialty protein source on weanling pig growth performance. In Exp. 1, 350 pigs (initially 13.4 lb) were used in a 35-d growth trial to compare the effects of fish meal, PepSoyGen, and dried porcine solubles (DPS 50) on weanling pig performance. Seven dietary treatments were fed: (1) negative control, (2) 3% fish meal, (3) 6% fish meal, (4) 3.75% PepSoyGen, (5) 7.50% PepSoyGen, (6) 1.88% PepSoyGen and 1.88% DPS 50, and (7) 3.75% PepSoyGen and 3.75% DPS 50. From d 0 to 14, pigs fed increasing PepSoyGen and PepSoyGen in combination with DPS 50 had improved (quadratic, P = 0.01, linear, P = 0.002, respectively) F/G. Average daily gain and F/G were improved (P = 0.05 and P = 0.03, respectively) for pigs fed diets containing PepSoyGen and DPS 50 combinations compared with pigs fed diets containing fish meal. Also, feeding the combination of PepSoyGen and DPS 50 improved ADG and ADFI (P = 0.01 and P = 0.02, respectively) compared with feeding only PepSoyGen. Overall (d 0 to 35), pigs fed increasing PepSoyGen from d 0 to 14 had improved F/G (quadratic, P = 0.03).

In Exp. 2, 252 pigs (initially 15.0 lb) were used to evaluate the effects of fish meal, PepSoyGen, and DPS 50 on nursery pig performance. A common pelleted starter diet was fed from weaning until the start of the experiment (d 7). Six dietary treatments were fed: (1) negative control, (2) 5% fish meal, (3) 3.5% DPS 50, (4) 6.0% PepSoyGen, (5) 1.75% PepSoyGen and 1.75% DPS 50, and (6) 3.0% PepSoyGen and 2.5% fish meal. During the treatment period (d 0 to 14), pigs fed DPS 50 alone or in combination with PepSoyGen had improved ADG and F/G (P < 0.05) compared with pigs fed all other diets. Overall (d 0 to 28), pigs fed DPS 50 from d 0 to 14 had improved ADG and F/G (P < 0.05) compared with pigs fed the control diet. Additionally, pigs fed DPS 50 had improved F/G (P < 0.05) compared with pigs fed PepSoyGen and fish meal in combination.

In conclusion, pigs fed DPS 50 alone or in combination with PepSoyGen had improved performance compared with pigs fed the control diet.

Key words: growth, nursery pig, protein sources

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[1] Appreciation is expressed to Nutra-Flo, Sioux City, IA, for providing the PepSoyGen and DPS 50 and for partial funding of the trials.

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

Introduction

Nursery pigs have relatively immature digestive systems at weaning, which limits their ability to utilize plant protein sources. However, newly weaned pigs absorb nearly two-thirds of dietary amino acids as peptides, or short amino acid chains. These peptides are absorbed nearly twice as fast as free amino acids. Therefore, supplying weaned pigs with protein containing higher levels of peptides or more highly digestible soy proteins should improve growth performance.

Research has indicated that pigs fed fermented rather than solvent-extracted soybean meal have improved nutrient digestibility. The fermentation process is thought to eliminate trypsin inhibitors and some oligosaccharides that may decrease pig performance. PepSoyGen (Nutra-Flo Company, Sioux City, IA) is a commercially available fermented soybean meal product.

Another possible protein source for nursery diets is DPS 50 (Nutra-Flo Company, Sioux City, IA), a coproduct of the heparin (a human pharmaceutical product) industry. DPS 50 is made from porcine intestinal mucosa and is thought to contain a high level of easily digestible peptides and amino acids. This protein source has previously been shown to improve growth performance of nursery pigs, possibly because the product supplies a high level of small peptides to assist in gut development.

Although the positive effects of DPS have been demonstrated in nursery pigs, less information is available on fermented soy products or the combined use of these protein products. Therefore, the objective of these experiments was to evaluate the effects of fish meal, PepSoyGen, and DPS 50 on growth performance of weanling pigs.

Procedures

All experimental procedures were approved by the Kansas State University (KSU) Animal Care and Use Committee. Protein sources were collected and analyzed for DM, CP, amino acids, Ca, and P (Table 1).

Experiment 1. A total of 350 pigs (initially 13.4 lb) were used in a 35-d growth trial to evaluate the effects of fish meal, PepSoyGen, and DPS 50 on weanling pig performance. Pigs were blocked by weight and allotted to 1 of 7 dietary treatments. There were 5 pigs per pen and 10 pens per treatment. Each pen (5 × 5 ft) contained a 4-hole dry self-feeder and 1 cup waterer to provide ad libitum access to feed and water. The study was conducted at the KSU Segregated Early Weaning Facility.

A common pelleted starter diet was fed from weaning until the start of the experiment (d 7). The 7 dietary treatments were (1) negative control, (2) 3% fish meal, (3) 6% fish meal, (4) 3.75% PepSoyGen, (5) 7.50% PepSoyGen, (6) 1.88% PepSoyGen and 1.88% DPS 50, and (7) 3.75% PepSoyGen and 3.75% DPS 50 (Table 2). Treatment diets 2, 4, and 6 were each formulated with 35.7% soybean meal; diets 3, 5, and 7 each had 29.8% soybean meal. Treatment diets were fed for 14 d; then, all pigs received a common phase 3 diet for 21 d. All diets were in meal form. Average daily gain, ADFI, and F/G were determined by weighing pigs and measuring feed disappearance on d 7, 14, 24, and 35 of the trial.

Experiment 2. A total of 252 pigs (initially 15.0 lb) were used in a 28-d growth trial to further evaluate the effects of fish meal, PepSoyGen, and DPS 50 on nursery pig performance. Pigs were blocked by weight and allotted to 1 of 6 dietary treatments. There were 6 pigs per pen and 7 pens per treatment.

Each pen contained 1 self-feeder and 1 nipple waterer to provide ad libitum access to feed and water. Pigs were housed in the KSU Swine Teaching and Research Center.

A common pelleted starter diet was fed from weaning until the start of the experiment. The 6 experimental treatments were (1) negative control, (2) 5% fish meal, (3) 3.5% DPS 50, (4) 6.0% PepSoyGen, (5) 1.75% PepSoyGen and 1.75% DPS 50, and (6) 3.0% PepSoyGen and 2.5% fish meal (Table 3). Treatments 2 through 6 were formulated to the same dietary soybean meal level (31.4%). Treatment diets were fed for 14 d; then, all pigs received a common phase 3 diet for 14 d. All diets were in meal form. Average daily gain, ADFI, and F/G were determined by weighing pigs and measuring feed disappearance on d 7, 14, 21, and 28 of the trial.

Statistical Analysis. Data were analyzed as a randomized complete block design with pen as the experimental unit. Data were analyzed with an analysis of variance by using the MIXED procedure of SAS with the weight block as a random effect and treatments as a fixed effect. Contrasts were used to determine the effects of protein source compared with the control.

Results and Discussion

Crude protein and amino acid analysis of the protein sources were consistent with the values supplied by the manufacturer that were used in diet formulation (Table 1).

Experiment 1. From d 0 to 14, pigs fed diets containing the lower (3%) level of fish meal had improved ADFI (quadratic, $P = 0.05$; Tables 4 and 5), leading to a tendency for improved (quadratic, $P = 0.08$) ADG compared with pigs fed the control diet. Pigs fed diets containing either 3 or 6% fish meal tended to have improved (linear, $P = 0.09$) F/G compared with pigs fed the control diet. Pigs fed diets containing 6% fish meal or PepSoyGen had ADG and ADFI similar ($P > 0.10$) to those of pigs fed the control diet. However, F/G was improved (quadratic, $P = 0.01$) for pigs fed diets containing PepSoyGen compared with pigs fed the control diet; the lower (3.75%) level of PepSoyGen was optimum. Pigs fed either diet with the combination of PepSoyGen and DPS 50 had improved F/G (linear, $P = 0.01$) and tended to have improved (linear, $P = 0.06$) ADG compared with pigs fed the control diet but had similar ($P > 0.10$) ADFI. Pigs fed diets containing PepSoyGen had ADF, ADFI, and F/G similar ($P > 0.10$) to those of pigs fed diets containing fish meal. Pigs fed diets containing the combination of PepSoyGen and DPS 50 had improved ADG and F/G ($P = 0.05$ and $P = 0.03$, respectively) compared with pigs fed diets containing fish meal but had similar ($P > 0.10$) ADFI. Pigs fed diets containing the combination of PepSoyGen and DPS 50 had improved ($P = 0.01$) ADG compared with pigs fed diets containing PepSoyGen without DPS 50, a direct result of improved ($P = 0.02$) ADFI. Thus, DPS 50 appears to stimulate feed intake and improve nursery pig growth rate compared with the other protein sources evaluated. There were no differences ($P > 0.10$) in F/G in pigs fed diets containing PepSoyGen alone or in combination with DPS 50.

During the common period (d 14 to 35), there were no changes ($P > 0.10$) in ADG, ADFI, or F/G for pigs previously fed fish meal, PepSoyGen, or the combination of PepSoyGen and DPS 50.

Overall (d 0 to 35), pigs fed diets containing PepSoyGen from d 0 to 14 had improved (quadratic, $P = 0.03$) F/G compared with pigs fed the control diet; feed efficiency was optimized at the lower (3.75%) level of

PepSoyGen. Moreover, pigs fed diets containing increasing amounts of PepSoyGen and DPS 50 in combination from d 0 to 14 tended to have improved F/G (linear, $P = 0.06$) compared with pigs fed the control diet. There were no other significant differences ($P > 0.10$) in ADG, ADFI, or F/G.

Experiment 2. During the treatment period (d 0 to 14), pigs fed diets containing DPS 50 alone or in combination with PepSoyGen had improved ($P < 0.05$) ADG and F/G compared with pigs fed all other diets (Table 6). Pigs fed diets containing fish meal, PepSoyGen, or the combination of PepSoyGen and fish meal had ADG similar ($P > 0.10$) to that of pigs fed the control diet. Pigs fed diets containing DPS 50 tended to have improved ($P < 0.10$) ADFI compared with pigs fed the control diet. No other differences in ADFI were seen ($P > 0.10$) among any other diets.

Overall (d 0 to 35), pigs fed diets containing DPS 50 from d 0 to 14 had improved ($P < 0.05$) ADG compared with pigs previously fed the control diet and tended to have improved ($P < 0.10$) ADG compared with pigs previously fed the diet containing PepSoyGen and fish meal in combination. There were no significant differences ($P > 0.10$) in ADFI. Pigs fed diets containing DPS 50 from d 0 to 14 had improved ($P < 0.05$) F/G from d 0 to 35 compared with pigs fed the control diet or the diet containing PepSoyGen and fish meal in combination from d 0 to 14. Pigs fed diets containing the combination of PepSoyGen and DPS 50 from d 0 to 14 tended to have improved ($P < 0.10$) overall F/G compared with pigs fed the control diet from d 0 to 14.

In conclusion, pigs fed DPS 50 alone or in combination with PepSoyGen had improved performance compared with those fed the control diet.

Table 1. Analyzed nutrient composition of ingredients (Exp. 1 & 2, as-fed basis)

	Fish meal		PepSoyGen[1]		DPS 50[2]	
Item	Formulated[3,4]	Analyzed[5]	Formulated[6]	Analyzed[5]	Formulated[6]	Analyzed[5]
CP, %	62.90	65.34	54.25	56.37	50.00	51.01
Amino acids, %						
Arginine	---	3.74	---	3.92	---	2.72
Histidine	---	1.35	---	1.45	---	1.06
Isoleucine	2.57	2.53	1.80	2.69	1.80	2.06
Leucine	4.54	4.46	3.40	4.55	3.40	3.94
Lysine	4.81	4.74	3.20	3.46	3.10	3.81
Methionine	1.77	1.71	0.71	0.80	0.90	0.96
Phenylalanine	---	2.55	---	3.12	---	2.23
Threonine	2.64	2.52	2.15	2.22	2.00	2.10
Tryptophan	0.66	0.59	0.49	0.75	0.35	0.25
Valine	3.03	2.96	2.32	2.83	2.40	2.60
Alanine	---	4.06	---	2.57	---	2.95
Cysteine	0.57	0.47	0.97	0.78	0.85	0.78
Glycine	---	4.82	---	2.47	---	3.65
Hydroxylysine	---	0.20	---	0.08	---	0.16
Hydroxyproline	---	0.99	---	0.00	---	0.71
Ornithine	---	0.08	---	0.08	---	0.32
Proline	---	2.94	---	2.98	---	2.83
Serine	---	2.19	---	2.55	---	1.86
Taurine	---	0.47	---	0.03	---	0.20
Tyrosine	---	1.99	---	2.18	---	1.86

[1] PepSoyGen (Nutra-Flo, Sioux City, IA).
[2] Dried porcine solubles 50 (Nutra-Flo, Sioux City, IA).
[3] Diets were prepared using formulated values.
[4] Nutrient values from NRC (1998).
[5] Mean value of 1 sample analyzed in duplicate.
[6] Nutrient values provided by the manufacturer.

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

		Fish meal		PepSoyGen[2]		PepSoyGen + DPS 50[3]		
Ingredient, %	Control	3%	6%	3.75%	7.50%	1.88% + 1.88%	3.75% + 3.75%	Common diet
Corn	45.46	48.26	50.73	46.96	48.13	46.98	48.13	61.28
Soybean meal (46.5% CP)	40.01	34.76	29.87	34.65	29.66	34.70	29.76	33.85
Select menhaden fish meal	---	3.00	6.00	---	---	---	---	---
PepSoyGen	---	---	---	3.75	7.50	1.88	3.75	---
DPS 50	---	---	---	---	---	1.88	3.75	---
Spray dried whey	10.00	10	10.00	10.00	10.00	10.00	10.00	---
Soybean oil	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Monocalcium P (21% P)	1.53	1.15	0.78	1.55	1.55	1.45	1.35	1.65
Limestone	0.98	0.80	0.60	1.00	1.03	1.05	1.13	0.95
Salt	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
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Lysine-HCl	0.15	0.15	0.15	0.19	0.23	0.19	0.23	0.30
DL-methionine	0.12	0.11	0.11	0.13	0.13	0.12	0.13	0.12
L-threonine	0.06	0.07	0.07	0.07	0.08	0.07	0.09	0.11
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis[4]								
Total amino acids, %								
Lysine	1.53	1.53	1.53	1.53	1.53	1.53	1.53	1.42
Isoleucine:lysine ratio	69	67	66	67	66	67	65	64
Leucine:lysine ratio	132	131	129	134	136	132	131	130
Methionine:lysine ratio	31	32	34	31	31	31	32	31
Met & Cys:lysine ratio	58	58	58	58	58	58	58	57
Threonine:lysine ratio	65	65	65	65	65	65	66	64
Tryptophan:lysine ratio	20	19	18	19	18	19	18	18
Valine:lysine ratio	75	74	73	73	72	73	72	71
CP, %	23.9	23.6	23.4	23.7	23.5	23.6	23.4	21.4
ME kcal/lb	1,508	1,517	1,526	1,507	1,507	1,511	1,514	1,518
Total lysine:ME ratio, g/Mcal	4.61	4.57	4.55	4.61	4.60	4.58	4.58	4.23
Ca, %	0.88	0.88	0.88	0.89	0.89	0.88	0.88	0.80
P, %	0.80	0.78	0.77	0.80	0.80	0.79	0.78	0.75
Available P, %	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.42

[1] Pigs were fed experimental diets from d 0 to 14 of the trial and a common diet from d 15 to 35 of the trial.
[2] PepSoyGen (Nutra-Flo, Sioux City, IA).
[3] Dried porcine solubles 50 (Nutra-Flo, Sioux City, IA).
[4] Nutrient values from NRC (1998) were used for fish meal, and nutrient values for PepSoyGen and DPS were provided by the manufacturer.

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

Ingredient, %	Control	Fish meal 5.0%	DPS 50[2] 3.5%	PepSoyGen[3] 6.0%	PepSoyGen + DPS 50 1.75% + 1.75%	PepSoyGen + Fish meal 3.0% + 2.5%
Corn	45.46	49.98	50.31	47.94	50.25	48.97
Soybean meal (46.5% CP)	40.01	31.42	31.38	31.40	31.40	31.39
Select menhaden fish meal	---	5.00	---	---	---	2.50
PepSoyGen	---	---	---	6.00	1.75	3.00
DPS 50	---	---	3.50	---	1.75	---
Spray dried whey	10.00	10.00	10.00	10.00	10.00	10.00
Soybean oil	1.00	1.00	1.00	1.00	1.00	1.00
Monocalcium P (21% P)	1.53	0.90	1.38	1.55	1.45	1.23
Limestone	0.98	0.68	1.13	0.98	1.08	0.83
Salt	0.30	0.30	0.30	0.30	0.30	0.30
Vitamin premix	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
Lysine-HCl	0.15	0.15	0.32	0.22	0.32	0.19
DL-methionine	0.12	0.11	0.16	0.14	0.17	0.13
L-threonine	0.06	0.07	0.13	0.08	0.13	0.08
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis[4]						
Total amino acids, %						
Lysine	1.53	1.53	1.53	1.53	1.53	1.53
Isoleucine:lysine ratio	69	6	62	66	62	66
Leucine:lysine ratio	132	130	123	135	125	132
Methionine:lysine ratio	31	33	33	32	33	33
Met & Cys:lysine ratio	58	58	58	58	58	58
Threonine:lysine ratio	65	65	65	65	65	65
Tryptophan:lysine ratio	20	19	17	18	17	18
Valine:lysine ratio	75	73	69	72	69	72
CP, %	23.9	23.5	22.3	23.5	22.4	23.5
ME, kcal/lb	1,508	1,523	1,515	1,508	1,512	1,515
Total lysine:ME ratio, g/Mcal	4.61	4.55	4.58	4.60	4.59	4.59
Ca, %	0.88	0.88	0.88	0.88	0.88	0.88
P, %	0.80	0.77	0.77	0.80	0.77	0.78
Available P, %	0.47	0.47	0.47	0.47	0.47	0.47

[1] Pigs were fed experimental diets from d 0 to 14 of the trial and a common diet from d 15 to 28 of the trial.
[2] Dried porcine solubles 50 (Nutra-Flo, Sioux City, IA).
[3] PepSoyGen (Nutra-Flo, Sioux City, IA).
[4] Nutrient values from NRC (1998) were used for fish meal, and nutrient values for PepSoyGen and DPS were provided by the manufacturer.

Table 4. Effects of fish meal, PepSoyGen, and DPS 50 on nursery pig performance (Exp. 1)[1]

	Negative	Fish meal		PepSoyGen		PepSoyGen[2] + DPS 50[3]	
Item	Control	3%	6%	3.75%	7.50%	1.88 + 1.88%	3.75% + 3.75%
d 0 to 14							
ADG, lb	0.58	0.63	0.56	0.57	0.58	0.65	0.65
ADFI, lb	0.76	0.79	0.69	0.70	0.73	0.77	0.78
F/G	1.33	1.26	1.26	1.21	1.27	1.20	1.20
d 14 to 35							
ADG, lb	1.29	1.31	1.28	1.28	1.31	1.26	1.32
ADFI, lb	1.91	1.94	1.87	1.85	1.93	1.89	1.93
F/G	1.48	1.48	1.47	1.45	1.48	1.50	1.47
d 0 to 35							
ADG, lb	1.00	1.04	0.98	0.99	1.01	1.01	1.05
ADFI, lb	1.45	1.48	1.39	1.39	1.44	1.44	1.47
F/G	1.44	1.43	1.42	1.39	1.43	1.43	1.40

[1] A total of 350 pigs (5 pigs per pen and 10 pens per treatment) with an initial BW of 13.1 lb. Pigs were fed a common diet from weaning until d 7 then fed experimental diets for 14 d.
[2] PepSoyGen (Nutra-Flo, Sioux City, IA).
[3] Dried porcine solubles 50 (Nutra-Flo, Sioux City, IA).

Table 5. Probability values for pigs fed fish meal, PepSoyGen, and DPS 50 on nursery pig performance (Exp. 1)[1,2,3]

	Probability, *P* <									
	Fish meal		PepSoyGen		Combination		Fish meal vs.		PepSoyGen vs.	
Item	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	PepSoyGen	Combination[4]	Combination	SE
d 0 to 14										
ADG, lb	0.71	0.08	1.00	0.89	0.06	0.32	0.45	0.05	0.01	0.042
ADFI, lb	0.08	0.05	0.39	0.14	0.69	0.90	0.24	0.24	0.02	0.049
F/G	0.09	0.37	0.16	0.01	0.01	0.06	0.47	0.03	0.13	0.030
d 14 to 35										
ADG, lb	0.74	0.45	0.77	0.52	0.60	0.24	0.84	0.78	0.93	0.055
ADFI, lb	0.52	0.38	0.83	0.17	0.77	0.53	0.63	0.94	0.58	0.082
F/G	0.70	0.77	0.99	0.19	0.70	0.16	0.55	0.49	0.20	0.019
d 0 to 35										
ADG, lb	0.58	0.17	0.91	0.73	0.24	0.70	0.73	0.46	0.28	0.049
ADFI, lb	0.22	0.14	0.86	0.19	0.67	0.67	0.55	0.56	0.24	0.069
F/G	0.29	0.83	0.55	0.03	0.06	0.82	0.15	0.26	0.86	0.016

[1] A total of 350 pigs (5 pigs per pen and 10 pens per treatment) with an initial BW of 13.1 lb. Pigs were fed a common diet from weaning until d 7 then fed experimental diets for 14 d.
[2] PepSoyGen (Nutra-Flo, Sioux City, IA).
[3] Dried porcine solubles 50 (Nutra-Flo, Sioux City, IA).
[4] 1.88% PepSoyGen + 1.88% DPS 50[4] and 3.75% PepSoyGen + 3.75% DPS 50.

Table 6. Effects of fish meal, PepSoyGen, and DPS 50 on nursery pig performance (Exp. 2)[1,2,3]

Item;	Negative Control	Fish meal 5.0%	DPS 50 3.5%	PepSoyGen 6.0%	PSG + DPS 50 1.75% + 1.75%	PSG + Fish meal 3.0% + 2.5%	SE
d 0 to 14							
ADG, lb	0.56[a]	0.59[a]	0.69[b]	0.59[a]	0.66[b]	0.56[a]	0.032
ADFI, lb	0.73[x]	0.78[xy]	0.81[y]	0.76[xy]	0.78[xy]	0.74[xy]	0.040
F/G	1.34[b]	1.34[b]	1.17[a]	1.28[b]	1.18[a]	1.32[b]	0.050
d 14 to 28							
ADG, lb	1.14[abxy]	1.18[abx]	1.17[abxy]	1.20[bxy]	1.10[ay]	1.19[bxy]	0.040
ADFI, lb	1.59	1.60	1.59	1.63	1.54	1.64	0.053
F/G	1.40	1.35	1.37	1.36	1.40	1.39	0.040
d 0 to 28							
ADG, lb	0.84[ay]	0.89[abxy]	0.93[bx]	0.90[abx]	0.88[abxy]	0.87[aby]	0.030
ADFI, lb	1.16	1.19	1.20	1.19	1.16	1.19	0.035
F/G	1.38[bx]	1.35[abxy]	1.29[axy]	1.33[abxy]	1.32[aby]	1.36[bxy]	0.032

[ab] Treatments without a common superscript letter differ $P < 0.05$.

[xy] Treatments without a common superscript letter differ $P < 0.10$.

[1] A total of 252 pigs (6 pigs per pen and 7 pens per treatment) with an initial BW of 15 lb. Pigs were fed a common diet from weaning until 15 lb then fed experimental diets for 14 d.

[2] Dried porcine solubles 50 (Nutra-Flo, Sioux City, IA).

[3] PepSoyGen (Nutra-Flo, Sioux City, IA).

EFFECTS OF COPPER SULFATE, TRI-BASIC COPPER CHLORIDE, AND ZINC OXIDE ON WEANLING PIG GROWTH AND PLASMA MINERAL CONCENTRATIONS[1]

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Summary

Two 28-d experiments were conducted to determine the effects of increasing dietary zinc and copper levels on weanling pig performance. In each experiment, 180 weanling pigs (PIC, 21 d of age, 12.5 lb in Exp. 1 and 13.2 lb in Exp. 2) were allotted to 1 of 6 treatments with 5 and 6 replications in Exp. 1 and 2, respectively. Diets were fed in 2 phases (d 0 to 14 and 14 to 28), and the trace mineral premix provided 165 ppm zinc and 16.5 ppm copper to all diets. In Exp. 1, treatments were arranged as a 2 × 3 factorial with 2 levels of added copper from tri-basic copper chloride (TBCC; 0 or 150 ppm) and 3 levels of added zinc from zinc oxide (0, 1,500, or 3,000 ppm from d 0 to 14 and 0, 1,000, or 2,000 ppm from d 14 to 28). In addition, blood collected on d 14 was analyzed for plasma zinc, copper, and phosphorus concentrations. No copper × zinc interactions were observed ($P > 0.25$) for any of the growth data. Addition of TBCC increased ($P < 0.03$) ADG and ADFI over control pigs from d 0 to 14, 14 to 28, and 0 to 28. Pigs fed increasing dietary zinc had increased (linear, $P < 0.003$) ADFI during both phases and increased ADG from d 0 to 14 and 0 to 28. No effects were observed for blood metabolites in plasma copper; however, copper × zinc interactions were observed ($P < 0.03$) for both plasma zinc and phosphorus. The interactions occurred because increasing dietary zinc oxide increased plasma zinc and phosphorus when TBCC was not included in the diet but had relatively little effect when TBCC was added to the diet.

In Exp. 2, treatments were arranged as a 2 × 3 factorial with 2 levels of added zinc from zinc oxide (0 or 3,000 ppm from d 0 to 14 and 0 or 2,000 from d 14 to 28) and 3 copper treatments (control, 125 ppm copper from TBCC, or 125 ppm copper from copper sulfate). In addition, blood collected on d 14 and 28 was analyzed for plasma zinc, copper, and phosphorus concentrations. Again, no copper × zinc interactions ($P > 0.10$) were observed for any performance data. Adding zinc oxide to the diet improved ($P < 0.03$) ADG, ADFI, and F/G from d 0 to 14 and ADG and ADFI from d 0 to 28. Adding copper to the diet increased ($P < 0.05$) ADG, ADFI, and F/G from d 0 to 14 and 0 to 28 with pigs fed copper sulfate having greater ($P < 0.02$) ADG and ADFI from d 0 to 14 than pigs fed TBCC. Similar to Exp. 1, plasma zinc was increased ($P < 0.001$) in pigs fed high levels of dietary zinc at d 14. Unlike many previous research trials, these two trials found additive effects to feeding high levels of dietary copper and zinc in diets for nursery pigs.

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Key words: copper, weanling pigs, zinc

Introduction

Zinc and copper are two minerals commonly added at pharmacological levels in weanling pig diets to serve as growth promoters. Nursery studies have demonstrated that increased dietary levels of zinc can promote growth rates and decrease diarrhea in weanling pigs. Typically, the greatest response to pharmacological levels of zinc is seen in the first 2 to 4 wk postweaning, and the most commonly used form is zinc oxide (ZnO). Dietary copper has also been shown to enhance growth rates in weanling pigs and growing pigs. Therefore, copper is typically added to late nursery and early grower diets; the most commonly used form is copper sulfate ($CuSO_4$). Research combining ZnO and $CuSO_4$ at high levels has shown growth rates similar to those when ZnO is used alone. Thus, early diets for nursery pigs often contain growth promoting levels of zinc without growth promoting levels of copper. Therefore, the objective of these trials was to characterize the effect of combining ZnO with a different copper source, tri-basic copper chloride (TBCC), as well as revaluate the response to utilizing both ZnO and $CuSO_4$ in weanling diets.

Procedures

The protocols used in these experiments were approved by the Kansas State University Institutional Animal Care and Use Committee. 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 per pig. Weights and feed disappearance were measured weekly to determine ADG, ADFI, and F/G.

Blood samples were collected from 2 pigs per pen (d 14 in Exp. 1 and d 14 and 28 in Exp. 2) by jugular venipuncture. Blood samples were chilled for approximately 1 h until they were centrifuged at 2,000 rpm 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, and phosphorus was measured by color spectrophotometry. Feed samples from both experiments were collected and analyzed for copper and zinc levels.

Pen was used as the experimental unit for all analyses in both experiments, and data were analyzed by using the PROC MIXED procedure in SAS.

Experiment 1. A total of 180 weanling pigs (initially 12.5 lb and 21 d of age) were used in a 28-d growth trial to compare the effects of supplemental zinc and copper from ZnO and TBCC, respectively. Pigs were allotted by initial BW in a completely randomized block design. There were 5 pens per treatment with 6 pigs per pen. Treatments were arranged as a 2 × 3 factorial with 2 levels of added copper from TBCC (0 or 150 ppm) and 3 levels of added zinc from ZnO (none, moderate, or high; 0, 1,500, or 3,000 ppm from d 0 to 14 and 0, 1,000, or 2,000 ppm from d 14 to 28). Diets were fed in 2 phases (d 0 to 14 and 14 to 28; Table 1). Phase 1 (d 0 to 14) and 2 (d 14 to 28) diets were fed in meal form and were formulated to contain 1.41 and 1.31% standardized ileal digestible (SID) lysine, respectively (Table 1). 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. Zinc oxide and TBCC were then supplemented by replacing corn starch to achieve the desired zinc and copper levels.

Experiment 2. Similar procedures and diets (Table 2) were utilized in experiment 2. A total of 180 weanling pigs (initially 13.2 lb and 21 d of age) were used in this 28-d growth trial. Pigs were allotted in a completely randomized block design with blocks by

weight and sex. There were 6 pens per treatment with 5 pigs per pen. Treatments were arranged as a 2 × 3 factorial with 2 levels of added zinc from ZnO (0 or 3,000 ppm from d 0 to 14 and 0 or 2,000 ppm from d 14 to 28) and 3 added copper sources (none, 125 ppm copper from TBCC, or 125 ppm copper from copper sulfate). All diets were supplemented with 165 ppm zinc and 16.5 ppm copper from the trace mineral premix.

Results and Discussion

Laboratory analysis of the diets indicated that nutrient levels were similar to those expected from diet formulation for Exp. 1 and 2 (Tables 3 and 4, respectively).

Experiment 1. No copper × zinc interactions (Table 5, $P > 0.25$) were observed for any of the performance criteria throughout the trial. An interaction was expected because previous research has found no response to added copper when high levels of ZnO are added to the diet. Similar to many earlier trials, ADG increased (linear, $P < 0.002$) as zinc concentration increased in the diet from d 0 to 14. The gain response was driven directly by increases in intake because ADFI increased (linear, $P < 0.003$) as dietary zinc was added. Dietary copper from TBCC also increased ($P < 0.02$) ADG and ADFI compared with non-copper-supplemented treatments. Dietary treatment did not influence F/G, which is in agreement with several previous trials. The greatest performance values were seen in treatments containing both high levels of zinc from ZnO and copper from TBCC.

From d 14 to 28, the addition of copper from TBCC continued to enhance ($P < 0.03$) both ADG and ADFI. Also, ADFI continued to increase (linear, $P < 0.002$) as dietary zinc increased. However, there was only a tendency ($P < 0.10$) for a change in ADG as dietary zinc increased. This agrees with other trials that showed the greatest response to zinc is typically found in the early phases postweaning.

Because of the responses during each phase, overall ADG and ADFI were improved ($P < 0.007$) for pigs supplemented with added copper from TBCC. Pigs fed TBCC weighed approximately 2.2 lb more on d 28 postweaning than pigs not supplemented with TBCC. Also, ADG and ADFI increased (linear, $P < 0.003$) as dietary zinc was added from ZnO. Again, pigs that received both added copper and a high level of zinc had the greatest gain and feed intake; no differences were observed in overall F/G.

From d 0 to 14, dietary treatments had no effect on feed cost per pound of gain, but income over feed cost (IOFC) increased as ZnO (linear, $P < 0.01$) and TBCC ($P < 0.02$) were added to the diet. Adding zinc to the diet increased ($P < 0.03$) feed cost per pound of gain from d 14 to 28 but also resulted in a linear increase ($P < 0.02$) in IFOC because of the increased growth rate of pigs fed high levels of ZnO. Adding TBCC to the diet tended ($P < 0.07$) to increase IOFC without changing feed cost per pound of gain. Overall, adding ZnO to the diet linearly increased ($P < 0.02$) feed cost per pound of gain. Despite the increase in feed cost per pound of gain, IOFC increased (linear, $P < 0.02$) as supplemental zinc was added. The response was due to the growth improvements from ZnO. Adding TBCC to the diet also increased ($P < 0.02$) IOFC by approximately $0.75/pig over pigs not supplemented with any added copper.

There were no treatment differences for plasma copper levels (Table 6). However, copper × zinc interactions were detected ($P < 0.03$) for both plasma zinc and phosphorus. The plasma zinc interaction occurred because a more dramatic increase in plasma zinc was seen in diets containing no supplemental copper when zinc level increased in the diet. The phosphorus interaction was due to plasma phosphorus increasing as dietary zinc

increased in diets without supplemental copper and plasma phosphorus decreasing as zinc was increased in diets receiving supplemental copper.

Experiment 2. No copper × zinc interactions were observed (Table 7, $P > 0.10$) for any of the growth criteria in this trial. From d 0 to 14, ADG, ADFI, and F/G were increased ($P < 0.03$) with zinc supplementation. Some studies have shown improvements in F/G with added zinc; however, most have shown gain responses related to increased ADFI. Pharmacological levels of copper also improved ($P < 0.02$) ADG, ADFI, and F/G, with copper sulfate improving ($P < 0.02$) ADG and ADFI more than TBCC.

From d 14 to 28, no differences were observed ($P > 0.10$) for ADG; however, numerical increases were observed for pigs fed either copper source. Daily feed intake increased ($P < 0.02$) in pigs supplemented with zinc. Added copper also improved ($P < 0.05$) F/G; copper sulfate improved ($P < 0.03$) and TBCC treatments tended to improve ($P < 0.06$) F/G compared with control treatments.

Over the entire 28-d trial, added zinc resulted in increases ($P < 0.02$) in ADG and ADFI. Copper supplementation also improved ($P < 0.05$) ADG, ADFI, and F/G. Copper sulfate increased ($P < 0.02$) ADG, ADFI, and F/G compared with the controls, and TBCC produced intermediate results that were numerically higher ($P < 0.07$) than controls in ADG and F/G.

Because of improvements in feed efficiency, zinc supplementation decreased ($P < 0.001$) feed cost per pound of gain from d 0 to 14. Copper sulfate also decreased ($P < 0.003$) feed cost per pound of gain compared with control pigs. Zinc and copper supplementation also increased ($P < 0.0001$) IOFC. From d 14 to 28, ZnO increased ($P < 0.02$) feed cost per pound of gain, which ultimately negated the lower cost during the first phase, resulting in no difference ($P > 0.67$) for the overall trial. However, both copper sources decreased ($P < 0.05$) feed cost per pound of gain. Copper sulfate increased ($P < 0.003$) IOFC for the entire 28-d trial. On average, copper sulfate and TBCC increased IOFC by \$1.43 and \$0.73/pig, respectively, compared with control pigs. Zinc supplementation also increased ($P < 0.06$) IOFC by approximately \$0.69/pig, with the entire benefit occurring during the first 14 d after weaning.

No dietary effects were observed (Table 8, $P > 0.41$) for plasma phosphorus at either bleeding time. Plasma zinc was increased ($P < 0.001$) on d 14 and tended ($P < 0.09$) to be higher at d 28 for pigs supplemented with ZnO. There was no effect seen for plasma copper on d 14, but a copper × zinc interaction was observed ($P < 0.02$) on d 28. In diets containing no added zinc, plasma copper increased when TBCC was added to the diet but decreased when copper sulfate was added to the diet. The opposite occurred in diets containing supplemental zinc; plasma copper decreased as TBCC was added to the diet and increased when copper sulfate was added.

Both trials showed additive responses to feeding pharmacological levels of copper and zinc to weanling pigs; in the second experiment, pigs had a greater response to copper sulfate than to TBCC. These findings are in contrast to previous research that did not find additive responses to added dietary copper and zinc. The reason we found additive responses is not clear. However, the majority of the early research used 250 ppm added dietary copper when testing for additive responses, whereas we used 125 and 150 ppm. More research is needed to determine the reasons for these additive effects and explain factors that influence the level of response to growth promoting levels of copper and zinc.

Table 1. Composition of diets in Exp. 1[1]

Item, %	Phase 1[2]	Phase 2[3]
Corn	48.75	60.75
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
Corn starch[4]	0.410	0.283
Total	100.00	100.00
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
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

[1] A total of 180 weanling pigs (PIC, initially 12.5 lb and 21 d of age) were used in a 28-d experiment.
[2] Pigs were fed phase 1 from d 0 to 14.
[3] Pigs were fed phase 2 from d 14 to 28.
[4] Corn starch was replaced with zinc oxide and tri-basic copper chloride to create treatment diets.
[5] SID = Standard ileal digestible (SID).

Table 2. Composition of diets in Exp. 2[1]

Item, %	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
Corn starch[4]	0.435	0.307
Total	100.00	100.00
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
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

[1] A total of 180 weanling pigs (PIC, initially 13.2 lb and 21 d of age) were used in a 28-d experiment.
[2] Pigs were fed phase 1 from d 0 to 14.
[3] Pigs were fed phase 2 from d 14 to 28.
[4] Corn starch was replaced with zinc oxide, copper sulfate, and/or tri-basic copper chloride to create treatment diets.
[5] SID = Standard ileal digestible (SID).

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

	Added copper[2]					
	No			Yes		
Added zinc[3]	None	Medium	High	None	Medium	High
Phase 1[4]						
CP, %	22.4	22.3	22.7	22.0	22.6	22.0
Zinc, ppm	212	1,472	2,519	190	1,431	2,831
Copper, ppm	23.2	22.4	23.6	196.1	169.8	191.0
Calcium, %	0.98	0.82	0.82	1.04	0.78	0.86
Phosphorus, %	0.75	0.83	0.84	0.82	0.83	0.87
Phase 2[5]						
CP, %	23.5	21.8	22.0	21.6	20.9	21.6
Zinc, ppm	217	1,201	1,993	427	840	1,713
Copper, ppm	26.0	19.3	62.7	124.2	137.1	169.1
Calcium, %	0.83	0.91	0.99	0.81	0.69	1.09
Phosphorus, %	0.76	0.77	0.89	0.77	0.71	0.82

[1] A total of 180 weanling pigs (PIC, initially 12.5 lb and 21 d of age) were used in a 28-d experiment.
[2] Added copper from tri-basic copper chloride was supplied at no (0 ppm) or yes (150 ppm) levels to the basal diet (16.5 ppm Cu).
[3] Added zinc from zinc oxide was supplied at none (0 ppm), medium (1,500 ppm in phase 1 and 1,000 in phase 2), or high (3,000 ppm in phase 1 and 2,000 in phase 2) levels to the basal diet (165 ppm Zn).
[4] Pigs were fed phase 1 from d 0 to 14.
[5] Pigs were fed phase 2 from d 14 to 28.

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

	Added zinc[2]					
	No			Yes		
Copper source[3]	None	TBCC	SO_4	None	TBCC	SO_4
Phase 1[4]						
CP, %	21.7	22.5	22.8	22.6	22.3	22.7
Zinc, ppm	286	183	197	2,798	2,721	2,599
Copper, ppm	28.4	152.3	149.4	27.3	156.4	140.9
Calcium, %	1.01	0.93	0.88	0.88	0.95	0.81
Phosphorus, %	0.85	0.82	0.85	0.82	0.83	0.80
Phase 2[5]						
CP, %	22.3	21.0	22.0	19.6	20.6	22.6
Zinc, ppm	183	229	176	2,360	1,897	1,930
Copper, ppm	24.6	177.9	188.1	47.6	140.1	144.2
Calcium, %	1.15	0.90	0.95	0.93	0.88	0.92
Phosphorus, %	0.81	0.78	0.88	0.77	0.78	0.81

[1] A total of 180 weanling pigs (PIC, initially 13.2 lb and 21 d of age) were used in a 28-d experiment.
[2] Added zinc from zinc oxide was supplied at no (0 ppm) or yes (3,000 ppm in phase 1 and 2,000 ppm in phase 2) levels to the basal diet (165 ppm Zn).
[3] Copper sources included none, tri-basic copper chloride (TBCC, 125 ppm) and copper sulfate (SO_4, 125ppm) and were supplemented to the basal diet (16.5 ppm Cu).
[4] Pigs were fed phase 1 from d 0 to 14.
[5] Pigs were fed phase 2 from d 14 to 28.

Table 5. Effects of dietary zinc oxide and tri-basic copper chloride on weanling pig performance and economics (Exp. 1)[1]

	Added copper[2]							*P* <				
	No			Yes				Zn ×			Zinc	
Added zinc[3]	None	Medium	High	None	Medium	High	SE	Cu	Cu	Zn	linear	quadratic
Initial wt (d 0), lb	12.4	12.5	12.5	12.5	12.5	12.5	0.76	0.45	0.29	0.40	0.26	0.45
d 0 to 14												
ADG, lb	0.35	0.40	0.50	0.47	0.45	0.53	0.04	0.30	0.02	0.004	0.002	0.18
ADFI, lb	0.44	0.48	0.61	0.56	0.57	0.62	0.04	0.26	0.02	0.006	0.003	0.29
F/G	1.28	1.27	1.22	1.21	1.27	1.18	0.06	0.74	0.30	0.38	0.37	0.28
Feed cost/lb gain, $[4]	0.286	0.286	0.278	0.270	0.286	0.269	0.013	0.75	0.36	0.51	0.69	0.28
IOMFC, $/pig[4,5]	1.55	1.81	2.26	2.17	2.00	2.44	0.233	0.32	0.02	0.02	0.01	0.17
d 14 to 28												
ADG, lb	1.05	1.10	1.16	1.15	1.16	1.22	0.06	0.78	0.03	0.10	0.04	0.68
ADFI, lb	1.48	1.54	1.66	1.61	1.64	1.75	0.08	0.87	0.01	0.005	0.002	0.32
F/G	1.42	1.39	1.44	1.40	1.41	1.44	0.02	0.72	0.94	0.24	0.19	0.29
Feed cost/lb gain, $	0.181	0.180	0.187	0.180	0.183	0.189	0.003	0.73	0.60	0.03	0.16	0.84
IOMFC, $/pig	6.15	6.47	6.69	6.79	6.75	7.00	0.336	0.75	0.07	0.36	0.02	0.29
d 0 to 28												
ADG, lb	0.70	0.75	0.83	0.81	0.80	0.87	0.05	0.38	0.007	0.008	0.003	0.34
ADFI, lb	0.96	1.01	1.14	1.09	1.10	1.18	0.06	0.43	0.005	0.002	0.001	0.26
F/G	1.38	1.35	1.37	1.34	1.37	1.36	0.02	0.29	0.49	0.94	0.76	0.86
Feed cost/lb gain, $	0.206	0.205	0.214	0.205	0.212	0.213	0.003	0.41	0.49	0.04	0.02	0.41
IOMFC, $/pig	7.69	8.28	8.95	8.96	8.75	9.45	0.511	0.43	0.02	0.05	0.02	0.60
Final wt (d 28), lb	31.9	33.4	35.7	35.1	35.0	37.5	1.87	0.61	0.006	0.006	0.003	0.29

[1] A total of 180 weanling pigs (PIC, initially 12.5 lb and 21 d of age) were used in a 28-d experiment.
[2] Added copper from tri-basic copper chloride was supplied at no (0 ppm) or yes (150 ppm) levels to the basal diet (16.5 ppm Cu).
[3] Added zinc from zinc oxide was supplied at none (0 ppm), medium (1,500 ppm from d 0 to 14 and 1,000 from d 14 to 28), or high (3,000 ppm from d 0 to 14 and 2,000 from d 14 to 28) levels to the basal diet (165 ppm Zn).
[4] Feed costs were based on corn at $5.00/bu, soybean meal at $350/ton, TBCC at $300/cwt and ZnO at $121.87/cwt.
[5] IOFC = Income over marginal feed costs (weight gain × $0.60/lb - feed cost).

Table 6. Effects of dietary zinc oxide and tri-basic copper chloride on plasma mineral levels in weanling pigs (Exp. 1)[1]

	Added copper[2]							*P* <				
	No			Yes							Zinc	
Added zinc[3]	None	Medium	High	None	Medium	High	SE	Zn × Cu	Cu	Zn	linear	quadratic
Plasma concentrations[4]												
Copper, µg/mL	1.88	1.88	1.81	1.81	1.98	1.89	0.10	0.58	0.63	0.57	0.97	0.30
Zinc, µg/mL	0.64	0.77	1.08	0.81	0.81	0.93	0.06	0.03	0.68	0.001	0.001	0.14
Phosphorus, mg/mL	0.070	0.083	0.085	0.081	0.080	0.077	0.002	0.003	0.95	0.05	0.03	0.21

[1] A total of 180 weanling pigs (PIC, initially 12.5 lb and 21 d of age) were used in a 28-d experiment.
[2] Added copper from tri-basic copper chloride was supplied at no (0 ppm) or yes (150 ppm) levels to the basal diet (16.5 ppm Cu).
[3] Added zinc from zinc oxide was supplied at none (0 ppm), medium (1,500 ppm from d 0 to 14 and 1,000 from d 14 to 28), or high (3,000 ppm from d 0 to 14 and 2,000 from d 14 to 28) levels to the basal diet (165ppm Zn).
[4] Plasma was collected on d 14 from 2 pigs per pen.

Table 7. Effects of zinc oxide, tri-basic copper chloride, and copper sulfate on weanling pig performance and economics (Exp. 2)[1]

	Added zinc[2]							*P* <					
	No			Yes							Copper source effects		
								Zn ×			None vs.		SO_4 vs.
Copper source[3]	None	TBCC	SO_4	None	TBCC	SO_4	SE	Cu	Zn	Cu	SO_4	TBCC	TBCC
Initial wt (d 0), lb	13.2	13.2	13.2	13.2	13.2	13.2	0.7	0.89	0.94	0.95	0.78	0.78	0.99
d 0 to 14													
ADG, lb	0.33	0.37	0.46	0.45	0.46	0.57	0.04	0.87	0.001	0.002	0.001	0.49	0.004
ADFI, lb	0.47	0.48	0.55	0.52	0.54	0.62	0.04	0.95	0.03	0.02	0.008	0.78	0.02
F/G	1.46	1.30	1.22	1.16	1.18	1.10	0.05	0.10	0.001	0.01	0.003	0.12	0.10
Feed cost/lb gain, $[4]	0.325	0.290	0.272	0.236	0.267	0.249	0.010	0.10	0.001	0.01	0.003	0.13	0.09
IOMFC, $/pig[4,5]	1.29	1.61	2.14	2.13	2.14	2.84	0.223	0.73	0.001	0.01	0.001	0.41	0.001
d 14 to 28													
ADG, lb	0.98	1.04	1.03	0.97	1.07	1.09	0.05	0.75	0.40	0.11	0.06	0.08	0.88
ADFI, lb	1.57	1.62	1.54	1.61	1.69	1.74	0.06	0.22	0.02	0.47	0.37	0.25	0.79
F/G	1.63	1.56	1.49	1.69	1.57	1.60	0.05	0.62	0.13	0.05	0.03	0.06	0.65
Feed cost/lb gain, $	0.208	0.200	0.191	0.220	0.206	0.209	0.006	0.63	0.02	0.08	0.03	0.08	0.65
IOMFC, $/pig	5.39	5.81	5.90	5.20	5.92	5.99	0.329	0.88	0.99	0.10	0.05	0.09	0.80
d 0 to 28													
ADG, lb	0.64	0.70	0.75	0.71	0.77	0.83	0.04	0.93	0.02	0.01	0.002	0.07	0.11
ADFI, lb	0.99	1.05	1.04	1.06	1.11	1.18	0.05	0.47	0.004	0.05	0.02	0.13	0.33
F/G	1.58	1.49	1.41	1.51	1.45	1.42	0.04	0.56	0.38	0.01	0.003	0.07	0.16
Feed cost/lb gain, $	0.236	0.223	0.215	0.233	0.224	0.223	0.005	0.61	0.68	0.02	0.005	0.05	0.37
IOMFC, $/pig	6.68	7.42	8.05	7.33	8.06	8.82	0.484	0.99	0.06	0.01	0.003	0.10	0.12
Final wt (d 28), lb	31.8	32.9	34.0	33.3	34.6	36.5	1.5	0.85	0.02	0.03	0.01	0.22	0.11

[1] A total of 180 weanling pigs (PIC, initially 13.2 lb and 21 d of age) were used in a 28-d experiment.
[2] Added zinc from zinc oxide was supplied at no (0 ppm) or yes (3,000 ppm from d 0 to 14 and 2,000 from d 14 to 28) levels to the basal diet (165 ppm Zn).
[3] Copper sources included none, tri-basic copper chloride (TBCC, 125 ppm Cu), and copper sulfate (SO_4, 125 ppm Cu).
[4] Feed costs were based on corn at $5.00/bu, 46.5% soybean meal at $350/ton, TBCC at $3.00/lb, copper sulfate at $1.19/lb, and zinc oxide at $1.22/lb.
[5] IOFC = Income over marginal feed costs (weight gain × $0.60/lb - feed cost).

Table 8. Effects of dietary zinc oxide, tri-basic copper chloride, and copper sulfate on weanling pig plasma mineral levels (Exp. 2)[1]

	Added zinc[2]							*P* <					
	No			Yes							Copper source effects		
											None vs.		
Copper source[3]	None	TBCC	SO_4	None	TBCC	SO_4	SE	Zn × Cu	Zn	Cu	SO_4	TBCC	SO_4 vs. TBCC
Plasma concentrations[4]													
d 14													
Copper, µg/mL	1.73	1.68	1.47	1.66	1.60	1.61	0.072	0.26	0.99	0.12	0.05	0.49	0.18
Zinc, µg/mL	0.68	0.63	0.60	1.11	1.12	1.21	0.059	0.31	0.001	0.88	0.84	0.77	0.62
Phosphorus, mg/mL	0.064	0.063	0.063	0.061	0.063	0.065	0.002	0.67	0.82	0.69	0.42	0.87	0.52
d 28													
Copper, µg/mL	1.78	1.88	1.56	1.75	1.61	1.82	0.085	0.02	0.86	0.71	0.42	0.83	0.56
Zinc, µg/mL	0.87	0.89	0.87	0.90	0.95	0.96	0.040	0.72	0.09	0.69	0.50	0.42	0.90
Phosphorus, mg/mL	0.074	0.073	0.073	0.072	0.075	0.070	0.002	0.48	0.42	0.52	0.48	0.68	0.26

[1] A total of 180 weanling pigs (PIC, initially 13.2 lb and 21 d of age) were used in a 28-d experiment.
[2] Added zinc from zinc oxide was supplied at no (0 ppm) or yes (3,000 ppm from d 0 to 14 and 2,000 from d 14 to 28) levels to the basal diet (165 ppm Zn).
[3] Copper sources included none, tri-basic copper chloride (TBCC, 125 ppm copper), and copper sulfate (SO_4, 125 ppm copper).
[4] Plasma was collected on d 14 and 28 from the same two pigs in each pen.

INFLUENCE OF ANTIMICROBIAL SEQUENCE IN THE NURSERY ON PIG PERFORMANCE AND ECONOMIC RETURN[1]

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Summary

A total of 1,008 pigs (11.9 lb and 19 d of age) were used in a 42-d experiment to determine the influence of antibiotic regimen on growth performance and economic return. From d 0 to 10, pigs were fed diets containing either no antibiotic or Denagard at 35 g/ton and chlortetracycline at 400 g/ton (Denagard/CTC). From d 10 to 21, diets contained no medication, Denagard/CTC, Mecadox at 25 g/ton and Oxytetracycline at 400 g/ton, or Mecadox at 50 g/ton. From d 21 to 42, diets contained either no medication or Denagard/CTC. Adding Denagard/CTC to the diet from d 0 to 10 improved ($P < 0.01$) ADG, F/G, and margin over feed cost (MOFC). Adding antibiotics to the diet from d 10 to 21 improved ($P < 0.01$) ADG, ADFI, F/G, and MOFC. There were no differences between pigs fed diets containing Mecadox at 25 g/ton in combination with Oxytetracycline and pigs fed diets containing Mecadox at 50 g/ton. Pigs fed diets containing Denagard CTC tended ($P < 0.09$) to have greater ADG than pigs fed either diet containing Mecadox and tended ($P < 0.07$) to have improved F/G and MOFC than pigs fed diets containing Mecadox at 50 g/ton. Adding Denagard/CTC to the diet from d 21 to 42 improved ($P < 0.05$) ADG, ADFI, and F/G. Denagard/CTC also improved ($P < 0.01$) MOFC when gain was valued at $1.00/lb of gain. For the overall trial, adding antibiotics to the diet during any phase improved ($P < 0.05$) ADG. Overall feed efficiency was improved when antibiotics were added to the diet from d 0 to 10 and 21 to 42. Overall feed cost per pig was increased ($P < 0.01$) by the addition of antibiotics to the diet; however, the improvement in ADG resulted in no change in overall feed cost per pound of gain ($P > 0.49$). Overall, MOFC was increased when antibiotics were added to the diet from d 0 to 10 and d 10 to 21 when gain was valued at $0.50 or $1.00/lb and tended to increase ($P < 0.06$) when Denagard/CTC was added to the diet from d 21 to 42 when the extra gain was valued at $1.00/lb. These results demonstrate that adding antibiotics to the nursery diet improved pig performance and economical return on this commercial farm.

Key words: antimicrobial, nursery pig

Introduction

Past research has continually demonstrated that including antibiotics in nursery pig diets improves pig growth performance. The greatest response is normally through an increase in feed intake, which increases daily gain. Although the benefit of including feed-grade

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antibiotics in the nursery stage is well documented, many production systems don't always include antibiotics in all of the nursery phases. The main reason for not including antibiotics in all the diets is to provide a period of time where oral vaccines can be administered. This trial was conducted to help determine the economic effect of removing the antibiotics from the diet.

A second purpose of this trial was to compare the growth and economic response of some of the antibiotic regimens that are commonly used in the commercial swine industry.

Procedures

A total of 1,008 pigs (19 d of age) were used in a 42-d experiment. Pigs were from a PRRSv positive, but stable, sow farm. 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); 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 8 treatment groups (126 pigs per treatment; 1,008 pigs total); each treatment group consisted of 6 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.

For the dietary antibiotic regimens, pigs were fed diets containing either no antibiotic or Denagard at 35 g/ton and chlortetracycline at 400 g/ton (Denagard/CTC) from d 0 to 10 (Table 2). From d 10 to 21, diets contained no medication, Denagard/CTC, Mecadox at 25 g/ton and Oxytetracycline at 400 g/ton, or Mecadox at 50 g/ton. From d 21 to 42, diets contained either no medication or Denagard/CTC.

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). Carbadox levels in the diet were slightly lower than expected.

All pigs were weighed on d 0, 10, 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. Margin over feed cost (MOFC) was calculated as pound of gain × the value of the gain minus feed cost per pig. Two different values of gain ($0.50 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.

Data were analyzed by using the MIXED procedure of SAS 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 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 sources of antibiotic during phase 2.

Results

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 indicated that antibiotic levels in the feed were slightly lower than target levels for all antibiotic treatments (Table 3).

Adding Denagard/CTC to the diet from d 0 to 10 improved ($P < 0.01$) ADG, F/G and MOFC (Tables 4, 5, and 6). Feed cost per pig was increased ($P < 0.04$); however, the extra gain was great enough that feed cost per pound of gain was reduced ($P < 0.04$). Including Denagard/CTC in the diet from d 0 to 10 after weaning resulted in 0.83 lb more gain per pig and a net increase in MOFC of $0.22/pig when gain was valued at $0.50/lb and $0.62/pig when the value of gain was increased to $1.00/lb.

Adding antibiotics to the diet from d 10 to 21 improved ($P < 0.01$) ADG, ADFI, F/G, and MOFC. Similar to the results from d 0 to 10, adding antibiotics to the diets increased ($P < 0.01$) feed cost per pig, but the growth response was great enough to result in lower ($P < 0.01$) feed cost per pound of gain. Either treatment containing Mecadox improved ADG, ADFI, F/G, feed cost per pound of gain, and MOFC. There were no differences between pigs fed diets containing Mecadox at 25 g/ton in combination with Oxytetracycline and pigs fed diets containing Mecadox at 50 g/ton. Pigs fed diets containing Denagard/CTC tended ($P < 0.09$) to have greater ADG than pigs fed either diet containing Mecadox and tended ($P < 0.07$) to have improved F/G and MOFC compared with pigs fed diets containing Mecadox at 50 g/ton. On average, adding Denagard/CTC to the diet increased pig weight 2.1 lb and MOFC $0.64 and $1.69 with the value of gain at $0.50 and $1.00/lb, respectively, compared with the control. The two diets containing Mecadox had a similar MOFC advantage over the control at $0.38 to 0.43/pig when gain was valued at $0.50/lb and $1.03 to $1.15/pig when gain was valued at $1.00/lb.

Adding Denagard/CTC to the diet from d 21 to 42 improved ADG ($P < 0.01$), ADFI ($P < 0.03$), and F/G ($P < 0.05$). Feed cost per pig increased ($P < 0.01$) with the addition of Denagard/CTC to the diet. The response in MOFC depended on the value assigned to the extra gain (2.2 lb/pig) created by the Denagard/CTC. When gain was valued at $0.50/lb of gain (MOFC 1), margin was numerically ($0.26/pig) but not significantly influenced ($P = 0.16$) by Denagard/CTC inclusion in the diet. When gain was valued at $1.00/lb of gain, however, MOFC increased ($P < 0.01$; $1.32) when Denagard/CTC was added to the diet from d 21 to 42. Many production systems remove antibiotics from the feed during this time period to prevent interference with oral vaccines that are added to the drinking water. The negative impact of removing antibiotics from the diet on pig performance and margin over feed should be considered when evaluating vaccine strategies.

For the overall trial, adding antibiotics to the diet from d 0 to 10, 10 to 21, and 21 to 42 improved ($P < 0.05$) ADG. Overall feed efficiency was improved when antibiotics were added to the diet from d 0 to 10 and 21 to 42. Overall feed cost per pig was increased ($P < 0.01$) by the addition of antibiotics to the diet; however, the improvement in ADG resulted in no change in overall feed cost per pound of gain ($P > 0.49$). Overall MOFC was increased when antibiotics were added to the diet from d 0 to 10 and 10 to 21 regardless of the value assigned to the gain. Overall MOFC also tended to increase ($P < 0.06$) when Denagard/

CTC was added to the diet from d 21 to 42 when the extra gain was valued at $1.00/lb but was not increased (P = 0.21) when the gain was valued at $0.50/lb. These results demonstrate that adding antibiotics to the nursery diet improved pig performance and economical return on this commercial farm.

Table 1. Composition of control diets

Ingredient, %	Phase 1	Phase 2	Phase 3
Corn[1]	46.87	51.99	53.85
Soybean meal (46.5% CP)	20.00	27.50	26.89
Lactose replacement	23.33	10.00	---
Spray-dried animal plasma	3.67	---	---
Dried distillers grains with solubles	0.00	5.00	15.00
Fat, AV blend	1.45	1.50	1.48
Limestone	0.92	0.92	1.04
Monocalcium P, 21% P	1.04	1.00	0.43
Salt	.39	.39	.45
L-lysine HCl	0.766	0.582	0.400
DL-methionine	0.361	0.228	0.074
L-threonine	0.305	0.197	0.064
L-valine	0.166	0.071	---
Zinc oxide	0.350	0.250	---
Vitamin premix[2]	0.150	0.150	0.125
Trace mineral premix[3]	0.125	0.125	0.100
Copper sulfate	0.075	0.075	0.075
Phytase 2500	0.030	0.030	0.030
Total	100.00	100.00	100.00
SID lysine[4], %	1.45	1.34	1.25
Total lysine, %	1.576	1.464	1.41
SID amino acid ratios			
Met & Cys:lysine, %	58	58	57
Threonine:lysine, %	60	60	60
Tryptophan:lysine, %	13	15	17
Valine:lysine, %	58	59	66
ME, Kcal/lb	1518	1475	1488
Lactose, %	14	6	0
Salt, %	0.42	0.39	0.43
Phytase, units/kg	750	750	750
CP, %	17.6	19.5	21.8
Fat, %	5.4	5.0	5.3
Ca, %	0.74	0.75	0.7
P, %	0.66	0.69	0.64
Available P, %	0.45	0.42	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 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 10	d 10 to 21	d 21 to 42
1	No medication	No medication	No medication
2	Denagard/CTC[1]	Mecadox 25 g/OTC[2]	Denagard/CTC
3	Denagard/CTC	Mecadox 50 g	Denagard/CTC
4	Denagard/CTC	Mecadox 25 g/OTC	No medication
5	Denagard/CTC	Mecadox 50 g	No medication
6	Denagard/CTC	No medication	Denagard/CTC
7	Denagard/CTC	Denagard/CTC	Denagard/CTC
8	Denagard/CTC	Denagard/CTC	No medication

[1]Chlortetracycline, 400 g/ton.

[2]Oxytetracycline, 400 g/ton.

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

Treatment	Carbadox	Oxytetracycline	Chlortetracycline	Tiamulin
Phase 1				
Control	< 1.14	< 5.68	< 1.82	< 2
Denagard/CTC[1]	---	---	298	24.0
Phase 2				
Control	< 1.14	11.9	2.62	< 2
Mecadox 25 g/OTC[2]	13.7	294	---	---
Mecadox 50 g	39.4	---	---	---
Denagard/CTC	---	---	251	22.7
Phase 3				
Control	< 1.14	< 5.68	< 1.82	< 2
Denagard/CTC	---	---	221	24.3

[1]Chlortetracycline, 400 g/ton.

[2]Oxytetracycline, 400 g/ton.

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

	Treatment								
	1	2	3	4	5	6	7	8	
d 0 to 10	No med	Den/CTC[1]	Den/CTC	Den/CTC	Den/CTC	Den/CTC	Den/CTC	Den/CTC	
d 10 to 21	No med	Mec/OTC[2]	Mec 50 g	Mec/OTC	Mec 50 g	No med	Den/CTC	Den/CTC	
d 21 to 42	No med	Den/CTC	Den/CTC	No med	No med	Den/CTC	Den/CTC	No med	SEM
d 0 to 10									
ADG, lb	0.20	0.25	0.30	0.26	0.27	0.28	0.31	0.29	0.043
ADFI, lb	0.40	0.41	0.45	0.42	0.45	0.44	0.47	0.46	0.046
F/G	2.00	1.74	1.52	1.68	1.81	1.64	1.63	1.67	0.148
d 10 to 21									
ADG, lb	0.48	0.63	0.60	0.58	0.61	0.47	0.68	0.66	0.068
ADFI, lb	0.78	0.88	0.87	0.84	0.88	0.78	0.93	0.93	0.086
F/G	1.66	1.41	1.48	1.46	1.46	1.65	1.40	1.39	0.049
d 21 to 42									
ADG, lb	0.88	1.06	1.01	0.91	0.99	1.07	1.03	0.98	0.125
ADFI, lb	1.36	1.64	1.56	1.49	1.55	1.63	1.64	1.57	0.192
F/G	1.56	1.54	1.54	1.64	1.58	1.52	1.59	1.61	0.045
d 0 to 42									
ADG, lb	0.61	0.75	0.73	0.67	0.71	0.72	0.76	0.73	0.083
ADFI, lb	0.97	1.14	1.10	1.06	1.10	1.11	1.17	1.15	0.122
F/G	1.62	1.52	1.52	1.60	1.56	1.54	1.53	1.56	0.036
Weight, lb									
d 0	11.7	12.0	11.7	11.7	12.0	12.1	11.7	12.1	1.229
d 10	13.7	14.5	14.7	14.4	14.7	14.9	14.8	15.0	1.495
d 21	19.1	21.5	21.5	20.8	21.5	20.3	22.3	22.4	2.149
d 42	38.4	43.8	42.8	40.7	42.7	43.1	44.4	43.1	4.411
Mortality, %	8.7	3.6	2.7	5.1	5.2	6.4	4.7	0.8	0.029
Treatments, n	7.2	4.7	7.5	7.5	6.3	7.3	5.0	6.2	1.222

[1] Denagard, Chlortetracycline.

[2] Mecadox (Mec), Oxytetracycline (OTC).

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

	Treatment								
	1	2	3	4	5	6	7	8	
d 0 to 10	No med	Den/CTC[2]	Den/CTC	Den/CTC	Den/CTC	Den/CTC	Den/CTC	Den/CTC	
d 10 to 21	No med	Mec/OTC[3]	Mec 50 g	Mec/OTC	Mec 50 g	No med	Den/CTC	Den/CTC	
d 21 to 42	No med	Den/CTC	Den/CTC	No med	No med	Den/CTC	Den/CTC	No med	SEM
Feed cost, $/pig									
d 0 to 10	1.02	1.12	1.22	1.15	1.22	1.20	1.29	1.25	0.125
d 10 to 21	1.45	1.71	1.72	1.65	1.74	1.44	1.87	1.86	0.167
d 21 to 42	3.99	5.24	5.01	4.34	4.54	5.24	5.24	4.62	0.593
d 0 to 42	6.45	8.08	7.93	7.14	7.50	7.88	8.39	7.82	0.794
Feed cost, $/lb gain									
d 0 to 10	0.518	0.471	0.412	0.455	0.490	0.445	0.441	0.454	0.04
d 10 to 21	0.280	0.250	0.266	0.260	0.262	0.278	0.254	0.253	0.008
d 21 to 42	0.217	0.235	0.235	0.229	0.220	0.232	0.242	0.224	0.007
d 0 to 42	0.258	0.257	0.260	0.258	0.253	0.261	0.262	0.252	0.008
Margin over feed cost 1[4], $/pig									
d 0 to 10	-0.03	0.11	0.30	0.15	0.12	0.21	0.26	0.19	0.113
d 10 to 21	1.21	1.74	1.53	1.54	1.60	1.16	1.85	1.80	0.215
d 21 to 42	5.28	5.90	5.64	5.26	5.89	6.02	5.61	5.71	0.745
d 0 to 42	6.37	7.62	7.33	6.88	7.46	7.23	7.65	7.75	1.002
Margin over feed cost 2[4], $/pig									
d 0 to 10	0.96	1.33	1.81	1.45	1.46	1.61	1.80	1.63	0.322
d 10 to 21	3.87	5.20	4.77	4.73	4.93	3.77	5.56	5.46	0.587
d 21 to 42	14.56	17.04	16.28	14.85	16.31	17.27	16.45	16.04	2.048
d 0 to 42	19.19	23.31	22.60	20.90	22.42	22.35	23.68	23.33	2.748

[1] Base diet costs were $516.37/ton from d 0 to 10; $337.19/ton from d 10 to 21; and $278.90/ton from d 21 to 42. Medication costs per ton were $26.40 for Denagard/CTC, and $18.10 for Mecadox/OTC, and $21.86 for Mecadox.
[2] Denagard, Chlortetracycline.
[3] Mecadox (Mec), Oxytetracycline (OTC).
[4] Margin over feed cost 1 assumed a value of gain at $0.50/lb. Margin over feed cost 2 assumed a value of gain of $1.00/lb.

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

	Treat-ment	Contrasts[1]							
		1	2	3	4	5	6	7	8
d 0 to 10									
ADG, lb	0.07	0.004	0.06	0.02	0.17	0.19	0.07	0.62	0.08
ADFI, lb	0.66	0.15	0.29	0.13	0.54	0.29	0.13	0.63	0.57
F/G	0.10	0.01	0.10	0.11	0.15	0.67	0.58	0.90	0.04
d 10 to 21									
ADG, lb	0.003	0.005	.0001	.0001	0.001	0.96	0.09	0.08	0.70
ADFI, lb	0.23	0.09	0.010	0.004	0.04	0.77	0.16	0.27	0.91
F/G	.0001	.0001	.0001	.0001	.0001	0.37	0.34	0.07	0.77
d 21 to 42									
ADG, lb	0.04	0.01	0.53	0.48	0.63	0.71	0.63	0.91	0.002
ADFI, lb	0.23	0.01	0.25	0.19	0.39	0.93	0.59	0.53	0.03
F/G	0.28	0.77	0.15	0.12	0.26	0.40	0.85	0.31	0.05
d 0 to 42									
ADG, lb	0.06	0.003	0.03	0.02	0.09	0.67	0.23	0.43	0.02
ADFI, lb	0.33	0.02	0.10	0.05	0.23	0.96	0.32	0.36	0.14
F/G	0.12	0.02	0.14	0.17	0.19	0.43	0.50	0.91	0.01
Weight, lb									
d 0	1.00	0.85	0.94	0.98	0.93	0.96	0.98	0.95	0.97
d 10	0.99	0.35	0.65	0.56	0.76	0.80	0.65	0.84	0.67
d 21	0.69	0.10	0.07	0.05	0.16	0.82	0.39	0.52	0.64
d 42	0.58	0.06	0.22	0.17	0.35	0.83	0.50	0.64	0.13
Mortality, %	0.28	0.05	0.03	0.03	0.07	0.85	0.45	0.57	0.69
Treatments, n	0.56	0.54	0.30	0.18	0.48	0.50	0.68	0.28	0.45
Feed cost, $/pig									
d 0 to 10	0.40	0.04	0.14	0.06	0.32	0.30	0.11	0.57	0.43
d 10 to 21	0.02	0.01	0.00	0.00	0.00	0.64	0.07	0.18	0.89
d 21 to 42	0.00	0.002	0.28	0.21	0.43	0.95	0.58	0.53	<.0001
d 0 to 42	0.05	0.003	0.06	0.03	0.16	0.80	0.24	0.36	0.01
Feed cost, $/lb gain									
d 0 to 10	0.29	0.04	0.25	0.24	0.33	0.67	0.58	0.90	0.07
d 10 to 21	0.04	0.02	0.00	0.00	0.00	0.20	0.87	0.16	0.79
d 21 to 42	0.02	0.02	0.14	0.10	0.25	0.38	0.80	0.26	0.00
d 0 to 42	0.82	0.90	0.49	0.56	0.52	0.87	0.91	0.97	0.17
Margin over feed cost 1, $/pig[2]									
d 0 to 10	0.04	0.003	0.07	0.04	0.17	0.22	0.14	0.81	0.02
d 10 to 21	0.004	0.01	<.0001	<.0001	0.005	0.56	0.18	0.07	0.73
d 21 to 42	0.34	0.12	0.94	0.97	0.93	0.47	0.75	0.69	0.16
d 0 to 42	0.22	0.01	0.04	0.03	0.12	0.70	0.25	0.44	0.21
Margin over feed cost 2, $/pig[2]									
d 0 to 10	0.04	0.002	0.05	0.02	0.15	0.18	0.08	0.66	0.04
d 10 to 21	0.004	0.007	<.0001	<.0001	0.001	0.75	0.13	0.07	0.76
d 21 to 42	0.10	0.02	0.66	0.63	0.73	0.61	0.66	0.94	0.01
d 0 to 42	0.10	0.005	0.04	0.02	0.11	0.72	0.21	0.38	0.06

[1] Contrast 1 = Response to antibiotic in phase 1 (Treatment 1 vs. all others).
Contrast 2 = Response to antibiotic in phase 2 (Treatments 1 and 6 vs. all others).
Contrast 3 = Denagard/CTC vs. no medication in phase 2 (Treatments 1 and 6 vs. 7 and 8).
Contrast 4 = Mecadox vs. no medication in phase 2 (Treatments 1 and 6 vs. 2, 3, 4, and 5).
Contrast 5 = Mecadox 25 g/OTC vs. Mecadox 50 g in phase 2 (Treatments 2 and 4 vs. 3 and 5).
Contrast 6 = Mecadox 25 g/OTC vs. Denagard CTC in phase 2 (Treatments 2 and 4 vs. 7 and 8).
Contrast 7 Mecadox 50 g vs. Denagard CTC in phase 2 (Treatments 3 and 5 vs. 7 and 8).
Contrast 8 Denagard CTC vs. no medication in phase 3 (Treatments 1, 4, 5, and 8 vs. 2, 3, 6, and 7).
[2] Margin over feed cost 1 assumed a value of gain at $0.50/lb. Margin over feed cost 2 assumed a value of gain of $1.00/lb.

EFFECTS OF INCREASING STANDARDIZED ILEAL DIGESTIBLE LYSINE:CALORIE RATIO ON GILTS GROWN IN A COMMERCIAL FINISHING ENVIRONMENT[1,2]

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Summary

A total of 2,165 commercial gilts (PIC 337 × 1050) were used in two 4-wk studies to determine the lysine requirement for growing and finishing gilts. All diets were corn-soybean meal based and contained 0.15% L-lysine HCl and 3% added fat. Desired lysine levels were achieved by altering the corn and soybean meal level in the diet. Each experiment consisted of 6 treatments with 7 pens per treatment and 24 to 27 pigs per pen. In Exp. 1, 1,085 gilts (initially 84.2 lb) were used with standardized ileal digestible (SID) lysine:calorie ratios of 2.01, 2.30, 2.58, 2.87, 3.16, and 3.45 g/Mcal. Both ADG and F/G improved (quadratic, $P < 0.003$) with increasing SID lysine:calorie ratio, with the greatest improvement in performance through 3.16 g SID lysine/Mcal ME and a smaller increase to the highest SID lysine:calorie level. Daily SID lysine intake increased (linear, $P < 0.001$) and SID lysine intake per pound of gain increased (quadratic, $P < 0.001$) as expected with increasing dietary lysine. Income over feed costs (IOFC) and feed cost per pound of gain also followed a similar pattern (quadratic, $P < 0.001$). In Exp. 2, 1,080 gilts (initially 185.3 lb) were used with SID lysine:calorie ratios of 1.55, 1.75, 1.95, 2.05, 2.35, and 2.55 g/Mcal. As SID lysine:calorie ratio increased, ADG, F/G, daily SID lysine intake, SID lysine intake per pound of gain, IOFC, and feed cost per pound of gain improved (linear, $P < 0.001$) through the highest lysine:calorie level of 2.55 g/Mcal. These studies indicate that feeding higher levels of lysine than previously thought to be optimal offers significant economic and biologic improvements in growing and finishing gilts. More research is needed to validate the ideal SID lysine:calorie ratio for today's evolving genetics.

Key words: gilt, income over feed costs, lysine

Introduction

Lysine is the first limiting amino acid in corn-soybean meal-based swine diets. Therefore, understanding lysine requirements for growing and finishing pigs is essential in developing cost-effective diets. It is common to express the lysine requirement in terms of standardized illeal digestible (SID) lysine percentage or as a ratio of SID lysine to the ME level in a diet. Using the ratio, nutritionists can formulate diets for a variety of feeding

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situations with different dietary energy densities. Continuous evaluation of the lysine requirements is necessary with today's increasingly high-lean genotypes. Recent research has shown an increased growth rate in pigs vaccinated with commercial porcine circo virus type 2 (PCV2) vaccine. With enhanced growth rates in vaccinated pigs and evolving genetic lines, the lysine requirement may have increased from requirements established 6 yr ago. Therefore, the objective of this trial was to observe the growth and economic effects of feeding increasing dietary lysine levels to gilts in a commercial finishing environment.

Procedures

A total of 1,085 (initially 84.2 lb) and 1,080 (initially 185.3 lb) gilts were used in Exp. 1 and 2 for 28 and 29 d, respectively. The gilts were vaccinated with 2 doses of a commercial PCV2 vaccine while in the nursery. There were 24 to 27 pigs per pen in each experiment; average number of pigs per pen was initially the same across treatments within each study. The study was conducted at a commercial research facility in southwest Minnesota, and similar genetics (PIC 337 × 1050) were used in each experiment.

All diets were corn-soybean meal based with 0.15% added L-lysine HCl. Amounts of soybean and corn were changed to achieve the desired lysine concentration in the diet. All diets contained 3% added fat (choice white grease). Diets were formulated to meet all other requirements recommended by NRC (1998). In Exp. 1, the SID lysine:calorie ratios for the experimental diets were 2.01, 2.30, 2.58, 2.87, 3.16, and 3.45 g/Mcal (Table 1). In Exp. 2, the SID lysine:calorie ratios were 1.55, 1.75, 1.95, 2.05, 2.35, and 2.55 g/Mcal (Table 2). During the trials, diet samples were collected and analyzed to validate the calculated amino acid values (Tables 3 and 4).

In each experiment, pens of pigs were allotted to 1 of the 6 dietary treatments in a completely randomized design with 7 pens per treatment. Pig weights (by pen) and feed disappearance were measured throughout the trials. Average daily gain, ADFI, F/G, daily SID lysine intake, SID lysine intake per pound of gain, feed cost per pound of gain, and income over feed costs (IOFC) were determined in each trial. Income over feed costs was calculated by assessing a value to the weight gain per pig (at $60/cwt) during the trial and subtracting the feed costs per pig. All data were then analyzed for linear and quadratic effects of increasing SID lysine:calorie ratios, with pen being the experimental unit in all analyses.

Results and Discussion

In Exp. 1 (85- to 140-lb gilts), ADG and F/G improved (quadratic, $P < 0.003$, Table 5) with increasing SID lysine:calorie ratios, with the greatest improvement through 3.16 g lysine/Mcal ME with a small improvement through the highest ratio of 3.45 g SID lysine/Mcal ME. Although the magnitude of response was relatively small, ADFI decreased (linear, $P < 0.04$) with increasing SID lysine:calorie ratio. As expected, daily SID lysine intake increased (linear, $P < 0.001$) with increasing dietary lysine. Lysine intake per pound of gain increased (quadratic, $P < 0.001$) with increasing dietary lysine. It appears that approximately 10 g SID lysine was required per pound of gain for optimal performance. Feed cost per pound of gain decreased (quadratic, $P < 0.001$) with increasing SID lysine:calorie ratios; the most economical value was reached at 3.16 g SID lysine/Mcal ME. Income over feed costs increased (quadratic, $P < 0.001$) with increasing SID lysine:calorie ratio, with the greatest return achieved at the highest ratio. This data illustrates that economical and biological responses were maximized at the SID lysine:calorie ratios of 3.16 to 3.45 g SID lysine/Mcal ME.

In Exp. 2 (185- to 245-lb gilts), ADG and F/G improved (linear, $P < 0.001$, Table 6)

with increasing SID lysine:calorie ratio. Feed intake was not ($P > 0.80$) affected by increasing dietary lysine. Daily SID lysine intake and SID lysine intake per pound of gain increased (linear, $P < 0.001$) with increasing SID lysine. Feed cost per pound of gain decreased (linear, $P < 0.001$) with increasing SID lysine:calorie ratio. These decreased costs were driven by the improvements in F/G. Income over feed costs increased (linear, $P < 0.001$) from $13.84/pig at 1.55 g SID lysine/Mcal ME to $17.94/pig at 2.55 g SID lysine/Mcal ME. The improvements in gain and F/G with increasing SID dietary lysine allowed for the improvements in IOFC. These data show that the most advantageous SID lysine:calorie ratio was the highest level tested (2.55 g SID lysine/Mcal ME).

The results from these trials indicate that 10 to 11 g of SID lysine per pound of gain were required in these trials for the optimal response. This is about 1 to 2 g higher than reported in previous trials (Main et al., 2002 Swine Day Report of Progress, p. 135). Figures 1 to 4 show data from Main et al. (2002) compared with results from our trials. These graphs indicate that growth performance achieved at the lower lysine levels in the current trials was similar to the performance achieved by pigs in the earlier research. In the Main et al. (2002) study, as lysine levels increased, growth performance reached a plateau, whereas growth performance continued to increase in the current trials. Both studies were conducted in the same research facility with the same genetic lines. The main differences are that 6 yr of genetic progress have occurred between the experiments and the pigs in the current research trials were vaccinated for PCV2. Research has demonstrated that pigs vaccinated for PCV2 have improved ADG and F/G compared with nonvaccinates. This suggests a greater capacity for protein deposition; thus, it is not surprising that these pigs may have a higher lysine requirement than nonvaccinates.

Kansas State University recommendations developed on the basis of previous research suggest using approximately 2.65 g SID lysine/Mcal ME for 85- to 140-lb gilts and 1.95 g SID lysine/Mcal ME for 185- to 245-lb gilts. As the data from these experiments demonstrate, because of the high growth performance potential, there are significant advantages in feeding higher levels of dietary lysine. As genetic advancement and improved health status occur, more research is needed to validate the optimal SID lysine:calorie ratio to maximize biological and economic responses.

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

	SID[2] lysine:ME, g/Mcal					
	2.01	2.3	2.58	2.87	3.16	3.45
	SID lysine, %					
Item, %	0.70	0.80	0.90	1.00	1.10	1.20
Corn	79.41	75.43	71.46	67.48	63.51	59.53
Soybean meal (46.5% CP)	15.49	19.47	23.44	27.42	31.39	35.37
Choice white grease	3.00	3.00	3.00	3.00	3.00	3.00
Monocalcium P (21% P)	0.50	0.50	0.50	0.50	0.50	0.50
Limestone	0.90	0.90	0.90	0.90	0.90	0.90
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Copper sulfate	0.03	0.03	0.03	0.03	0.03	0.03
Vitamin premix	0.08	0.08	0.08	0.08	0.08	0.08
Trace mineral premix	0.08	0.08	0.08	0.08	0.08	0.08
Lysine HCl	0.15	0.15	0.15	0.15	0.15	0.15
Natuphos classic[3]	0.02	0.02	0.02	0.02	0.02	0.02
Total	100	100	100	100	100	100
Calculated analysis						
SID amino acids, %						
Lysine	0.7	0.8	0.9	1.0	1.1	1.2
Isoleucine:lysine	70	70	69	69	69	69
Leucine:lysine	175	165	157	151	146	141
Methionine:lysine	31	29	28	27	26	26
Met & Cys:lysine	64	60	58	56	54	53
Threonine:lysine	63	62	61	60	60	59
Tryptophan:lysine	19	19	19	19	20	20
Valine:lysine	83	81	79	78	77	76
ME, kcal/lb	1,581	1,580	1,579	1,579	1,578	1,577
Total lysine, %	0.79	0.90	1.01	1.12	1.23	1.34
CP, %	14.1	15.6	17.1	18.6	20.1	21.7
Ca, %	0.51	0.52	0.54	0.55	0.56	0.57
P, %	0.43	0.45	0.47	0.48	0.50	0.52
Available P, %[4]	0.24	0.24	0.25	0.25	0.26	0.26
Diet cost, $/ton[5]	232.50	239.32	246.13	252.95	259.76	266.58

[1] A total of 1,085 gilts (PIC 337 × 1050) were housed at approximately 27 pigs per pen and 7 replications per treatment in a 28-d trial.
[2] Standardized ileal digestible.
[3] Provided per pound of diet: 136 units of phytase.
[4] Phytase provided 0.08% available P to the diet.
[5] Diet costs were based on corn at $5.00/bu and 46.5% soybean meal at $350/ton.

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

	SID[2] lysine:ME, g/Mcal					
	1.55	1.75	1.95	2.15	2.35	2.55
	SID lysine, %					
Item, %	0.54	0.61	0.68	0.75	0.82	0.89
Corn	85.84	83.07	80.31	77.54	74.77	72.00
Soybean meal (46.5% CP)	9.12	11.91	14.69	17.47	20.25	23.03
Choice white grease	3.00	3.00	3.00	3.00	3.00	3.00
Monocalcium P (21% P)	0.58	0.56	0.55	0.53	0.52	0.50
Limestone	0.85	0.85	0.85	0.85	0.85	0.85
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.05	0.05	0.05	0.05	0.05	0.05
Trace mineral premix	0.05	0.05	0.05	0.05	0.05	0.05
Lysine HCl	0.15	0.15	0.15	0.15	0.15	0.15
L-Threonine	---	---	---	---	0.005	0.010
Optiphos 2000[3]	0.01	0.01	0.01	0.01	0.01	0.01
Total	100	100	100	100	100	100
Calculated analysis						
SID amino acids, %						
Lysine	0.54	0.61	0.68	0.75	0.82	0.89
Isoleucine:lysine	71	71	70	70	70	69
Leucine:lysine	200	188	178	170	164	158
Methionine:lysine	35	33	31	30	29	28
Met & Cys:lysine	71	68	64	62	60	58
Threonine:lysine	65	64	63	62	62	62
Tryptophan:lysine	18	18	19	19	19	19
Valine:lysine	88	85	83	82	80	79
ME, kcal/lb	1,583	1,583	1,582	1,582	1,582	1,582
Total lysine, %	0.62	0.69	0.77	0.85	0.92	1.00
CP, %	11.70	12.70	13.80	14.90	15.90	17.00
Ca, %	0.49	0.49	0.50	0.50	0.51	0.52
P, %	0.42	0.43	0.44	0.45	0.46	0.47
Available P, %[4]	0.22	0.22	0.22	0.22	0.22	0.22
Diet cost, $/ton[5]	220.51	225.18	229.86	234.53	239.32	244.11

[1] A total of 1,080 gilts (PIC 337 × 1050) were housed at approximately 27 pigs per pen and 7 replications per treatment in a 29-d trial.
[2] Standardized ileal digestible.
[3] Provided per pound of diet: 91 units of phytase.
[4] Phytase provided 0.05% available P to the diet.
[5] Diet costs were based on corn at $5.00/bu and 46.5% soybean meal at $350/ton.

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

	SID[2] lysine:ME, g/Mcal					
	2.01	2.30	2.58	2.87	3.16	3.45
	SID lysine, %					
Item, %[3]	0.7	0.8	0.9	1.0	1.1	1.2
CP	13.57 (14.10)	14.64 (15.61)	16.07 (17.12)	16.80 (18.63)	19.05 (20.14)	19.37 (21.65)
Lysine	0.78 (0.79)	0.86 (0.90)	0.99 (1.01)	1.06 (1.12)	1.14 (1.23)	1.24 (1.34)
Threonine	0.50 (0.52)	0.54 (0.51)	0.60 (0.50)	0.62 (0.50)	0.71 (0.49)	0.77 (0.49)
Methionine	0.22 (0.24)	0.23 (0.23)	0.25 (0.22)	0.28 (0.21)	0.27 (0.20)	0.29 (0.20)
Met+Cys	0.45 (0.50)	0.47 (0.48)	0.52 (0.46)	0.55 (0.44)	0.57 (0.43)	0.60 (0.42)
Isoleucine	0.54 (0.56)	0.59 (0.55)	0.67 (0.55)	0.71 (0.55)	0.81 (0.55)	0.84 (0.55)
Leucine	1.31 (1.35)	1.36 (1.28)	1.48 (1.23)	1.54 (1.18)	1.68 (1.14)	1.74 (1.11)
Valine	0.63 (0.66)	0.68 (0.65)	0.76 (0.63)	0.80 (0.63)	0.87 (0.62)	0.91 (0.61)
Tryptophan	0.14 (0.15)	0.15 (0.15)	0.18 (0.15)	0.20 (0.15)	0.22 (0.16)	0.23 (0.16)

[1] A total of 1,085 gilts (PIC 337 × 1050) were housed with approximately 27 pigs per pen and 7 replications per treatment in a 28-d trial.
[2] Standardized ileal digestible.
[3] Analyzed values for protein and amino acids are shown with calculated values located in parentheses.

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

	SID[2] lysine:ME, g/Mcal					
	1.55	1.75	1.95	2.15	2.35	2.55
	SID lysine, %					
Item, %[3]	0.54	0.61	0.68	0.75	0.82	0.89
CP	10.93 (11.68)	14.97 (12.74)	13.17 (13.80)	15.86 (14.86)	15.21 (15.92)	15.94 (16.98)
Lysine	0.62 (0.62)	0.92 (0.69)	0.79 (0.77)	0.99 (0.85)	0.93 (0.92)	1.07 (1.00)
Threonine	0.42 (0.42)	0.60 (0.46)	0.51 (0.50)	0.64 (0.55)	0.58 (0.60)	0.64 (0.64)
Methionine	0.19 (0.21)	0.27 (0.22)	0.22 (0.23)	0.28 (0.25)	0.24 (0.26)	0.27 (0.28)
Met+Cys	0.40 (0.44)	0.51 (0.47)	0.45 (0.50)	0.55 (0.53)	0.50 (0.55)	0.54 (0.58)
Isoleucine	0.42 (0.44)	0.59 (0.49)	0.54 (0.54)	0.65 (0.59)	0.63 (0.65)	0.71 (0.70)
Leucine	1.11 (1.18)	1.42 (1.26)	1.29 (1.33)	1.49 (1.41)	1.41 (1.48)	1.58 (1.56)
Valine	0.48 (0.54)	0.67 (0.59)	0.60 (0.65)	0.78 (0.70)	0.71 (0.75)	0.80 (0.80)
Tryptophan	0.12 (0.11)	0.17 (0.13)	0.16 (0.14)	0.17 (0.16)	0.17 (0.18)	0.17 (0.19)

[1] A total of 1,080 gilts (PIC 337 × 1050) were housed with approximately 27 pigs per pen and 7 replications per treatment in a 29-d trial.
[2] Standardized ileal digestible.
[3] Analyzed values for protein and amino acids are shown with calculated values located in parentheses.

Table 5. Effects of standardized ileal digestible (SID) lysine:calorie ratio on 85- to 140-lb gilts (Exp. 1)[1]

	SID lysine:ME, g/Mcal								
	2.01	2.30	2.58	2.87	3.16	3.45			
	SID lysine, %							Probability, *P* <	
	0.7	0.8	0.9	1.0	1.1	1.2	SE	Linear	Quadratic
Initial weight, lb	84.2	84.0	84.2	84.3	84.4	84.2	2.19	0.94	0.98
ADG, lb	1.81	1.91	2.04	2.09	2.13	2.15	0.024	0.001	0.003
ADFI, lb	4.34	4.30	4.29	4.24	4.21	4.20	0.057	0.04	0.93
F/G	2.39	2.25	2.10	2.03	1.98	1.96	0.014	0.001	0.001
Final weight, lb	135.0	137.5	141.4	142.7	143.9	144.3	2.58	0.004	0.38
Daily SID lysine intake, g	13.79	15.62	17.54	19.24	21.02	22.87	0.250	0.001	0.85
SID Lysine intake/lb gain, g	7.60	8.17	8.59	9.22	9.89	10.66	0.060	0.001	0.001
Feed cost/lb gain, $[2]	0.278	0.269	0.259	0.257	0.257	0.261	0.002	0.001	0.001
IOFC, $/head[2,3]	16.35	17.72	19.50	20.02	20.39	20.39	0.257	0.001	0.001

[1] A total of 1,085 gilts (PIC 337 × 1050) were housed with approximately 27 pigs per pen and 7 replications per treatment in a 28-d trial.

[2] Feed costs were based on corn at $5.00/bu and 46.5% soybean meal at $350/ton.

[3] Income over feed costs = value of gain on a $60/live cwt weight basis - feed costs during trial period.

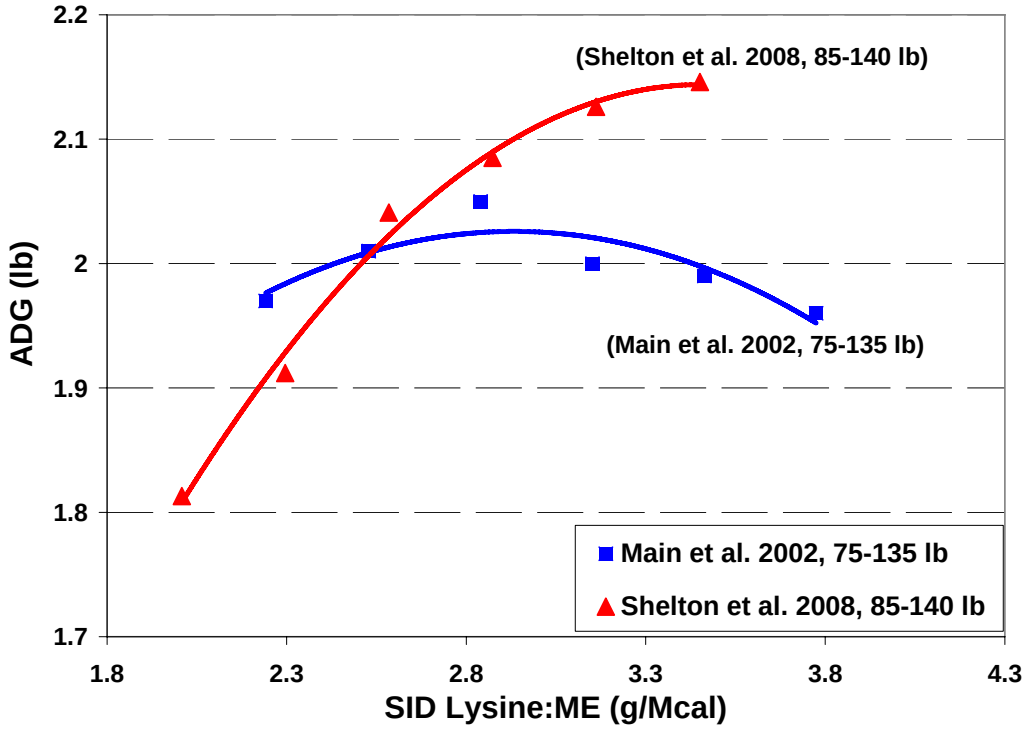

Figure 1. Comparison of standardized ileal digestible (SID) lysine:calorie ratio on ADG for 2 gilt studies.

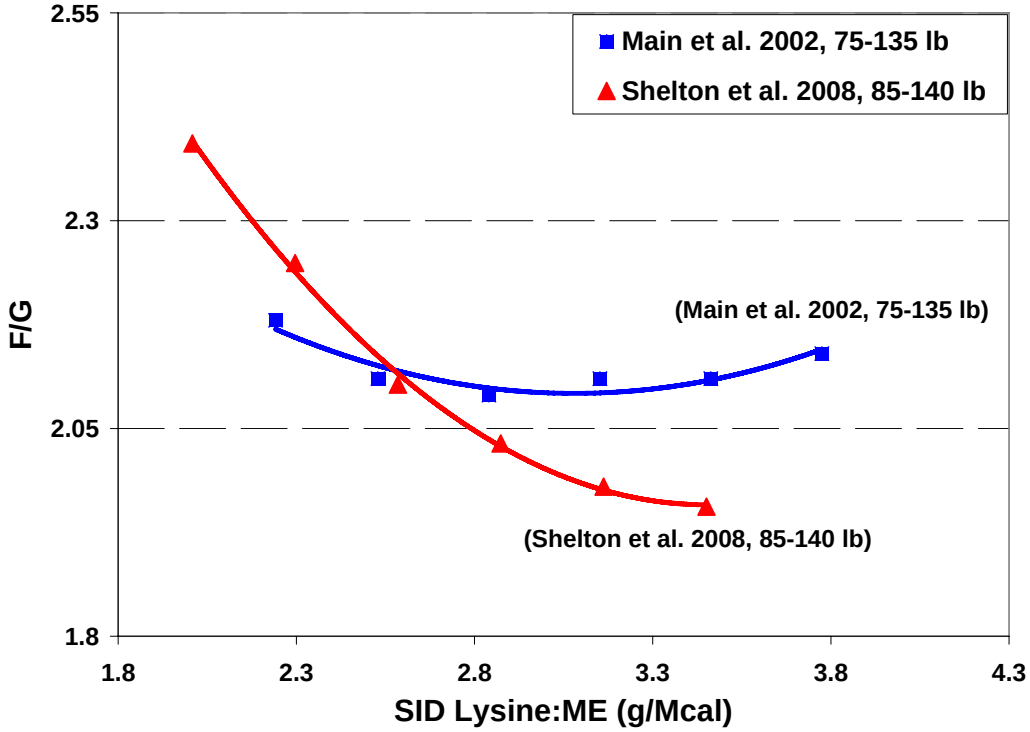

Figure 2. Comparison of standardized ileal digestible (SID) lysine:calorie ratio on F/G for 2 gilt studies.

Table 6. Effects of standardized ileal digestible (SID) lysine:calorie ratio on 185- to 245-lb gilts (Exp. 2)[1]

	SID lysine:ME, g/Mcal								
	1.55	1.75	1.95	2.15	2.35	2.55			
	SID lysine, %							Probability, *P* <	
	0.54	0.61	0.68	0.75	0.82	0.89	SE	Linear	Quadratic
Initial weight, lb	185.4	185.3	185.4	185.2	185.3	185.3	2.79	0.98	0.98
ADG, lb	1.82	1.92	1.93	2.05	2.08	2.17	0.032	0.001	0.90
ADFI, lb	5.59	5.68	5.55	5.58	5.60	5.60	0.067	0.81	0.87
F/G	3.07	2.96	2.90	2.71	2.69	2.58	0.036	0.001	0.64
Final weight, lb	238.3	241.2	241.7	244.7	246	248.2	3.08	0.02	0.99
Daily SID lysine intake, g	13.69	15.75	17.15	19.02	20.85	22.62	0.233	0.001	0.91
SID lysine intake/lb gain, g	7.53	8.21	8.91	9.28	10.01	10.43	0.110	0.001	0.26
Feed cost/lb gain, $[2]	0.339	0.334	0.332	0.32	0.322	0.315	0.004	0.001	0.87
IOFC, $/head[2,3]	13.84	14.91	15.11	16.7	16.93	17.94	0.463	0.001	0.97

[1] A total of 1,080 gilts (PIC 337 × 1050) were housed at approximately 27 pigs per pen and 7 replications per treatment in a 29-d trial.

[2] Feed costs were based on corn at $5.00/bu and 46.5% soybean meal at $350/ton.

[3] Income over feed costs = value of gain on a $60/live cwt weight basis - feed costs during trial period.

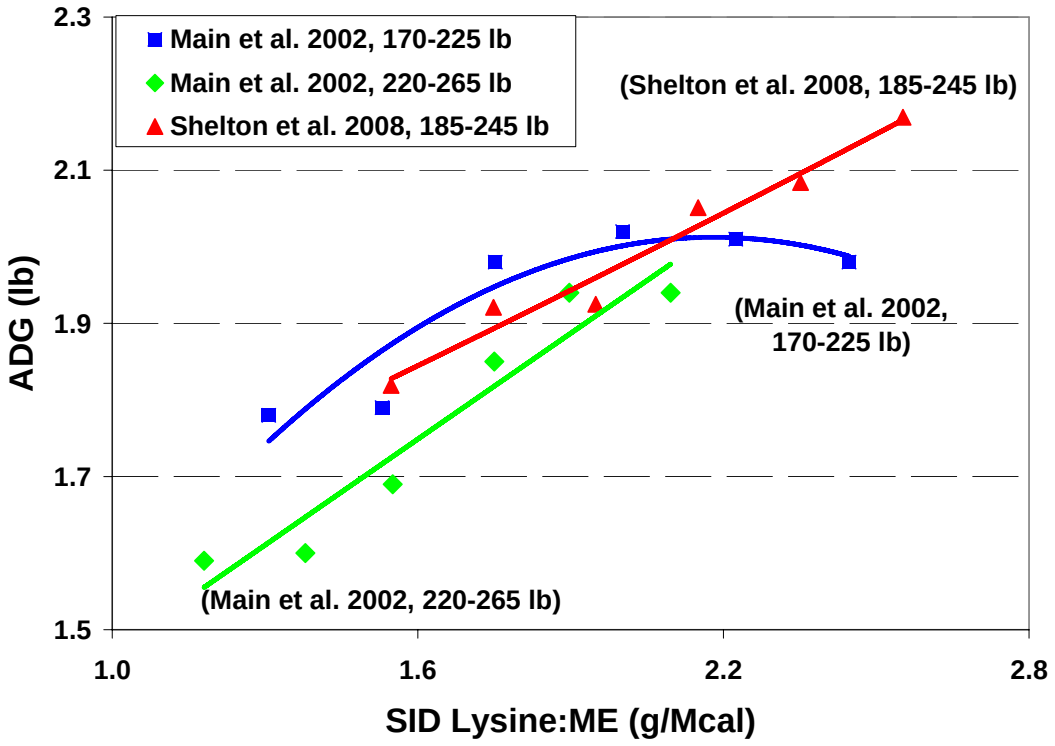

Figure 3. Comparison of standardized ileal digestible (SID) lysine:calorie ratio on ADG for 3 gilt studies.

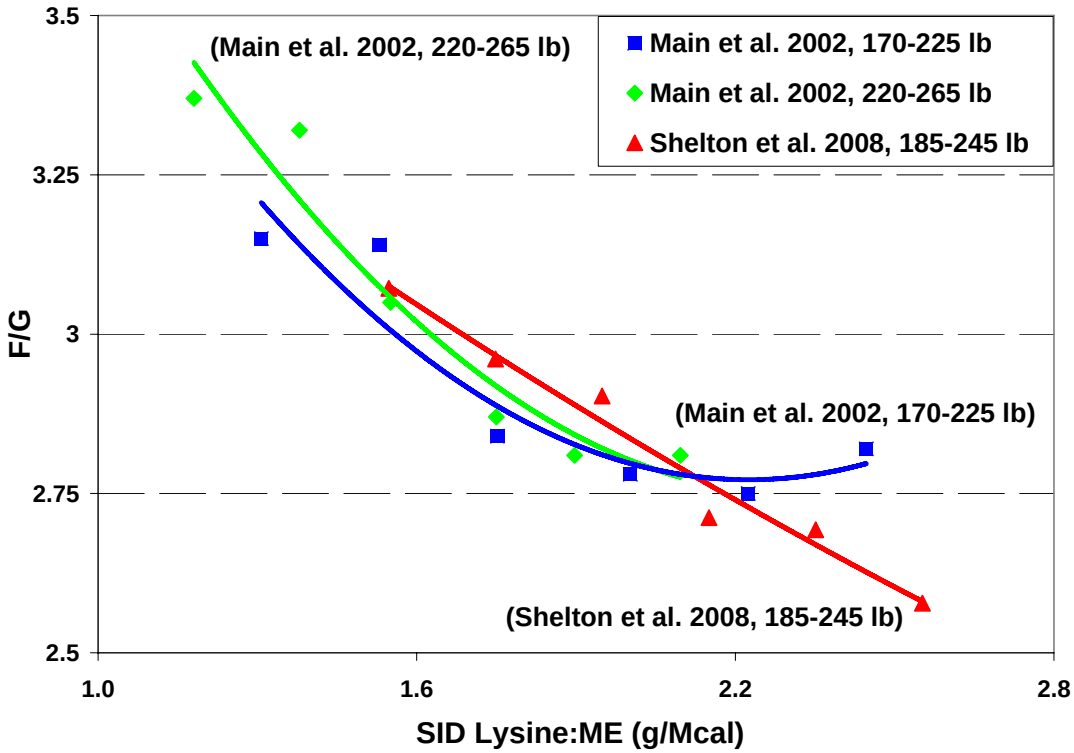

Figure 4. Comparison of standardized ileal digestible (SID) lysine:calorie ratio on F/G for 3 gilt studies.

EFFECTS OF INCREASING STANDARDIZED ILEAL DIGESTIBLE LYSINE:CALORIE RATIO FOR 120- TO 180-lb GILTS GROWN IN A COMMERCIAL FINISHING ENVIRONMENT[1,2]

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Summary

A 28-d growth trial was conducted to estimate the lysine requirement for 120- to 180-lb gilts. A total of 1,092 gilts (initially 121.7 lb, PIC 337 × 1050) were allotted to treatment diets with standardized ileal digestible (SID) lysine/ME ratios of 1.89, 2.12, 2.35, 2.58, 2.81, and 3.04 g/Mcal. All diets contained 0.15% L-lysine HCl and 3% choice white grease and were formulated to meet or exceed all other requirements. Seven replicate pens per treatment were used; there were approximately 26 pigs per pen. Gilts were vaccinated with 2 doses of commercial porcine circo virus type 2 (PCV2) vaccine while in the nursery. As the SID lysine content of the diet increased, both ADG and F/G improved (linear, $P < 0.001$) with the greatest values at the SID lysine/ME ratio of 2.58 g/Mcal. Daily SID lysine intake and SID lysine intake per pound of gain increased (linear, $P < 0.001$) as lysine density of the diet increased. Diet did not influence ($P > 0.25$) feed cost per pound of gain; however, there was a tendency for improved (linear, $P < 0.06$) income over marginal feed cost (IOMFC) as SID lysine level increased in the diet. The SID lysine/ME ratio that yielded the greatest IOMFC value, 2.58 g/Mcal, corresponded to the treatment with the greatest growth response. On the basis of this trial, 2.58 g SID lysine/Mcal ME appears to provide the greatest biological and economical response for 120- to 180-lb gilts.

Key words: gilt, lysine, requirement

Introduction

As feed prices continue to increase, producers must optimize feed efficiencies to minimize feed costs. Because lysine is the first limiting amino acid in corn-soybean meal-based swine diets, it is essential for nutritionists and producers to utilize the most effective lysine level to maximize efficiency without incurring extra costs. Lysine requirements are often expressed in terms of standardized ileal digestible (SID) lysine or as a ratio of SID lysine to the ME level in a diet. This ratio allows dietary lysine levels to be altered for a variety of feeding situations in which different feed ingredients are used. Lysine requirements need to be routinely reevaluated as genotype and heath status change within the production system. Currently, porcine circovirus type 2 (PCV2) vaccine is used to protect against the performance and economic effects related to porcine circovirus disease. The vaccine also has been shown to increase growth rates.

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

Therefore, the objective of this experiment was to estimate the lysine requirement of 120- to 180-lb gilts vaccinated with PCV2 vaccine.

Procedures

Procedures in this experiment were approved by the Kansas State University Institutional Animal Care and Use Committee. A total of 1,092 gilts (initially 121.7 lb, PIC 337 × 1050) were used in a 28-d growth trial to estimate the lysine requirement for 120 to 180 lb gilts. Gilts were vaccinated with 2 doses of commercial PCV2 vaccine while in the nursery and housed in a curtain-sided commercial finishing barn located in southwest Minnesota. There were 26 pigs per pen.

All diets were corn-soybean meal based with 0.15% added L–lysine HCl. Soybean and corn levels were altered to achieve the desired lysine concentration in the diet. All diets contained 3% added fat in the form of choice white grease. Diets were formulated to meet all other requirements recommended by NRC (1998). The SID lysine/ME ratios for the experimental diets were 1.89, 2.12, 2.35, 2.58, 2.81, and 3.04 g/Mcal (Table 1). During the trial, diet samples were collected and analyzed to validate the calculated amino acid values.

Pens of pigs were allotted to 1 of 6 dietary treatments in a completely randomized design with 7 replicate pens per treatment. Pig weights (by pen) and feed disappearance were measured throughout the trial at 14-d intervals to determine ADG, ADFI, F/G, daily SID lysine intake, SID lysine intake per pound of gain, feed cost per pound of gain, and income over marginal feed costs (IOMFC). Income over marginal feed costs was calculated by assessing a value to the weight gain per pig ($60/cwt) during the trial and subtracting the feed costs incurred per pig. The data were analyzed for linear and quadratic effects of increasing SID lysine:calorie ratios by using the PROC MIXED procedure in SAS with pen as the experimental unit.

Results and Discussion

Daily gain and F/G improved (linear, $P < 0.001$, Table 2) as SID lysine:calorie ratios increased in the diet. The greatest numeric increases in ADG and F/G were observed up to 2.58 g SID lysine/Mcal ME. No statistical trends were detected ($P > 0.70$) for ADFI. Therefore, daily SID lysine intake increased (linear, $P < 0.001$) as dietary SID lysine levels increased. SID lysine intake per pound of gain also increased (linear, $P < 0.001$) as lysine density of the diets increased. On the basis of the performance results, it appears that approximately 9 g SID lysine were required for each pound of gain. No differences were observed ($P > 0.25$) for feed cost per pound of gain; however, IOMFC tended ($P < 0.06$) to increase linearly as SID lysine:calorie ratio increased. The greatest economical response was at 2.58 g SID lysine/Mcal ME, which corresponds to the growth response. These data illustrate that 2.58 g SID lysine/Mcal ME provides the most efficient growth and economic responses for 120- to 180-lb gilts.

Figures 1 and 2 show results from our trial compared with those from a similar trial conducted by Main et al. (2002) in the same southwest Minnesota research facility with the same genetic line of pigs (PIC 337 × 1050). Growth plateaus were reached at slightly higher SID lysine:ME ratios in our trial than in the earlier trial.

This higher lysine requirement was not surprising as we continue to reap the benefits of growth due to genetic advancement as well as improved overall health with PCV2 vaccination. Kansas State University previously recommended using approximately 2.35 g SID lysine/Mcal ME for 120- to 180-lb gilts. The data from this trial show that utilizing a slightly higher value of approximately 2.58 g SID lysine/Mcal ME will help maximize biological and economic responses in healthy pigs with good feed intakes and growth rates.

Table 1. Composition of diets

	SID[1] lysine:calorie ratio (g/Mcal)					
	1.89	2.12	2.35	2.58	2.81	3.04
	SID lysine, %					
Item	0.66	0.74	0.82	0.90	0.98	1.06
Corn	81.00	77.85	74.65	71.50	68.30	65.15
Soybean meal (46.5% CP)	13.90	17.10	20.25	23.45	26.60	29.80
Choice white grease	3.00	3.00	3.00	3.00	3.00	3.00
Monocalcium P (21% P)	0.63	0.61	0.59	0.58	0.56	0.54
Limestone	0.85	0.85	0.85	0.85	0.85	0.85
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.05	0.05	0.05	0.05	0.05	0.05
Trace mineral premix	0.05	0.05	0.05	0.05	0.05	0.05
Lysine HCl	0.15	0.15	0.15	0.15	0.15	0.15
DL-Methionine	---	---	---	0.005	0.015	0.035
L-Threonine	---	---	0.005	0.010	0.015	0.025
Optiphos 2000	0.025	0.025	0.025	0.025	0.025	0.025
Total	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis						
Lysine:ME ratio, g/mcal	2.15	2.40	2.65	2.90	3.16	3.41
SID amino acids, %						
Lysine	0.66	0.74	0.82	0.90	0.98	1.06
Isoleucine:lysine	70	70	70	69	69	69
Leucine:lysine	180	171	163	157	152	148
Methionine:lysine	32	30	29	29	29	30
Met & Cys:lysine	65	62	60	58	58	58
Threonine:lysine	63	62	62	62	62	62
Tryptophan:lysine	19	19	19	19	19	20
Valine:lysine	84	82	80	79	78	77
ME, kcal/lb	1,581	1,581	1,580	1,580	1,580	1,580
Total lysine, %	0.75	0.84	0.92	1.01	1.10	1.19
CP, %	13.5	14.7	15.9	17.1	18.3	19.6
Ca, %	0.51	0.52	0.52	0.53	0.54	0.54
P, %	0.46	0.46	0.47	0.48	0.49	0.50
Available P, %[2]	0.29	0.29	0.29	0.29	0.29	0.29
Avail P:calorie, g/Mcal	0.82	0.82	0.82	0.82	0.82	0.82
Diet cost, $/ton[3]	232.62	237.94	243.38	248.96	254.62	260.62

[1] SID = standardized ileal digestible.
[2] Phytase provided 0.1% available P to the diet.
[3] Diet costs were based on corn at $5.00/bu and 46.5% soybean meal at $350/ton.

Table 2. Effects of standardized ileal digestible (SID) lysine:calorie ratio on performance of 120- to 180-lb gilts[1]

	SID lysine:calorie ratio (g /Mcal)								
	1.89	2.12	2.35	2.58	2.81	3.04			
	SID lysine, %							Probability, *P* <	
	0.66	0.74	0.82	0.90	0.98	1.06	SE	Linear	Quadratic
Initial weight, lb	121.7	121.7	121.7	121.7	121.7	121.7	2.22	0.99	0.98
ADG, lb	1.99	1.96	2.10	2.15	2.15	2.13	0.03	0.001	0.12
ADFI, lb	4.72	4.63	4.77	4.66	4.82	4.64	0.10	0.95	0.71
F/G	2.37	2.36	2.27	2.17	2.24	2.18	0.04	0.001	0.35
Final weight, lb	177.5	176.9	180.3	181.8	182.5	182.2	2.41	0.05	0.68
Daily lysine intake, g	14.2	15.6	17.8	19.0	21.5	22.4	0.365	0.001	0.63
Lysine intake/lb gain, g	7.10	7.94	8.47	8.89	9.96	10.51	0.160	0.001	0.61
Feed cost/lb gain, $[2]	0.276	0.281	0.277	0.271	0.285	0.285	0.005	0.26	0.35
IOMFC, $/pig[3]	18.12	17.51	19.01	19.81	18.99	18.76	0.499	0.06	0.12

[1] A total of 1,092 gilts (PIC 337 × 1050) were housed at approximately 26 pigs per pen and 7 replications per treatment in a 28-d trial.
[2] Feed costs were based on corn at $5.00/bu and 46.5% soybean meal at $350/ton.
[3] IOMFC = Income over marginal feed costs (weight gain × $0.60/lb - feed cost).

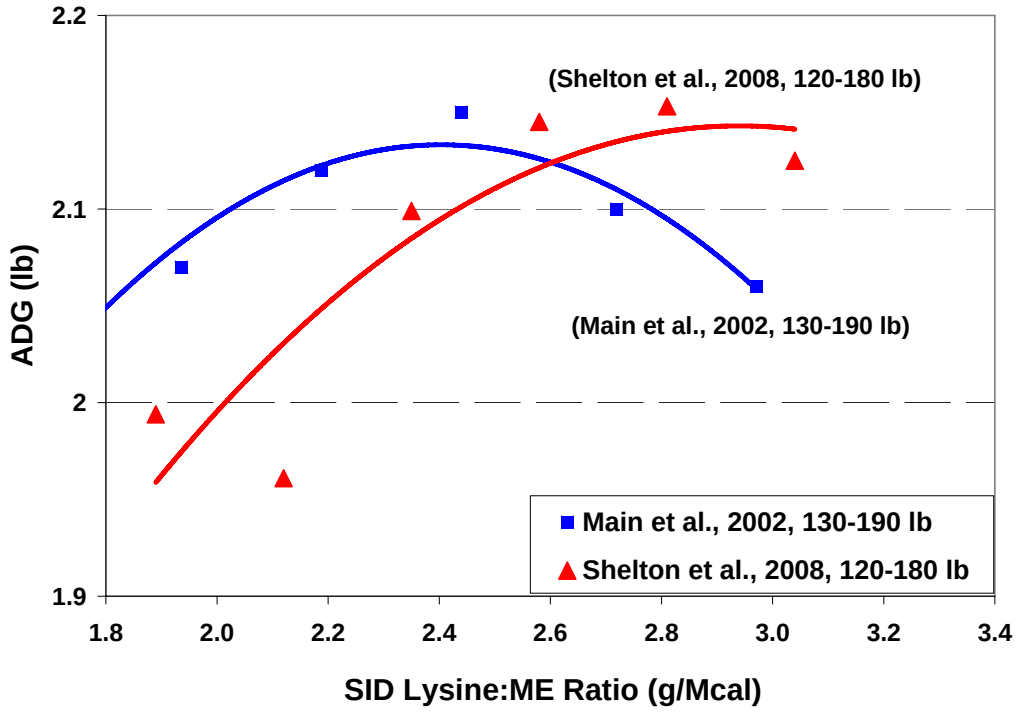

Figure 1. Comparison of ADG response to standardized ileal digestible (SID) lysine:calorie ratio for two gilt studies.

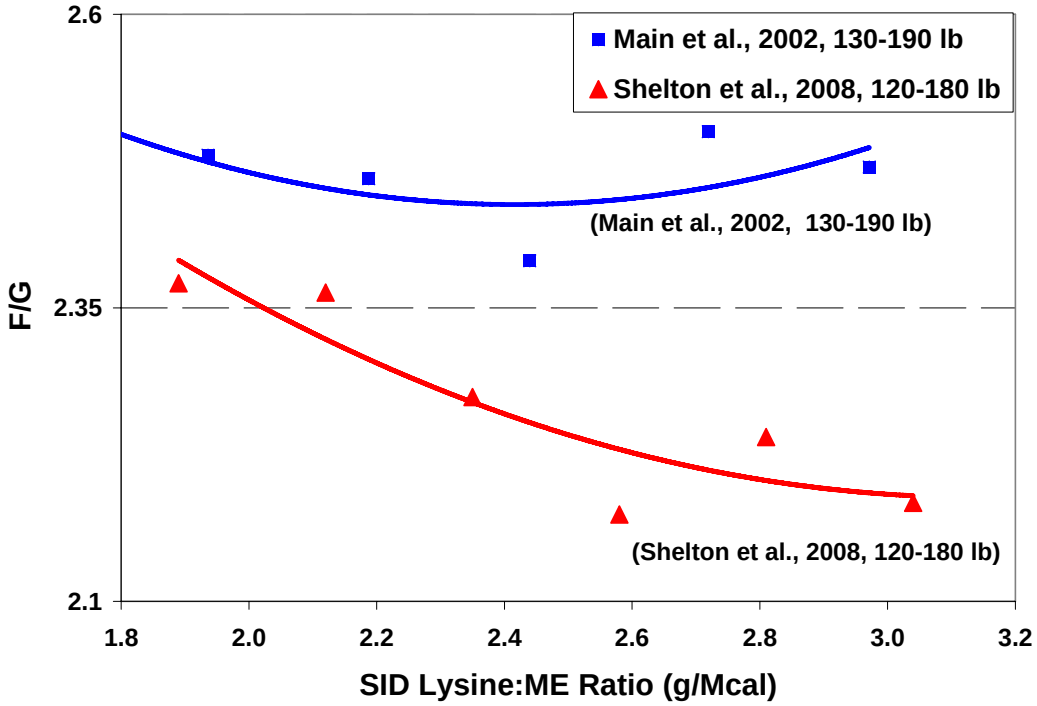

Figure 2. Comparison of F/G response to standardized ileal digestible (SID) lysine:calorie ratio for two gilt studies.

EFFECTS OF FEEDING EXCESS CRUDE PROTEIN ON GROWTH PERFORMANCE AND CARCASS TRAITS OF FINISHING PIGS

S. M. Williams, J. D. Hancock, C. Feoli, S. Issa, and T. L. Gugle

Summary

A total of 176 pigs (88 barrows and 88 gilts, average initial BW of 209 lb) were used in a 33-d experiment to determine the effects of excess dietary CP on growth performance and carcass measurements of finishing pigs. Pigs were sorted by sex and ancestry and blocked by weight with 11 pigs per pen and 4 pens per treatment. Treatments were corn-soybean meal based and formulated to a minimum of 0.80% total lysine but with 12, 14, 16, and 18% CP. Feed and water were consumed on an ad libitum basis until pigs were slaughtered (average final BW of 275 lb) at a commercial abattoir. Increasing CP concentration had no effect ($P > 0.20$) on ADG, ADFI, F/G, and HCW. With HCW used as a covariate, there were linear decreases in dressing percentage ($P < 0.01$) and loin depth at the last rib ($P < 0.04$) as CP concentration in the diet was increased from 12 to 18%. However, fat thickness at the last rib and percentage carcass lean were not affected ($P > 0.34$) by CP treatment. Our results indicate that increasing CP from 12 to 18% in diets for late-finishing pigs does not affect growth performance or carcass leanness but has small negative effects on dressing percentage and loin depth.

Key words: carcass, finishing pigs, growth, protein

Introduction

It has been suggested that excess CP in diets for finishing pigs reduces energetic efficiency, causes greater organ weights, and leads to decreased carcass yield. These concerns are especially relevant today because diets based on dried distillers grains with solubles tend to have excess CP. Therefore, the objective of this experiment was to determine the effects of excess dietary CP on growth performance and carcass measurements of finishing pigs.

Procedure

A total of 176 pigs (88 barrows and 88 gilts, average initial BW of 209 lb) were used in a 33-d growth assay. Pigs were sorted by sex and ancestry, blocked by weight, and assigned to pens. There were 11 pigs per pen and 4 pens per treatment. The pigs were housed in a finishing facility having 6-ft × 16-ft pens with half solid and half slatted concrete flooring. Each pen had a self-feeder and nipple waterer to allow ad libitum consumption of feed and water.

All diets had at least 0.8% lysine but with 12, 14, 16, and 18% CP (Table 1). The diets were corn-soybean meal based, with the soybean meal fraction of the diet increased (largely at the expense of corn and synthetic amino acids) to supply greater CP to the diet. Pigs and feeders were weighed at d 0 and 33 to allow calculation of ADG, ADFI, and F/G, and the pigs were killed (average BW of 275 lb) so carcass data could be collected.

All data were analyzed as a randomized complete block design by using the MIXED procedure of SAS. Polynomial regression was used to describe the shape of the response to increasing concentrations of CP in the diet. Because differences in HCW are known to

affect other carcass measurements, HCW was used as a covariate to correct for slaughtering pigs at a constant age rather than constant weight.

Results and Discussion

Increasing CP concentration in the diet had no effect on ADG, ADFI, F/G, and HCW ($P > 0.20$). However, there were slight decreases in dressing percentage (linear, $P < 0.01$) and loin depth at the last rib (linear, $P < 0.04$) as CP concentration in the diet was increased from 12 to 18%. Fat thickness at the last rib and percentage carcass lean were not affected ($P > 0.34$) as CP concentration in the diet was increased.

In conclusion, increasing CP from 12 to 18% did not affect growth performance, carcass weight, or carcass leanness. There were linear decreases in dressing percentage and loin depth as CP was increased from 12 to 18%, but the effects were small.

Table 1. Composition of diets

	CP, %			
Ingredient, %	12	14	16	18
Corn	88.51	83.28	78.01	72.98
Soybean meal (47.5% CP)	8.80	14.50	20.06	25.15
Limestone	1.06	1.07	1.04	1.01
Monocalcium phosphate (21% P)	0.66	0.55	0.51	0.48
Salt	0.23	0.23	0.23	0.23
L-lysine HCl	0.39	0.19	---	---
L-threonine	0.11	0.02	---	---
L-tryptophan	0.05	0.01	---	---
DL- methionine	0.04	---	---	---
Vitamin premix	0.06	0.06	0.06	0.06
Trace mineral premix	0.04	0.04	0.04	0.04
Antibiotic [1]	0.05	0.05	0.05	0.05
Calculated analysis, %				
Lysine, %	0.80	0.80	0.81	0.95
Ca	0.55	0.55	0.55	0.55
P total	0.45	0.45	0.46	0.48

[1] To provide 40 g/ton tylosin.

Table 2. Effects of increasing CP concentration on growth performance and carcass characteristics of finishing pigs[1]

	CP, %					*P* value		
Item	12	14	16	18	SE	Linear	Quad	Cubic
ADG, lb	2.08	2.04	2.03	2.06	0.04	---[2]	---	---
ADFI, lb	6.30	6.28	6.24	6.15	0.18	---	---	---
F/G	3.03	3.08	3.07	2.99	0.08	---	---	---
HCW, lb	204.2	202.0	200.6	202.1	4.48	---	---	---
Dress, %[3]	73.6	73.3	73.1	73.2	0.21	0.01	---	---
Carcass lean, %[3]	55.0	54.5	54.5	54.4	0.7	---	---	---
Backfat thickness, in.[3]	0.74	0.76	0.76	0.76	0.04	---	---	---
Loin depth, in.[3]	2.50	2.45	2.43	2.41	0.04	0.03	---	---

[1] A total of 176 pigs (initial BW of 209 lb) with 11 pigs per pen and 4 pens per treatment.
[2] Dashes indicate $P > 0.15$.
[3] HCW used as a covariate.

EFFECTS OF EXCESS DIETARY CRUDE PROTEIN FROM SOYBEAN MEAL AND DRIED DISTILLERS GRAINS WITH SOLUBLES IN DIETS FOR FINISHING PIGS

S. M. Williams, J. D. Hancock, C. Feoli, S. Issa, and T. L. Gugle

Summary

A total of 180 pigs (90 barrows and 90 gilts, average initial weight of 148 lb) were used in a 67-d experiment to determine the effects of excess dietary CP on growth performance and carcass measurements in finishing pigs. The pigs were sorted by ancestry and blocked by weight with 12 pigs per pen and 5 pens per treatment. Treatments were corn-soybean meal-based diets formulated to 15.3 and 18.3% CP and a corn-soybean-DDGS-based diet formulated to 18.3% CP. Feed and water were consumed on an ad libitum basis until the pigs were slaughtered (average final weight of 282 lb) at a commercial abattoir. Pigs fed diets with high CP had lower ($P < 0.001$) final weight, ADG, ADFI, and HCW, but these results were caused entirely by the diet with 40% DDGS. Our results indicated that diets with 40% DDGS decreased growth performance and economically important carcass measurements. However, the excess CP in those diets does not seem to be the culprit.

Key words: carcass, dried distillers grains with solubles, finishing pigs, growth, protein

Introduction

Many scientists (particularly in Europe) suggest that excess CP in diets reduces energetic efficiency in pigs. This lost efficiency should be reflected in poor growth performance measurements. Additionally, excess CP in diets has been blamed for increased organ weights leading to lower carcass yields. These arguments are of particular interest to us because diets with high inclusion of dried distillers grains with soluble (DDGS) have an abundance of CP. Thus, we designed an experiment to determine the effects of excess dietary CP from soybean meal vs. DDGS on growth performance and carcass measurements of finishing pigs.

Procedures

A total of 180 pigs (90 barrows and 90 gilts, average initial weight of 148 lb) were used in a 67-d growth assay. The pigs were sorted by sex and ancestry, blocked by weight, and assigned to pens. There were 12 pigs per pen and 5 pens per treatment. The pigs were housed in a finishing facility with 6-ft × 16-ft pens having half solid and half slatted concrete flooring. Each pen had a self-feeder and nipple waterer to allow ad libitum consumption of feed and water until the pigs were slaughtered at an average weight of 282 lb.

The first treatment was a corn-soybean meal-based diet formulated to 15.3% CP with added lysine and threonine (Table 1). For the second treatment, a simple corn-soybean meal-based diet was formulated to 18.5% CP. Finally, a diet with 40% DDGS (Sioux River Ethanol, Hudson, SD) was formulated; that diet also had 18.5% CP.

Pigs and feeders were weighed on d 0, 34, and 67 to allow calculation of ADG, ADFI, and F/G. The pigs were killed on d 67 (average weight of 282 lb), and carcass data were collected. Because differences in slaughter weight and, thus, HCW are known to affect carcass measurements, carcass data were analyzed without and with HCW used as a

covariate to remove the effects of slaughtering pigs at a constant age rather than constant weight.

All data were analyzed as a randomized complete block design by using the MIXED procedure of SAS. Orthogonal contrasts were used to separate treatment means with comparisons between the control vs. high protein treatments and high protein from soybean meal vs. high protein from DDGS.

Results and Discussion

Pigs fed the 15.3% CP corn-soybean meal-based diet had greater ($P < 0.03$) ADG, ADFI, HCW, and dressing percentage than pigs fed the 18.3% CP treatments. The negative effects of the high protein treatments were caused entirely by the low ($P < 0.001$) ADG, ADFI, and HCW for pigs fed the DDGS diet compared with pigs fed the high protein corn-soybean meal-based diet. For further analysis of our results, HCW was used as a covariate to adjust the pigs to the same carcass weight. When this was done, there were no treatment effects ($P > 0.1$) for dressing percentage and percentage carcass lean. However, pigs fed the control diet had greater ($P < 0.09$) fat thickness than pigs fed the high protein treatments. Also, pigs fed the soybean meal treatment had less ($P < 0.04$) backfat than those fed the DDGS diet.

In conclusion, our data demonstrate that pigs fed 15.3% protein had greater ADG, ADFI, and HCW than pigs fed the 18.5% protein treatments. However, those negative effects resulted only from addition of 40% DDGS, suggesting that it is not the excess CP causing the negative effects.

Table 1. Composition of diets

	d 0 to 34			d 34 to 67		
Ingredient, %	Control	High SBM[1]	40% DDGS[2]	Control	High SBM	40% DDGS
Corn	79.78	72.06	52.82	81.70	74.13	54.74
DDGS	---	---	40.00	---	---	40.00
Soybean meal (47.5% CP)	17.80	25.85	4.95	16.20	24.00	3.25
Limestone	1.09	1.05	1.34	1.06	1.01	1.24
Monocalcium phosphate (21% P)	0.73	0.67	0.05	0.54	0.49	---
Salt	0.23	0.23	0.23	0.23	0.23	0.23
L-lysine HCl	0.20	---	0.47	0.13	---	0.40
L-threonine	0.03	---	---	---	---	---
Vitamin premix	0.04	0.04	0.04	0.04	0.04	0.04
Trace mineral premix	0.05	0.05	0.05	0.05	0.05	0.05
Antibiotic[3]	0.05	0.05	0.05	0.05	0.05	0.05
Calculated analysis, %						
Lysine	0.90	0.97	0.90	0.80	0.92	0.80
Ca	0.60	0.60	0.60	0.55	0.55	0.55
Total P	0.50	0.52	0.50	0.45	0.48	0.48
CP	15.3	18.3	18.3	14.6	17.6	17.6

[1] Soybean meal.
[2] Dried distillers grains with solubles.
[3] To provide 40 g/ton tylosin.

Table 2. Effects of excess dietary CP from soybean mean and dried distillers grains with solubles in diets for finishing pigs[1]

Item	Control	High CP corn-soy	High CP DDGS[2]	SE	*P* value: Control vs. others	*P* value: SBM vs. DDGS
d 0 to 67						
ADG, lb	2.11	2.10	1.88	0.03	0.001	0.001
ADFI, lb	6.55	6.41	5.82	0.09	0.001	0.001
F/G	3.10	3.05	3.10	0.03	---[3]	0.09
HCW, lb	215.2	213.9	200.9	3.55	0.001	0.001
Dress, %	74.2	74.2	73.3	0.33	0.02	0.08
Backfat thickness, in.	0.77	0.70	0.73	0.02	0.03	---
Loin depth, in.	2.42	2.46	2.36	0.05	---	0.11
Carcass lean, %	54.3	55.6	54.8	0.4	0.06	0.15
Adjusted dress, %[4]	73.8	73.6	74.0	0.41	---	---
Adjusted backfat, in.[4]	0.76	0.68	0.75	0.02	0.09	0.03
Adjusted loin depth, in.[4]	2.38	2.43	2.42	0.03	---	---
Adjusted carcass lean, %[4]	55.2	55.7	54.8	0.4	---	0.11

[1] A total of 180 pigs (90 barrows and 90 gilts, initially 148 lb) with 12 pigs per pen and 5 pens per treatment.
[2] Dried distillers grains with solubles.
[3] Dashes indicate $P > 0.15$.
[4] HCW used as a covariate.

EFFECTS OF ADDING ENZYMES TO DIETS WITH CORN- AND SORGHUM-BASED DRIED DISTILLERS GRAINS WITH SOLUBLES ON GROWTH PERFORMANCE AND NUTRIENT DIGESTIBILITY IN NURSERY AND FINISHING PIGS

C. Feoli, J. D. Hancock, T. L. Gugle, S. D. Carter[1], and N. A. Cole[2]

Summary

Two experiments were conducted to determine the effects of added enzymes on the nutritional value of diets with corn- and sorghum-based dried distillers grains with solubles (DDGS). For Exp. 1, 180 weanling pigs (initially 16.6 lb) were fed the same starter diet for 10 d and then used in a 27-d growth assay. There were 6 pigs per pen and 6 pens per treatment. Treatments were a corn-soybean meal-based control and diets with 30% corn-based (Hudson, SD) and sorghum-based (Russell, KS) DDGS with and without enzymes (a cocktail of ß-glucanase, protease, α-amylase, and xylanase to supply 331, 1,102, 2,205, and 8,818 units of activity, respectively, per pound of diet). Pigs fed the control diet had greater ($P < 0.003$) ADG, ADFI, and digestibility of DM, N, and GE than pigs fed the DDGS treatments; sorghum-based DDGS supported worse ($P < 0.04$) F/G and digestibilities of N and GE than corn-based DDGS. Addition of enzymes tended to improve F/G ($P < 0.09$) and did improve digestibility of DM ($P < 0.04$) for pigs fed diets with 30% DDGS, and this response was similar regardless of DDGS source. For Exp. 2, 330 finishing pigs (initially 141 lb) were used in a 65-d growth assay. There were 11 pigs per pen and 6 pens per treatment. Treatments were the same as in Exp. 1, but 40% DDGS was used in diets for the finishing experiment. Pigs fed the control diet had greater ADG, ADFI, and digestibility of DM, N, and GE and lower iodine value than pigs fed the DDGS treatments ($P < 0.008$). Pigs fed the corn-based DDGS treatments had better F/G and digestibility of DM, N, and GE but greater iodine value of jowl fat than pigs fed the sorghum-based DDGS treatments ($P < 0.04$). Enzymes improved digestibility of DM, N, and GE ($P < 0.01$), especially for diets with sorghum-based DDGS (DDGS source × enzyme interaction, $P < 0.10$). In conclusion, growth performance and nutrient digestibility were decreased with addition of DDGS to diets for nursery and finishing pigs, but adding enzymes partially restored the losses in nutrient digestibility.

Key words: digestibility, dried distillers grains with solubles, enzyme supplementation

Introduction

Price and availability make using ethanol industry coproducts in diets for pigs a very attractive option. However, previous studies from this laboratory indicated that inclusion of high levels of dried distillers grains with solubles (DDGS) in diets for nursery and finishing pigs had negative effects on growth performance and nutrient digestibility. Dried distillers grains with solubles have approximately 16% cellulose, 8% xylans, and 5% arabinans and are known to reduce digestibility of

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nutrients. We have reported that enzymes can improve nutrient digestibility in wheat-based diets when their specific substrates are present. Thus, it seems likely that adding enzymes to DDGS-based diets might improve nutrient utilization. Therefore, the objective of these experiments was to determine the effects of enzyme additions on the nutritional value of diets with corn- and sorghum-based DDGS in nursery and finishing pigs.

Procedures

For Exp. 1, 180 weanling pigs (initially 16.6 lb) were fed the same starter diet for 10 d and then used in a 27-d growth assay. The pigs were sorted by sex and ancestry, blocked by weight, and assigned to pens. There were 6 pigs per pen and 6 pens per treatment. The pigs were housed in an environmentally controlled nursery room having 4-ft × 4-ft pens with woven-wire flooring. Each pen had a self-feeder and nipple waterer to allow ad libitum consumption of feed and water. The diets (Table 1) were offered to the pigs in meal form.

Treatments were arranged as a 2 × 2 factorial plus control with main effects of DDGS source (corn-based DDGS from Sioux River Ethanol, Hudson, SD, and sorghum-based DDGS from U.S. Energy Partners, Russell, KS) and enzyme addition (with and without 331, 1,102, 2,205, and 8,818 units of β-glucanase, protease, α-amylase, and xylanase per pound of diet).

Pigs and feeders were weighed on d 0, 10, and 27 to allow calculation of ADG, ADFI, and F/G. Feces were collected on d 15 and 16 from no less than 3 pigs per pen, and DM, N, GE, and Cr were determined to allow calculation of apparent nutrient digestibility.

Data were analyzed as a randomized complete block design by using the MIXED procedure of SAS with initial weight as the blocking criterion and pen as the experimental unit. Orthogonal contrasts were used to separate treatment means with comparisons of (1) control vs. DDGS treatments, (2) effect of DDGS source, (3) effect of enzyme addition, and (4) interaction among DDGS source and enzyme addition.

For Exp. 2, a total of 330 finishing pigs (initially 141 lb) were used in a 65-d growth assay. The pigs were sorted by sex and ancestry, blocked by weight, and assigned to pens. There were 11 pigs per pen and 5 pens per treatment. The pigs were housed in an environmentally controlled finishing facility having 6-ft × 16-ft pens with half solid and half slatted concrete flooring. Each pen had a self-feeder and nipple waterer to allow ad libitum consumption of feed and water. Treatments were arranged as a 2 × 2 factorial plus control as in Exp. 1, but 40% DDGS was used in diets for the finishing experiment (Table 2).

Pigs and feeders were weighed on d 0, 35, and 65 to allow calculation of ADG, ADFI, and F/G. Feces were collected mid-experiment from no less than 6 pigs per pen, and DM, N, GE, and Cr were determined to allow calculation of apparent nutrient digestibility. Half of the pigs were slaughtered (average BW of 270 lb) to allow collection of carcass data and samples of jowl fat. Fatty acid profile of jowl fat was determined and iodine value was calculated following AOCS (1998) procedures.

Growth performance, nutrient digestibility, and carcass data were analyzed as a randomized complete block design by using the MIXED procedure of SAS with initial weight as the blocking criterion and pen as the experimental unit. Orthogonal contrasts were used to separate treatment means with comparisons of (1) control vs. DDGS treatments, (2) effect of DDGS source, (3) effect of enzyme addition, and (4) interaction among DDGS source and enzyme addition.

Results and Discussion

In the nursery experiment (Table 3), pigs fed the control diet had greater overall ADG, ADFI, and digestibility of DM, N, and GE than pigs fed the DDGS treatments ($P < 0.003$). Pigs fed diets with corn-based DDGS had greater ($P < 0.04$) digestibility of N and GE than pigs fed diets with sorghum-based DDGS. Addition of enzymes improved ADG for pigs fed corn-based DDGS but decreased ADG for pigs fed sorghum-based DDGS (DDGS source × enzyme interaction, $P < 0.04$). Additionally, enzyme addition tended to improve ($P < 0.09$) F/G and did improve ($P < 0.04$) digestibility of DM regardless of DDGS source.

In the finishing experiment (Table 4), pigs fed the control diet had greater ($P < 0.008$) overall ADG and ADFI and digestibility of DM, N, and GE than pigs fed the DDGS diets. Furthermore, pigs fed the corn-based DDGS treatments had better ($P < 0.04$) overall F/G and digestibility of DM, N, and GE than pigs fed the sorghum-based DDGS treatments. Enzymes had no effect on growth performance ($P > 0.14$) but improved ($P < 0.01$) digestibility of DM, N, and GE, especially for diets with sorghum-based DDGS (DDGS source × enzyme interaction, $P < 0.10$). As for carcass data, the effects of DDGS on ADG were reflected in the lower ($P < 0.002$) HCW for pigs fed diets with DDGS. Percentage carcass lean, backfat thickness, and loin depth were not affected ($P > 0.11$) by treatment, but addition of 40% DDGS increased ($P < 0.001$) iodine value of jowl fat. Diets with corn-based DDGS resulted in greater ($P < 0.001$) iodine value of jowl fat than diets with sorghum-based DDGS.

In conclusion, rate of gain and nutrient digestibility were decreased with addition of DDGS to diets for nursery and finishing pigs, and adding enzymes partially restored those losses in nutrient digestibility.

Table 1. Composition of nursery diets

	d 0 to 10		d 10 to 27	
Ingredient, %	Control	DDGS[1]	Control	DDGS
Corn	47.60	27.58	62.86	42.97
DDGS	---	30.00	---	30.00
Soybean meal (47.5% CP)	28.70	19.00	32.60	22.85
Whey	15.00	15.00	---	---
Fish meal	3.00	3.00	---	---
Spray-dried plasma	2.50	2.50	---	---
Limestone	0.87	1.06	1.11	1.36
Monocalcium phosphate (21% P)	0.62	0.11	1.30	0.67
Salt	0.30	0.30	0.36	0.35
L-lysine HCl	0.21	0.41	0.32	0.53
DL-methionine	0.13	0.03	0.12	0.02
L-threonine	0.02	-	0.09	0.05
Vitamin premix	0.08	0.08	0.11	0.11
Mineral premix	0.07	0.03	0.08	0.05
Antibiotic[2]	0.70	0.70	0.70	0.70
Chromic oxide[3]	---	---	0.25	0.25
Zinc oxide	0.20	0.20	---	---
Copper sulfate	---	---	0.10	0.09
Calculated analysis, %				
Lysine	1.60	1.60	1.40	1.40
Ca	0.80	0.80	0.75	0.75
Total P	0.70	0.70	0.65	0.65

[1] Dried distillers grains with solubles.
[2] To supply 140 g/ton oxytetracycline and 140 g/ton neomycin.
[3] Used as an indigestible marker.

Table 2. Composition of finishing diets

	d 0 to 35		d 35 to 65	
Ingredient, %	Control	DDGS [1]	Control	DDGS
Corn	79.72	52.75	81.56	54.67
DDGS	---	40.00	---	40.00
Soybean meal (47.5% CP)	17.80	4.95	16.20	3.25
Limestone	1.09	1.34	1.06	1.24
Monocalcium phosphate (21% P)	0.73	0.05	0.54	---
Salt	0.30	0.30	0.38	0.30
L-lysine HCl	0.20	0.47	0.13	0.40
L-threonine	0.03	---	---	---
Vitamin premix	0.04	0.04	0.04	0.04
Mineral premix	0.04	0.05	0.04	0.05
Antibiotic [2]	0.05	0.05	0.05	0.05
Calculated analysis, %				
Lysine	0.90	0.90	0.80	0.80
Ca	0.60	0.60	0.55	0.55
Total P	0.50	0.50	0.45	0.45

[1] Dried distillers grains with solubles.
[2] To provide 40 g/ton tylosin.

Table 3. Effects of adding enzymes to diets with corn- and sorghum-based dried distillers grains with solubles (DDGS) on growth performance and nutrient digestibility in nursery pigs[1]

		Corn-DDGS		Sorghum-DDGS			*P* value			
Item	Control	no enzyme	with enzyme	no enzyme	with enzyme	SE	Cont. vs. DDGS	DDGS source effect	Enzyme effect	DDGS × Enzyme
d 0 to 10										
ADG, lb	1.10	0.94	0.99	1.09	1.02	0.05	0.003	0.002	---[2]	0.02
ADFI, lb	1.34	1.15	1.16	1.32	1.23	0.06	0.001	0.001	---	0.07
F/G	1.22	1.22	1.17	1.21	1.21	0.01	---	---	---	0.08
d 0 to 27										
ADG, lb	1.27	1.16	1.19	1.20	1.15	0.04	0.001	---	---	0.04
ADFI, lb	1.82	1.64	1.65	1.80	1.70	0.06	0.001	0.001	0.15	0.08
F/G	1.43	1.41	1.39	1.50	1.48	0.01	---	0.001	0.09	---
Digestibility of DM, %[3]	80.4	75.0	76.7	75.6	76.3	0.5	0.001	---	0.04	---
Digestibility of N, %	75.9	75.5	76.4	68.5	68.2	1.0	0.003	0.001	---	---
Digestibility of GE, %	78.4	73.6	75.0	72.6	72.9	0.7	0.001	0.04	---	---

[1]A total of 180 nursery pigs (31 d old, initially 16.6 lb) with 6 pigs per pen and 6 pens per treatment.
[2]Dashes indicate $P > 0.15$.
[3]Fecal samples were collected on d 15 and 16 with chromic oxide used as an indigestible marker.

Table 4. Effects of adding enzymes to diets with corn- and sorghum-based dried distillers grains with solubles (DDGS) on growth performance, nutrient digestibility, and carcass characteristics in finishing pigs[1]

		Corn-DDGS		Sorghum-DDGS			*P* value			
Item	Control	no enzyme	with enzyme	no enzyme	with enzyme	SE	Cont. vs DDGS	DDGS source effect	Enzyme effect	DDGS × Enzyme
d 0 to 35										
ADG, lb	2.23	1.89	1.92	1.97	2.00	0.08	0.001	0.06	---[2]	---
ADFI, lb	6.50	5.58	5.60	5.98	6.13	0.19	0.001	0.001	---	---
F/G	2.91	2.95	2.92	3.04	3.07	0.09	0.12	0.02	---	---
d 0 to 65										
ADG, lb	2.14	1.91	1.90	1.96	1.96	0.07	0.001	0.13	---	---
ADFI, lb	6.71	6.00	6.12	6.43	6.55	0.25	0.008	0.004	---	---
F/G	3.14	3.14	3.22	3.28	3.34	0.07	0.08	0.02	0.15	---
Digestibility of DM, %[3]	84.5	77.5	79.1	73.0	78.5	1.1	0.001	0.04	0.004	0.10
Digestibility of N, %	78.0	76.1	77.5	62.3	70.0	1.3	0.001	0.001	0.002	0.02
Digestibility of GE, %	82.9	76.7	77.9	70.3	75.6	1.1	0.001	0.001	0.01	0.09
HCW, lb	200.0	189.0	184.0	187.5	188.1	6.8	0.002	---	---	---
Dress, %[4]	73.0	72.7	72.7	72.1	72.3	0.2	0.11	0.06	---	---
Carcass lean, %[4]	54.2	53.9	54.0	54.3	54.2	0.6	---	---	---	---
Backfat thickness, in.[4]	0.65	0.64	0.64	0.62	0.60	0.05	---	---	---	---
Loin depth, in.[4]	2.34	2.25	2.25	2.29	2.24	0.04	0.12	---	---	---
Iodine value[4,5]	70.3	80.4	80.1	74.6	74.3	0.7	0.001	0.001	---	---

[1] A total of 330 finishing pigs (initially 141 lb) with 11 pigs per pen and 6 pens per treatment.
[2] Dashes indicate $P > 0.15$.
[3] Fecal samples were collected mid-experiment with chromic oxide used as an indigestible marker.
[4] HCW used as a covariate.
[5] As calculated from fatty acid profile of jowls.

EVALUATION OF COMMERCIAL ENZYME SUPPLEMENTATION ON GROWING PIG PERFORMANCE[1]

J. Y. Jacela[2], S. S. Dritz[2], M. D. Tokach, J. M. DeRouchey, J. L. Nelssen, R. D. Goodband, and P. Brown[3]

Summary

A total of 1,129 pigs were used in a 56-d study to evaluate the effect of a commercial enzyme on growth performance and assess its energy replacement value in swine diets. Pigs were blocked on the basis of pen weights and allotted to 1 of 6 dietary treatments fed in 3 phases. Dietary treatments had increasing levels of fat (0, 2.5, and 5.0%) with or without added enzyme (0.05% or 0% Agri-King REAP). Phase 1 was fed from approximately 75 to 110 lb BW, phase 2 was fed from 110 to 160 lb BW, and phase 3 was fed from 160 to 200 lb BW. Diets were based on cornmeal and soybean meal with 15% added dried distillers grains with solubles (DDGS) and balanced to a constant lysine to calorie ratio (2.98, 2.68, and 2.38 g/Mcal ME for phases 1, 2, and 3, respectively) within diet phase. Pen weights and feed intake were obtained every 2 wk from d 0 to 56 to determine ADG, ADFI, and F/G. There were no interactions ($P > 0.11$) between the addition of enzyme and added fat for ADG, ADFI, or F/G of pigs throughout the duration of the 84-d experiment. There was no difference ($P = 0.53$) in ADG, ADFI, or F/G between pigs fed diets with and without added enzyme. However, pigs fed diets with increasing added fat levels had improved (linear, $P < 0.03$) ADG and F/G. In conclusion, the addition of the commercial enzyme did not affect growth performance of pigs in this study, but ADG and F/G improved with the addition of fat in the corn-soybean meal-based diets with 15% DDGS.

Key words: enzyme, fat, growth, pig

Introduction

Grains such as corn comprise the majority portion of swine diets mainly as an energy source. However, a fraction of nutrients in these ingredients are found in forms known as dietary fiber that monogastric animals like pigs are unable to fully digest. For this reason, use of commercial enzymes in swine diets may become an important tool in improving feeding efficiency by providing a means for the pig to digest fiber components that can then be utilized for growth. As feed costs increase, the economic value of additives like enzymes, which have the potential to improve energy digestibility and, therefore, feed efficiency, also increases. Enzymes are designed to act on specific substrates. Thus, the use of a multienzyme preparation can potentially have more beneficial effects than single enzyme preparations because it acts on several

[1] Appreciation is expressed to Agri-King, Inc., Fulton, IL, for partial funding of the study, New Horizon Farms for use of pigs and facilities, and Richard Brobjorg and Marty Heintz for technical assistance.
[2] Food Animal Health and Management Center, College of Veterinary Medicine, Kansas State University.
[3] Agri-King Inc., Fulton, IL.

substrates and releasing nutrients trapped within the indigestible components of grains.

Agri-King REAP (Agri-King Inc., Fulton, IL) is a proprietary blend of enzymes that has β-glucanase, cellulase, and protease activities. These enzymes act on dietary fiber found in the plant cell wall as well as a smaller group of storage carbohydrates found in common ingredients like cornmeal and soybean meal. Although many studies have been conducted on enzyme supplementation on pig diets, data for this relatively new enzyme product are needed to evaluate its effects in a commercial pig production setting. Therefore, this trial was conducted to evaluate the effect of a commercial enzyme (Agri-King REAP) on growth performance and assess its energy replacement value in swine diets.

Procedures

Procedures for this trial were approved by the Kansas State University Institutional Animal Care and Use Committee. The trial was conducted in a commercial research finishing barn in southwest Minnesota. The barns were double curtain sided with 18-ft × 10-ft pens that have completely slatted flooring and deep pits for manure storage. Each pen contained 1 self-feeder and 1 cup waterer. The barn was equipped with a robotic feeding system to provide feed intake on an individual pen basis.

A total of 1,129 pigs (PIC 337 × C22) were blocked on the basis of pen weights and allotted to 1 of 6 dietary treatments. The dietary treatments were increasing levels of fat (0, 2.5, and 5.0%) with or without added enzyme (0.05 or 0% Agri-King REAP). Diets were fed in 3 phases with phase 1 fed from approximately 75 to 110 lb BW, phase 2 fed from 110 to 160 lb BW, and phase 3 fed from 160 to 200 lb BW (Table 1). Diets were based on cornmeal and soybean meal with 15% added dried distillers grains with solubles and balanced to a constant lysine to calorie ratio (2.98, 2.68, and 2.38 g/Mcal ME for phases 1, 2, and 3, respectively) within diet phase. Pigs from each pen were weighed as a group every 2 wk from d 0 to 56 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 by using the MIXED procedure of SAS. Data were analyzed as a randomized complete block design with pen as the experimental unit. Linear and polynomial contrasts were used to determine the main effects of increasing fat levels.

Results and Discussion

There were no significant interactions ($P > 0.32$; Table 2) between the addition of enzyme and increasing fat additions for any of the time periods or overall.

Pigs fed diets with added enzyme had lower ($P = 0.04$; Table 3) ADG from d 0 to 28 than pigs fed diets without enzyme. From d 28 to 56, however, ADG and feed intake were greater ($P < 0.03$) for pigs fed diets with added enzyme. There was no difference ($P = 0.94$) in growth performance between pigs fed diets with and without added enzyme from d 0 to 56. Addition of enzyme did not affect F/G ($P > 0.51$) in any phase or for the overall 56-d period.

The addition of fat improved (linear, $P < 0.01$) F/G, and feed intake tended to decrease ($P < 0.06$) as fat levels were increased from 0 to 5% in the diet for the d 0 to 28 period. In the second period (d 28 to 56), feed intake was lower and F/G improved (linear, $P < 0.01$) as the level of fat addition increased. For the overall period (d 0 to 56), ADG increased, ADFI decreased, and F/G improved (linear, $P < 0.01$) as fat was increased from 0 to 5%. For every 1% added fat, F/G was improved 1.3 and 1.2% in pigs fed 2.5 and 5.0% added fat in their diets, respectively. The observed

improvement in feed efficiency for every 1% added fat in this study was lower than the previously reported improvement of 1.8% for every 1% increment of added fat in growing-finishing pig diets. In conclusion, the addition of the commercial enzyme did not affect growth performance of pigs in this study. As expected, ADG and F/G improved with the addition of fat in the diets.

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

		Phase 1			Phase 2			Phase 3		
Item	Fat, %	0	2.5	5.0	0	2.5	5.0	0	2.5	5.0
Ingredient, %										
Corn		60.59	56.54	52.45	64.73	60.82	56.92	68.76	64.98	61.21
Soybean meal (46.5% CP)		22.36	23.86	25.40	18.37	19.78	21.18	14.39	15.67	16.94
DDGS[3]		15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Choice white grease		0.00	2.50	5.00	0.00	2.50	5.00	0.00	2.50	5.00
Monocalcium P (21% P)		0.15	0.20	0.25	0.00	0.00	0.00	0.00	0.00	0.00
Limestone		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Salt		0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix with phytase[4]		0.15	0.15	0.15	0.15	0.15	0.15	0.13	0.13	0.13
Trace mineral premix		0.15	0.15	0.15	0.15	0.15	0.15	0.13	0.13	0.13
L-lysine HCl		0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Total		100	100	100	100	100	100	100	100	100
Calculated analysis										
Standardized ileal digestible (SID) amino acids										
Lysine, %		1.00	1.03	1.07	0.90	0.93	0.96	0.80	0.83	0.85
Methionine:lysine ratio, %		30	29	28	31	30	30	33	32	31
Met & Cys:lysine ratio, %		61	59	58	63	62	60	67	65	63
Threonine:lysine ratio, %		62	61	61	62	62	61	63	63	62
Tryptophan:lysine ratio, %		18	18	18	18	18	18	18	18	18
Total lysine, %		1.15	1.18	1.22	1.04	1.07	1.10	0.93	0.96	0.98
CP, %		19.9	20.2	20.6	18.4	18.7	19.0	16.9	17.1	17.4
SID Lysine:calorie ratio, g/Mcal ME		2.98	2.98	2.98	2.68	2.68	2.68	2.38	2.38	2.38
ME, kcal/lb		1,520	1,571	1,621	1,523	1,575	1,626	1,525	1,576	1,627
Ca, %		0.51	0.52	0.53	0.47	0.47	0.47	0.45	0.46	0.46
P, %		0.46	0.47	0.48	0.41	0.41	0.41	0.40	0.40	0.39
Available P, %		0.31	0.32	0.33	0.27	0.27	0.27	0.25	0.25	0.25

[1] Phase 1 was fed from 75 to 110 lb, phase 2 was fed from 110 to 160 lb, and phase 3 was fed from 160 to 200 lb.
[2] Agri-King REAP (Agri-King Inc., Fulton, IL) added at 0.05% in all phases at increasing levels of fat to make the enzyme treatments.
[3] Dried distillers grains with solubles.
[4] Provided 898 FTU/kg phytase with an expected phytate P release of 0.14% for phase 1, 898 FTU/kg phytase with an expected phytate P release of 0.13% for phase 2, and 748 FTU/kg phytase with an expected phytate P release of 0.12% for phase 3.

Table 2. Effect of enzyme at increasing levels of fat on growth performance[1,2]

	No Enzyme			Enzyme				
	Added fat,%			Added fat, %				Probability, *P* <
Item	0	2.50	5.0	0	2.50	5.0	SE	Enzyme × Fat
Weight, lb								
d 0	75.9	75.7	75.6	75.7	76.0	74.51	1.8	0.93
d 28	135.1	135.8	134.9	132.9	133.8	133.7	2.4	0.98
d 56	191.3	193.9	192.8	190.9	192.4	193.1	2.6	0.94
d 0 to 28								
ADG, lb	2.04	2.07	2.03	1.97	1.99	2.04	0.03	0.32
ADFI, lb	4.76	4.54	4.50	4.54	4.40	4.42	0.10	0.75
FG	2.34	2.20	2.21	2.30	2.21	2.17	0.04	0.73
d 28 to 56								
ADG, lb	2.08	2.13	2.14	2.12	2.16	2.21	0.02	0.80
ADFI, lb	5.38	5.37	5.09	5.48	5.51	5.36	0.07	0.44
FG	2.59	2.52	2.38	2.58	2.54	2.43	0.04	0.72
d 0 to 56								
ADG, lb	2.06	2.10	2.09	2.04	2.07	2.12	0.02	0.33
ADFI, lb	5.06	4.94	4.78	4.99	4.93	4.87	0.08	0.58
FG	2.46	2.35	2.29	2.44	2.38	2.30	0.03	0.79

[1] A total of 1,129 pigs (initially 75.8 lb) with 27 pigs per pen were used with 7 replications per treatment.

[2] One pen on the 5% fat with enzyme treatment was excluded from data analysis as an outlier.

Table 3. Effect of enzyme and increasing levels of fat on growth performance[1,2]

								Probability, $P <$		
	Enzyme			Fat					Fat	
Item	No	Yes	SE	0%	2.50%	5.0%	SE	Enzyme	Linear	Quadratic
Weight, lb										
d 0	75.7	75.4	1.0	75.8	75.8	75.1	1.3	0.81	0.69	0.81
d 28	135.3	133.5	1.4	134.0	134.8	134.3	1.7	0.36	0.87	0.75
d 56	192.7	192.1	1.5	191.1	193.1	193.0	1.8	0.80	0.47	0.62
d 0 to 28										
ADG, lb	2.05	2.00	0.02	2.01	2.03	2.03	0.02	0.04	0.32	0.67
ADFI, lb	4.60	4.45	0.06	4.65	4.47	4.46	0.07	0.07	0.06	0.34
FG	2.25	2.23	0.02	2.32	2.20	2.19	0.02	0.51	0.001	0.08
d 28 to 56										
ADG, lb	2.12	2.16	0.01	2.10	2.15	2.17	0.02	0.03	0.01	0.61
ADFI, lb	5.28	5.45	0.04	5.43	5.44	5.22	0.05	0.01	0.01	0.09
FG	2.50	2.52	0.02	2.59	2.53	2.41	0.03	0.54	0.0001	0.27
d 0 to 56										
ADG, lb	2.08	2.08	0.01	2.05	2.09	2.10	0.01	0.94	0.01	0.54
ADFI, lb	4.93	4.93	0.04	5.02	4.94	4.83	0.05	0.95	0.01	0.84
FG	2.37	2.37	0.02	2.45	2.37	2.30	0.02	0.82	0.0001	0.77

[1] A total of 1,129 pigs (initially 75.8 lb) with 27 pigs per pen were used with 21 replications per treatment for the enzyme effects and 14 replications per treatment for the fat levels.

[2]One pen on the 5% fat with enzyme treatment was excluded from data analysis as an outlier.

EFFECTS OF COMMERCIAL ENZYMES IN DIETS CONTAINING DRIED DISTILLERS GRAINS WITH SOLUBLES FOR NURSERY PIGS[1]

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Summary

Two experiments utilizing a total of 530 pigs were conducted to evaluate the effects of commercial enzymes in diets containing dried distillers grains with solubles (DDGS) on nursery pig growth performance. In Exp. 1, 180 pigs (initially 19.9 lb) were used in a 27-d growth trial to compare the effects of Easyzyme, Hemicell-W, and Porzyme in diets containing 30% DDGS on weanling pig performance. The 5 dietary treatments fed were a positive control (corn-soybean meal-based diet), negative control (diet with 30% corn DDGS), and the negative control diet with either 0.05% Easyzyme, 0.05% Hemicell-W, or 0.05% Porzyme added. Overall (d 0 to 27), pigs fed the diet containing Easyzyme had lower ($P < 0.05$) ADG than pigs fed the positive control diet. Pigs fed diets containing Hemicell-W had lower ($P < 0.05$) ADG than pigs fed the control diet with or without 30% DDGS or the diet containing Porzyme. Pigs fed the diet containing Porzyme had ADG similar ($P > 0.10$) to that of pigs fed the control diets with or without 30% DDGS. There were no differences ($P > 0.10$) in ADFI or F/G.

In Exp. 2, 350 pigs (initially 24.3 lb) were used to evaluate the effects of a commercial enzyme in diets containing a variety of levels and sources of DDGS on nursery pig performance. The 10 experimental treatments were (1) corn-soybean meal positive control, (2) 15% corn DDGS, (3) 30% corn DDGS, (4) 30% corn DDGS + 0.05% Easyzyme, (5) 15% milo DDGS from source 1, (6) 30% milo DDGS from source 1, (7) 30% milo DDGS from source 1 + 0.05% Easyzyme, (8) 15% milo DDGS from source 2, (9) 30% milo DDGS from source 2, and (10) 30% milo DDGS from source 2 + 0.05% Easyzyme. Overall (d 0 to 21), there was no ($P > 0.10$) enzyme × DDGS source interaction for any of the measured growth variables. Pigs fed diets with increasing corn DDGS had ADG, ADFI, and F/G similar ($P > 0.10$) to those of pigs fed the control diet. Pigs fed diets with increasing milo DDGS had poorer (linear, $P = 0.002$) F/G than pigs fed the control diet. Also, pigs fed diets containing milo DDGS had poorer ($P = 0.04$) F/G than pigs fed diets containing corn DDGS. However, pigs fed different sources of milo DDGS had similar ($P > 0.10$) ADG, ADFI, and F/G. Adding 0.05% Easyzyme to the diets containing 30% DDGS did not influence ($P > 0.10$) ADG, ADFI, or F/G.

[1] Appreciation is expressed to ADM, Decatur, IL; Danisco, New Century, MO; and Form-A-Feed, Inc., Stewart, MN, for providing the enzymes and Chief Ethanol Fuels, Inc., Hastings, NE; Kansas Ethanol, Lyons, KS; and U.S. Energy Partners, Russell, KS, for providing the various sources of DDGS.
[2] Food Animal Health and Management Center, College of Veterinary Medicine, Kansas State University.

In summary, feeding diets with milo DDGS resulted in poorer F/G with no change in ADG compared with feeding the control diet or diets containing corn DDGS. Adding enzymes to corn-soybean meal-based diets containing high levels of DDGS did not improve any of the growth performance variables.

Key words: distillers, enzyme, growth, nursery pig

Introduction

Rising feed ingredient costs have prompted the swine industry to utilize products that improve feed efficiency. Enzymes have been used extensively in Europe, where feedstuffs with high fiber concentrations are the primary source of carbohydrates in swine diets. Enzymes are used to improve feed utilization and decrease the cost of gain. Because corn is highly digestible and has a low fiber content, enzymes have not consistently shown economic improvements in growth performance when used in corn-based diets.

Recently, high ingredient costs have led to increasing use of coproduct ingredients in swine diets. Dried distillers grains with solubles (DDGS) are one such coproduct that is widely used. Because the starch fraction is removed, DDGS have a greater fiber fraction than corn. Therefore, enzymes may be more beneficial in diets containing DDGS than in corn-soybean meal-based diets. The objective of these experiments was to evaluate the effects of different commercial enzymes in diets containing a variety of sources of DDGS on weanling pig growth performance.

Procedures

All experimental procedures were approved by the Kansas State University (KSU) Institutional Animal Care and Use Committee.

Experiment 1. A total of 180 pigs (initially 19.9 lb) were used in a 27-d growth trial to evaluate the effects of 3 different commercial enzymes in diets containing corn DDGS on weanling pig performance. Pigs were blocked by weight and allotted to 1 of 5 dietary treatments. There were 6 pigs per pen and 6 pens per treatment. Each pen contained 1 self-feeder and 1 nipple waterer to provide ad libitum access to feed and water. Pigs were housed in the KSU Swine Teaching and Research Center.

A common pelleted starter diet was fed from weaning until the start of the experiment. The 5 dietary treatments fed were (1) positive control (corn-soybean meal diet), (2) negative control (corn-soybean meal diet with 30% corn DDGS; Chief Ethanol Fuels, Hastings, NE), and the negative control diet with either (3) 0.05% Easyzyme (Archer Daniels Midland Company, Decatur, IL), (4) 0.05% Hemicell-W (Form-A-Feed, Inc., Stewart, MN), or (5) 0.05% Porzyme (Danisco, New Century, MO) added (Table 1). Inclusion levels were based on manufacturers' recommendations and guaranteed analysis (Table 2). Treatment diets were fed for 27 d and were in meal form. Average daily gain, ADFI, and F/G were determined by weighing pigs and measuring feed disappearance on d 7, 14, and 27 of the trial.

Data were analyzed as a randomized complete block design with pen as the experimental unit. Pigs were blocked on the basis of weight at the beginning of the trial, and analysis of variance was performed by using the MIXED procedure of SAS. Contrasts were used to determine the effects of enzyme source compared with the control.

Experiment 2. A total of 350 pigs (initially 24.3 lb) were used in a 21-d growth trial to evaluate the effects of a commercial enzyme in diets containing corn or milo DDGS on nursery pig performance. Pigs were blocked by weight and allotted to 1 of 10 dietary treatments. There were 5 pigs per pen and

7 pens per treatment. Each pen (5 ft × 5 ft) contained a 4-hole dry self-feeder and 1 cup waterer to provide ad libitum access to feed and water. The study was conducted at the KSU Segregated Early Weaning Facility.

Analyzed nutrient values were used in diet formulation (Table 3). The 10 experimental treatments were (1) positive control (corn-soybean meal diet), (2) 15% corn DDGS (Chief Ethanol Fuels, Hastings, NE), (3) 30% corn DDGS, (4) 30% corn DDGS + 0.05% Easyzyme (Archer Daniels Midland Company, Decatur, IL), (5) 15% milo DDGS from source 1 (Kansas Ethanol, Lyons, KS), (6) 30% milo DDGS from source 1, (7) 30% milo DDGS from source 1 + 0.05% Easyzyme,(8) 15% milo DDGS from source 2 (U.S. Energy Partners, Russell, KS), (9) 30% milo DDGS from source 2, and (10) 30% milo DDGS from source 2 + 0.05% Easyzyme (Table 4). Treatment diets were fed for 21 d. All diets were in meal form. Average daily gain, ADFI, and F/G were determined by weighing pigs and measuring feed disappearance on d 7, 14, and 21 of the trial.

Data were analyzed as a completely randomized design with pen as the experimental unit. Data were analyzed with an analysis of variance by using the MIXED procedure of SAS with treatment as a fixed effect. Contrasts were used to determine the effects of DDGS source and enzyme inclusion compared with the control.

Results and Discussion

Experiment 1. Diet analysis was similar to expected levels (Table 5). Overall (d 0 to 27), there were no differences ($P > 0.10$) between pigs fed the corn-soybean meal diet or the corn-soybean meal diet with 30% DDGS (Table 6). Furthermore, pigs fed diets containing Porzyme had ADG, ADFI, and F/G similar ($P > 0.10$) to those of pigs fed the corn-soybean meal diet with or without 30% DDGS. However, pigs fed diets containing Hemicell-W and Easyzyme had poorer ($P < 0.05$) ADG than pigs fed the positive control diet, and pigs fed the diet containing Hemicell-W also had lower ($P < 0.05$) ADG than pigs fed the negative control diet or diet containing Porzyme. There were no differences ($P > 0.10$) in ADFI or F/G.

Experiment 2. Diet analysis was similar to expected levels (Table 7). Corn DDGS had lower CP and fiber contents but higher crude fat content than milo DDGS. Milo DDGS from source 1 had higher CP, fat, fiber, and ash contents than milo DDGS from source 2. Overall (d 0 to 21), there were no ($P > 0.10$) enzyme × DDGS source interactions for any of the measured growth variables (Tables 8 and 9). Pigs fed diets with increasing corn DDGS had ADG, ADFI, and F/G similar ($P > 0.10$) to those of pigs fed the control diet. Pigs fed diets with increasing milo DDGS had poorer (linear, $P = 0.002$) F/G than pigs fed the control diet but similar ADG. Also, pigs fed diets containing milo DDGS diets had poorer ($P = 0.04$) F/G than pigs fed diets containing corn DDGS. Pigs fed different sources of milo DDGS had similar ($P > 0.10$) ADG, ADFI, and F/G. However, pigs fed diets containing 30% DDGS had ADG, ADFI, and F/G similar ($P > 0.10$) to those of pigs fed diets including 30% DDGS with 0.05% enzyme.

In summary, adding different enzymes to diets containing 30% DDGS did not improve performance compared with either a corn-soybean meal-based diet or a corn-soybean meal-based diet with 30% added DDGS. Feeding diets including milo DDGS resulted in poorer feed efficiency because of the lower energy content of milo DDGS. Neither source of milo DDGS nor inclusion of an enzyme affected growth performance variables.

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

Ingredient, %	0 % DDGS[2]	30% Corn DDGS[3,4]
Corn	65.42	41.35
Soybean meal (46.5%)	30.55	25.05
Corn DDGS	---	30.00
Monocalcium P (21% P)	1.65	0.90
Limestone	0.98	1.38
Salt	0.35	0.35
Vitamin premix	0.25	0.25
Trace mineral premix	0.15	0.15
Lysine-HCl	0.37	0.45
DL-methionine	0.15	0.06
L-threonine	0.14	0.06
Total	100.00	100.00
Calculated analysis		
Standardized ileal digestible amino acids, %		
Lysine	1.25	1.25
Isoleucine:lysine	60	68
Leucine:lysine	127	159
Methionine:lysine	35	33
Met & Cys:lysine	59	62
Threonine:lysine	63	63
Tryptophan:lysine	17	17
Valine:lysine	67	75
Total lysine, %	1.38	1.45
CP, %	20.3	23.8
ME, kcal/lb	1,496	1,421
Total lysine:ME ratio, g/Mcal	3.79	3.99
Ca, %	0.80	0.80
P, %	0.74	0.69
Available P, %	0.42	0.41

[1] Pigs were fed experimental diets for 27 d.
[2] Dried distillers grains withsolubles.
[3] Diets were formulated from the same lot of corn DDGS from Chief Ethanol Fuels, Hastings, NE.
[4] Easzyme, Hemicell-W, and Porzyme were added in place of corn.

Table 2. Guaranteed analysis of enzymes (Exp. 1 and 2)

Item	Easyzyme[1,2]	Hemicell-W[3]	Porzyme[4]
β-glucanase, units/g	1,100	---	---
β-mannanase, units/g	110	140,000,000	---
Xylanase, units/g	1,500	70,000,000	40,000

[1] Easyzyme (Archer Daniels Midland Company, Decatur, IL).
[2] One unit is micromoles total reducing sugars (glucose equivalent) released per minute at 30°C and pH 4.0.
[3] Hemicell-W (Form-A-Feed, Inc., Stewart, MN).
[4] Porzyme (Danisco, New Century, MO).

Table 3. Proximate analysis of DDGS[1] (Exp. 2, as-fed basis)[2]

	Corn DDGS[3]	Milo DDGS Source 1[4]	Milo DDGS Source 2[5]
DM, %	88.50	88.34	88.43
CP, %	25.94	30.74	29.67
Crude fat, %	8.93	10.22	8.91
Crude fiber, %	5.72	7.21	6.90
Ash, %	5.13	4.06	3.91
Ca, %	0.37	0.04	0.07
P, %	0.82	0.72	0.69

[1] Dried distillers grains with solubles.
[2] Results of analyzed values on which the diets were formulated.
[3] Chief Ethanol Fuels (Hastings, NE).
[4] Kansas Ethanol (Lyons, KS).
[5] U.S. Energy Partners (Russell, KS).

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

					Milo DDG[2]					
		Corn DDGS[3]			Source 1[4]			Source 2[5]		
	Control	15%	30%	30%	15%	30%	30%	15%	30%	30%
Enzyme[6]	No	No	No	Yes	No	No	Yes	No	No	Yes
Ingredient, %										
Corn	65.73	55.86	44.10	44.04	55.26	43.17	43.11	55.13	42.61	42.56
Soybean meal, 46.5%	30.24	25.38	22.55	22.55	25.88	23.22	23.23	25.97	23.73	23.74
DDGS	---	15.00	30.00	30.00	15.00	30.00	30.00	15.00	30.00	30.00
Monocalcium P, 21% P	1.63	1.25	0.85	0.85	1.30	0.95	0.96	1.30	1.00	1.00
Limestone	1.00	1.08	1.15	1.15	1.18	1.38	1.38	1.18	1.33	1.33
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.25	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	0.15
Lysine-HCl	0.38	0.44	0.44	0.44	0.44	0.45	0.45	0.45	0.46	0.46
DL-methionine	0.14	0.11	0.06	0.06	0.09	0.02	0.02	0.10	0.05	0.05
L-threonine	0.14	0.14	0.11	0.11	0.12	0.07	0.07	0.12	0.08	0.08
Easyzyme	---	---	---	0.05	---	---	0.05	---	---	0.05
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis										
Standardized ileal amino acids, %										
Lysine	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Isoleucine:lysine	59	59	61	61	62	67	67	62	67	67
Leucine:lysine	127	135	147	147	147	171	171	147	171	171
Methionine:lysine	34	33	31	31	32	29	29	32	30	30
Met & Cys:lysine	58	58	58	58	58	58	58	58	58	58
Threonine:lysine	62	62	62	62	62	62	62	62	62	62
Tryptophan:lysine	17	16	16	16	16	16	16	16	16	16
Valine:lysine	66	67	67	67	71	79	79	71	78	78
Total lysine, %	1.38	1.42	1.47	1.47	1.41	1.45	1.45	1.41	1.44	1.44
CP, %	20.2	21.0	22.5	22.5	21.9	24.2	24.2	21.8	24.1	24.1
ME, kcal/lb	1,496	1,502	1,507	1,506	1,494	1,491	1,490	1494	1491	1490
Total lysine:ME ratio, g/Mcal	3.79	3.77	3.76	3.76	3.80	3.80	3.81	3.80	3.80	3.81
Ca, %	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
P, %	0.73	0.72	0.70	0.70	0.71	0.70	0.70	0.71	0.70	0.70
Available P, %	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42

[1] Pigs were fed experimental diets for 21 d. [2] Dried distillers grains with solubles (DDGS). [3] Diets were formulated from the same lot of corn DDGS from Chief Ethanol Fuels, Hastings, NE. [4] Diets were formulated from the same lot of milo DDGS from Kansas Ethanol, Lyons, KS. [5] Diets were formulated from the same lot of milo DDGS from U.S. Energy Partners, Russell, KS. [6] Easyzyme (Archer Daniels Midland Company, Decatur, IL).

Table 5. Analysis of diets (Exp. 1, as-fed basis)

	Corn-soy	30% Corn DDGS[1,2]			
Enzyme	No	No	Easyzyme[3]	Hemicell-W[4]	Porzyme[5]
DM, %	87.07	88.71	88.86	88.42	88.75
CP, %	19.88	22.56	24.06	22.97	24.15
Crude fat, %	2.18	4.54	4.43	4.26	4.64
Crude fiber, %	2.24	3.70	3.73	3.57	3.69
Ash, %	5.67	7.08	7.24	6.80	7.18

[1] Dried distillers grains with solubles.
[2] Diets were formulated from the same lot of corn DDGS from Chief Ethanol Fuels, Hastings, NE.
[3] Easyzyme (Archer Daniels Midland Company, Decatur, IL).
[4] Hemicell-W (Form-A-Feed, Inc., Stewart, MN).
[5] Porzyme (Danisco, New Century, MO).

Table 6. Effects of dried distillers grains with solubles (DDGS) enzymes on nursery pig performance (Exp. 1)[1]

		30% DDGS[2]				
Item	No Enzyme	No Enzyme	Easyzyme[3]	Hemicell-W[4]	Porzyme[5]	SE
d 0 to 27						
ADG, lb	1.17[a]	1.13[ab]	1.10[bc]	1.05[c]	1.15[ab]	0.033
ADFI, lb	1.70	1.70	1.61	1.55	1.74	0.084
F/G	1.45	1.51	1.45	1.47	1.52	0.048

[abc] Within a row, means without a common superscript letter differ ($P < 0.05$).
[1] A total of 180 pigs (6 pigs per pen and 6 pens per treatment) with an initial BW of 19.9 lb. Pigs were fed a common diet from weaning until the start of the trial then fed experimental diets for 27 d.
[2] Diets were formulated from the same lot of corn DDGS from Chief Ethanol Fuels, Hastings, NE.
[3] Easyzyme (Archer Daniels Midland Company, Decatur, IL).
[4] Hemicell-W (Form-A-Feed, Inc., Stewart, MN).
[5] Porzyme (Danisco, New Century, MO).

Table 7. Analysis of diets (Exp. 2, as-fed basis)

					Milo DDGS[1]					
		Corn DDGS[2]			Source 1[3]			Source 2[4]		
	Control	15%	30%	30%	15%	30%	30%	15%	30%	30%
Enzyme[5]	No	No	No	Yes	No	No	Yes	No	No	Yes
DM, %	86.98	87.60	88.28	88.48	87.64	88.62	87.48	87.08	87.81	87.50
CP, %	21.08	20.51	23.07	22.94	20.82	23.57	24.10	20.90	23.00	23.10
Crude fat, %	3.15	4.39	5.21	4.75	3.60	4.68	4.36	3.14	4.14	4.10
Crude fiber, %	2.37	2.84	3.27	3.40	3.10	3.90	3.55	2.71	3.76	3.45
Ash, %	5.49	5.44	5.81	5.66	5.55	5.40	5.71	5.32	5.29	5.10

[1] Dried distillers grains with solubles.
[2] Diets were formulated from the same lot of corn DDGS from Chief Ethanol Fuels, Hastings, NE.
[3] Diets were formulated from the same lot of milo DDGS from Kansas Ethanol, Lyons, KS.
[4] Diets were formulated from the same lot of milo DDGS from U.S. Energy Partners, Russell, KS.
[5] Easyzyme (Archer Daniels Midland Company, Decatur, IL).

Table 8. Effects of dried distillers grains with solubles (DDGS) with enzymes on nursery pig performance (Exp. 2)[1]

					Milo DDGS					
		Corn DDGS[2]			Source 1[3]			Source 2[4]		
	Control	15%	30%	30%	15%	30%	30%	15%	30%	30%
Enzyme[5]	No	No	No	Yes	No	No	Yes	No	No	Yes
d 0 to 21										
ADG, lb	1.05	1.02	1.03	1.03	1.07	1.01	0.98	1.05	1.02	1.04
ADFI, lb	1.60	1.60	1.60	1.62	1.68	1.65	1.57	1.68	1.68	1.69
F/G	1.53	1.57	1.55	1.57	1.57	1.63	1.60	1.59	1.65	1.63

[1] Pigs were fed experimental diets for 21 d.
[2] Diets were formulated from the same lot of corn DDGS from Chief Ethanol Fuels, Hastings, NE.
[3] Diets were formulated from the same lot of milo DDGS from Kansas Ethanol, Lyons, KS.
[4] Diets were formulated from the same lot of milo DDGS from U.S. Energy Partners, Russell, KS.
[5] Easyzyme (Archer Daniels Midland Company, Decatur, IL).

Table 9. Probability effects of dried distillers grains with solubles (DDGS) enzymes on nursery pig performance (Exp. 2)[1]

	Probability, *P* <								
	Corn DDGS[2]		Milo DDGS		Corn DDGS vs.	Source 1 Milo DDGS[3] vs.	Enzyme[4] vs.	30% DDGS vs.	
Item;	Linear	Quadratic	Linear	Quadratic	Milo DDGS	Source 2 Milo DDGS[5]	DDGS Source	30% DDGS + Enzyme	SEM
D 0 to 21									
ADG, lb	0.53	0.37	0.19	0.12	0.76	0.40	0.91	0.87	0.022
ADFI, lb	0.98	0.94	0.19	0.20	0.06	0.12	0.35	0.58	0.038
F/G	0.52	0.36	0.002	0.82	0.04	0.34	0.29	0.62	0.030

[1] Pigs were fed experimental diets for 21 d.
[2] Diets were formulated from the same lot of corn DDGS from Chief Ethanol Fuels, Hastings, NE.
[3] Diets were formulated from the same lot of milo DDGS from Kansas Ethanol, Lyons, KS.
[4] Easyzyme (Archer Daniels Midland Company, Decatur, IL).
[5] Diets were formulated from the same lot of milo DDGS from U.S. Energy Partners, Russell, KS.

EVALUATION OF DEOILED CORN DRIED DISTILLERS GRAINS WITH SOLUBLES (SOLVENT EXTRACTED) ON GROWTH PERFORMANCE OF NURSERY PIGS[1]

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Summary

A total of 210 pigs (initially 22.0 lb) were used in a 28-d study to evaluate the effects of increasing deoiled corn dried distillers grains with solubles, solvent extracted (dDGS) on nursery pig growth performance. Pigs were blocked on the basis of pen weight and randomly allotted to 1 of 5 dietary treatments containing 0, 5, 10, 20, or 30% dDGS. There were 7 pens per treatment and 6 pigs per pen. All diets were formulated to equivalent ME and standardized ileal digestible lysine concentrations. Soybean oil was added to the dDGS diets as an energy source to equalize dietary ME of the 5 treatments. Pigs from each pen were weighed as a group and feed consumption was obtained on d 0, 14, and 28 to determine ADG, ADFI, and F/G. Overall, feeding diets with increasing dDGS had no effect ($P > 0.46$) on nursery pig ADG, ADFI, and F/G. In conclusion, dDGS can be included at levels up to 30% in nursery pig diets for pigs weighing between 22 to 50 lb without affecting growth performance provided fat is added to the diet to offset the low energy content of dDGS.

Key words: deoiled corn dried distillers grains with solubles, feed ingredient, growth, nursery pig

Introduction

Because of recent increases in corn and soybean prices, the swine industry is seeking alternatives to these major feed ingredients. Coproducts of ethanol production such as dried distillers grains with solubles (DDGS) are widely available for use in livestock diets, and traditional DDGS are used frequently. As a result of increased ethanol production, the volume of DDGS as well as other coproducts is increasing. One such coproduct is deoiled corn DDGS, solvent extracted, (dDGS), which has higher CP, fiber, and mineral content than traditional DDGS. However, the energy value of dDGS is lower than that of traditional DDGS, a result of the deoiling process.

In a previous experiment conducted at Kansas State University, we were able to establish the amino acid digestibility coefficients and energy values of dDGS for swine. These values, aimed to provide reference values for diet formulation, were validated in a growth performance trial in growing and finishing pigs. Although use of dDGS in growing and finishing pig diets has been researched, the potential for using this coproduct in nursery diets has not been examined. Therefore, the objective of this trial was to evaluate the

[1] Appreciation is expressed to Verasun Energy Inc., Brookings, SD, for partial funding of the study.
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[4] DairyNet Inc., Brookings, SD.

effects of the dDGS on growth performance of nursery pigs.

Procedures

Experimental procedures used in this study were approved by the South Dakota State University Animal Care and Use Committee.

A total of 210 pigs (initially 22.0 lb) were blocked on the basis of pen weights and randomly allotted to 1 of 5 dietary treatments with 7 pens per treatment and 6 pigs per pen. Barrows and gilts were housed in separate mechanically ventilated barns. Both barns have completely slatted flooring; barrows were housed in 4-ft × 4-ft pens, gilts in 4-ft × 5-ft pens. Each pen was equipped with nipple waterers and 3-hole feeders. All pigs were fed similar starter diets until the start of the experiment.

The dDGS utilized in this experiment was analyzed for DM, CP, amino acids, crude fat, NDF, ADF, Ca and P (Table 1). Metabolizable energy and standardized ileal digestible (SID) amino acids values were determined from a previous study (Jaycela et al., 2007 Swine Day Report of Progress, p. 137). These values were then used in diet formulation. The 5 dietary treatments contained dDGS at 0, 5, 10, 20, or 30% (Table 2). All diets were formulated to contain equal ME and SID lysine concentrations. Soybean oil was added to the dDGS diets as an energy source to equalize dietary ME levels of the 5 treatments. To determine ADG, pigs from each pen were weighed as a group on d 0, 14, and 28. Feed consumption for each pen was also obtained during these times to determine ADFI and calculate F/G.

Data were analyzed as a randomized complete block design by using the PROC MIXED procedure of SAS. Pen served as the experimental unit. Linear and polynomial contrasts were used to determine the effects of increasing dDGS. Contrast coefficients were determined for unequally spaced treatments by using the IML procedure of SAS.

Results and Discussion

The analyzed nutrient content of dDGS was similar to values anticipated for this new ethanol coproduct. The CP was 28.3%, and the lysine concentration was 0.84%, giving a lysine:CP ratio of 2.97, indicating this is a high quality ethanol coproduct source.

Overall (d 0 to 28), nursery pigs fed increasing dDGS had similar ($P > 0.46$) ADG, ADFI, and F/G. These data indicate that increasing dietary dDGS up to 30% did not affect growth performance for nursery pigs weighing 22 to 50 lb when diets were balanced for both SID amino acids and ME.

Previous research evaluating the effects of traditional DDGS on nursery pig growth performance has shown that DDGS can be fed at levels up to 25% without negatively affecting growth performance. In this study, dDGS was added at levels up to 30%, and the resulting growth performance in nursery pigs was comparable to that of pigs fed diets without dDGS.

In conclusion, dDGS can be added to nursery diets for pigs weighing 22 to 50 lb without influencing growth performance provided fat is added to the diets to offset the decreased ME content of dDGS. In addition, these results further validate the accuracy of previously determined ME (1,137 kcal/lb) and SID amino acid values for dDGS.

Table 1. Analyzed nutrient composition content of deoiled corn dried distillers grains with solubles, solvent extracted (dDGS)

Item	Nutrient composition[1]	SID, %[2]
Proximate analysis, %		
DM	90.7	
CP	28.3	
Crude fat	4.1	
ADF	15.6	
NDF	34.2	
Ca	0.14	
P	0.69	
ME, kcal/lb[3]	1,137	
Amino acids, %		
Arginine	1.21	82.70
Histidine	0.74	74.63
Isoleucine	1.05	74.52
Leucine	3.26	83.79
Lysine	0.84	50.38
Methionine	0.58	80.41
Phenylalanine	1.37	80.77
Threonine	1.02	68.91
Tryptophan	0.19	77.96
Valine	1.43	73.75
Alanine	1.96	79.12
Aspartic acid	1.76	64.58
Cysteine	0.48	66.94
Glutamic acid	4.07	79.01
Glycine	1.09	64.63
Proline	2.01	87.79
Serine	1.21	76.86
Tyrosine	1.03	82.35

[1] As-fed basis.

[2] Standardized ileal digestibility (SID) values were determined in a previous study (Jacela et al., 2007 Swine Day Report of Progress, p. 137).

[3] Used in diet formulation and determined in a previous study (Jacela et al., 2007 Swine Day Report of Progress, p. 137).

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

	dDGS[2], %				
Item	0	5	10	20	30
Corn	63.76	59.08	54.46	45.18	35.88
Soybean meal (46.5% CP)	32.57	31.39	30.21	27.84	25.48
dDGS	---	5.00	10.00	20.00	30.00
Soybean oil	---	0.90	1.75	3.50	5.25
Monocalcium phosphate (21% P)	1.65	1.50	1.40	1.15	0.90
Limestone	0.95	1.05	1.10	1.23	1.38
Salt	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.05	0.05	0.05	0.05	0.05
Trace mineral premix	0.15	0.15	0.15	0.15	0.15
L-lysine HCl	0.30	0.33	0.35	0.40	0.45
DL-methionine	0.12	0.11	0.10	0.08	0.06
L-threonine	0.10	0.10	0.09	0.08	0.06
Total	100.00	100.00	100.00	100.00	100.00
Calculated analysis					
Standardized ileal digestible amino acids					
Lysine, %	1.25	1.25	1.25	1.25	1.25
Methionine:lysine ratio, %	33	33	33	33	33
Met & Cys:lysine ratio, %	58	58	58	58	58
Threonine:lysine ratio, %	62	62	62	62	62
Tryptophan:lysine ratio, %	18	18	18	17	17
Total lysine, %	1.38	1.40	1.42	1.45	1.48
CP, %	21.0	21.6	22.2	23.5	24.7
SID Lysine:calorie ratio, g/Mcal ME	3.79	3.79	3.79	3.79	3.79
ME, kcal/lb	1,496	1,496	1,496	1,496	1,496
Ca, %	0.80	0.80	0.80	0.80	0.80
P, %	0.75	0.73	0.73	0.71	0.69
Available P, %	0.42	0.42	0.42	0.42	0.42

[1] Fed from approximately 22 to 50 lb.
[2] Deoiled corn dried distillers grains with solubles, solvent extracted.

Table 3. Effects of increasing deoiled corn dried distillers grains with solubles, solvent extracted (dDGS) on nursery pig growth performance[1]

	dDGS, %						Probability, *P* <
Item	0	5	10	20	30	SE	Linear	Quadratic
Weight, lb								
d 0	22.0	22.0	21.1	21.9	21.9	1.0	0.94	0.70
d 28	50.0	50.3	49.0	49.4	49.2	1.2	0.56	0.77
d 0 to 28								
ADG, lb	1.00	1.01	1.00	0.98	0.97	0.04	0.50	0.97
ADFI, lb	1.65	1.70	1.67	1.66	1.68	0.02	0.99	0.89
F/G	1.66	1.70	1.72	1.70	1.75	0.08	0.46	0.93

[1] A total of 210 pigs with 6 pigs per pen and 7 replications per treatment.

EFFECT OF DEOILED CORN DRIED DISTILLERS GRAINS WITH SOLUBLES (SOLVENT EXTRACTED) ON GROWTH PERFORMANCE, CARCASS CHARACTERISTICS, AND CARCASS FAT QUALITY OF GROWING AND FINISHING PIGS[1]

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Summary

A total of 1,215 pigs (initially 65.2 lb) were used in a 99-d study to determine the effects of deoiled corn dried distillers grains with solubles, solvent extracted (dDGS) on growing and finishing pig growth performance, carcass characteristics, and carcass fat quality. Pigs were blocked on the basis of pen weight and randomly allotted to 1 of 5 dietary treatments containing either 0, 5, 10, 20, or 30% dDGS. Pigs were fed in 4 phases; all dietary treatments were formulated to similar dietary ME and standardized ileal digestible (SID) lysine concentrations within each phase. Choice white grease (CWG) was included at increasing amounts as dDGS increased in the diet to maintain uniform dietary ME. Overall (d 0 to 99), ADG and ADFI decreased (linear, $P < 0.01$) with increasing dDGS in the diet. This reduction was especially pronounced when pigs were fed more than 20% dDGS. However, there was no difference in F/G ($P > 0.12$) for pigs fed increasing dDGS. For carcass characteristics, carcass weight and percent yield were reduced (linear, $P < 0.01$) and loin depth tended to decrease ($P < 0.09$) with increasing dDGS. However, there were no differences in backfat ($P < 0.26$), percent lean ($P < 0.16$) or fat-free lean index ($P < 0.20$). Jowl, backfat, and belly fat iodine values increased (linear, $P < 0.01$) with increasing dDGS. These increases were expected because of the increasing CWG in diets with increasing dDGS. In summary, feeding increasing levels of dDGS lowered ADG and ADFI but did not affect F/G as a result of the added fat in the diet. These data confirm the accuracy of the previously determined ME (1,137 kcal/lb) and SID amino acid values for dDGS; however, reasons for the reduced ADFI need further investigation.

Key words: deoiled corn dried distillers grains with solubles, feed ingredient, growth, pork quality

Introduction

The U.S. ethanol industry has experienced rapid growth over the last several years. In January 2008, there were 139 plants that accounted for 7.9 billion gal of ethanol produced, and more plants are being built to meet the increasing demand for ethanol. This

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rapid growth has led to an increased availability of ethanol manufacturing coproducts such as dried distillers grains with solubles (DDGS). Although the cattle industry historically has been the major market for this coproduct, its use as a feed ingredient in the swine industry has increased because improved manufacturing processes allow for a high quality coproduct with greater nutrient digestibility.

As the amount of DDGS increases and technologies improve, new coproducts are also being developed. One such product is deoiled corn DDGS, solvent extracted (dDGS), which is traditional DDGS with a majority of the oil removed. The deoiling process increases the CP, fiber, and mineral content of this coproduct. Because dDGS is a new coproduct that has the potential to be used in swine diets, an evaluation of its use in a commercial swine environment is necessary. We have previously determined the digestibility of amino acids and energy in dDGS; however, the effect on growth performance and carcass parameters has not been determined. Therefore, the objectives of this trial were to determine the effect of dDGS on the growth performance, carcass characteristics, and carcass fat quality of growing and finishing pigs.

Procedures

Procedures for this trial were approved by the Kansas State University Institutional Animal Care and Use Committee. The trial was conducted in a commercial research finishing barn in southwest Minnesota. The barns were double curtain sided with 18-ft × 10-ft pens that have completely slatted flooring and deep pits for manure storage. Each pen contained 1 self-feeder and 1 cup waterer. A robotic feeding system was utilized to provide feed on an individual pen basis.

A total of 1,215 pigs were used in a 99-d growth study. Pigs were blocked on the basis of pen weights and randomly allotted to 1 of 5 dietary treatments in meal form. There were initially 27 pigs in each pen. The 5 treatments consisted of diets containing 0, 5, 10, 20, or 30% dDGS. Pigs were fed in 4 phases with phase 1 fed from approximately 65 to 120 lb BW, phase 2 fed from 120 to 170 lb, phase 3 fed from 170 to 220 lb, and phase 4 fed from 220 to 265 lb (Tables 1 and 2). Diets were formulated to 0.94, 0.80, 0.69, and 0.95% standardized ileal digestible (SID) lysine and to maintain available P concentration of at least 0.27, 0.24, 0.22, and 0.21% for phases 1 to 4, respectively. All dietary treatments were formulated to similar dietary ME and SID lysine concentrations within each phase. The SID and energy content of dDGS were determined in a previous research study (Jaycela et al., 2007 Swine Day Report, p. 137; Table 3). Choice white grease (CWG) increased as dDGS increased in the diet to maintain uniform dietary ME levels.

Pen weights were obtained on d 0; every 14 d until d 70; and on d 78, 93, and 99 to determine ADG. Two middle-weight pigs from each pen were selected and slaughtered on d 93 to collect jowl, belly, and backfat (BF) samples for fatty acid analysis. Feed intake and F/G were determined on the basis of the feed delivery data generated through an automated feeding system and the amount of feed remaining in each pen's feeder on each weigh date.

Pigs from each pen were individually tattooed with the pen numbers at the end of the trial and transported to the JBS Swift & Company processing plant (Worthington, MN). Standard carcass criteria of loin and BF depth, HCW, percent lean, and yield were collected. Fat-free lean index (FFLI) was determined by using the equation 50.767 + (0.035 × HCW) – (8.979 × BF).

Fatty acids from each of the fat samples were expressed as a percentage of the total fatty acids. Iodine value was calculated by using the fatty acid profile of each sample

according to the following equation (AOCS, 1998).

C16:1 (0.95) + C18:1 (0.86) + C18:2 (1.732) + C18:3 (2.616) + C20:1 (0.785) + C22:1 (0.723).

Statistical analysis was performed by analysis of variance by using the MIXED procedure of SAS. Data were analyzed as a randomized complete block design with pen as the experimental unit. Carcass weight was used as a covariate for BF, loin depth, percent lean, and FFLI. Linear and polynomial contrasts were used to determine the effects of increasing dDGS. Contrast coefficients were determined for unequally spaced treatments by using the IML procedure of SAS.

Results and Discussion

Overall (d 0 to 99), ADG and ADFI decreased (linear, $P < 0.01$; Table 4) with increasing dDGS in the diet. These effects were due to a modest reduction in ADG and ADFI at low levels of dDGS inclusion and a large reduction when dDGS were fed at 30% of the diet. However, F/G was not affected ($P > 0.12$) by increasing dDGS in the diet.

As dDGS increased, carcass weight and percent yield decreased (linear, $P < 0.01$), and loin depth tended to decrease (linear, $P < 0.09$). There was no difference in BF ($P > 0.25$), percent lean ($P > 0.16$), or FFLI ($P > 0.19$). The reduction in carcass weight can be attributed to the decreased ADG and yield as pigs were fed increasing dDGS.

Increasing dDGS in pig diets also increased (linear, $P < 0.01$) the iodine values of jowl, BF, and belly fat depots in pigs (Table 5). These increases were expected because of the increasing levels of CWG in diets with increasing dDGS. Iodine values from the 3 fat stores increased between 5.0 and 6.6 g/100 g in pigs fed 30% dDGS in the diet compared with the control pigs. This translates into an approximate 1.7 to 2.2 g/100 g increase for every 10% dDGS inclusion in the diet when fed in combination with CWG. In a previous study at Kansas State University in which growing-finishing pigs were fed diets with traditional DDGS, iodine values of various fat stores (jowl, BF, and belly fat) increased by similar levels when level of CWG was constant for all dietary treatments. The increase in iodine values herein, however, would not be expected to be nearly as large without the increase in added CWG needed to maintain isocaloric diets within each phase.

We hypothesize that the reduction in percent yield is related to the higher fiber content of the dDGS diets. Diets containing higher levels of fiber have been shown to increase basal metabolic rate, which could account for the lower percent yield in pigs that were fed diets containing dDGS. Previous studies have also shown that diets high in fiber increase rate of passage in the gastrointestinal tract, resulting in increased gut cell proliferation and intestinal growth. The higher fiber could have led to a greater volume of intestinal fluid and increased weight of digesta, intestines, and other visceral organs. Because visceral organs are excluded from the carcass, percent yield is negatively affected in pigs fed the dDGS diets because of the higher volume and weight of entrails removed during slaughter. In addition, the majority of the energy required for maintenance is used by visceral organs like the liver and the gastrointestinal tract. Thus, the resulting increase in weight of the visceral organs could have resulted in a further increase in maintenance requirement and diverted the utilization of nutrients away from the production of edible carcass. The reduction in carcass yield is not unexpected; this effect has been consistently reported in finishing pigs fed traditional DDGS.

Results from this trial appear similar to previous research evaluating traditional DDGS in which feed intake was reduced when DDGS were fed at more than 20% of the diet. The addition of dDGS to growing and

finishing diets appears to negatively affect palatability, but reasons for the decrease in feed intake are not clear. However, these data validate the accuracy of the previously determined ME (1,137 kcal/lb) and SID amino acid values for dDGS because there were no changes in F/G when dDGS were fed at increasing levels in the diet.

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

	dDGS[2], %									
	Phase 1 diet					Phase 2 diet				
Item	0	5	10	20	30	0	5	10	20	30
Ingredient, %										
Corn	73.11	68.36	63.61	54.13	44.50	78.78	74.06	69.28	59.81	50.09
Soybean meal (46.5% CP)	24.79	23.62	22.44	20.09	17.75	19.22	18.04	16.87	14.52	12.18
dDGS	---	5.00	10.00	20.00	30.00	---	5.00	10.00	20.00	30.00
Choice white grease	---	0.95	1.93	3.80	5.75	---	0.95	1.93	3.80	5.80
Monocalcium phosphate (21% P)	0.60	0.48	0.35	0.13	---	0.50	0.35	0.25	---	---
Limestone	0.85	0.93	0.98	1.10	1.20	0.85	0.93	0.98	1.13	1.13
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix with phytase[3]	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Trace mineral premix	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
L-lysine HCl	0.15	0.18	0.20	0.25	0.30	0.15	0.18	0.20	0.25	0.30
Total	100	100	100	100	100	100	100	100	100	100
Calculated analysis										
Standardized ileal digestible amino acids										
Lysine, %	0.94	0.94	0.94	0.94	0.94	0.80	0.80	0.80	0.80	0.80
Methionine:lysine ratio, %	28	29	30	32	34	30	31	32	34	36
Met & Cys:lysine ratio, %	58	59	60	62	64	61	62	64	66	68
Threonine:lysine ratio, %	61	62	62	64	65	62	63	64	65	67
Tryptophan:lysine ratio, %	19	19	19	19	18	19	19	19	18	18
Total lysine, %	1.06	1.07	1.09	1.12	1.15	0.90	0.92	0.93	0.96	0.99
CP, %	17.89	18.52	19.15	20.42	21.68	15.78	16.41	17.04	18.31	19.57
ME, kcal/lb	1,517	1,517	1,517	1,517	1,517	1,520	1,520	1,520	1,520	1,520
SID Lysine:calorie ratio, g/Mcal ME	2.81	2.81	2.81	2.81	2.81	2.39	2.39	2.39	2.39	2.39
Ca, %	0.54	0.54	0.54	0.54	0.54	0.50	0.50	0.50	0.50	0.50
P, %	0.50	0.49	0.48	0.47	0.48	0.46	0.44	0.44	0.42	0.45
Available P, %	0.27	0.27	0.27	0.27	0.30	0.24	0.24	0.24	0.24	0.29
Dietary fat iodine value	121.4	108.4	97.8	98.1	88.4	117.2	108.0	100.9	94.2	88.7
Iodine value product[4]	25.5	36.8	42.1	55.9	69.8	16.4	30.2	39.3	57.5	70.9

[1] Phase 1 fed from approximately 65 to 120 lb and phase 2 fed from 120 to 170 lb.
[2] Deoiled corn dried distillers grains with solubles, solvent extracted.
[3] Provided 450 FTU/kg phytase with an expected phytate P release of 0.08% in phases 1 and 2.
[4] Iodine value of diet oil × % diet oil × 0.10.

Table 2. Phase 3 and 4 diet composition (as-fed basis)[1]

	dDGS[2], %									
	Phase 3 diet					Phase 4 diet				
Item	0	5	10	20	30	0	5	10	20	30
Ingredient, %										
Corn	83.21	78.47	73.71	64.21	54.49	73.03	68.26	63.53	53.93	44.07
Soybean meal (46.5% CP)	14.84	13.66	12.49	10.14	7.81	25.17	23.99	22.82	20.47	18.15
dDGS	---	5.00	10.00	20.00	30.00	---	5.00	10.00	20.00	30.00
Choice white grease	---	0.95	1.90	3.80	5.80	---	0.98	1.90	3.85	5.90
Monocalcium phosphate (21% P)	0.45	0.34	0.23	---	---	0.35	0.23	0.1	---	---
Limestone	0.88	0.93	1.00	1.13	1.13	0.8	0.88	0.95	1.00	1.08
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix with phytase[3]	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Trace mineral premix	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
L-lysine HCl	0.15	0.18	0.20	0.25	0.30	0.15	0.18	0.20	0.25	0.30
Paylean (9 g/lb)	---	---	---	---	---	0.025	0.025	0.025	0.025	0.025
Total	100	100	100	100	100	100	100	100	100	100
Calculated analysis										
Standardized ileal digestible amino acids										
Lysine, %	0.69	0.69	0.69	0.69	0.69	0.95	0.95	0.95	0.95	0.95
Methionine:lysine ratio, %	32	33	34	37	39	28	29	30	32	33
Met & Cys:lysine ratio, %	65	66	68	70	73	58	58	59	61	63
Threonine:lysine ratio, %	63	64	65	67	69	61	62	62	64	65
Tryptophan:lysine ratio, %	19	18	18	18	17	19	19	19	19	18
Total lysine, %	0.78	0.8	0.81	0.84	0.87	1.07	1.08	1.10	1.13	1.16
CP, %	14.12	14.75	15.38	16.65	17.91	18.05	18.69	19.32	20.58	21.83
ME, kcal/lb	1,521	1,521	1,521	1,521	1,521	1,522	1,522	1,522	1,522	1,522
SID Lysine:calorie ratio, g/Mcal ME	2.06	2.06	2.06	2.06	2.06	2.83	2.83	2.83	2.83	2.83
Ca, %	0.49	0.49	0.49	0.49	0.49	0.48	0.48	0.48	0.48	0.50
P, %	0.43	0.42	0.42	0.4	0.43	0.45	0.44	0.43	0.44	0.48
Available P, %	0.22	0.22	0.22	0.23	0.28	0.21	0.21	0.21	0.24	0.29
Dietary fat iodine value	116.1	107.5	100.8	94.2	89.4	121.6	107.8	100.2	94.7	88.2
Iodine value product[4]	19.7	33.3	41.3	59.3	69.8	26.8	31.3	40.1	54.9	67.9

[1] Phase 3 fed from 170 to 220 lb and phase 4 fed from 220 to 265 lb.
[2] Deoiled corn dried distillers grains with solubles, solvent extracted.
[3] Provided 375 FTU/kg phytase with an expected phytate P release of 0.07% in phases 3 and 4.
[4] Iodine value of diet oil × % diet oil × 0.10.

Table 3. Analyzed nutrient composition and standardized ileal digestible (SID) amino acids and energy content of deoiled corn dried distillers grains with solubles, solvent extracted (dDGS)[1]

	dDGS	
Item	Nutrient composition[2]	SID, %
Proximate analysis, %		
DM	87.69	
CP	31.20	
Crude fat	4.00	
ADF	16.10	
NDF	34.60	
Ca	0.05	
P	0.76	
Ash	4.64	
Metabolizable energy, kcal/lb[3]	1,137	
Amino acids, %		
Arginine	1.31	82.70
Histidine	0.82	74.63
Isoleucine	1.21	74.52
Leucine	3.64	83.79
Lysine	0.87	50.38
Methionine	0.58	80.41
Phenylalanine	1.69	80.77
Threonine	1.10	68.91
Tryptophan	0.19	77.96
Valine	1.54	73.75
Alanine	2.13	79.12
Aspartic acid	1.84	64.58
Cysteine	0.54	66.94
Glutamic acid	4.26	79.01
Glycine	1.18	64.63
Proline	2.11	87.79
Serine	1.30	76.86
Tyrosine	1.13	82.35

[1] Values were determined in a previous study (Jacela et al., 2007 KSU Swine Day Report of Progress, p. 137).
[2] As-fed basis.
[3] Calculated.

Table 4. Effects of increasing deoiled corn dried distillers grains with solubles, solvent extracted (dDGS) on growth performance and carcass characteristics[1]

	dDGS, %					Probability, *P* <		
Item	0	5	10	20	30	Linear	Quadratic	SE
Weight, lb								
d 0	65.2	65.2	65.2	65.3	65.3	0.94	0.99	1.0
d 99	267.6	262.9	262.0	260.5	256.3	0.001	0.68	2.1
d 0 to 99								
ADG, lb	2.00	1.97	1.96	1.96	1.93	0.01	0.61	0.02
ADFI, lb	4.76	4.78	4.64	4.65	4.49	0.003	0.72	0.07
F/G	2.38	2.43	2.37	2.38	2.33	0.12	0.44	0.03
Slaughter wt, lb	265.8	261.9	262.1	259.2	255.7	0.001	0.89	2.1
Carcass wt, lb	200.9	196.2	196.5	193.4	190.2	0.0001	0.66	1.8
Yield, %	75.5	75.0	75.0	74.7	74.3	0.01	0.73	0.3
Backfat, in[2]	0.65	0.65	0.65	0.65	0.67	0.26	0.25	0.01
Loin depth, mm[2]	2.50	2.45	2.46	2.48	2.39	0.09	0.55	0.03
Lean, %[2]	56.5	55.9	56.3	56.4	55.8	0.16	0.28	0.2
FFLI, %[2,3]	50.4	50.4	50.4	50.5	50.2	0.20	0.19	0.1

[1] A total of 1,215 pigs (initially 65.2 lb, 27 pigs per pen) were used in this study; there were 9 replications per treatment.
[2] Data analyzed using carcass weight as a covariate.
[3] Fat-free lean index.

Table 5. Effects of increasing deoiled corn dried distillers grains with solubles, solvent extracted (dDGS) on fat quality

	dDGS[1], %					Gender[2]		Probability, *P* <			SE	
Item	0	5	10	20	30	Barrow	Gilt	Linear	Quadratic	Gender	Trt	Gender
Iodine value, g/100g												
Jowl	67.5	68.1	69.0	71.1	73.3	68.9	70.7	0.01	0.41	0.01	0.45	0.30
Backfat	68.5	68.4	69.2	73.0	73.5	69.2	71.9	0.01	0.99	0.01	0.63	0.42
Belly fat	67.1	68.0	69.1	72.4	73.7	68.7	71.5	0.01	0.64	0.01	0.60	0.40
C 18:2 fatty acids, %												
Jowl	13.6	13.7	14.7	15.9	17.1	14.5	15.4	0.01	0.75	0.01	0.31	0.20
Backfat	16.5	16.3	17.0	18.9	18.4	16.5	18.3	0.01	0.40	0.01	0.43	0.29
Belly fat	15.3	15.4	16.3	17.8	18.2	15.7	17.5	0.01	0.50	0.01	0.39	0.26
Saturated fatty acids, %												
Jowl	35.7	35.1	35.0	33.8	32.3	34.9	33.9	0.01	0.34	0.01	0.34	0.22
Backfat	37.6	37.5	37.2	34.8	33.6	36.7	35.5	0.01	0.34	0.01	0.39	0.26
Belly fat	37.9	36.9	36.5	34.3	33.0	36.4	35.0	0.01	0.85	0.01	0.40	0.26

[1] Values are means of 18 observations per treatment.
[2] Values are means of 45 observations.

AMINO ACID DIGESTIBILITY OF HIGH-PROTEIN CORN DRIED DISTILLERS GRAINS WITH SOLUBLES IN PIGS[1]

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Summary

The objective of this experiment was to determine the digestibility of amino acids (AA) in a high-protein dried distillers grains with solubles (DDGS) product. Six growing barrows (initially 50 lb) were surgically fitted with a T-cannula at the terminal ileum to allow for ileal digesta collection. After recovery, the pigs were randomly allotted to 2 dietary treatments in a crossover design with 2 periods. The first diet contained high-protein DDGS (67% of the diet) as the sole protein source; the second was a nitrogen-free diet for determining basal endogenous AA loss. Chromic oxide was added to both diets as an indigestible marker. Ileal digesta samples were collected each period and analyzed for AA concentration. Standardized and apparent ileal digestibilities (SID and AID, respectively) of AA were calculated after chemical analysis of the high-protein DDGS, diets, digesta, and fecal samples. Nutrient composition analysis of the high-protein DDGS showed a CP value of 36.5%, crude fat of 4.8%, and phosphorous content of 0.38%. The AID for lysine, methionine, threonine, and tryptophan were 65.9, 87.0, 72.8, and 76.2%, respectively. Values for SID AA were calculated to be 67.8, 87.5, 75.0, and 78.6% for lysine, methionine, threonine, and tryptophan, respectively. In conclusion, this high-protein DDGS product has greater AA digestibility values than traditional DDGS. Therefore, this product appears well-suited for use in swine diets but needs further evaluation to determine its effects on pig growth performance.

Key words: amino acids, digestibility, dried distillers grains with solubles, swine

Introduction

As the biofuel industry continues to evolve and mature, improvements and new technologies in ethanol fuel production are being adapted by the ethanol biorefineries to cut costs and increase efficiency and profitability. This has resulted in production of more coproducts and increased attention being paid to the quality of these coproducts. LifeLine Foods is a company that, in addition to from food products for human consumption, produces ethanol from corn by utilizing the dry defractionation method. Dry defractionation is a relatively new technology that optimizes the use of corn by separating the kernel into its bran, germ, and endosperm components before fermentation. The process involves tempering the seed with warm water to make it expand, enabling the removal of bran (pericarp) from the kernel. The germ (oil-rich fraction) is then removed, and the remaining portion of the kernel is sent to the food mill

[1] Appreciation is expressed to LifeLine Foods, St. Joseph, MO, for supplying the high-protein dried distillers grains with solubles product and partial funding.
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where the hard yellow endosperm is removed for food companies. The soft endosperm (starch) is then sent to the ethanol facility for fermentation. The distillers grains that remain after fermentation are dried with steam instead of direct heat, resulting in a product that may have increased quality and digestibility. Also, as a result of breaking down and segregating the kernel into its components, CP becomes more concentrated, whereas the crude fat is lower in the final high-protein product compared with traditional dried distillers grains with solubles (DDGS). Although this product may command a higher value than conventional DDGS because of its higher CP content, this product needs to be valued on the basis of digestibility of its nutrients. Therefore, this study was conducted to determine the digestibility of amino acids (AA) in high-protein DDGS in growing pigs.

Procedures

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

Six growing barrows (PIC, initially 50 lb BW) were surgically fitted with a T-cannula on their right flank approximately 6 in. anterior to the ileocecal valve. The pigs were allowed to recover from surgery and were then placed in individual stainless steel metabolism cages in an environmentally controlled building. Each cage was equipped with a feeder and a nipple waterer for ad libitum access to water. During the first 9 d post-surgery (recovery period), the pigs were fed a common diet. On d 10 post-surgery, the pigs were randomly allotted to 1 of 2 dietary treatments in a crossover design. The first diet contained 67% of a high-protein corn DDGS; the second diet was formulated to be nitrogen-free to allow for the determination of basal AA endogenous losses (Table 1). Chromic oxide was added to both diets at 0.25% as an indigestible marker. There were 2 periods in the experiment; each period consisted of 7 d. The first 5 d of each period were used to allow pigs to adapt to the dietary treatment. Ileal digesta was collected on d 6 and 7 over a 10-h period (between 0700 and 1700 each day). Pig weights were determined at the start of each period prior to switching to the next diet to determine the daily feed allocation. Daily feed allocation was divided into 2 equal amounts and given twice a day at 0600 and 1800 hours. No feed was given at the end of each period before the next experimental diet was fed the following morning.

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

Ingredient, %	High-protein DDGS[1]	N-free
Corn starch	26.20	80.90
High-protein DDGS	66.70	---
Soybean oil	1.00	3.00
Monocalcium P (21% P)	1.05	1.75
Limestone	0.80	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
Magnessium oxide	---	0.10
Chromic oxide	0.25	0.25
Solka floc	---	3.00
Sucrose	3.00	9.00
Total	100.00	100.00
Calculated analysis, %		
Total lysine	0.41	0.00
CP	25.15	0.00
Ca	0.60	0.48
P	0.45	0.37
Available P	0.40	0.37

[1] Dried distillers grains with solubles from Life-Line Foods LLC, St. Joseph, MO.

During collection days, each pig's cannula was opened to allow the digesta to flow out of the ileum; ileal digesta was collected by attaching a latex balloon to the cannula. The balloons were checked for the level of fill and removed every 30 min or as soon as they were full. The contents of the balloons were then transferred to a 1-L plastic container and stored in a freezer until further chemical

analyses were conducted. After the collection phase of the experiment, digesta samples from each period from each animal were thawed and homogenized. A subsample from each homogenized ileal digesta was then transferred to a 1.25-in. × 6-in. × 8.5-in. aluminum pan, freeze-dried, and ground for AA analysis.

The amount of chromic oxide in the diets, digesta, and fecal samples was determined by using atomic absorption spectroscopy. Chromic oxide served as the indigestible marker for calculating AA digestibility values. The high-protein DDGS, 2 diets, and digesta samples were also analyzed for DM, CP, and AA. Amino acid analysis for the diets, high-protein 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 DDGS diet was calculated by 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 on the basis of the digesta samples obtained when the pigs were fed with the nitrogen-free diet by using 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:

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

Results and Discussion

The nutrient profile of the high-protein DDGS used in the experiment is reported in Table 2. The CP level was 36.5%, which is about 9% higher than the published average CP value in traditional DDGS. In addition, the fat content of the high-protein DDGS was 4.8%, which, as expected, is less than half of the average amount typically found in traditional DDGS. The lower fat content found in the high-protein DDGS was a result of the mechanical separation of the germ portion from the rest of the corn kernel components during defractionation. On the other hand, though ADF and NDF for the high-protein DDGS were expected to be lower because of the separation of the bran during the defractionation process, the values were even higher than published book values for traditional DDGS. The ADF and NDF values for the product used in this experiment were 20.50 and 32.80%, respectively. It is possible that there was a significant amount of bran added back to the final DDG product. Although the amount of calcium in the high-protein DDGS was almost similar to traditional DDGS at 0.04%, phosphorus content was relatively low at only 0.38%. The lower phosphorus content may be due to the minimal amount of solubles present in the final product. The higher CP content of the high-protein DDG resulted in every AA being higher when compared with the amount of AA in traditional DDGS. The lysine content of the DDGS product was 1.22%, resulting in a lysine:CP ratio of 3.34%. A lysine:CP ratio of not less than 2.8% is the recommended value when evaluating the quality of DDGS for use in swine diets. Thus, the high ratio found in the high-protein DDGS indicates the product should have high lysine digestibility.

Swine diets are ideally formulated on the basis of the digestibility of the nutrients found in each ingredient that goes with the diet. More specifically, these diets should be formulated on the basis of SID AA. This study was conducted with the aim of establishing

digestibility coefficients for AA values for the high-protein DDGS. In this product, the AID for lysine, methionine, threonine, and tryptophan were 65.9, 87.0, 72.8, and 76.2%, respectively (Table 3). These values were higher than published AID values for traditional DDGS. After correcting the AID values for basal ileal endogenous AA loss, the SID values were calculated to be 67.8, 87.5, 75.0, and 78.6% for lysine, methionine, threonine, and tryptophan, respectively. These values are also higher than those found in traditional DDGS. The most significant difference between the high-protein DDGS and traditional DDGS appears to be the high digestibility coefficient for lysine. Lysine is considered the most variable among the AA because of the heating process involved in the production of conventional DDGS. The high amount of lysine in the high-protein DDGS and its high digestibility values increased its overall AA value in swine diets compared with traditional DDGS.

This experiment established the values for the digestibility coefficients of AA for the high-protein DDGS for use in swine diet formulation. The results of this experiment suggest a coproduct of high quality and value in terms of CP, AA content, and AA digestibility. However, this product has a relatively lower phosphorus content compared with traditional DDGS. Further evaluation of this coproduct is needed to determine its effects on pig growth performance.

Table 2. Analyzed nutrient composition of a high-protein corn DDGS product[1]

Nutrient, %	DM basis	As-fed basis
DM	100.00	89.54
CP	40.76	36.50
Crude fat	5.36	4.80
ADF	22.89	20.50
NDF	36.63	32.80
Ca	0.04	0.04
P	0.42	0.38
Ash	1.84	1.65
Indispensable amino acids		
Arginine	1.84	1.65
Histidine	1.16	1.04
Isoleucine	1.69	1.51
Leucine	5.45	4.88
Lysine	1.36	1.22
Methionine	0.88	0.79
Phenylalanine	2.14	1.92
Threonine	1.45	1.30
Tryptophan	0.26	0.23
Valine	2.21	1.98
Dispensable amino acids		
Alanine	3.06	2.74
Aspartic acid	2.66	2.38
Cysteine	0.85	0.76
Glutamic acid	6.99	6.26
Glycine	1.49	1.33
Proline	3.17	2.84
Serine	1.72	1.54
Tyrosine	1.66	1.49

[1] Dried distillers grains with solubles from LifeLine Foods, LLC St. Joseph, MO.

Table 3. Standardized and apparent ileal digestibility (%) of amino acids in a high-protein corn DDGS product[1,2]

Amino acid	SID[3]	AID[4]
Indispensable amino acids		
Arginine	85.32	83.79
Histidine	80.00	79.04
Isoleucine	81.35	80.23
Leucine	88.87	88.31
Lysine	67.82	65.91
Methionine	87.53	86.96
Phenylalanine	86.10	85.24
Threonine	75.00	72.75
Tryptophan	78.61	76.23
Valine	79.70	78.13
Dispensable amino acids		
Alanine	84.37	83.40
Aspartic acid	73.83	72.13
Cysteine	76.84	75.51
Glutamic acid	85.73	84.94
Glycine	66.69	61.34
Proline	79.12	74.52
Serine	82.87	81.24
Tyrosine	86.07	85.10

[1] Values are means of 6 pigs (initially 50 lb) used in a crossover design.
[2] Dried distillers grains with solubles from LifeLine Foods LLC, St. Joseph, MO.
[3] Standardized ileal digestibility.
[4] Apparent ileal digestibility.

EFFECTS OF ADDING SATURATED FAT TO DIETS WITH SORGHUM-BASED DRIED DISTILLERS GRAINS WITH SOLUBLES ON GROWTH PERFORMANCE AND CARCASS CHARACTERISTICS IN FINISHING PIGS

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Summary

Two experiments were conducted to determine the effects of adding sources of saturated fat to diets with sorghum-based dried distillers grains with solubles (DDGS). For Exp. 1, 112 barrows (initially 140 lb) were used in a 69-d growth assay with 7 pigs per pen and 4 pens per treatment. Treatments were a corn-soybean meal-based control and diets having 40% sorghum-based DDGS (U.S. Energy Partners, Russell, KS) without and with 5% added tallow or palm oil. Feed and water were consumed on an ad libitum basis until pigs were slaughtered (average BW 283 lb) to allow collection of carcass data and jowl samples. Fatty acid composition of jowl samples was used to calculate iodine value (IV) as an indicator of carcass fat firmness. Overall (d 0 to 69), the corn-soybean control supported greater ADG and ADFI ($P < 0.001$) with no difference in F/G ($P > 0.9$) compared with the DDGS treatments. Adding 5% beef tallow and palm oil to diets with DDGS improved overall F/G ($P < 0.02$). Pigs fed the control diet had greater ($P < 0.04$) HCW and dressing percentage than pigs fed the DDGS treatments. Adding fat to DDGS diets tended to improve dressing percentage ($P < 0.07$), but there were no effects of fat source on carcass measurements ($P > 0.14$). Changes in IV indicated softer fat in pigs fed DDGS ($P < 0.001$) than in pigs fed the control diet even when sources of saturated fatty acids were added to the diets. For Exp. 2, 112 barrows (initially 150 lb) were used in a 67-d growth assay with 7 pigs per pen and 4 pens per treatment. Treatments were the same as in Exp. 1, but fat sources were stearic acid and coconut oil. At slaughter (average BW 270 lb), in addition to collection of carcass data and jowl samples, belly firmness was determined by using a subjective scoring system and by measuring the distance from tip to tip of the belly after it was drooped over a 1-in.^{2} bar for 5 min. The corn-soybean control tended to support greater overall ADG ($P < 0.09$) with no difference in ADFI and F/G ($P > 0.14$) compared with DDGS treatments. Adding fat sources to diets with DDGS tended to improve ($P < 0.06$) overall F/G, and coconut oil improved F/G compared with stearic acid ($P < 0.001$). Pigs fed the control diet had greater ($P < 0.05$) HCW than pigs fed the DDGS treatments. Pigs fed the control diet had lower IV and greater firmness score than pigs fed diets with added DDGS ($P < 0.02$). Adding fat sources to diets with DDGS improved these estimates of carcass firmness and tip to tip distance for suspended bellies ($P < 0.001$); coconut oil had a much greater effect than stearic acid ($P < 0.001$). In conclusion, adding beef tallow, palm oil, and coconut oil to diets with 40% DDGS improved efficiency of gain in finishing pigs. However, only coconut oil restored carcass firmness to levels at or above a corn-soybean diet without DDGS.

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Key words: carcass firmness, coconut oil, dried distillers grains with solubles, palm oil

Introduction

With conversion of starch to ethanol, other proximate components in cereal grain (e.g., protein, fiber, and fat) are concentrated by about three times in dried distillers grains with solubles (DDGS). Existing data suggest negative effects of the vegetable oil in DDGS on firmness of pork carcasses. Work at North Carolina State University demonstrated that hydrogenated choice white grease added to corn-soybean diets increased carcass firmness in pigs. However, we reported in the 2007 Swine Day Report of Progress (Feoli et al., page 122) that increasing tallow (a source of saturated fatty acids) from 0 to 5% of the diet did not improve iodine value (IV) of jowl fat (an indicator of carcass firmness) in finishing pigs fed diets with DDGS. Beef tallow is only 50% saturated and mainly long-chain fatty acids, which seems to not be saturated enough to compensate for the negative effects of DDGS on firmness of carcass fat. Therefore, the objective of the present experiments was to determine the effects of adding various sources of saturated fat (beef tallow, palm oil, stearic acid, and coconut oil) to diets with sorghum-based DDGS.

Procedures

In Exp. 1, 112 barrows (initially 140 lb) were used in a 69-d growth assay. The pigs were sorted by ancestry, blocked by weight, and assigned to pens. There were 7 pigs per pen and 4 pens per treatment. The pigs were housed in a finishing facility having 6-ft × 16-ft pens with half solid and half slatted concrete flooring. Each pen had a self-feeder and nipple waterer to allow ad libitum consumption of feed and water.

Treatments were a corn-soybean meal-based control and diets having 40% sorghum-based DDGS (U.S. Energy Partners, Russell, KS) without and with 5% added tallow or palm oil (Table 1). The control diet and first DDGS treatment were formulated to 0.90% lysine, 0.60% Ca, and 0.50% total P for d 0 to 36 and 0.70% lysine, 0.55% Ca, and 0.45% total P for d 36 to 69. However, nutrient:calorie ratios were kept constant for diets with added fat.

Pigs and feeders were weighed at d 0, 36, and 69 to allow calculation of ADG, ADFI, and F/G, and the pigs were slaughtered (average BW 283 lb). Carcass data were collected, and samples of jowl fat were collected, their fatty acid profile was determined, and their IV was calculated following AOCS (1998) procedures.

All data were analyzed as a randomized complete block design by using the MIXED procedure of SAS with HCW as a covariate for carcass measurements. Orthogonal contrasts were used to separate treatment means with comparisons between control vs. DDGS treatments, DDGS without vs. with added fat, and tallow vs. palm oil.

In Exp. 2, 112 barrows (initially 150 lb) were used in a 67-d growth assay. The pigs were sorted by ancestry, blocked by weight, and assigned to pens. There were 7 pigs per pen and 4 pens per treatment. The pigs were housed in the same finishing facility as in Exp. 1. Treatments were a corn-soybean meal-based control and diets having 40% DDGS without and with 5% added stearic acid and coconut oil (Table 1). The diets were formulated to the same nutrient specifications as used in Exp. 1.

Pigs and feeders were weighed on d 0, 30, and 67 to allow calculation of ADG, ADFI, and F/G, and the pigs were slaughtered (average BW 270 lb). Carcass data were collected, and samples of jowl fat were collected, their fatty acid profile was determined, and their IV was calculated. In addition, belly firmness was determined by using a subjective scoring

system (scale of 1 = very soft to 10 = very firm) and by measuring the distance from tip to tip of the belly after it was drooped over a 1-in.^{2} bar for 5 min.

All data were analyzed as a randomized complete block design by using the MIXED procedure of SAS with HCW as a covariate for carcass measurements. Orthogonal contrasts were used to separate treatment means with comparisons between control vs. DDGS treatments, DDGS without vs. with added fat, and stearic acid vs. coconut oil.

Results and Discussion

Analyses of the DDGS (Table 2) indicated that its fat was mainly long-chain and unsaturated (e.g., C18:2) as is expected for the oil in cereal grains. Fatty acid composition of the other fat sources was similar to expected compositions; tallow and palm oil were about 50% saturated, and the stearic acid and coconut oil products were more than 90% saturated.

In the first growth assay (Exp. 1), the corn-soybean control supported greater overall ADG and ADFI ($P < 0.001$) with no difference in F/G ($P > 0.9$) compared with the DDGS treatments (Table 3). Adding 5% beef tallow or palm oil to diets with DDGS improved overall F/G by 6.5% ($P < 0.02$), but there was no difference ($P > 0.12$) in growth performance between pigs fed tallow vs. palm oil. For carcass data, pigs fed the control diet had greater ($P < 0.04$) HCW and dressing percentage than pigs fed the DDGS treatments. Adding fat to the DDGS diets tended to improve dressing percentage ($P < 0.07$), but there were no effects of fat source on carcass measurements ($P > 0.14$). Changes in IV indicated softer fat in pigs fed DDGS ($P < 0.001$) than in pigs fed the control diet even when the sources of saturated fatty acids (tallow and palm oil) were added to the diets.

In Exp. 2, the corn-soybean control tended to support greater overall ADG ($P < 0.09$) with no difference in ADFI and F/G ($P > 0.14$) compared with the DDGS treatments (Table 4). Adding fat sources to diets with DDGS tended to improve ($P < 0.06$) overall F/G, and coconut oil improved F/G compared with stearic acid ($P < 0.001$). For carcass data, pigs fed the control diet had greater ($P < 0.05$) HCW than pigs fed the DDGS treatments. However, dressing percentage, percentage carcass lean, backfat thickness, and loin depth were not affected by adding DDGS or fat to the diets ($P > 0.18$). Pigs fed the control diet had lower IV and greater firmness scores compared with pigs fed diets with added DDGS ($P < 0.02$). Adding fat sources to diets with DDGS improved these estimates of carcass firmness and the tip to tip distance for suspended bellies ($P < 0.001$); coconut oil had a much greater effect than stearic acid ($P < 0.001$).

In conclusion, the use of 40% DDGS in diets for finishing pigs tended to reduce ADG and indicators of carcass firmness. Adding tallow, palm oil, or coconut oil to diets with DDGS improved feed efficiency, but only coconut oil restored indicators of carcass firmness to levels as good as or better than those achieved with the corn-soybean meal-based control treatment.

Table 1. Composition of diets

	Phase 1			Phase 2		
Ingredient, %	Control	DDGS	DDGS + fat	Control	DDGS	DDGS + fat
Corn	79.90	53.10	49.32	84.96	58.10	54.56
DDGS[1]	---	40.00	40.00	---	40.00	40.00
Fat	---	---	5.00	---	---	5.00
Soybean meal (47.5% CP)	17.70	4.80	6.00	12.90	---	1.00
Limestone	1.09	1.35	1.34	1.07	1.27	1.31
Monocalcium phosphate (21% P)	0.73	0.04	0.13	0.59	---	---
Salt	0.23	0.10	0.10	0.23	0.10	0.10
L-lysine HCl	0.20	0.47	0.47	0.12	0.39	0.39
L-threonine	0.03	---	---	---	---	---
Vitamin premix	0.04	0.04	0.04	0.04	0.04	0.04
Mineral premix	0.03	0.05	0.05	0.04	0.05	0.05
Antibiotic[2]	0.05	0.05	0.05	0.05	0.05	0.05
Calculated analysis, %[3]						
Lys	0.90	0.90	0.93	0.70	0.70	0.73
Ca	0.60	0.60	0.62	0.55	0.55	0.57
Total P	0.50	0.50	0.52	0.45	0.45	0.47

[1] Dried distillers grains with solubles.
[2] To provide 40 g/ton tylosin.
[3] Nutrient:calorie ratios were kept constant for diets with added fat.

Table 2. Fatty acid composition of dried distillers grains with solubles (DDGS) and fat sources

Fatty acid, %	DDGS	Beef tallow	Palm oil	Stearic acid	Coconut oil
C8:0	0.43	0.01	0.05	0.01	7.87
C10:0	0.00	0.10	0.05	0.06	6.02
C12:0	0.04	0.07	0.35	0.09	47.82
C14:0	0.11	3.16	1.09	2.65	17.53
C16:0	16.58	24.24	42.46	27.20	8.61
C16:1	0.50	2.15	0.07	0.40	0.06
C17:0	0.16	2.00	0.14	1.89	0.02
C18:0	1.96	20.25	4.45	65.34	3.24
C18:1	28.15	41.88	37.81	0.08	6.14
C18:2	48.30	3.04	11.68	0.27	2.08
C18:3	2.70	0.25	0.59	0.02	0.06
C20:0	0.30	0.15	0.37	1.25	0.09
Saturated fatty acids	19.88	50.62	49.14	98.97	91.31
Unsaturated fatty acids	80.12	49.38	50.86	1.03	8.69
Unsaturated/saturated	4.03	0.98	1.03	0.01	0.10
Iodine value	115.6	44.1	54.5	1.0	9.1

Table 3. Effects of adding beef tallow and palm oil to diets with sorghum-based dried distillers grains with solubles (DDGS) on growth performance and carcass characteristics in finishing pigs[1]

		40% DDGS				*P* value		
Item	Control	No added fat	Tallow	Palm oil	SE	Control vs. DDGS	Fat effect	Tallow vs. Palm
d 0 to 36								
ADG, lb	2.32	2.04	1.95	2.07	0.06	0.001	---[2]	0.13
ADFI, lb	6.72	6.18	5.75	5.83	0.14	0.002	0.06	---
F/G	2.90	3.03	2.95	2.82	0.06	---	0.09	0.15
d 0 to 69								
ADG, lb	2.27	2.04	1.96	2.06	0.04	0.001	---	0.13
ADFI, lb	7.37	6.91	6.34	6.40	0.13	0.001	0.006	---
F/G	3.25	3.39	3.23	3.11	0.05	---	0.02	0.15
HCW, lb	214.8	195.6	195.5	198.2	6.6	0.001	---	---
Dressing, %[3]	71.9	70.0	71.1	70.4	0.4	0.04	0.07	0.14
Carcass lean, %[3]	53.8	54.2	54.2	54.4	0.4	---	---	---
Backfat thickness, in.[3]	0.76	0.73	0.72	0.72	0.02	---	---	---
Loin depth, in.[3]	2.23	2.21	2.12	2.18	0.05	---	---	---
Iodine value [3,4]	67.9	72.1	73.1	73.2	0.6	0.001	---	---

[1] A total of 112 barrows (initially 140 lb) with 7 pigs per pen and 4 pens per treatment.
[2] Dashes indicate $P > 0.15$.
[3] HCW used as a covariate.
[4] As calculated from fatty acid profile of the jowls.

Table 4. Effects of adding stearic acid and coconut oil to diets with sorghum-based dried distillers grains with solubles (DDGS) on growth performance and carcass characteristics in finishing pigs[1]

		40% DDGS				*P* value		
Item	Control	No added fat	Stearic	Coconut	SE	Control vs. DDGS	Fat effect	Stearic vs. Coconut
d 0 to 30								
ADG, lb	1.71	1.53	1.53	1.67	0.03	0.009	0.12	0.02
ADFI, lb	6.45	6.05	6.17	5.87	0.19	0.02	---[2]	0.13
F/G	3.77	3.95	4.03	3.51	0.07	---	0.02	0.001
d 0 to 67								
ADG, lb	1.80	1.69	1.72	1.75	0.05	0.09	---	---
ADFI, lb	6.32	6.07	6.32	5.75	0.18	0.14	---	0.02
F/G	3.51	3.59	3.67	3.29	0.05	---	0.06	0.001
HCW, lb	197.5	188.0	189.5	194.2	5.1	0.05	---	---
Dressing, %[3]	71.7	70.8	70.5	71.4	0.6	---	---	---
Carcass lean, %[3]	55.4	55.7	55.7	55.0	0.3	---	---	0.09
Backfat thickness, in.[3]	0.67	0.64	0.64	0.69	0.02	---	---	0.06
Loin depth, in.[3]	2.25	2.18	2.22	2.27	0.04	---	---	---
Iodine value[3,4]	67.4	71.7	70.5	66.6	0.3	0.001	0.001	0.001
Belly firmness score[3,5]	5.8	4.7	4.9	6.1	0.3	0.02	0.001	0.001
Tip to tip distance, in.[3]	7.3	5.7	6.4	9.4	0.3	---	0.001	0.001

[1] A total of 112 barrows (initially 150 lb) with 7 pigs per pen and 4 pens per treatment.
[2] Dashes indicate $P > 0.15$.
[3] HCW used as a covariate.
[4] As calculated from fatty acid profile of the jowls.
[5] Scale of 1 = very soft to 10 = very firm.

EFFECTS OF EXPANDER CONDITIONING ON THE NUTRITIONAL VALUE OF DIETS WITH DRIED DISTILLERS GRAINS WITH SOLUBLES IN NURSERY AND FINISHING PIGS

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Summary

Three experiments were conducted to determine the effects of expander conditioning on nutritional value of diets without and with corn- and sorghum-based dried distillers grains with solubles (DDGS). In Exp. 1, 180 nursery pigs (average weight 29 lb) were assigned to 30 pens. Treatments were arranged as a 3 × 2 factorial with main effects of diet formulation (corn-soybean meal vs. 30% corn- or sorghum-based DDGS) and conditioning (standard steam vs. expander) prior to pelleting. Pigs fed corn-soybean meal diets had better ($P < 0.005$) ADG, F/G, and digestibility of DM, N, and GE than pigs fed diets with DDGS. Diets with corn-based DDGS supported better ($P < 0.03$) ADG, F/G, and digestibility of DM and N than diets with sorghum-based DDGS. Expander processing improved ($P < 0.009$) ADG, F/G, and digestibility of DM, N, and GE compared with standard conditioning. Pigs fed diets with sorghum-based DDGS showed the greatest response in F/G to expander conditioning leading to a DDGS source × conditioning interaction ($P < 0.008$). In Exp. 2, 176 finishing pigs (average weight 164 lb) were assigned to 16 pens. Treatments were arranged as a 2 × 2 factorial with main effects of diet formulation (corn-soybean meal vs. 40% sorghum-based DDGS) and conditioning (standard steam vs. expander) prior to pelleting. Net electrical energy required for feed processing was lower ($P < 0.001$) and production rate was greater ($P < 0.005$) for the corn-soybean meal diets than for diets with DDGS. However, pellet durability was improved ($P < 0.001$) by addition of DDGS to the diets. Pigs fed corn-soybean meal diets had better ($P < 0.03$) overall ADG and F/G than pigs fed diets with DDGS. Expander conditioning did not affect ADG ($P > 0.83$) but improved overall F/G and dressing percentage ($P < 0.007$). In Exp. 3, 192 finishing pigs (average weight 222 lb) were assigned to 16 pens to determine nutrient digestibility. Treatments were the same as in Exp. 2. Feed and water was consumed ad libitum during a 6-d adjustment period; then, feces were collected for 2 d. Corn-soybean meal diets had greater ($P < 0.001$) digestibility of DM, N, and GE than diets with DDGS, and expander conditioning improved ($P < 0.02$) digestibility of DM, N, and GE compared with standard conditioning. However, the improved digestibility of DM with expander conditioning was apparent primarily for the DDGS diets (diet × conditioning interaction, $P < 0.01$). In conclusion, expanding diets improved ADG, F/G, and nutrient digestibility in nursery pigs and F/G, dressing percentage, and nutrient digestibility in finishing pigs fed diets without and with DDGS.

Key words: digestibility, dried distillers grains with solubles, expander conditioning

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Introduction

The U.S. Renewable Fuel Standard mandates that 15 billion gal of ethanol from grain starch will be needed by 2015. Thus, it seems certain that coproducts from the ethanol industry, such as dried distillers grains with solubles (DDGS), will continue to increase in supply and use in diets for pigs. Dried distillers grains with solubles have about three times as much fiber as the cereals from which they are produced. In the 2007 Swine Day Report of Progress, (Feoli et al., page 126 and Feoli et al., page 131), we suggested that addition of high levels of DDGS in diets for nursery and finishing pigs had negative effects on nutrient digestibility and growth rate. Previous experiments from our laboratory have shown that conditioning wheat midds-based diets high in fiber in an expander prior to pelleting improved nutrient digestibility in nursery and finishing pigs. Therefore, the objective of the present experiments was to determine the effects of expander conditioning on the nutritional value of diets with and without DDGS.

Procedures

For Exp. 1, 180 nursery pigs (42 d old and initially 29 lb) were used in a 14-d growth assay. The pigs were sorted by sex and ancestry, blocked by weight, and assigned to pens. There were 3 gilts and 3 barrows in each pen and 5 pens per treatment. The pigs were housed in an environmentally controlled nursery having 4-ft × 4-ft pens with woven-wire flooring. Each pen had a self-feeder and nipple waterer to allow ad libitum consumption of feed and water.

Treatments were arranged as a 3 × 2 factorial with main effects of diet formulation (Table 1; corn-soybean meal vs. diets with 30% corn-based DDGS from Sioux River Ethanol, Hudson, SD, and 30% sorghum-based DDGS from U.S. Energy Partners, Russell, KS) and conditioning (standard steam vs. expander) prior to pelleting. All diets (Table 1) were formulated to 1.4% lysine, 0.75% Ca, and 0.65% P.

Table 1. Composition of nursery diets

Ingredient, %	Corn-soybean meal	DDGS[1]
Corn	62.86	42.97
DDGS	---	30.00
Soybean meal (47.5% CP)	32.60	22.85
Limestone	1.11	1.36
Monocalcium phosphate (21% P)	1.30	0.67
Salt	0.36	0.35
L-lysine HCl	0.32	0.53
DL-methionine	0.12	0.02
L-threonine	0.09	0.05
Vitamin premix	0.11	0.11
Mineral premix	0.08	0.05
Antibiotic[2]	0.70	0.70
Chromic oxide[3]	0.25	0.25
Copper sulfate	0.10	0.09
Calculated analysis		
Lysine	1.40	1.40
Ca	0.75	0.75
Total P	0.65	0.65

[1] Dried distillers grains with solubles.
[2] To supply 140 g/ton oxytetracycline and 140 g/ton neomycin.
[3] Used as an indigestible marker.

Diets were either steam conditioned to 180°F or expanded conditioned (302°F, 200 PSI) before passing into a pelleting press (30 HD Master Model, California Pellet Mill, San Francisco, CA) equipped with a 7/8-in.-thick die having 5/32-in. openings. Samples of the processed diets were collected, and pellet durability index (PDI) was determined by using the tumbling-box technique (ASAE S269.4 DEC1991). Additionally, the PDI procedure was modified to induce more stress on the pellets by adding 5 hexagonal nuts into the tumbling box.

Pigs and feeders were weighed on d 0 and 14 to allow calculation of ADG, ADFI, and F/G. Feces were collected on d 4 and 5 from

no less than 3 pigs per pen to allow determination of apparent digestibility for DM, N, and GE.

Data were analyzed as a randomized complete block design (initial weight as a covariate) by using the MIXED procedure of SAS. Orthogonal contrasts were used to separate treatment means with comparisons of (1) control vs. DDGS diets, (2) corn- vs. sorghum-based DDGS, 3) standard vs. expander conditioning, (4) corn-soy vs. DDGS × standard vs. expander conditioning, and (5) corn- vs. sorghum-based DDGS × standard vs. expander conditioning.

For Exp. 2, 176 finishing pigs (initially 164 lb) were used in a 54-d growth assay. The pigs were sorted by sex and ancestry, blocked by weight, and assigned to pens. There were 11 pigs per pen and 4 pens per treatment. The pigs were housed in an environmentally controlled finishing facility having 6-ft × 16-ft pens with half solid and half slatted concrete flooring. Each pen had a self-feeder and nipple waterer to allow ad libitum consumption of feed and water.

Treatments were arranged as a 2 × 2 factorial with main effects of diet formulation (corn-soybean meal vs. 40% sorghum-based DDGS) and conditioning (standard steam vs. expander) prior to pelleting. All diets (Table 2) were formulated to 0.90% lysine, 0.60% Ca, and 0.50% P. Feed was processed as in Exp. 1, but 6 batches of feed were made, and more extensive processing data were collected. Voltage and cone pressure of the expander were kept constant at 250 volts and 200 PSI, respectively. Then, motor load and production rate for the pellet mill, net electrical consumption for the pellet mill and the expander, and PDI were measured and analyzed as a randomized complete block design by using the MIXED procedure of SAS with batch as the blocking criterion. Orthogonal contrasts for a 2 × 2 factorial were used to separate means for the main effects of diet formulation and conditioning.

Pigs and feeders were weighed on d 0, 26, and 54 to allow calculation of ADG, ADFI, and F/G. The pigs were slaughtered (average weight 287 lb) at a commercial slaughter facility, and carcass data were collected. Growth performance and carcass data were analyzed as a randomized complete block design by using the MIXED procedure of SAS with initial weight as the blocking criterion and pen as the experimental unit. Hot carcass weight was used as a covariate in analysis of data for dressing percentage, carcass lean percentage, backfat thickness, and loin depth. Orthogonal contrasts for a 2 × 2 factorial were used to separate treatment means with main effects of diet formulation and conditioning.

For Exp. 3, 176 finishing pigs (initially 222 lb) were used in an 8-d digestibility study. The pigs were sorted by sex and ancestry, blocked by weight, and assigned to pens. There were 11 pigs per pen and 4 pens per treatment. The pigs were housed in an environmentally controlled finishing facility having 6-ft × 16-ft pens with half solid and half slatted concrete flooring. Each pen had a self-feeder and nipple waterer to allow ad libitum consumption of feed and water with pigs and feeders weighed on d 0 and 8. Feces were collected on d 7 and 8 from no less than 6 pigs per pen. Concentrations of DM, N, GE, and Cr in the diets and feces were determined to allow for calculation of apparent digestibilities. Treatments and diets were the same as in the growth assay (Exp. 2).

Data were analyzed as a randomized complete block design by using the MIXED procedure of SAS with initial weight as the blocking criterion and pen as the experimental unit. Orthogonal contrasts for a 2 × 2 factorial were used to separate means for the main effects of diet formulation and conditioning.

Results and Discussion

In Exp. 1 (Table 3), the corn-soybean meal diets supported better ($P < 0.005$) ADG, ADFI, F/G, and digestibility of DM, N, and GE, than diets with DDGS. Also, pigs fed diets with corn-based DDGS had better ($P < 0.03$) ADG, F/G, and digestibility of DM and N than pigs fed diets with sorghum-based DDGS. Expander conditioning improved ($P < 0.009$) ADG, F/G, and digestibility of DM, N, and GE compared with standard conditioning. However, expander conditioning tended to improve digestibility of DM most in diets with DDGS as indicated by the corn-soybean meal vs. DDGS × standard vs. expander conditioning interaction ($P < 0.08$). Finally, pigs fed diets with sorghum-based DDGS had greater improvement in F/G with expander conditioning than pigs fed diets with corn-based DDGS (corn- vs. sorghum-based DDGS × standard vs. expander; $P < 0.008$).

Milling data (Table 4) for the finishing diets used in Exp. 2 indicated that addition of 40% DDGS decreased pellet mill throughput (i.e., production rate) and increased energy used in the pelleting process ($P < 0.005$). However, contrary to some reports, high inclusion of DDGS improved PDI ($P < 0.001$). As for pig growth (Table 5), adding 40% DDGS to diets for finishing pigs reduced ($P < 0.02$) overall ADG and ADFI and increased ($P < 0.03$) overall F/G. Expander conditioning improved ($P < 0.002$) F/G, but this response was consistent for diets with and without DDGS (i.e., no diet formulation × expander conditioning interaction; $P > 0.41$).

Pigs had lower ($P < 0.001$) HCW when fed diets with 40% DDGS. Even when corrected to a constant HCW (via covariate analysis), dressing percentage ($P < 0.03$) and loin depth ($P < 0.06$) were greater for pigs fed the corn-soybean meal diets than for pigs fed the DDGS treatments. However, half the loss in HCW and all the loss in dressing percentage were recovered when diets with DDGS were expander processed prior to pelleting.

Nutrient digestibility in finishing pigs (Table 6) was greater ($P < 0.001$) for pigs fed diets without DDGS. Expander conditioning improved ($P < 0.02$) digestibility of N and GE compared with standard conditioning, but digestibility of DM was improved with expander conditioning only in the DDGS diets (diet × conditioning interaction, $P < 0.01$).

In conclusion, adding 30 and 40% DDGS to nursery and finishing diets decreased growth performance and nutrient digestibility compared with a corn-soybean meal control. However, expanding diets improved ADG, F/G, and nutrient digestibility in nursery pigs and F/G, dressing percentage, and nutrient digestibility in finishing pigs fed diets without and with DDGS.

Table 2. Composition of finishing diets

	d 0 to 26		d 26 to 54	
Ingredient, %	Corn-soybean meal	DDGS[1]	Corn-soybean meal	DDGS
Corn	79.63	52.67	81.47	54.54
DDGS	---	40.00	---	40.00
Soybean meal (47.5% CP)	17.80	4.95	16.20	3.30
Limestone	1.09	1.34	1.06	1.24
Monocalcium phosphate (21% P)	0.73	0.05	0.54	---
Salt	0.30	0.30	0.38	0.30
L-lysine HCl	0.20	0.47	0.13	0.40
L-threonine	0.03	---	---	---
Vitamin premix	0.12	0.12	0.12	0.12
Mineral premix	0.05	0.05	0.05	0.05
Antibiotic [2]	0.05	0.05	0.05	0.05
Calculated analysis				
Lysine	0.90	0.90	0.80	0.80
Ca	0.60	0.60	0.55	0.55
Total P	0.50	0.50	0.45	0.45

[1] Dried distillers grains with solubles.
[2] To provide 40 g/ton tylosin.

Table 3. Effects of expander conditioning of diets with corn- and sorghum-based dried distillers grains with solubles (DDGS) on growth performance and nutrient digestibility in nursery pigs[1]

	Corn-soybean meal		Corn-based DDGS		Sorghum-based DDGS			Contrasts[2]				
Item	Std[3]	Exp[4]	Std	Exp	Std	Exp	SE	1	2	3	4	5
PDI, %[5]	88.5	94.9	93.0	95.0	91.9	96.6						
ADG, lb	1.48	1.59	1.33	1.44	1.21	1.39	0.04	0.001	0.02	0.002	---[6]	---
ADFI, lb	2.15	2.23	1.93	2.04	2.06	2.07	0.05	0.001	0.09	---	---	---
F/G	1.45	1.40	1.45	1.42	1.70	1.50	0.03	0.005	0.001	0.009	---	0.008
Digestibility of DM, %[7]	82.5	83.7	76.9	79.9	76.4	78.3	0.4	0.001	0.03	0.001	0.08	---
Digestibility of N, %	78.3	81.5	76.4	79.6	70.1	73.4	0.7	0.001	0.001	0.001	---	---
Digestibility of GE, %	81.2	83.8	76.5	78.4	75.6	77.3	0.5	0.001	0.09	0.001	---	---

[1] A total of 180 nursery pigs (initially 29 lb) with 6 pigs per pen and 5 pens per treatment.
[2] Contrasts were (1) control vs. DDGS diets, (2) corn- vs. sorghum-based DDGS, (3) standard vs. expander conditioning, (4) corn-soybean meal vs. DDGS × standard vs. expander conditioning, and (5) corn- vs. sorghum-based DDGS × standard vs. expander conditioning.
[3] Standard conditioning prior to pelleting.
[4] Expander conditioning prior to pelleting.
[5] Pellet durability index (ASAE S269.4 DEC1991).
[6] Dashes indicate $P > 0.15$.
[7] Fecal samples collected on d 4 and 5 with chromic oxide used as an indigestible marker.

Table 4. Effects of expander conditioning of finishing diets with corn- and sorghum-based dried distillers grains with solubles (DDGS) on production efficiency (Exp. 2)[1]

	Corn-soybean meal		DDGS			*P* value		
Item	Std[2]	Exp[3]	Std	Exp	SE	Diet effect	Condit. effect	Diet × Cond.
Conditioning temp, °F[4]	181	244	182	315	4	0.001	0.001	0.001
Amperage, amps	19.0	18.9	17.4	16.2	0.3	0.001	0.03	0.04
Motor load, %	33.5	30.0	29.8	28.2	1.4	0.05	0.07	---[5]
Production rate, lb/h	2,553	2,550	2,213	2,312	113	0.005	---	---
Net energy, kWh/t	9.6	41.9	10.1	53.8	1.6	0.001	0.001	0.001
Pellet durability								
Standard, %[6]	76.3	90.8	87.7	96.0	1.3	0.001	0.001	0.007
Modified, %[7]	69.6	88.8	85.2	95.5	1.6	0.001	0.001	0.002

[1] Each diet was replicated by manufacturing a new batch of feed 6 times.
[2] Standard conditioning prior to pelleting.
[3] Expander conditioning prior to pelleting.
[4] Measured at the exit of the standard conditioner and at the expander cone.
[5] Dashes indicate $P > 0.15$.
[6] Pellet durability index (ASAE S269.4 DEC1991).
[7] Modified by adding 5 hexagonal nuts (1/2-in. diameter) to the tumbling box.

Table 5. Effects of expander conditioning of diets with corn- and sorghum-based dried distillers grains with solubles (DDGS) on growth performance and carcass characteristics in finishing pigs[1]

	Corn-soybean meal		DDGS			*P* value		
Item	Std[2]	Exp[3]	Std	Exp	SE	Diet effect	Condit. effect	Diet × Cond.
d 0 to 26								
ADG, lb	2.43	2.46	2.22	2.25	0.08	0.02	---[4]	---
ADFI, lb	6.78	6.46	6.22	6.07	0.30	0.004	0.09	---
F/G	2.79	2.63	2.80	2.70	0.07	---	0.02	---
d 0 to 54								
ADG, lb	2.37	2.32	2.16	2.23	0.05	0.004	---	0.14
ADFI, lb	7.13	6.63	6.60	6.59	0.26	0.02	0.03	0.04
F/G	3.01	2.86	3.06	2.96	0.06	0.03	0.002	---
HCW, lb	215.3	215.6	204.0	210.0	5.6	0.001	0.10	0.13
Dressing, %[5]	73.5	74.3	72.7	73.7	0.3	0.03	0.007	---
Carcass lean, %[5]	53.8	53.6	54.0	53.3	0.7	---	---	---
Backfat thickness, in[5]	0.80	0.81	0.77	0.82	0.04	---	---	---
Loin depth, in[5]	2.38	2.42	2.31	2.31	0.04	0.06	---	---

[1] A total of 176 finishing pigs (initially 164 lb) with 11 pigs per pen and 4 pens per treatment.
[2] Standard conditioning prior to pelleting.
[3] Expander conditioning prior to pelleting.
[4] Dashes indicate $P > 0.15$.
[5] HCW used as a covariate.

Table 6. Effects of expander conditioning of diets with corn- and sorghum-based dried distillers grain with solubles (DDGS) on nutrient digestibility in finishing pigs[1]

	Corn-soybean meal		DDGS			*P* value		
Item	Std[2]	Exp[3]	Std	Exp	SE	Diet effect	Condit. effect	Diet × Cond.
Pellet durability								
Standard, %[4]	74.6	94.7	90.9	97.2				
Modified, %[5]	67.7	94.4	89.2	97.1				
ADG, lb	1.77	2.02	1.83	1.80	0.11	---[6]	---	---
ADFI, lb	6.81	6.57	6.57	6.34	0.30	---	---	---
F/G	3.85	3.25	3.59	3.52	0.27	---	0.15	---
Digestibility of DM, %[7]	86.8	86.7	79.5	81.9	0.4	0.001	0.02	0.01
Digestibility of N, %	83.2	85.4	72.5	76.5	0.7	0.001	0.001	---
Digestibility of GE, %	86.1	87.7	77.5	81.1	0.8	0.001	0.02	---

[1] A total of 176 finishing pigs (initially 222 lb) with 11 pigs per pen and 4 pens per treatment.
[2] Standard conditioning prior to pelleting.
[3] Expander conditioning prior to pelleting.
[4] Pellet durability index (ASAE S269.4 DEC1991).
[5] Modified by adding five hexagonal nuts (1/2-in. diameter) to the tumbling box.
[6] Dashes indicate $P > 0.15$.
[7] Fecal samples collected on d 7 and 8 with chromic oxide used as an indigestible marker.

VARIATION IN CHEMICAL COMPOSITION OF SOYBEAN HULLS[1]

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Summary

The objective of this study was to examine the variation in chemical composition of soybean hulls. Our goal was to develop regression equations characterizing the nutritive value of soybean hulls for use in swine diets. Samples (n = 39) were collected from different processing plants across the United States and analyzed for CP, GE, crude fiber (CF), ADF, NDF, fat, ash, Ca, P, and essential amino acids. One sample was excluded from these results because it contained approximately 10 times the amount of Ca (5.2% vs. a mean of 0.57%) as other samples. The results of chemical analysis of the samples were used to determine maximum, minimum, and mean values on a DM basis. Estimated DE values were calculated according to an equation described by Noblet and Perez (1993). Regression equations among the nutrients also were established. A high correlation was observed between CF and CP (R^2 = 0.92), ADF (R^2 = 0.96), NDF (R^2 = 0.97), and estimated DE (R^2 = 0.94), indicating that the analyzed fiber content of soybean hulls could be used to predict the other components. A high correlation also was observed between CP and estimated DE (R^2 = 0.90). Lower correlations were observed between ash concentration and Ca and P. High correlations were observed between CP and lysine (R^2 = 0.89), methionine (R^2= 0.88), threonine (R^2 = 0.93), and tryptophan (R^2 = 0.93). In summary, the chemical composition of soybean hulls can be highly variable; however, CF content can help explain much of the variation in CP, ADF, NDF, and estimated DE, and CP content can be used to predict individual amino acid levels.

Key words: nutritive value, soybean hulls

Introduction

The United States is among the world's top soybean-producing countries. One of the by-products of soybean processing is soybean hulls, which are separated during the oil extraction process. Soybean hulls represent 7 to 8% of the weight of the soybean. Thus, large amounts of soybean hulls are available for swine feeding. Many of the ingredient composition tables used by swine nutritionists do not list the composition for soybean hulls. Tables in some foreign publications (e.g., Brazilian tables for poultry and swine) list values for soybean hulls; however, these values may be based on a limited number of samples and influenced by soybean source and processing techniques. Research to determine the nutrional values of soybean hulls from U.S. soybean crushing facilities has not been completed. Therefore, this study was conducted to examine the variation in chemical composition of soybean hulls. Our goal was to develop regression equations characterizing the nutritive value of soybean hulls for use in swine diets.

[1] The authors thank Anjinomoto Heartland Lysine, Chicago, IL, for conducting the amino acid analysis.
[2] Food Animal Health and Management Center, College of Veterinary Medicine, Kansas State University.

Procedures

Samples were collected from feed mills and soy processors throughout the United States. A total of 39 samples were collected from processing plants in Alabama (1 sample), Colorado (3 samples), Georgia (1 sample), Illinois (10 samples), Indiana (2 samples), Iowa (6 samples), Kansas (3 samples), Minnesota (6 samples), Missouri (1 sample), North Carolina (1 sample), North Dakota (1 sample), Ohio (2 samples), Oklahoma (1 sample), and Wisconsin (1 sample). The samples were analyzed for crude fiber (CF), GE, CP, ADF, NDF, fat, ash, Ca, P, and indispensable amino acids content. Gross energy was analyzed by bomb calorimetry in the Kansas State University Analytical Lab. Amino acids were analyzed by Ajinomoto Heartland LLC Amino Acid lab (Chicago, IL). All other analysis was conducted by Ward Labs (Kearney, NE). After the analysis of nutrient values, 1 sample was excluded because it contained approximately 10 times the amount of Ca (5.22% vs. a mean of 0.57%) as other samples. Therefore, all the results were obtained from 38 samples. The results for amino acid concentration were obtained from all 39 samples. Estimated DE values were calculated according to an equation described by Noblet and Perez (1993): DE = 4,151 + (122 × % Ash) + (23 × % CP) + (38 × % EE) - (64 x % CF (R^2 = 0.89). Estimated ME values were calculated according to the equation described by May and Bell (1971): ME = DE × (1.012 − (0.0019 × % CP (R^2 = 0.91).

The mean, minimum, maximum, and standard deviation for each analytical variable were determined. Regression equations were developed to determine the relationship between major analytical components.

Results and Discussion

The wide range in soy hull nutrient levels is shown in Table 1. Crude protein ranged from 9.0 to 26.7% with a majority of the samples between 9 and 12%. Crude fiber content ranged from 21.8 to 36.1% on an as-fed basis with the majority of the samples being between 34 and 36% (Figure 1).

Because the wide range in nutrient values was not evenly distributed, the mean values should not be used for diet formulation. Thus, regression equations were developed to predict the nutrient levels from 1 or 2 variables that could be measured relatively inexpensively (Table 2). These equations are an important tool in formulating diets for pigs, reducing the time and cost of laboratory analysis. A high correlation was observed between CF and CP with CF predicting 92% of the variation in CP content (Figure 1). Crude fiber also was highly correlated to other variables with CF predicting almost 96% of the variation in ADF content, 97% of the variation in NDF content, 90% of the variation in estimated DE, and 89% of the variation in estimated ME (Figures 2 to 5, respectively). A high correlation also was observed between CP and estimated DE (Y = 74.79x + 521.9; R^2 = 0.90). Lower correlations were observed between ash concentration and Ca and P. Also, lower correlations were observed between GE and all the other nutrients.

Because of the high variability in CP levels, it was not surprising that individual amino acids were highly variable between soy hull sources (Table 1). When expressed relative to the CP content in the soy hulls, most of the variability can be explained. Crude protein explained most of the variability in lysine (89%), methionine (88%), threonine (93%), and tryptophan (93%) (Figures 6 to 9, respectively) as well many other amino acids.

The chemical composition of the soybean hulls can be influenced by many factors including processing procedure and growing conditions for the soybeans. These data indicate that the chemical composition of soybean hulls can be highly variable; however, CF content can help explain much of the variation

in CP, ADF, NDF, and energy content. Crude protein content can explain much of the variation in amino acid content. Thus, the most of the nutrient values for soybean hulls that are required for diet formulation can be estimated from laboratory analysis of the CF and CP level.

Table 1. Nutritional values of soybean hulls on an as-fed basis[1]

Nutrient	Minimum	Mean	Maximum	SD
Moisture, %	3.39	8.18	9.51	1.16
CP, %	9.00	12.27	26.70	3.68
GE, kcal/kg	3,668	4,017	4,401	159
Est. DE, kcal/kg	1,056	1,425	2,413	291
Est. ME, kcal/kg	1,037	1,387	2,272	268
Crude fiber, %	21.80	33.32	36.10	3.04
ADF, %	27.50	42.42	46.70	3.95
NDF, %	37.80	57.28	62.10	5.16
Fat, %	0.60	1.54	4.30	0.83
N free extract, %	36.00	39.18	41.10	1.26
Ash, %	4.11	4.87	6.12	0.46
Ca, %	0.42	0.52	0.70	0.05
P, %	0.10	0.15	0.32	0.05
Amino acids, %				
Lysine	0.67	0.86	1.83	0.21
Methionine	0.10	0.16	0.48	0.07
Threonine	0.37	0.48	1.15	0.14
Tryptophan	0.11	0.15	0.37	0.05
Arginine	0.43	0.65	1.81	0.29
Histidine	0.24	0.31	0.68	0.09
Leucine	0.58	0.82	1.99	0.30
Isoleucine	0.34	0.48	1.17	0.17
Phenylalanine	0.31	0.54	1.26	0.19
Valine	0.39	0.55	1.30	0.18

[1] Values represent the data from 38 samples (39 for amino acids).

Table 2. Regression equations to predict CP, ADF, NDF, estimated DE, and estimated ME from crude fiber (CF) and to predict amino acids content from CP (as-fed basis)

Nutrient	Equation	R^2
Nutrient predicted from CF[1]		
CP	= -1.1622 x CF + 50.998	0.92
ADF	= 1.2697 x CF + 0.1143	0.96
NDF	= 1.6689 x CF + 1.6755	0.97
Estimated DE	= -90.699 x CF + 4447.4	0.90
Estimated ME	= -83.072 x CF + 4155.2	0.89
Amino acid predicted from CP[2]		
Lysine	= 0.05735 x CP + 0.1048	0.89
Methionine	= 0.0168 x CP − 0.0551	0.88
Threonine	= 0.038 x CP − 0.0189	0.93
Tryptophan	= 0.0123 x CP − 0.0078	0.93
Arginine	= 0.0758 x CP − 0.2757	0.93
Histidine	= 0.0241 x CP + 0.0162	0.93
Leucine	= 0.0776 x CP + 0.136	0.93
Isoleucine	= 0.0459 x CP − 0.0162	0.93
Phenylalanine	= 0.0486 x CP − 0.0574	0.93
Valine	= 0.0474 x CP − 0.0339	0.92

[1] CF is expressed as a percentage of the soy hulls on an as-fed basis.
[2] CP is expressed as a percentage of the soy hulls on an as-fed basis.

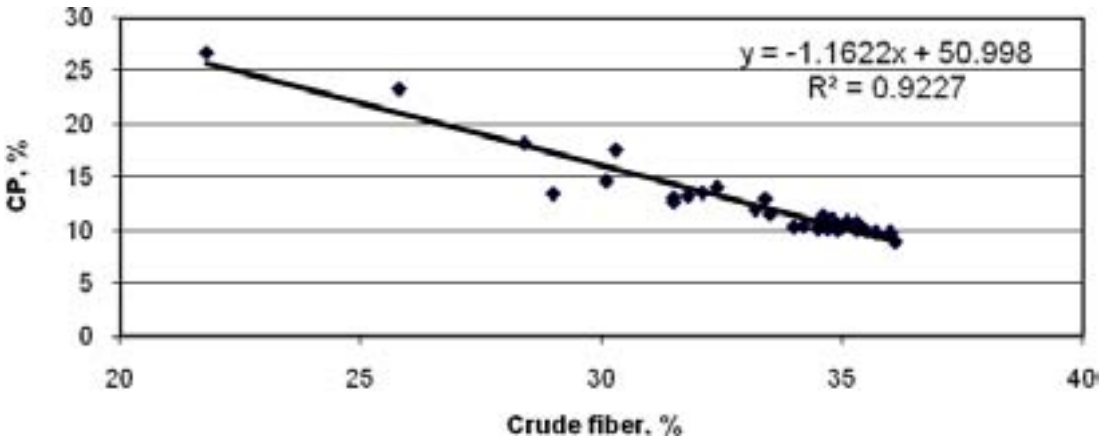

Figure 1. Relationship between crude fiber and CP content of soybean hulls (as-fed basis).

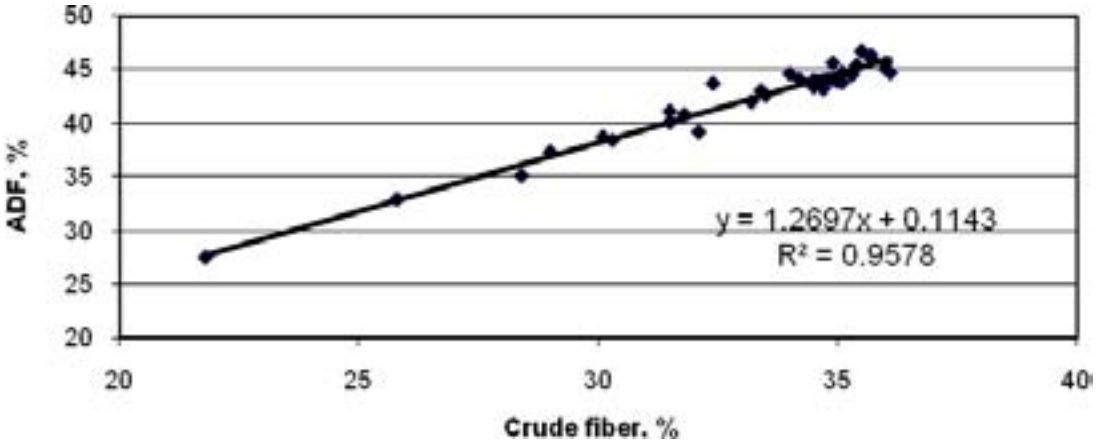

Figure 2. Relationship between crude fiber and ADF content of soybean hulls (as-fed basis).

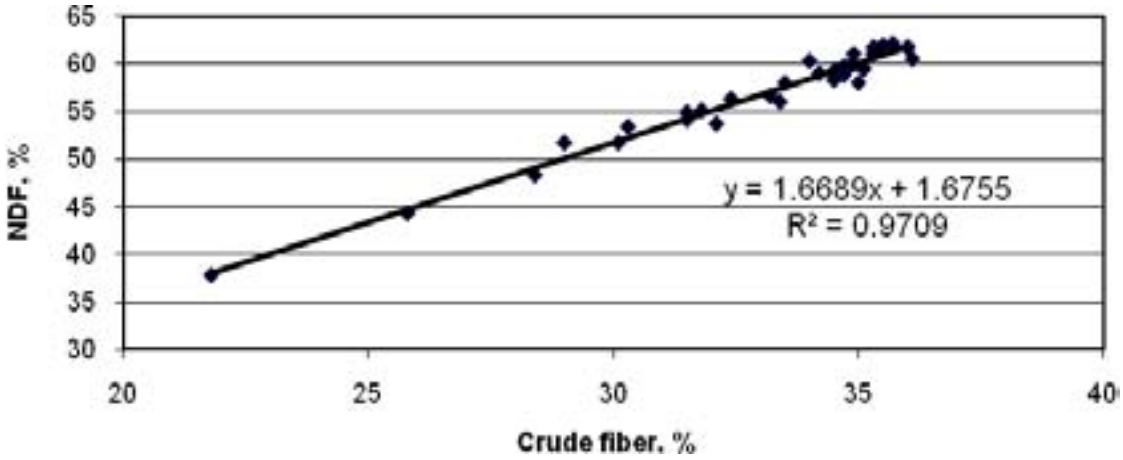

Figure 3. Relationship between crude fiber and NDF content of soybean hulls (as-fed basis).

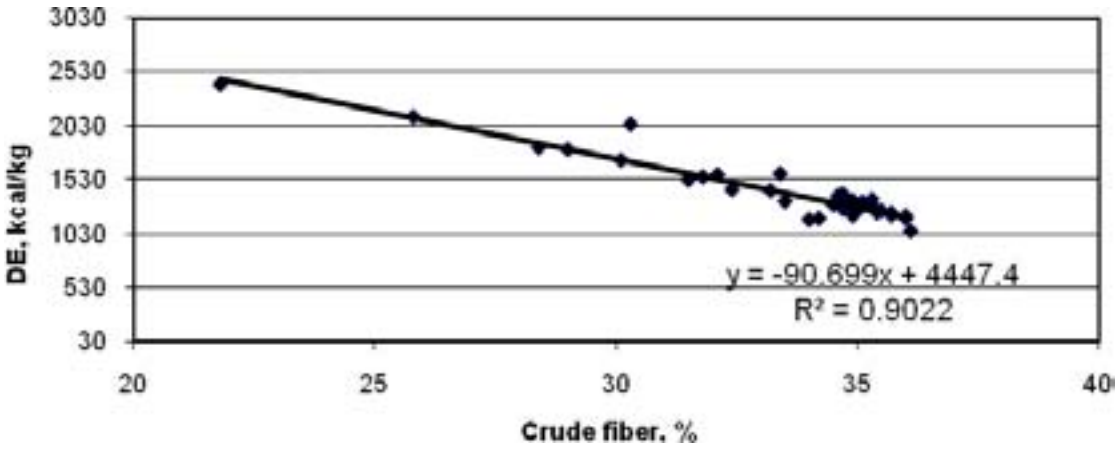

Figure 4. Relationship between crude fiber and estimated DE content of soybean hulls (as-fed basis).

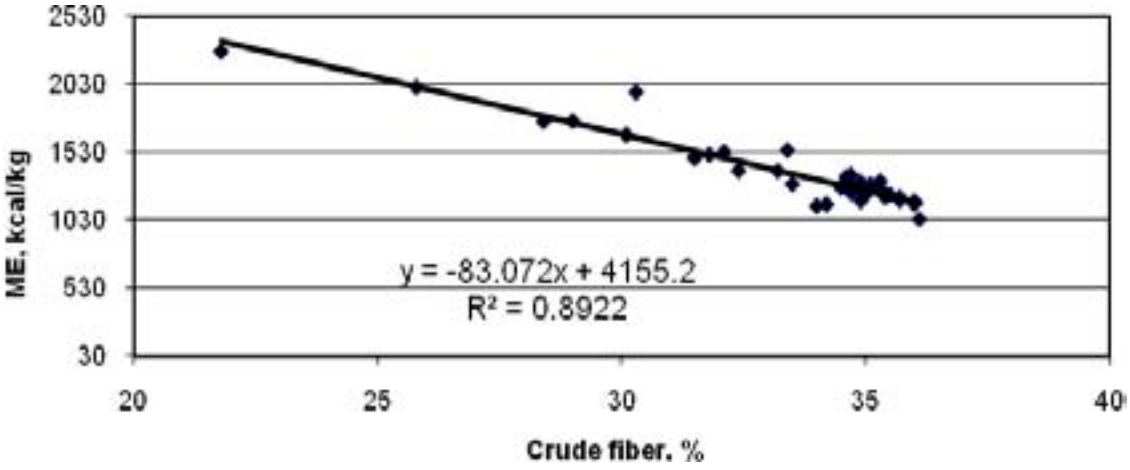

Figure 5. Relationship between crude fiber and estimated ME content of soybean hulls (as-fed basis).

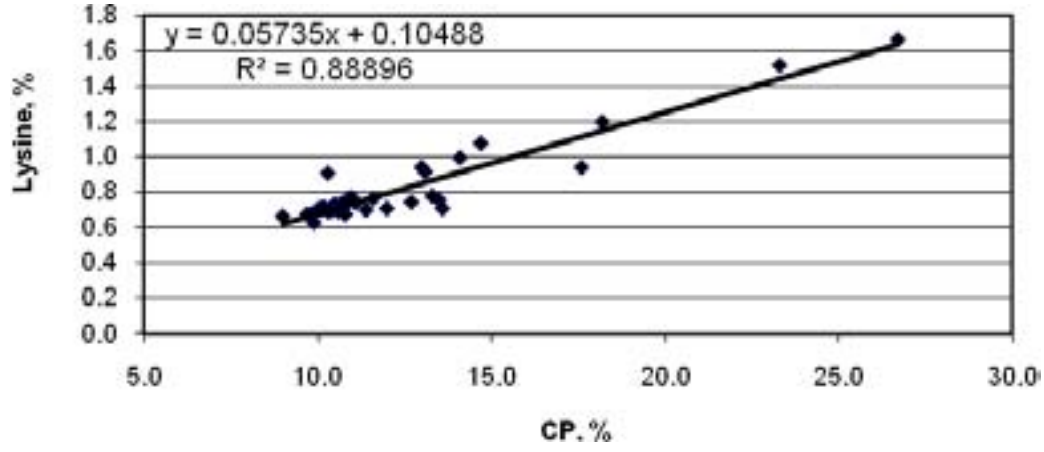

Figure 6. Relationship between CP and lysine content of soybean hulls (as-fed basis).

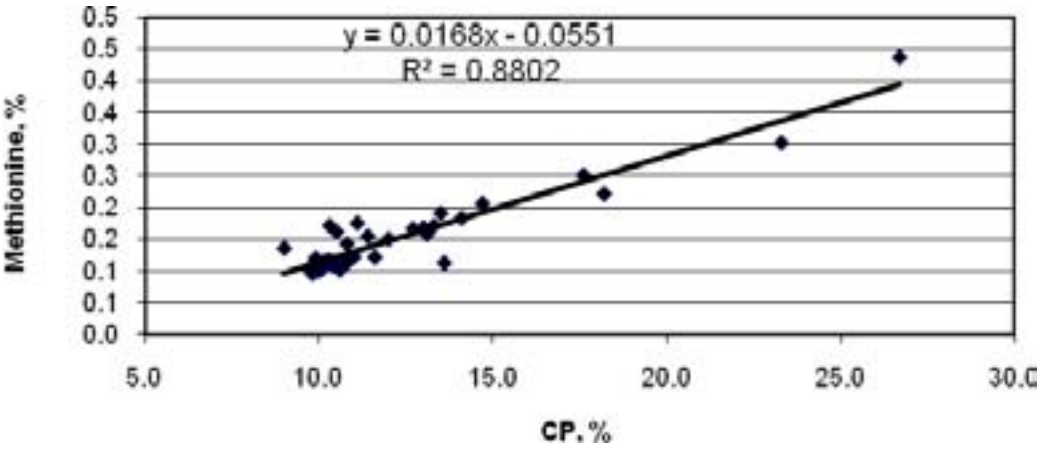

Figure 7. Relationship between CP and methionine content of soybean hulls (as-fed basis).

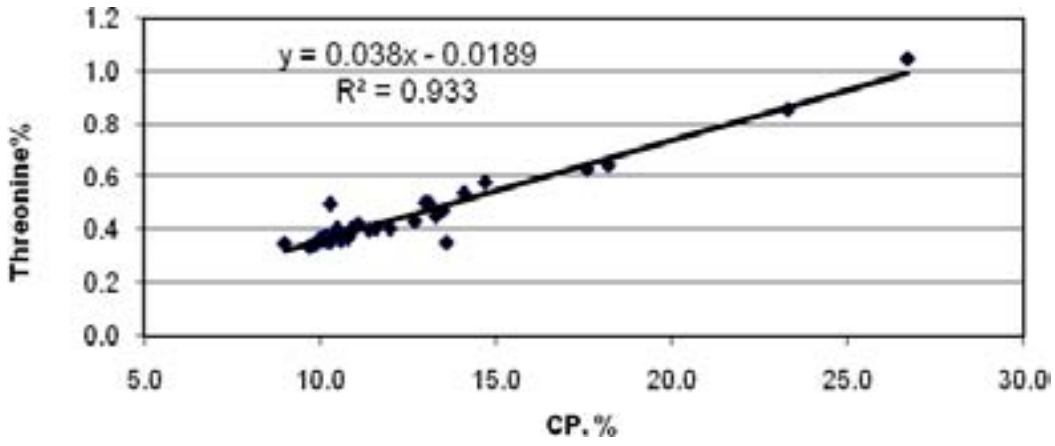

Figure 8. Relationship between CP and threonine content of soybean hulls (as-fed basis).

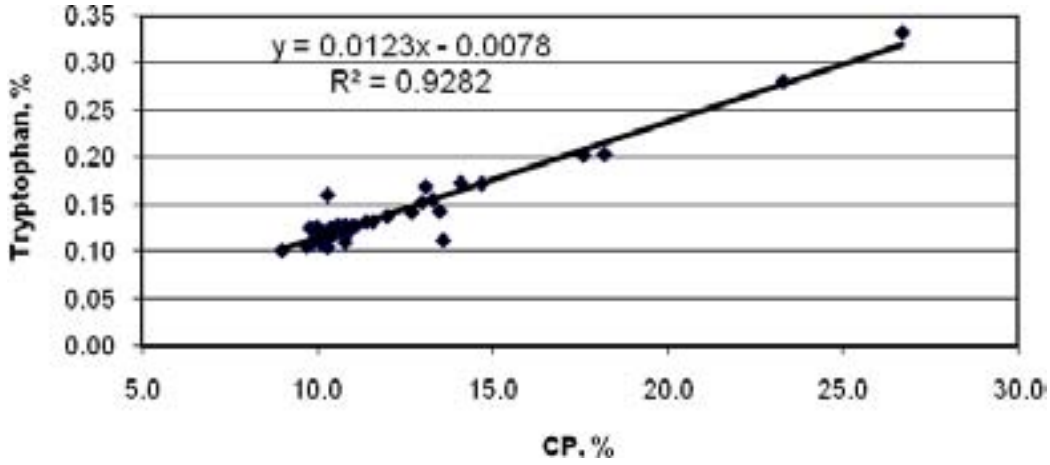

Figure 9. Relationship between CP and tryptophan content of soybean hulls (as-fed basis).

USE OF DRIED DISTILLERS GRAINS WITH SOLUBLES AND SOYBEAN HULLS IN NURSERY PIG DIETS

F. F. Barbosa, S. S. Dritz[1], M. D. Tokach, J. M. DeRouchey, R. D. Goodband, and J. L. Nelssen

Summary

A total of 3,186 pigs were used in two 21-d experiments to evaluate growth performance of nursery pigs fed different levels of dried distillers grains with soluble (DDGS) or soybean hulls. In each experiment, pigs (n = 1,593, and 24.0 lb in Exp. 1 and n = 1,593, and 27.3 lb in Exp. 2) were allotted to 72 pens (36 pens of barrows and 36 pens of gilts) with 21 or 22 pigs per pen on d 21 after weaning. A pen of barrows and pen of gilts shared a common feeder; thus, feeder was the experimental unit. In Exp. 1, treatments were a corn-soybean meal-based control diet or the same diet with 7.5, 15, or 22.5% added DDGS. Increasing DDGS from 0 to 22.5% did not affect ADG ($P > 0.26$) or ADFI ($P > 0.21$) but linearly ($P < 0.004$) improved F/G. The survival rate of pigs (99.0 to 99.5%) was not affected ($P > 0.60$) by diet. In Exp. 2, treatments were arranged as a 2 × 2 factorial with either 0 or 15% DDGS and 0 or 4% soybean hulls. Adding DDGS, soybean hulls, or the combination of DDGS and soybean hulls to the control diet did not affect ($P > 0.17$) ADG. There was an interaction ($P < 0.01$) between DDGS and soybean hulls for ADFI and a trend for an interaction ($P < 0.09$) for F/G. Adding DDGS reduced ADFI and improved ($P < 0.04$) F/G to a greater extent when added to the control diet than when added to the diet containing soybean hulls. Adding soybean hulls to the control diet did not affect ($P > 0.17$) pig performance. The survival rate of pigs (99.5 to 100%) was not affected ($P > 0.31$) by treatments. In summary, 15 to 22.5% DDGS and up to 4% soybean hulls were added to diets for 25- to 50-lb pigs without affecting ADG; increasing levels of DDGS (up to 22.5%) improved feed efficiency in these experiments.

Key words: dried distillers grains with solubles, nursery pig, soybean hulls

Introduction

In the last few years, the utilization of cereal grains to produce ethanol has rapidly increased in the United States. Because of its abundance, higher starch content, and greater ethanol yield compared with other cereal grains, corn is the most common grain used to produce ethanol. One of the most relevant coproducts obtained from ethanol production is dried distillers grains with solubles (DDGS), and great interest has been generated regarding the use of this coproduct in swine diets. Another by-product that has been studied for use in swine diets is soybean hulls, which originate from soybean processing. The United States is one of world's largest producers of soybeans, with more than 70 million tons produced in 2007. The hulls represent 7 to 8% of the weight of the soybean;

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therefore, approximately 6 million tons of soybean hulls are produced every year. Recent research has indicated that low levels (2 to 4%) of soybean hulls may be added to nursery diets without reducing pig performance. Because soybean hulls are normally less expensive than corn, use at these low levels could reduce diet cost. Limited data is available to determine the influence of soybean hulls on pig performance in commercial farms. Thus, these trials were conducted to evaluate growth performance of nursery pigs fed different levels of DDGS or soybean hulls in a commercial nursery.

Procedures

Procedures used in these experiments were approved by the Kansas State University Institutional Animal Care and Use Committee. A total of 3,186 pigs were used in two 21-d experiments. In each experiment, 1,593 pigs were allotted to 72 pens (36 pens of barrows and 36 pens of gilts) with 21 or 22 pigs per pen on d 21 after weaning. A pen of barrows and pen of gilts shared a common feeder; thus, feeder was the experimental unit.

Experiment 1. Pigs (initially 24.0 lb) were randomly allotted to 1 of 4 dietary treatments. Treatments consisted of a corn-soybean meal-based control diet or the same diet with 7.5, 15, or 22.5% added DDGS (Table 1). On d 21, 28, 35, and 42 after weaning, pigs were weighed and feed disappearance was measured to calculate ADG, ADFI, and F/G. Survival rate was calculated for each feeder by dividing the number of pigs at the end of the experiment by the initial number of pigs (2 pens per feeder; initially 22 pigs per pen). Data were analyzed by using the PROC MIXED procedure in SAS. Contrasts were used to test for linear and quadratic responses to DDGS level.

Experiment 2. Pigs (initially 27.3 lb) were randomly allotted to 1 of 4 dietary treatments. Diets were corn-soybean meal-based. Dietary treatments were arranged as a 2 × 2 factorial with either 0 or 15% DDGS and 0 or 4% soybean hulls (Table 2). The experimental procedures followed the same methodology as described for Exp. 1. Data were analyzed by using PROC MIXED in SAS as a randomized complete block design with pens (one barrow pen and one gilt pen) consuming feed from a single feeder as the experimental unit. Data were analyzed for interactions and the main effects of DDGS and soybean hulls.

Results and Discussion

Experiment 1. Increasing DDGS in the diet from 0 to 22.5% did not influence ($P > 0.21$) ADG or ADFI (Table 3). However, increasing DDGS in the diet from 0 to 22.5% linearly ($P < 0.004$) improved F/G. Survival rate of pigs was not affected ($P > 0.60$) by dietary treatment.

Experiment 2. Adding DDGS, soybean hulls, or the combination of DDGS and soybean hulls to the control diet did not influence ($P > 0.09$) ADG (Table 4). An interaction ($P < 0.01$) was observed between DDGS and soybean hulls for ADFI. Feed intake was reduced to a greater extent when DDGS was added to the control diet than when added to the diet containing soybean hulls. There was also a trend for an interaction ($P < 0.09$) between DDGS and soy hulls for F/G. Adding DDGS to the control diet improved F/G, whereas adding DDGS to the diet containing soy hulls had no influence on F/G. Adding soybean hulls to the control diet did not influence pig performance. Survival rate of pigs (99.5 to 100%) was not affected ($P > 0.31$) by the treatments.

In conclusion, 15 to 22.5% DDGS and 4% soybean hulls were added to diets for 25- to 50-lb pigs without negatively affecting ADG. Increasing DDGS (up to 22.5%) improved feed efficiency in these experiments.

Table 1. Diet composition (Exp. 1)

	Dried distillers grains with solubles, %			
Ingredient, %	0	7.5	15	22.5
Corn	60.83	55.78	50.68	45.58
Soybean meal (46.5% CP)	34.25	31.91	29.57	27.24
Dried distillers grains with solubles	---	7.50	15.00	22.50
Choice white grease	1.50	1.50	1.50	1.50
Dicalcium phosphate (18.5% P)	1.45	1.20	1.00	0.80
Limestone	0.80	0.90	1.00	1.10
Salt	0.35	0.35	0.35	0.35
L-lysine HCl	0.30	0.35	0.40	0.45
DL-methionine	0.10	0.09	0.07	0.06
L-threonine	0.12	0.12	0.12	0.12
Vitamin and trace mineral premix	0.30	0.30	0.30	0.30
Total	100.0	100.0	100.0	100.0
Calculated analysis				
Standardized ileal digestible amino acids				
Lysine, %	1.29	1.29	1.29	1.29
Methionine:lysine ratio, %	31%	31%	31%	31%
Met & Cys:lysine ratio, %	55.9%	56.6%	57.3%	58.0%
Threonine:lysine ratio, %	63.5%	64.0%	64.4%	64.8%
Tryptophan:lysine ratio, %	17.91%	17.47%	17.03%	16.60%
ME, kcal/lb	1,533	1,536	1,538	1,540
Lysine:ME ratio, g/Mcal	3.82	3.81	3.80	3.80
Protein, %	21.5	22.1	22.6	23.1
Ca, %	0.74	0.72	0.71	0.70
P, %	0.67	0.65	0.64	0.62
Available P, %	0.41	0.41	0.41	0.41

Table 2. Diet composition (Exp. 2)

Ingredients, %	Control diet	15% DDGS[1]	4% soy hulls	DDGS + soy hulls
Corn	60.83	50.72	57.46	47.30
Soybean meal (46.5% CP)	34.24	29.43	33.71	28.89
DDGS	---	15.00	---	15.00
Soy hulls	---	---	4.00	4.00
Choice white grease	1.50	1.50	1.50	1.50
Dicalcium phosphate (18.5% P)	1.45	1.05	1.40	1.05
Limestone	0.80	1.05	0.75	1.00
Salt	0.35	0.35	0.35	0.35
L-lysine HCl	0.30	0.40	0.30	0.40
DL-methionine	0.10	0.07	0.10	0.07
L-threonine	0.12	0.12	0.12	0.12
Vitamin and trace mineral premix	0.30	0.30	0.30	0.30
Total	100.0	100.0	100.0	100.0
Calculated analysis				
Standardized ileal digestible amino acids				
Lysine, %	1.29	1.29	1.29	1.29
Methionine:lysine ratio, %	31%	31%	31%	31%
Met & Cys:lysine ratio, %	55.9%	57.3%	55.0%	56.4%
Threonine:lysine ratio, %	63.5%	64.4%	63.1%	63.9%
Tryptophan:lysine ratio, %	17.9%	17.0%	17.7%	16.8%
ME, kcal/lb	1,533	1,537	1,512	1,515
Lysine:ME ratio, g/Mcal	3.82	3.81	3.87	3.86
Protein, %	21.5	22.6	21.5	22.5
Ca, %	0.74	0.74	0.74	0.75
P, %	0.67	0.65	0.66	0.64
Available P, %	0.42	0.42	0.42	0.42

[1] Dried distillers grains with solubles.

Table 3. Effects of increasing dried distillers grains with solubles (DDGS) in nursery diets on pig performance and survival rate (Exp. 1)[1]

	DDGS, %					
Item	0	7.5	15	22.5	SE	*P* values
ADG, lb	1.12	1.13	1.14	1.14	0.01	0.26
ADFI, lb	1.67	1.66	1.62	1.64	0.02	0.21
F/G	1.50	1.47	1.43	1.44	0.02	0.004
Avg wt, lb						
d 21[2]	24.0	24.1	24.1	24.0	0.2	0.91
d 42	47.5	47.8	48.1	48.0	0.4	0.43
Survival, %	99.0%	99.5%	99.2%	99.2%	0.5	0.83

[1] Each number is the mean of 6 feeders (1 barrow pen and 1 gilt pen per feeder with 22 pigs per pen initially).
[2] The trial began 21 d after weaning.

Table 4. Effects of dried distillers grains with solubles (DDGS) and soybean hulls in nursery diets on pig performance and survival rate (Exp. 2)[1]

					P values			
Item	Control	15% DDGS	4% soy hulls	15% DDGS & 4% soy hulls	SE	DDGS	Soy hulls	DDGS × soy hulls
ADG, lb	1.23	1.23	1.22	1.20	0.01	0.30	0. 09	0.26
ADFI, lb	1.81[a]	1.73[b]	1.77[ab]	1.74[b]	0.02	0.25	0.35	0.01
F/G	1.47[a]	1.41[b]	1.45[ab]	1.45[ab]	0.02	0.07	0.61	0.09
Avg wt, lb								
d 21[2]	27.2	27.3	27.3	27.3	0.3	0.95	0.92	0.99
d 42	53.1	53.2	53.0	52.4	0.4	0.42	0.23	0.50
Survival, %	99.5	99.7	100.0	99.7	0.2	0.31	0.31	1.00

[1] Each number is the mean of 6 feeders (1 barrow pen and 1 gilt pen per feeder with 22 pigs per pen initially).
[2] The trial began 21 d after weaning.
[ab] Within a row, means without a common superscript letter differ ($P < 0.05$).

INFLUENCE OF GLYCEROL AND ADDED FAT ON FINISHING PIG PERFORMANCE[1]

A. W. Duttlinger, M. D. Tokach, S .S. Dritz[2], J. L. Nelssen, R. D. Goodband, and J. M. DeRouchey

Summary

A 28-d study was conducted to determine the influence of dietary glycerol on grow-finish pig performance. The experiment was conducted at a commercial swine research facility in southwest Minnesota. A total of 1,093 pigs (initially 171.3 lb, PIC) were blocked by weight and randomly allotted to 1 of 6 dietary treatments. Pigs were fed corn-soybean meal-based diets. The treatments were arranged in a 2 × 3 factorial with main effects of glycerol (0, 2.5, or 5%) and added fat (0 or 6%). Overall (d 0 to 28), there was a fat × glycerol interaction ($P < 0.04$) for ADFI. When 5% glycerol was added to diets without added fat, ADFI decreased; however, ADFI did not change when glycerol was added to diets containing 6% added fat.

Pigs fed diets with added fat had improved ($P < 0.01$) ADG and F/G compared with pigs fed diets with no added fat. Increasing glycerol decreased ADG (linear, $P < 0.02$) and ADFI (linear, $P < 0.04$) and tended (linear, $P < 0.08$) to worsen F/G, a result of the negative effect of adding glycerol to diets without fat. In conclusion, 6% added fat improved ADG and F/G, but the glycerol used in this study decreased ADG and ADFI when added to diets without added fat.

Key words: fat, glycerol

Introduction

According to the National Biodiesel Board, in October 2007 there were 105 operating biodiesel production facilities and 77 facilities in the planning or construction stage in the United States. If all of these plants were built, estimated U.S. biodiesel production capacity would exceed 2.5 billon gal. This level of production would produce nearly 1.3 million tons of glycerol, the primary coproduct of biodiesel production. There has been much interest in utilizing crude glycerol as a feed ingredient in animal diets to reduce diet costs. However, little is known about glycerol's nutritional value. Previous research at Kansas State University found that feeding glycerol to nursery pigs increased ADG and ADFI and slightly improved F/G. In addition, dietary fat has continually shown improved ADG and F/G in grow-finish performance. However, because fat and glycerol are both in liquid form, questions exist regarding whether their effects on performance will be additive when included in the diet. Therefore, the objective of this study was to evaluate the effects of glycerol added to diets with or without added fat on growth performance in finishing pigs.

[1] Appreciation is expressed to New Horizon Farms for use of pigs and facilities and Richard Brobjorg, Cal Hulstein, and Marty Heintz for technical assistance.

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

Procedures

Procedures used in these experiments were approved by the Kansas State University (KSU) Institutional Animal Care and Use Committee. The experiment was conducted at a commercial research facility in southwest Minnesota. The facility had a totally slatted floor, and each pen was equipped with a 4-hole dry self-feeder and 1 cup waterer. The facility was a double-curtain-sided, deep-pit barn that operated on natural ventilation during the summer and mechanical ventilation during the winter. The experiment was conducted in August.

A total of 1,093 pigs (initially 171.3 lb, PIC 337 × 1050) were used in the 28-d study. Each pen contained 24 to 28 pigs with an equal distribution of barrows and gilts. Pigs were randomly allotted and blocked to 1 of 6 dietary treatments with 7 pens per treatment. Pigs were fed corn-soybean meal-based experimental diets (Table 1) in meal form. The treatments were arranged in a 2 × 3 factorial with main effects of crude glycerol (0, 2.5, or 5%) and added fat (0 or 6%). A single lot of crude glycerol was stored and used in the trial. All experimental diets were balanced to maintain a constant standardized ileal digestible lysine:ME ratio. Pigs and feeders were weighed on d 0, 14, and 28 to determine the response criteria of ADG, ADFI, and F/G.

Data were analyzed as a randomized complete block design by using the PROC MIXED procedure of SAS with pen as the experimental unit. The main effects and interaction between fat and glycerol were tested. Linear and quadratic polynomial contrasts were used to determine the effects of increasing added glycerol.

Results

Overall (d 0 to 28), there was a fat × glycerol interaction ($P < 0.04$) for ADFI (Table 2). When 5% glycerol was added to diets without added fat, ADFI decreased; however, ADFI did not change when glycerol was added to diets containing 6% added fat.

Pigs fed diets with added fat had greater ($P < 0.01$) ADG than pigs fed diets with no added fat. Adding fat to the diet improved ($P < 0.01$) F/G because pigs fed added fat converted feed more efficiently than pigs fed diets with no added fat.

Increasing glycerol decreased ADG (linear, $P < 0.02$) and ADFI (linear, $P < 0.04$) and tended (linear, $P < 0.08$) to worsen F/G, a result of the negative effect of adding glycerol to diets without fat.

Discussion

Adding fat to diets of these finishing pigs resulted in significant improvement in ADG and F/G. Adding 6% fat to the diet increased ADG 9.7% and improved F/G 9.3%. Compared with previous research trials in this facility, the growth response was greater than expected for this weight range; however, the response in F/G was similar to previous trials.

Previous research at KSU has shown increases in ADG and ADFI and slight improvement in F/G when feeding glycerol to nursery pigs. Our trial was designed to test performance in finishing pigs. Because crude glycerol has been reported to have energy content similar to corn, we did not expect that adding up to 5% glycerol to the diet would influence growth performance. We speculated that any negative effects, if observed, may be due to poor diet flowability when 5% glycerol was added to diets containing 6% fat. Because adding glycerol to diets containing 6% fat did not influence growth performance, flowability does not appear to be a major problem. Conversely, adding glycerol to diets without added fat resulted in poorer ADFI, ADG, and F/G.

The negative effect of glycerol on feed intake in diets without added fat was surprising. Glycerol from this same lot was used in the previous nursery trial conducted at KSU. It is

possible that storing this lot of glycerol in the feed mill for 3 mo (over the summer) may have resulted in decreased stability or oxidation of the glycerol thus decreasing palatability. Further research is planned at KSU to investigate this possibility.

Table 1. Diet composition (as-fed basis)

	0% added fat			6% added fat		
Item, %	0% glycerol	2.50% glycerol	5% glycerol	0% glycerol	2.50% glycerol	5% glycerol
Corn	82.84	80.14	77.43	74.37	71.66	68.96
Soybean meal, 46.5% CP	15.24	15.44	15.64	17.71	17.91	18.11
Glycerol	---	2.50	5.00	---	2.50	5.00
Choice white grease	---	---	---	6.00	6.00	6.00
Monocalcium P, 21% P	0.45	0.45	0.45	0.50	0.50	0.50
Limestone	0.85	0.85	0.85	0.80	0.80	0.80
Salt	0.35	0.35	0.35	0.35	0.35	0.35
L-lysine HCl	0.15	0.15	0.15	0.15	0.15	0.15
Vitamin premix with phytase[1]	0.06	0.06	0.06	0.06	0.06	0.06
Trace mineral premix	0.07	0.07	0.07	0.07	0.07	0.07
Total	100	100	100	100	100	100
Calculated analysis						
Total lysine, %	0.79	0.79	0.79	0.85	0.85	0.85
SID[2] Lysine:ME, g/Mcal	2.09	2.09	2.09	2.07	2.07	2.07
Standardized ileal amino acids, %						
Lysine	0.70	0.70	0.70	0.75	0.75	0.75
Isoleucine:lysine	0.71	0.70	0.70	0.70	0.69	0.69
Leucine:lysine	1.79	1.76	1.74	1.67	1.65	1.62
Methionine:lysine	0.31	0.31	0.31	0.3	0.29	0.29
Met & Cys:lysine	0.65	0.64	0.63	0.61	0.6	0.59
Threonine:lysine	0.63	0.63	0.62	0.62	0.61	0.61
Tryptophan:lysine	0.19	0.19	0.19	0.19	0.19	0.19
Valine:lysine	0.84	0.83	0.82	0.81	0.8	0.79
ME, kcal/lb	1,522	1,522	1,522	1,645	1,645	1,645
Protein, %	14.3	14.1	14.0	14.7	14.6	14.4
Ca, %	0.48	0.48	0.48	0.48	0.48	0.48
P, %	0.43	0.43	0.42	0.44	0.43	0.42
Available P, %[3]	0.22	0.22	0.22	0.23	0.23	0.23

[1] Provided per pound of diet: 170 phytase unit (FTU) of phytase.
[2] SID = Standardized ileal digestible.
[3] Includes expected P release of .07% from added phytase.

Table 2. Effects of glycerol on grow-finish pig performance[1]

	0% added fat			6% added fat				Contrasts, $P <$				
											Glycerol	
Item	0% glycerol	2.50% glycerol	5% glycerol	0% glycerol	2.50% glycerol	5% glycerol	SE	Fat × Glycerol	Fat	Glycerol	Linear	Quadratic
d 0 to 28												
Initial wt, lb	171.2	171.5	171.2	171.3	171.5	171.3	2.31	1.00	0.96	0.99	1.00	0.90
ADG, lb	1.85	1.78	1.67	2.03	1.98	2.00	0.04	0.14	0.01	0.05	0.02	0.82
ADFI, lb	6.38	6.44	6.03	6.33	6.21	6.29	0.09	0.04	0.86	0.08	0.04	0.38
F/G	3.45	3.63	3.63	3.13	3.13	3.14	0.06	0.28	0.01	0.14	0.08	0.35

[1] A total of 1,093 pigs (initially 171.3 lb) were used in a 28-d experiment. Each pen contained 24 to 28 pigs with an equal distribution of barrows and gilts. There were 7 pens (replications) per treatment.

EFFECTS OF INCREASING GLYCEROL AND DRIED DISTILLERS GRAINS WITH SOLUBLES ON THE GROWTH PERFORMANCE AND CARCASS CHARACTERISTICS OF FINISHING PIGS[1,2]

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Summary

A total of 1,160 barrows (PIC, initially 68.4 lb) were used in a 97-d study to determine the influence of glycerol and dried distillers grains with solubles (DDGS) on growing-finishing pig performance, carcass characteristics, and fat quality. Pigs were blocked by weight and randomly allotted to 1 of 6 dietary treatments with 7 replications per treatment. Pigs were fed corn-soybean meal-based diets arranged in a 2 × 3 factorial with main effects of glycerol (0, 2.5, or 5%) and DDGS (0 or 20%). Overall (d 0 to 97), there were no glycerol × DDGS interactions ($P > 0.12$) for growth performance, carcass characteristics, and carcass fat iodine value (IV). Increasing glycerol did not affect ($P > 0.14$) ADG or F/G. Adding 20% DDGS to the diet did not affect ADG. However, pigs fed diets with 20% added DDGS had greater ($P < 0.02$) ADFI resulting in poorer ($P < 0.01$) F/G than pigs fed diets with no DDGS. For carcass characteristics, pigs fed increasing glycerol tended to have increased (linear, $P < 0.11$) yield. Pigs fed diets with added DDGS had increased ($P < 0.01$) jowl fat, belly fat, and backfat IV compared with pigs fed diets with no DDGS. However, increasing dietary glycerol tended to decrease (linear, $P < 0.11$) backfat IV. In conclusion, feeding pigs 20% DDGS worsened F/G and increased carcass fat IV, whereas feeding glycerol did not influence growth performance but tended to improve carcass yield and reduce backfat IV.

Key words: dried distiller grains with solubles, glycerol, growing-finishing pig

Introduction

According to the National Biodiesel Board, in October 2007 there were 105 biodiesel production facilities operating and 77 facilities in the planning or construction stage in the United States. If all of these facilities were operational, the estimated U.S. biodiesel production capacity would exceed 2.5 billon gal. This level of production would produce nearly 1.3 million tons of glycerol, the primary coproduct of biodiesel production. There has been much interest in utilizing crude glycerol as a feed ingredient in animal diets. However, little is known about glycerol's nutritional value and its effect on carcass characteristics. Previous research has shown that the unsaturation index of carcass fat can be reduced when pigs are fed glycerol.

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Thus, combining glycerol with an ingredient high in unsaturated fat, such as dried distillers grains with solubles (DDGS), may improve carcass fat firmness.

In addition, research has shown that DDGS levels ranging from 0 to 20% of the diet could be fed without negatively affecting growth performance. Feeding DDGS has been shown to affect carcass quality and characteristics when fed to growing-finishing pigs. Specifically, feeding DDGS has been shown to reduce percent yield and carcass weight, increase carcass fat softness, and reduce belly firmness. Therefore, the objective of this trial was to evaluate the effect of dietary glycerol and DDGS on growing-finishing pig performance, carcass characteristics, and iodine value (IV) of belly fat, jowl fat, and backfat (BF).

Procedures

Procedures used in these experiments were approved by the Kansas State University (KSU) Institutional Animal Care and Use Committee. The experiment was conducted at a commercial research facility in southwest Minnesota. The facility had a totally slatted floor, and each pen was equipped with a 4-hole dry self-feeder and 1 cup waterer. The facility was a double-curtain-sided, deep-pit barn that operated on mechanical ventilation during the summer and on automatic ventilation during the winter. The experiment was conducted in late summer and fall of 2007.

A total of 1,160 barrows (PIC, 337 × 1050, initially 68.4 lb) were used in the 97-d study. Pigs were blocked by weight and randomly allotted to 1 of 6 dietary treatments with 7 pens per treatment. Each pen contained 27 to 28 barrows. Pigs were fed corn-soybean meal-based experimental diets (Tables 1, 2, 3, and 4) in meal form across 4 phases. The treatments were arranged in a 2 × 3 factorial with main effects of glycerol (0, 2.5, or 5%) and DDGS (0 or 20%). Multiple lots of glycerol from the same soybean biodiesel production facility (Minnesota Soybean Processors, Brewster, MN) were used in the trial. All experimental diets were balanced to maintain a constant standardized ileal digestible (SID) lysine:ME ratio within each phase. For both DDGS and glycerol, the NRC (1998) ME value of corn (1,551 kcal/lb) was used in diet formulation.

Pigs and feeders were weighed on d 0, 14, 28, 42, 56, 70, 84, and 97 to determine the response criteria of ADG, ADFI, and F/G. The pigs in this study were marketed in 2 different groups. First, on d 70, the barn was "topped," meaning the 2 heaviest pigs from each pen were visually selected, removed, and marketed. The remaining pigs were marketed on d 97.

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). Standard carcass criteria of BW, loin and BF depth, HCW, lean percentage, and yield were collected. Fat-free lean index (FFLI) was also measured by using the equation:

$$50.767 + (0.035 \times \text{HCW}) - (8.979 \times \text{BF}).$$

Jowl, BF, and belly samples were collected from 2 randomly selected barrows from each pen from the d-97 marketing group to analyze fat for individual fatty acids. Samples were collected and frozen until further processing and analysis.

Iodine value was calculated from the following equation following AOCS (1998) procedures:

$$\text{C16:1}(0.95)+\text{C18:1}(0.86)+\text{C18:2}(1.732)+\text{C18:3}(2.616)+\text{C20:1}(0.785)+\text{C22:1}(0.723).$$

The fatty acids results are represented as a percentage of the total fatty acids in the sample.

Data were analyzed as a randomized complete block design by using the PROC MIXED procedure of SAS with pen as the experimental unit. Main effects and interactions between pigs fed glycerol and DDGS were tested. Linear and quadratic polynomial contrasts were used to determine the effects of increasing added glycerol.

Results

Overall (d 0 to 97), there were no glycerol × DDGS interactions ($P > 0.12$) for growth performance, carcass characteristics, and IV. Increasing dietary glycerol did not affect ($P > 0.14$) any growth performance criteria (Table 5). Adding 20% DDGS to the diet did not affect ($P > 0.73$) ADG; however, pigs fed diets with added DDGS had greater ($P < 0.02$) ADFI and poorer ($P < 0.01$) F/G than pigs not fed DDGS. For carcass characteristics, increasing dietary glycerol tended to increase (linear, $P < 0.11$) yield (Table 6). However, increasing glycerol in the diet did not affect ($P > 0.17$) carcass weight, carcass weight variation, BF depth, loin depth, FFLI, or lean percentage. Adding 20% DDGS to the diet did not affect ($P > 0.18$) any carcass characteristics. For carcass fat quality, pigs fed diets with added DDGS had increased ($P < 0.01$) linoleic acid, total polyunsaturated fats (PUFA), Unsaturated fatty acid:saturated fatty acids (UFA:SFA), and polyunsaturated:saturated fatty acids (PUFA:SFA) in jowl fat, belly fat, and BF compared with pigs fed diets with no DDGS (Table 7, 8, and 9). However, increasing glycerol tended to decrease (linear, $P < 0.08$) linoleic acid, total PUFA, (linear, $P < 0.10$) PUFA:SFA, and (linear, $P < 0.11$) IV in BF, with no change to jowl and belly fat IV ($P > 0.24$).

Discussion

Adding up to 5% glycerol to the diet did not influence growth performance. This response was expected because glycerol has been reported to have energy content similar to that of corn. However, in previous research at KSU, we observed reduced ADFI when finishing pigs were fed dietary glycerol; we believed this was due to decreased palatability as a result of prolonged storage. Because adding glycerol to diets did not influence ADFI in this study, palatability does not appear to be an issue with this glycerol source.

Contrary to previous research in this facility, the addition of DDGS to diets increased ADFI and worsened F/G. We hypothesize that the DDGS used in this trial had an actual ME value lower than our formulated value, which was the same as corn. Even though there was not a DDGS × glycerol interaction ($P = 0.12$), the 2% poorer F/G and greater ADFI for pigs fed diets with 20% DDGS was largely a result of responses when DDGS was added to diets containing glycerol. The F/G for the diets without glycerol was similar regardless whether DDGS was included in the diet (2.52 vs. 2.51).

Previous research has demonstrated that feeding DDGS results in decreased carcass yield and increased carcass fat IV. Although a decrease in yield was not observed in our trial, carcass fat did become softer when DDGS was added to the diet. Glycerol appeared to improve percent yield, which was not expected.

In conclusion, feeding pigs 20% DDGS worsened F/G and increased carcass fat IV, whereas feeding glycerol did not influence growth performance but tended to improve carcass yield and reduce backfat IV.

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

	DDGS, %[2]					
	0			20		
Ingredient, %	0% glycerol	2.50% glycerol	5% glycerol	0% glycerol	2.50% glycerol	5% glycerol
Corn	68.18	65.47	62.77	55.16	52.46	49.75
Soybean meal (46.5% CP)	26.63	26.83	27.03	19.69	19.89	20.09
Glycerol	---	2.50	5.00	---	2.50	5.00
DDGS	---	---	---	20.00	20.00	20.00
Choice white grease	3.00	3.00	3.00	3.00	3.00	3.00
Monocalcium P, (21% P)	0.63	0.63	0.63	0.18	0.18	0.18
Limestone	0.85	0.85	0.85	1.13	1.13	1.13
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.08	0.08	0.08	0.08	0.08	0.08
Trace mineral premix	0.10	0.10	0.10	0.10	0.10	0.10
Optiphos 2000[3]	0.03	0.03	0.03	0.03	0.03	0.03
L-Lysine HCl	0.15	0.15	0.15	0.30	0.30	0.30
DL-Methionine	0.01	0.02	0.02	---	---	---
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis						
SID[4] amino acids, %						
Lysine	0.98	0.98	0.98	0.98	0.98	0.98
Methionine:lysine	28	28	29	30	30	29
Met & Cys:lysine	57	57	57	61	61	60
Threonine:lysine	60	60	60	61	61	60
Tryptophan:lysine	19	19	19	18	18	18
SID Lysine:calorie ratio, g/Mcal ME	2.82	2.82	2.82	2.81	2.81	2.81
ME, kcal/lb	1,578	1,578	1,578	1,582	1,582	1,582
Total lysine, %	1.10	1.10	1.10	1.13	1.13	1.13
CP, %	18.33	18.20	18.06	19.57	19.44	19.30
Ca, %	0.55	0.55	0.55	0.55	0.55	0.55
P, %	0.51	0.50	0.49	0.47	0.46	0.46
Available P, %[5]	0.28	0.28	0.28	0.28	0.28	0.28

[1] Fed from 68 to 120 lb.
[2] Dried distillers grains with solubles.
[3] Provided per pound of diet: 227 phytase unit (FTU) of phytase.
[4] Standardized ileal digestible .
[5] Includes expected P release of .07% from added phytase.

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

	DDGS, %[2]					
	0			20		
Ingredient, %	0% glycerol	2.50% glycerol	5% glycerol	0% glycerol	2.50% glycerol	5% glycerol
Corn	74.27	71.57	68.87	61.20	58.50	55.80
Soybean meal (46.5% CP)	20.66	20.86	21.06	13.72	13.92	14.12
Glycerol	---	2.50	5.00	---	2.50	5.00
DDGS	---	---	---	20.00	20.00	20.00
Choice white grease	3.00	3.00	3.00	3.00	3.00	3.00
Monocalcium P, (21% P)	0.55	0.55	0.55	0.13	0.13	0.13
Limestone	0.85	0.85	0.85	1.13	1.13	1.13
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.06	0.06	0.06	0.06	0.06	0.06
Trace mineral premix	0.08	0.08	0.08	0.08	0.08	0.08
Optiphos 2000[3]	0.03	0.03	0.03	0.03	0.03	0.03
L-Lysine HCl	0.15	0.15	0.15	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis						
SID[4] amino acids, %						
Lysine	0.83	0.83	0.83	0.83	0.83	0.83
Methionine:lysine	29	29	28	32	32	32
Met & Cys:lysine	60	59	58	66	65	64
Threonine:lysine	61	61	61	62	62	61
Tryptophan:lysine	19	19	19	17	17	17
SID Lysine:calorie ratio, g/Mcal ME	2.38	2.38	2.38	2.38	2.38	2.38
ME, kcal/lb	1,580	1,580	1,580	1,585	1,585	1,585
Total lysine, %	0.93	0.93	0.93	0.97	0.96	0.96
CP, %	16.06	15.93	15.79	17.31	17.17	17.04
Ca, %	0.52	0.52	0.52	0.52	0.52	0.52
P, %	0.47	0.46	0.45	0.43	0.43	0.42
Available P, %[5]	0.25	0.24	0.24	0.25	0.25	0.25

[1] Fed from 120 to 170 lb.
[2] Dried distillers grains with solubles.
[3] Provided per pound of diet: 227 phytase unit (FTU) of phytase.
[4] Standardized ileal digestible.
[5] Includes expected P release of .07% from added phytase.

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

	DDGS, %[2]					
	0			20		
Ingredient, %	0% glycerol	2.50% glycerol	5% glycerol	0% glycerol	2.50% glycerol	5% glycerol
Corn	78.67	75.97	73.27	64.12	61.42	58.72
Soybean meal (46.5% CP)	16.28	16.48	16.68	10.90	11.10	11.30
Glycerol	---	2.50	5.00	---	2.50	5.00
DDGS	---	---	---	20.00	20.00	20.00
Choice white grease	3.00	3.00	3.00	3.00	3.00	3.00
Monocalcium P, (21% P)	0.55	0.55	0.55	0.10	0.10	0.10
Limestone	0.85	0.85	0.85	1.13	1.13	1.13
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.05	0.05	0.05	0.05	0.05	0.05
Trace mineral premix	0.07	0.07	0.07	0.07	0.07	0.07
Optiphos 2000[3]	0.03	0.03	0.03	0.03	0.03	0.03
L-Lysine HCl	0.15	0.15	0.15	0.25	0.25	0.25
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis						
SID[4] amino acids, %						
Lysine	0.72	0.72	0.72	0.72	0.72	0.72
Methionine:lysine	31	30	30	35	35	35
Met & Cys:lysine	63	62	61	72	71	71
Threonine:lysine	62	62	62	66	66	65
Tryptophan:lysine	19	19	19	17	17	17
SID Lysine:calorie ratio, g/Mcal ME	2.06	2.06	2.06	2.06	2.06	2.06
ME, kcal/lb	1,582	1,582	1,582	1,586	1,586	1,586
Total lysine, %	0.81	0.81	0.81	0.85	0.85	0.85
CP, %	14.40	14.27	14.13	16.20	16.06	15.93
Ca, %	0.50	0.50	0.50	0.51	0.51	0.51
P, %	0.45	0.44	0.44	0.42	0.41	0.41
Available P, %[5]	0.23	0.23	0.23	0.23	0.23	0.23

[1] Fed from 170 to 220 lb.
[2] Dried distillers grains with solubles.
[3] Provided per pound of diet: 227 phytase unit (FTU) of phytase.
[4] Standardized ileal digestible.
[5] Includes expected P release of .07% from added phytase.

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

	DDGS, %[2]					
	0			20		
Ingredient, %	0% glycerol	2.50% glycerol	5% glycerol	0% glycerol	2.50% glycerol	5% glycerol
Corn	80.64	77.93	75.23	66.09	63.39	60.69
Soybean meal (46.5% CP)	14.29	14.50	14.70	8.91	9.11	9.31
Glycerol	---	2.50	5.00	---	2.50	5.00
DDGS	---	---	---	20.00	20.00	20.00
Choice white grease	3.00	3.00	3.00	3.00	3.00	3.00
Monocalcium P, (21% P)	0.60	0.60	0.60	0.15	0.15	0.15
Limestone	0.85	0.85	0.85	1.13	1.13	1.13
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.04	0.04	0.04	0.04	0.04	0.04
Trace mineral premix	0.05	0.05	0.05	0.05	0.05	0.05
Optiphos 2000[3]	0.03	0.03	0.03	0.03	0.03	0.03
L-Lysine HCl	0.15	0.15	0.15	0.25	0.25	0.25
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis						
SID[4] amino acids, %						
Lysine	0.64	0.64	0.64	0.64	0.64	0.64
Methionine:lysine	31	31	31	37	36	36
Met & Cys:lysine	65	64	63	75	74	73
Threonine:lysine	63	62	62	67	67	66
Tryptophan:lysine	19	19	18	17	17	17
SID Lysine:calorie ratio, g/Mcal ME	1.92	1.92	1.92	1.92	1.92	1.92
ME, kcal/lb	1,582	1,582	1,582	1,586	1,586	1,586
Total lysine, %	0.76	0.76	0.76	0.79	0.79	0.79
CP, %	13.65	13.51	13.37	15.44	15.31	15.17
Ca, %	0.51	0.51	0.51	0.51	0.51	0.51
P, %	0.45	0.44	0.44	0.42	0.41	0.41
Available P, %[5]	0.22	0.22	0.22	0.22	0.22	0.22

[1] Fed from 220 to 273 lb.
[2] Dried distillers grains with solubles.
[3] Provided per pound of diet: 227 phytase unit (FTU) of phytase.
[4] Standardized ileal digestible.
[5] Includes expected P release of .07% from added phytase.

Table 5. Influence of glycerol and DDGS[1] on growing-finishing pig performance[2]

	0% DDGS			0% DDGS							Contrasts, *P* <	
	Glycerol, %			Glycerol, %							Glycerol	
Item	0	2.50	5	0	2.50	5	SE	D×G	DDGS	Glycerol	Linear	Quadratic
d 0 to 97												
Initial wt, lb	68.0	68.2	69.0	68.2	68.9	68.2	2.46	0.95	0.98	0.98	0.84	0.94
ADG, lb	2.14	2.11	2.12	2.14	2.12	2.13	0.02	0.99	0.73	0.44	0.38	0.35
ADFI, lb	5.37	5.28	5.30	5.39	5.41	5.53	0.06	0.29	0.02	0.59	0.63	0.37
F/G	2.51	2.50	2.50	2.52	2.56	2.60	0.02	0.12	0.01	0.31	0.14	0.72
Final wt, lb	273.5	272.0	271.9	273.8	273.8	272.1	3.20	0.96	0.76	0.87	0.60	0.98
Removals	6	7	6	6	10	6						

[1] Dried distillers grain with solubles.
[2] A total of 1,160 pigs (initially 68.4 lb.) were used in a 97-d experiment with 27 to 28 pigs per pen and 7 replications per treatment.

Table 6. Influence of glycerol and DDGS[1] on grow-finish pig carcass characteristics for pigs marketed on d 97[2,3]

	0% DDGS			0% DDGS							Contrasts, *P* <	
	Glycerol, %			Glycerol, %							Glycerol	
Item	0	2.50	5	0	2.50	5	SE	D×G	DDGS	Glycerol	Linear	Quadratic
Carcass wt, lb	205.3	204.7	203.1	201.6	202.5	204.3	2.4	0.63	0.45	0.99	0.92	0.98
Carcass wt CV, %	9.0	9.4	9.2	8.8	8.1	8.9	0.67	0.67	0.35	0.94	0.82	0.76
Yield, %	75.1	75.5	75.7	74.5	75.9	75.7	0.47	0.56	0.93	0.17	0.11	0.37
Backfat, in	0.78	0.78	0.78	0.76	0.75	0.77	0.02	0.87	0.18	0.81	0.86	0.54
Loin depth, in	2.48	2.47	2.39	2.40	2.41	2.44	0.03	0.12	0.27	0.77	0.57	0.62
FFLI, %[4]	49.2	49.1	49.1	49.3	49.4	49.3	0.24	0.93	0.32	0.96	0.81	0.89
Lean, %	54.3	54.3	54.2	54.4	54.6	54.4	0.33	0.95	0.43	0.86	0.76	0.64

[1] Dried distillers grain with solubles.
[2] A total of 1,160 pigs (initially 68.4 lb.) were used in a 97-d experiment with 27 to 28 pigs per pen and 7 replications per treatment.
[3] A total of 1,035 pigs were marketed with 23 to 26 pigs per pen.
[4]Fat-free lean index.

Table 7. Influence of glycerol and DDGS[1] on grow-finish pig jowl fat quality[2,3]

	0% DDGS			0% DDGS							Contrasts, *P* <	
	Glycerol, %			Glycerol, %							Glycerol	
Item	0	2.50	5	0	2.50	5	SE	D×G	DDGS	Glycerol	Linear	Quadratic
Myristic acid (14:0), %	1.32	1.48	1.46	1.31	1.30	1.35	0.04	0.10	0.005	0.06	0.03	0.35
Palmitic acid (16:0), %	21.40	22.10	22.14	20.78	20.91	20.89	0.29	0.51	0.0002	0.27	0.16	0.43
Palmitoleic acid (16:1), %	2.75	3.02	2.97	2.48	2.44	2.46	0.12	0.40	0.0001	0.61	0.43	0.55
Margaric acid (17:0), %	0.53	0.49	0.56	0.53	0.50	0.53	0.03	0.73	0.63	0.14	0.52	0.07
Stearic acid (18:0), %	9.30	8.95	9.22	8.93	9.09	8.75	0.26	0.47	0.29	0.88	0.63	0.89
Oleic acid (18:1c9), %	41.28	42.17	41.21	39.50	40.19	39.99	0.45	0.63	0.0001	0.29	0.89	0.12
Vaccenic acid (18:1n7), %	3.29	3.60	3.45	2.99	3.03	3.02	0.08	0.28	0.0001	0.13	0.25	0.10
Linoleic acid (18:2n6), %	14.48	13.04	13.61	18.63	17.04	17.70	0.68	0.99	0.0001	0.11	0.20	0.09
α-linolenic acid (18:3n3), %	0.71	0.65	0.69	0.73	0.73	0.72	0.73	0.48	0.11	0.64	0.64	0.42
γ-linolenic acid (18:3n6), %	0.47	0.30	0.36	0.23	0.40	0.33	0.47	0.57	0.68	0.99	0.99	0.99
Arachidic acid (20:0), %	0.35	0.31	0.36	0.26	0.33	0.29	0.06	0.60	0.35	0.92	0.69	0.89
Eicosadienoic acid (20:2), %	0.85	0.76	0.79	0.95	0.97	0.97	0.03	0.23	0.0001	0.57	0.51	0.41
Arachidonic acid (20:4n6), %	0.12	0.12	0.10	0.12	0.12	0.12	0.009	0.22	0.42	0.55	0.33	0.64
Other fatty acids, %	1.57	1.48	1.52	1.20	1.46	1.37	0.20	0.66	0.28	0.92	0.79	0.76
Total SFA, %[4]	33.39	33.79	34.22	32.22	32.58	32.25	0.47	0.64	0.0007	0.61	0.37	0.69
Total MUFA, %[5]	49.15	50.69	49.46	46.55	47.40	47.24	0.50	0.56	0.0001	0.08	0.36	0.04
Total PUFA, %[6]	17.46	15.52	16.32	21.23	20.02	20.51	0.72	0.88	0.0001	0.11	0.21	0.09
Total *trans* fatty acids, %[7]	0.61	0.55	0.60	0.41	0.58	0.52	0.13	0.69	0.45	0.90	0.70	0.79
UFA:SFA ratio[8]	2.00	1.96	1.93	2.11	2.08	2.11	0.04	0.70	0.0007	0.66	0.41	0.71
PUFA:SFA ratio[9]	0.53	0.46	0.48	0.66	0.62	0.64	0.03	0.91	0.0001	0.19	0.23	0.17
Iodine value, g/100 g[10]	70.5	68.6	68.9	74.1	73.3	74.0	0.88	0.69	0.01	0.33	0.36	0.24

[1] Dried distillers grain with solubles.
[2] A total of 1,160 pigs (initially 68.4 lb.) were used in a 97-d experiment with 27 to 28 pigs per pen and 7 replications per treatment.
[3] A total of 84 pigs were used for fat sample collection with 2 pigs per pen and 7 replications per treatment.
[4] Total saturated fatty acids = {[C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]}, where the brackets indicate concentration.
[5] Total monounsaturated fatty acids = {[C14:1] + [C16:1] + [C18:1c9] + [C18:1n7] + [C20:1] + [C24:1]}, where the brackets indicate concentration.
[6] Total polyunsaturated fatty acids = {[C18:2n6] + [C18:3n3] + [C18:3n6] + [C20:2] + [C20:4n6]}, where the brackets indicate concentration.
[7] Total *trans* fatty acids = {[C18:1t] + [C18:2t] + [C18:3t]}, where the brackets indicate concentration.
[8] UFA:SFA ratio = [Total MUFA + Total PUFA] / Total SFA.
[9] PUFA:SFA ratio = Total PUFA / Total SFA.
[10] Calculated as IV=[C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 +[C18:3] × 2.616 + [C20:1] × 0.785+[C22:1] × 0.723, where the brackets indicate concentration (AOCS, 1998).

Table 8. Influence of glycerol and DDGS[1] on grow-finish pig belly fat quality[2,3]

	0% DDGS			0% DDGS							Contrasts, *P* <	
	Glycerol, %			Glycerol, %							Glycerol	
Item	0	2.50	5	0	2.50	5	SE	D×G	DDGS	Glycerol	Linear	Quadratic
Myristic acid (14:0), %	1.32	1.39	1.43	1.26	1.24	1.27	0.04	0.26	0.0002	0.22	0.09	0.82
Palmitic acid (16:0), %	23.20	23.12	23.62	21.60	21.95	21.57	0.33	0.42	0.0001	0.84	0.56	0.89
Palmitoleic acid (16:1), %	2.16	2.26	2.37	2.01	1.95	1.93	0.08	0.19	0.0001	0.75	0.47	0.85
Margaric acid (17:0), %	0.54	0.53	0.57	0.54	0.49	0.55	0.02	0.76	0.30	0.11	0.35	0.06
Stearic acid (18:0), %	11.81	11.30	11.55	10.32	10.90	10.49	0.35	0.31	0.002	0.98	0.90	0.85
Oleic acid (18:1c9), %	39.09	39.49	39.21	37.16	38.41	37.84	0.36	0.35	0.0001	0.40	0.79	0.18
Vaccenic acid (18:1n7), %	2.72	2.83	2.85	2.53	2.51	2.51	0.04	0.32	0.0001	0.59	0.33	0.76
Linoleic acid (18:2n6), %	14.51	14.08	13.52	19.88	17.86	18.82	0.66	0.42	0.0001	0.16	0.14	0.23
α-linolenic acid (18:3n3), %	0.65	0.66	0.65	0.72	0.68	0.71	0.03	0.53	0.04	0.90	0.83	0..68
γ-linolenic acid (18:3n6), %	0.25	0.33	0.29	0.22	0.25	0.29	0.12	0.94	0.67	0.87	0.64	0.79
Arachidic acid (20:0), %	0.34	0.35	0.36	0.29	0.33	0.32	0.04	0.91	0.25	0.75	0.55	0.66
Eicosadienoic acid (20:2), %	0.78	0.77	0.75	0.94	0.90	0.98	0.03	0.15	0.0001	0.54	0.96	0.28
Arachidonic acid (20:4n6), %	0.10	0.12	0.11	0.11	0.10	0.11	0.007	0.20	0.51	0.99	0.86	0.97
Other fatty acids, %	1.12	1.32	1.28	1.11	1.13	1.21	0.12	0.76	0.37	0.56	0.32	0.69
Total SFA, %[4]	37.61	37.12	38.00	34.42	35.30	34.59	0.60	0.38	0.0001	0.90	0.65	0.93
Total MUFA, %[5]	45.60	46.32	46.12	43.18	44.43	43.91	0.39	0.55	0.0001	0.35	0.41	0.20
Total PUFA, %[6]	16.79	16.56	15.87	22.40	20.27	21.50	0.72	0.33	0.0001	0.25	0.22	0.26
Total *trans* fatty acids, %[7]	0.43	0.55	0.52	0.42	0.48	0.51	0.10	0.96	0.72	0.57	0.38	0.57
UFA:SFA ratio[8]	1.67	1.70	1.63	1.91	1.84	1.90	0.05	0.41	0.0001	0.89	0.66	0.86
PUFA:SFA ratio[9]	0.45	0.45	0.42	0.65	0.58	0.63	0.03	0.35	0.0001	0.37	0.30	0.35
Iodine value, g/100 g[10]	66.7	66.8	65.5	73.6	71.5	72.9	1.07	0.40	0.01	0.60	0.40	0.58

[1] Dried distillers grain with solubles.
[2] A total of 1,160 pigs (initially 68.4 lb.) were used in a 97-d experiment with 27 to 28 pigs per pen and 7 replications per treatment.
[3] A total of 84 pigs were used for fat sample collection with 2 pigs per pen and 7 replications per treatment.
[4] Total saturated fatty acids = {[C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]}, where the brackets indicate concentration.
[5] Total monounsaturated fatty acids = {[C14:1] + [C16:1] + [C18:1c9] + [C18:1n7] + [C20:1] + [C24:1]}, where the brackets indicate concentration.
[6] Total polyunsaturated fatty acids = {[C18:2n6] + [C18:3n3] + [C18:3n6] + [C20:2] + [C20:4n6]}, where the brackets indicate concentration.
[7] Total *trans* fatty acids = {[C18:1t] + [C18:2t] + [C18:3t]}, where the brackets indicate concentration.
[8] UFA:SFA ratio = [Total MUFA + Total PUFA] / Total SFA.
[9] PUFA:SFA ratio = Total PUFA / Total SFA.
[10] Calculated as IV=[C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 +[C18:3] × 2.616 + [C20:1] × 0.785+[C22:1] × 0.723, where the brackets indicate concentration (AOCS, 1998).

Table 9. Influence of glycerol and DDGS[1] on grow-finish pig backfat quality[2,3]

	0% DDGS			0% DDGS							Contrasts, *P* <	
	Glycerol, %			Glycerol, %							Glycerol	
Item	0	2.50	5	0	2.50	5	SE	D×G	DDGS	Glycerol	Linear	Quadratic
Myristic acid (14:0), %	1.36	1.44	1.46	1.31	1.27	1.34	0.04	0.30	0.0006	0.19	0.08	0.70
Palmitic acid (16:0), %	23.62	23.78	24.54	22.12	22.38	22.40	0.34	0.51	0.0001	0.22	0.09	0.78
Palmitoleic acid (16:1), %	2.24	2.28	2.36	1.92	1.95	1.95	0.09	0.81	0.0001	0.69	0.40	0.98
Margaric acid (17:0), %	0.54	0.54	0.57	0.54	0.50	0.54	0.03	0.76	0.34	0.44	0.65	0.23
Stearic acid (18:0), %	11.97	11.70	12.25	10.86	11.11	10.93	0.38	0.63	0.003	0.87	0.66	0.78
Oleic acid (18:1c9), %	38.55	39.01	38.89	36.62	37.99	37.23	0.35	0.43	0.0001	0.07	0.26	0.04
Vaccenic acid (18:1n7), %	2.69	2.78	2.76	2.41	2.46	2.46	0.05	0.95	0.0001	0.41	0.30	0.41
Linoleic acid (18:2n6), %	14.59	14.10	12.98	19.99	18.03	18.80	0.76	0.44	0.0001	0.16	0.08	0.44
α-linolenic acid (18:3n3), %	0.65	0.64	0.59	0.70	0.66	0.68	0.03	0.45	0.02	0.37	0.16	0.91
γ-linolenic acid (18:3n6), %	0.19	0.16	0.17	0.13	0.14	0.16	0.03	0.64	0.29	0.90	0.97	0.64
Arachidic acid (20:0), %	0.33	0.29	0.31	0.24	0.25	0.25	0.02	0.64	0.003	0.76	0.80	0.49
Eicosadienoic acid (20:2), %	0.74	0.73	0.68	0.88	0.86	0.89	0.02	0.18	0.0001	0.51	0.25	0.98
Arachidonic acid (20:4n6), %	0.10	0.09	0.09	0.11	0.11	0.09	0.008	0.40	0.21	0.32	0.15	0.70
Other fatty acids, %	1.13	1.18	1.03	0.96	1.06	1.01	0.06	0.45	0.05	0.25	0.70	0.11
Total SFA, %[4]	38.24	38.17	39.55	35.44	35.89	35.84	0.66	0.56	0.0001	0.42	0.21	0.69
Total MUFA, %[5]	44.98	45.60	45.52	42.33	43.85	43.10	0.41	0.53	0.0001	0.05	0.12	0.05
Total PUFA, %[6]	16.78	16.22	14.93	22.23	20.26	21.06	0.82	0.44	0.0001	0.16	0.08	0.48
Total *trans* fatty acids, %[7]	0.38	0.40	0.33	0.30	0.37	0.34	0.04	0.52	0.31	0.42	0.99	0.20
UFA:SFA ratio[8]	1.62	1.62	1.53	1.83	1.80	1.80	0.05	0.63	0.0001	0.46	0.24	0.74
PUFA:SFA ratio[9]	0.44	0.43	0.38	0.63	0.57	0.59	0.03	0.52	0.0001	0.23	0.10	0.64
Iodine value, g/100 g[10]	66.1	65.7	63.5	73.1	71.0	71.8	1.22	0.48	0.01	0.27	0.11	0.79

[1] Dried distillers grain with solubles.
[2] A total of 1,160 pigs (initially 68.4 lb.) were used in a 97-d experiment with 27 to 28 pigs per pen and 7 replications per treatment.
[3] A total of 84 pigs were used for fat sample collection with 2 pigs per pen and 7 replications per treatment.
[4] Total saturated fatty acids = {[C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]}, where the brackets indicate concentration.
[5] Total monounsaturated fatty acids = {[C14:1] + [C16:1] + [C18:1c9] + [C18:1n7] + [C20:1] + [C24:1]}, where the brackets indicate concentration.
[6] Total polyunsaturated fatty acids = {[C18:2n6] + [C18:3n3] + [C18:3n6] + [C20:2] + [C20:4n6]}, where the brackets indicate concentration.
[7] Total *trans* fatty acids = {[C18:1t] + [C18:2t] + [C18:3t]}, where the brackets indicate concentration.
[8] UFA:SFA ratio = [Total MUFA + Total PUFA] / Total SFA.
[9] PUFA:SFA ratio = Total PUFA / Total SFA.
[10] Calculated as IV=[C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 +[C18:3] × 2.616 + [C20:1] × 0.785+[C22:1] × 0.723, where the brackets indicate concentration (AOCS, 1998).

EFFECTS OF INCREASING DIETARY DRIED DISTILLERS GRAINS WITH SOLUBLES AND GLYCEROL ON PORK LOIN QUALITY[1,2]

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Summary

A total of 1,160 barrows (PIC, initially 68.4 lb) were used in a 70-d study to determine the influence of dried distillers grains with solubles (DDGS) and glycerol on pork loin quality attributes. The pigs were blocked by weight and randomly assigned to 1 of 6 dietary treatments with 7 replications per treatment. Pigs were fed corn-soybean meal-based diets with the addition of DDGS, glycerol, or a combination of these. The treatments were arranged in a 2 × 3 factorial with main effects of DDGS (0 or 20%) and glycerol (0, 2.5, or 5%). Pork loins from the 2 heaviest barrows from each pen were utilized for analysis. There were no DDGS × glycerol interactions for purge loss, instrumental color (L*a*b*), visual color, marbling score, drip loss, visual color, pH, Warner-Bratzler shear force (WBSF), cook loss, and most sensory characteristics. However, there was a DDGS × glycerol interaction ($P < 0.03$) for off-flavor intensity. Specifically, pigs fed 20% DDGS without added glycerol had more off-flavors than pigs fed any other treatment. Pigs fed diets with added DDGS had higher WBSF values, lower myofibrillar tenderness, lower overall tenderness scores, lower connective tissue scores, and more off-flavors ($P < 0.04$) than pigs fed diets with no DDGS. In conclusion, feeding pigs 20% DDGS resulted in less tender chops with more off-flavors. Yet, the inclusion of glycerol in the diet decreased the intensity of off-flavors in pork chops.

Key words: dried distillers grains with solubles, glycerol, off-flavor, pork quality, tenderness

Introduction

The rapid expansion of the biofuels industry has increased the amount of grain coproducts available for livestock production while simultaneously decreasing the amount of traditional feedstuffs. The increased costs of traditional feedstuffs and limitations on inclusion rates of coproducts due to their unique chemical properties has presented many new challenges to pork producers. For example, dried distillers grains with solubles (DDGS) have an oil content of roughly 10%, which is primarily made up of highly unsaturated fatty acids. Monogastrics, such as swine and poultry, will assimilate subcutaneous, intermuscular, and intramuscular fat with a fatty acid profile similar to their diet. Therefore, feeding highly unsaturated fatty acids may result in softer, less oxidatively stable adipose tissue, which will in

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turn affect consumer acceptability. Additionally, glycerol, a coproduct of biodiesel manufacturing, has potential as a feedstuff in animal diets because of its price and availability.

To date, some limited research has been conducted on growth and performance of pigs fed DDGS and glycerol. Yet, research addressing the effects of DDGS and glycerol on palatability parameters of pork loins is not currently available. Therefore, the objective of this research was to determine the effects of feeding various levels of DDGS and glycerol on economically important quality traits including purge loss, drip loss, color, marbling, Warner-Bratzler shear force (WBSF), pH, and sensory panel scores for tenderness, juiciness, and off-flavor.

Procedures

Procedures used in this experiment were approved by the Kansas State University Institutional Animal Care and Use Committee. The experiment was conducted in southwest Minnesota in a commercial swine facility. The facility had a slatted floor, and each pen was equipped with a 4-hole dry self-feeder and 1 cup waterer. The facility was a double-curtain-sided, deep-pit barn that operated on mechanical ventilation during the summer and automatic ventilation during the winter. Pigs were fed in late summer and fall of 2007.

A total of 1,160 barrows (PIC 337 × 1050, initially 68.4 lb) were used in the 70-d study. The pigs were blocked by weight and randomly assigned to 1 of 6 treatments with 7 replications per treatment. The pigs were fed a corn-soybean meal-based diet in 4 phases (Duttlinger et al., Swine Day 2008 Report of Progress, p. 171). The treatments were arranged in a 2 × 3 factorial with main effects of DDGS (0 or 20%) and glycerol (0, 2.5, or 5%).

On d 70 of the study, the 2 heaviest barrows were visually selected, removed, individually tattooed, and shipped to a commercial swine harvest facility (JBS Swift & Company processing plant, Worthington, MN) for slaughter. Following slaughter and chilling (24 h), the loins were removed from the left side of the carcass. The loins were then transported and stored at the Kansas State University Meat Laboratory. On the d 10 postmortem, purge loss, drip loss, visual color, marbling score, and instrumental color were measured.

Purge loss was measured by weighing the whole loin in the packaging material, removing the loin, blotting it dry, and reweighing the loin and the dried packaging material. Purge loss was calculated by taking the initial weight minus the packaging weight minus the final weight divided by the initial weight minus the packaging weight. Loins were fabricated into 1-in. chops and allowed to bloom for at least 1 h prior to visual and instrumental color measurements. Color measurements were taken on a cross section of the *longissimus dorsi* muscle located in the center loin region immediately posterior to the end of the *spinalis dorsi* muscle. Instrumental color was measured by using a Hunter Lab Miniscan Colorimeter with A illuminate (Hunter Associated Laboratories Inc., Reston, VA) and is reported as L* (lightness), a* (redness), and b* (yellowness) values. Visual color and marbling were evaluated by using the 1999 National Pork Producers Council's color and marbling standards. Drip loss was measured from a single 1-in. center-cut chop from each loin. Each chop was weighed and placed into a plastic bag immediately following fabrication. This chop was then placed into refrigerated storage (32 to 38°F) for 24 h. Chops were then reweighed to determine the amount of purge loss accumulation for the preceding 24-h period. Drip loss was calculated by taking initial weight minus final weight divided by initial weight.

Five center-cut chops were individually vacuum packaged and frozen (-40°F) for pH, WBSF, cook loss, and sensory characteristics. Chops were removed from the freezer and thawed in a refrigerator (32 to 38°F) over-

night. Chops were removed from the package, pH was measured, and chops were weighed to determine initial weight. The pH was measured by using an Accumet Basic pH Meter (Fisher Scientific, Waltham, MA) and Pinnacle Series Gel Spear Point electrode (Nova Analytics Corporation, Woburn, MA). The chops were 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 reweighed to determine cooking loss percentages. Chops were chilled at 32 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 by using 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 cross head speed of 250 mm/min. Peak shear force values were recorded.

Sensory 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 panel conducted sensory analysis on a warm-up chop and a chop from each treatment. Sensory characteristics evaluated include myofibrillar tenderness, juiciness, pork flavor intensity, connective tissue, overall tenderness, and off-flavor intensity.

The experimental design was a 2 × 3 factorial. Data were analyzed as a completely randomized design by using the PROC GLM procedure of SAS with pen serving as the experimental unit. Main effects and interactions between pigs fed DDGS and glycerol were tested.

Results and Discussion

The results of instrumental and visual measurements for the effects of DDGS and glycerol treatments are listed in Table 1. There were no DDGS × glycerol interactions ($P > 0.05$) observed for purge loss, instrumental color (L*, a*, and b*), visual color, marbling score, drip loss, pH, WBSF, and cooking loss. Yet, there were main effect differences for L* and WBSF. The L* values decreased for pigs fed 2.5% glycerol, which is indicative of a darker color. This effect was not linear in nature because the 5.0% glycerol treatment was not different ($P > 0.05$) from the control treatment. In addition, WBSF values were ($P < 0.04$) higher in loins from pigs fed 20% DDGS regardless of glycerol level, indicating a less tender product.

The results of trained sensory panel measurements for the effects of DDGS and glycerol treatments are listed in Table 2. There were no interactions observed ($P > 0.05$) for DDGS × glycerol treatments for myofibrillar tenderness, juiciness, pork flavor intensity, connective tissue amount, and overall tenderness. In contrast, there was an interaction observed ($P < 0.03$) for DDGS × glycerol treatments for off-flavor intensity. Specifically, the 20% DDGS treatment without glycerol addition had more off-flavor than all other treatments. Off-flavors commonly cited by panelists were sour, metallic, oxidized, stale, and rancid. This indicates that the addition of glycerol at 2.5 and 5.0% in the diet decreases off-flavor scores as a result of 20% DDGS inclusion. The increase in off-flavors is of concern for diets with 20% DDGS inclusion. However, because this was not a consumer study, we cannot extrapolate these results to mean that

consumers will find the product objectionable. Furthermore, the addition of 20% DDGS to the diet increased ($P < 0.03$) myofibrillar toughness, increased ($P < 0.03$) the amount of connective tissue, and decreased ($P < 0.02$) overall tenderness as observed from the greater WBSF values compared with diets containing no DDGS. Tenderness is a very important sensory trait to consumers who purchase meat products. Therefore, any decrease in tenderness as a result of a feeding regime should be further investigated to determine its short- and long-term effects on pork consumption.

In summary, feeding 0 and 20% DDGS in combination with 0, 2.5, and 5% glycerol had minimal effects on most of the pork loin quality parameters tested in this study. However, feeding pigs 20% DDGS increased WBSF values and lowered overall tenderness scores, indicating that the product was less tender than controls. In addition, feeding 20% DDGS resulted in increased levels of detectable off-flavors in pork loin chops, but off-flavors of these chops were not different from controls when glycerol was added to the diet at 2.5 and 5.0%. This indicates that glycerol may be beneficial when added to the diet to control off-flavor production but will not mitigate the decrease in tenderness observed in this study for chops from pigs fed 20% DDGS.

Table 1. Influence of dried distillers grains with solubles (DDGS) and glycerol on purge loss, instrumental color (L*a*b*), visual color, marbling score, drip loss, pH, Warner-Bratzler shear force (WBSF), and cooking loss

	0% DDGS			20% DDGS						
	Glycerol, %			Glycerol, %				*P*-value		
Item	0	2.5	5	0	2.5	5	SE	D×G	DDGS	Glycerol
Purge loss, %	1.76	1.75	1.45	1.55	1.61	1.69	0.24	0.57	0.84	0.89
Instrumental color										
L*[1]	61.03	59.96	61.96	61.91	59.95	62.34	0.91	0.87	0.56	0.05
a*[2]	20.51	20.11	20.97	20.16	20.31	20.64	0.41	0.72	0.61	0.29
b*[3]	17.85	17.10	17.94	17.57	17.61	18.07	0.48	0.69	0.75	0.37
Visual color[4]	3.2	3.5	3.3	3.0	3.4	3.1	0.20	0.96	0.29	0.13
Marbling score[5]	2.2	1.6	2.0	2.3	2.0	1.8	0.27	0.50	0.82	0.25
Drip loss, %	2.47	2.89	2.35	2.99	3.02	2.95	0.44	0.86	0.26	0.78
pH	5.7	5.7	5.7	5.7	5.7	5.7	0.003	0.95	0.13	0.78
WBSF, lb	7.0	7.2	6.8	7.3	8.7	7.2	0.20	0.27	0.04	0.06
Cooking loss, %	25.55	25.72	25.72	25.82	24.82	27.62	0.85	0.24	0.52	0.23

[1] 0 = black, 100 = white.
[2] Increasing redness.
[3] Increasing yellowness.
[4] 1 = pale pinkish gray to white, 2 = grayish pink, 3 = reddish pink, 4 = dark reddish pink, 5 = purplish red, 6 = dark purplish red (NPPC, 1999).
[5] Visual scale, which approximates the percentage of intramuscular fat content (NPPC, 1999).

Table 2. Influence of dried distillers grains with solubles (DDGS) and glycerol on trained sensory panel scores

	0% DDGS			20% DDGS						
	Glycerol, %			Glycerol, %				*P*-value		
Item	0	2.5	5	0	2.5	5	SE	D×G	DDGS	Glycerol
Myofibrillar tenderness[1]	5.9	5.9	6.0	5.7	5.6	5.7	0.16	0.92	0.03	0.85
Juiciness[2]	5.3	5.2	5.2	5.1	5.2	5.2	0.11	0.31	0.21	0.86
Pork flavor intensity[3]	5.5	5.5	5.5	5.4	5.4	5.5	0.08	0.57	0.35	0.92
Connective tissue amount[4]	7.5	7.6	7.6	7.5	7.2	7.4	0.10	0.25	0.03	0.56
Overall tenderness[1]	6.2	6.3	6.3	6.0	6.0	6.0	0.14	0.82	0.02	0.84
Off-flavor intensity[4]	7.7	7.6	7.7	7.2	7.7	7.5	0.11	0.03	0.04	0.11

[1] Myofibrillar and overall tenderness scale: 1 = extremely tough, 2 = very tough, 3 = moderately tough, 4 = slightly tough, 5 = slightly tender, 6 = moderately tender, 7 = very tender, and 8 = extremely tender.
[2] Juiciness scale: 1 = extremely dry, 2 = very dry, 3 = moderately dry, 4 = slightly dry, 5 = slightly juicy, 6 = moderately juicy, 7 = very juice, and 8 = extremely juicy.
[3] Pork flavor scale: 1 = extremely bland, 2 = very bland, 3 = moderately bland, 4 = slightly bland, 5 = slightly intense, 6 = moderately intense, 7 = very intense, and 8 = extremely intense.
[4] Connective tissue and off flavor intensity scale: 1 = abundant, 2 = moderately abundant, 3 = slightly abundant, 4 = moderate, 5 = slight, 6 = traces, 7 = practically none, and 8 = none.

EFFECTS OF DRIED DISTILLERS GRAINS WITH SOLUBLES ON SOW CARCASS FAT QUALITY

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Summary

A pilot experiment was conducted to determine the effects of feeding nonpregnant (open) sows a diet containing 50% dried distillers grains with solubles (DDGS) on growth and carcass fat quality. A total of 8 open sows were allotted to 1 of 2 diets by parity and BW. One diet was a standard corn-soybean meal-based gestation diet; the second diet was a corn-soybean meal-based diet that contained 50% DDGS. All sows were fed 5 lb/d of feed in a single feeding for 92 d. All sows were harvested on d 92 at the Kansas State University Meat Laboratory for determination of carcass fat quality. As expected, no differences in BW or backfat change were found ($P > 0.62$) for the feeding period. Additionally, no differences ($P > 0.23$) in lipid oxidation as measured by 2-thiobarbituric acid reactive substances (TBARS) assay were reported either initially or after 5 d of retail display for sows fed 50% DDGS compared with controls. Lipid oxidation increased ($P < 0.003$) as measured by TBARS assay for both treatments from d 1 to 5 as expected. Jowl fatty acid analysis revealed an increase in linoleic acid ($P < 0.01$), total polyunsaturated fatty acids ($P < 0.01$), and the ratio of polyunsaturated fatty acids to saturated fatty acids ($P < 0.03$). Also, there was a trend for increased jowl iodine value ($P < 0.08$) for sows fed 50% DDGS compared with the controls. In summary, feeding 50% DDGS to open sows for 92 d did not significantly affect BW, backfat, and lipid oxidation compared with controls. However, feeding 50% DDGS increased the concentration of linoleic acid and total polyunsaturated fatty acids and tended to increase jowl iodine value compared with controls.

Key words: carcass fat quality, dried distillers grains with solubles, lipid oxidation, sow

Introduction

With the increase in biofuel production, the availability of feed coproducts from ethanol manufacturing has greatly increased. Dried distillers grains with solubles (DDGS) is the product that remains after the ethanol is removed from the fermented corn mash and contains high levels of nutrients compared with corn. One such nutrient is fat, which is approximately 3 times higher in DDGS than in corn (10.7 vs. 3.9%). Because of the high level of unsaturated fatty acids present in DDGS, carcass fat of

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finishing pigs fed DDGS has been shown to decrease in firmness and percentage of saturated fat. When using iodine value (IV) as the fat firmness measurement, for every 10% DDGS fed to finishing pigs, the IV increases approximately 2 g/100 g. This increase has been documented in grow-finish pigs fed ad libitum while body fat levels increase during the finishing period. However, research has not evaluated whether the same results will occur at all or at the same rate of change in limit-fed sows that have less change in body fat accumulation than finishing pigs. Additionally, most cull sows in the United States are harvested and processed into fresh sausage products. As a result, the stability of the fat from cull sow trimmings is very important to retail shelf life and consumer acceptance of fresh sausage products. Therefore, the objective of this study was to determine in a pilot project the effects of feeding open sows a diet containing 50% DDGS on carcass fat quality and stability.

Procedures

The Kansas State University (KSU) Institutional Animal Care and Use Committee approved protocols used in this experiment. Sows were housed at the KSU Swine Teaching and Research farm.

Eight nonpregnant sows were used in a 92-d study. Sows were allotted in a randomized design to 1 of 2 diets by parity and BW. One diet was a standard corn-soybean meal-based gestation diet; the second diet was a corn-soybean meal-based diet that contained 50% DDGS (Table 1). All sows were fed 5 lb/d of feed in a single feeding. Each sow was maintained in a gestation stall and had ad libitum access to water via a nipple waterer. Sow BW and and backfat thickness (taken 1 to 2 in. from the midline over the last rib (P2)) were measured on d 0 and 92.

On d 92, sows were transported to the KSU Meat Laboratory for harvesting. After slaughter, all carcasses were chilled for 48 h, fabricated into lean trimmings, ground, packaged in oxygen permeable overwrap, and placed into simulated retail display. At the time of fabrication, the jowl was removed from each carcass for fatty acid analysis. Lipid oxidation, a measurement of oxidative rancidity, was measured on all the samples on d 1 (the day of grinding) and after 5 d of retail display. Lipid oxidation was measured by using the 2-thiobarbituric acid reactive substances (TBARS) assay, which measures milligrams of malonaldehyde and other lipid degradation products per kilogram of sample. TBARS values over 1.0 mg/kg are considered rancid.

Fatty acids from each of the fat samples were expressed as a percentage of the total fatty acids. Iodine value was calculated by using the fatty acid profile of each sample according to the following equation (AOCS, 1998).

C16:1 (0.95) + C18:1 (0.86) + C18:2 (1.732) + C18:3 (2.616) + C20:1 (0.785) + C22:1 (0.723).

Data were analyzed as a randomized design with sow as the experimental unit. Sows were blocked based on parity and initial weight at the beginning of the trial.

Results and Discussion

As expected, no differences in sow BW and P2 backfat existed at the start or end of the experiment between sows fed the 2 dietary treatments (Table 2; $P > 0.62$).

There were no differences in TBARS values as a result of treatment (Table 3; $P > 0.23$), which indicates that the amount of lipid oxidation was not significantly higher in sows fed 50% DDGS compared with controls. In addition, the rate of lipid oxidation was similar between the two treatment groups over the 5-d display period. As expected, TBARS values increased *(P* < 0.003) regardless of treatment from d 1 to d 5. It is well known that lipid oxidation increases with increased storage time.

The results of fatty acid analysis for jowl samples are reported in Table 4. Feeding 50% DDGS for 92 d increased ($P < 0.01$) linoleic acid and total polyunsaturated fatty acids , and increased ($P < 0.03$) the ratio of polyunsaturated fatty acids to saturated fatty acids. These changes may be a result of the increased crude fat level of the diet for sows fed DDGS. Because the oil content of DDGS is high in unsaturated fatty acids, this appears to have resulted in fat composition changes for sows fed DDGS. Thus, in the changes in fatty acid composition, a trend for an increased IV ($P < 0.08$) was observed for sows fed 50% DDGS compared with control sows. The magnitude of change in IV for sows fed DDGS on a limit-fed basis was not as great as previously observed in finishing pigs fed diets containing DDGS ad libitum. In fact, we found a change of only approximately 3.1 g/100 g increase with a 50% inclusion; finishing pigs typically have an increase of approximately 2 g/100 g for every 10% DDGS in the diet fed ad libitum. This may be due to sows not gaining weight or backfat rather than to sows being fed at maintenance. In conclusion, feeding 50% DDGS to open sows increased the concentration of linoleic acid and total polyunsaturated fatty acids and tended to increase jowl IV compared with control sows.

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

Ingredient, %	Control	DDGS[2]
Corn	80.92	37.11
Soybean meal (46.5% CP)	14.93	9.26
DDGS	---	50.00
Monocalcium phosphate (21% P)	1.70	0.55
Limestone	1.20	1.83
Salt	0.50	0.50
Vitamin premix	0.25	0.25
Trace mineral premix	0.15	0.15
Sow add pack	0.25	0.25
Phytase 600[3]	0.10	0.10
Total	100.00	100.00
Calculated analysis		
Standardized ileal digestible lysine, %	0.57	0.57
CP, %	13.8	21.1
Crude fat, %	3.4	6.9
ME, kcal/lb	1,484	1,493
Ca, %	0.85	0.85
P, %	0.69	0.64
Available P, %[4]	0.52	0.52

[1] Diets fed for 92 d with all sows receiving 5 lb/d in a single feeding.
[2] Dried distillers grains with solubles.
[3] Provided per pound of diet: 227 phytase unit (FTU) of phytase.
[4] Includes expected P release of 0.12% from added phytase.

Table 2. BW and backfat of sows[1]

Item	Control	50% DDGS	SE	Probability *P* <
BW, lb				
Initial	468.0	480.8	34.6	0.80
Final	466.5	482.0	21.3	0.62
Change	- 1.5	1.2	18.9	0.92
P2 backfat, mm[2]				
Initial	12.5	13.3	1.7	0.76
Final	13.3	13.3	0.8	0.99
Change	0.8	0.0	1.1	0.64

[1] A total of 8 nonpregnant sows (4 per treatment) fed for 92 d.
[2] P2 backfat is measured approximately 1 to 2 in. from the midline over the last rib.

Table 3. Lipid oxidation values for cull sow trim[1]

	Control	50% DDGS	Probability $P <$ [2]
TBARS, mg/kg			
d 1	0.128	0.171	0.335
d 5	0.249	0.283	0.452
Probability $P <$	0.0163	0.0249	
SE = 0.0307			

[1] A total of 8 nonpregnant sows (4 per treatment).
[2] Day effect, $P < 0.003$.

Table 4. Effects of dried distillers grains with solubles (DDGS) on sow jowl fat quality[1]

Item	Control	50% DDGS	SE	Probability, $P <$
Myristic acid (14:0), %	1.41	1.36	0.03	0.32
Palmitic acid (16:0), %	21.08	20.54	0.33	0.30
Palmitoleic acid (16:1), %	3.01	2.79	0.09	0.12
Margaric acid (17:0), %	0.28	0.33	0.03	0.26
Stearic acid (18:0), %	8.62	8.27	0.51	0.64
Oleic acid (18:1c9), %	43.90	41.93	0.81	0.13
Vaccenic acid (18:1n7), %	4.16	3.92	0.09	0.12
Linoleic acid (18:2n6), %	12.66	15.58	0.53	0.01
α-linolenic acid (18:3n3), %	0.56	0.58	0.05	0.81
Arachidic acid (20:0), %	0.33	0.37	0.03	0.42
Eicosadienoic acid (20:2), %	0.93	1.12	0.03	0.01
Arachidonic acid (20:4n6), %	0.13	0.13	0.01	0.51
Other fatty acids, %	15.60	18.66	0.59	0.01
Total SFA, %[2]	32.03	31.20	0.84	0.51
Total MUFA, %[3]	53.03	50.69	0.80	0.08
Total PUFA, %[4]	14.94	18.12	0.65	0.01
Total *trans* fatty acids, %[5]	0.37	0.49	0.10	0.44
UFA:SFA ratio[6]	2.13	2.21	0.08	0.49
PUFA:SFA ratio[7]	0.47	0.58	0.03	0.03
Iodine value, g/100 g[8]	69.33	72.38	1.03	0.08

[1] Total of 8 sows with 4 sows per treatment.
[2] Total saturated fatty acids = {[C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]}; brackets indicate concentration.
[3] Total monounsaturated fatty acids = {[C14:1] + [C16:1] + [C18:1c9] + [C18:1n7] + [C20:1] + [C24:1]}; brackets indicate concentration.
[4] Total polyunsaturated fatty acids = {[C18:2n6] + [C18:3n3] + [C18:3n6] + [C20:2] + [C20:4n6]}; brackets indicate concentration.
[5] Total *trans* fatty acids = {[C18:1t] + [C18:2t] + [C18:3t]}; brackets indicate concentration.
[6] UFA:SFA ratio = [Total MUFA + Total PUFA] / Total SFA.
[7] PUFA:SFA ratio = Total PUFA / Total SFA.
[8] Calculated as IV=[C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 +[C18:3] × 2.616 + [C20:1] × 0.785+[C22:1] × 0.723; brackets indicate concentration (AOCS, 1998).

EFFECTS OF FEEDER DESIGN ON GROWTH PERFORMANCE AND CARCASS CHARACTERISTICS OF FINISHING PIGS[1]

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Summary

Two experiments were conducted to compare the effects of feeder design (conventional dry vs. wet-dry feeder) on finishing pig performance. In Exp. 1, 1,186 pigs (PIC 337 × 1050) were used in a 69-d experiment. Pigs were weighed (avg. 70.8 lb) and allotted to 1 of 2 feeder types in a completely randomized design. There were 22 pens per feeder type with 26 to 28 pigs per pen. All pigs were fed the same dietary sequence in 4 phases (d 0 to 10, 10 to 28, 28 to 50, and 50 to 69). Overall (d 0 to 69), pigs using the wet-dry feeder had greater (P < 0.001) ADG, ADFI, and final weight compared with pigs using the conventional dry feeder. In Exp. 2, 1,236 pigs (PIC 337 × 1050) were used in a 104-d experiment. Pigs were weighed (avg. 63.2 lb) and allotted to 1 of the 2 feeder types in a completely randomized design. There were 23 pens per feeder type with 25 to 28 pigs per pen. All pigs were fed the same feed budget (diet 1 = 59 lb/pig, diet 2 = 88 lb/pig, diet 3 = 121 lb/pig, and diet 4 = 130 lb/pig). On d 84, the 3 largest pigs per pen were marketed. Afterward, all remaining pigs were fed a fifth dietary phase containing Paylean until d 104. Carcass measurements were obtained after pigs were transported to a commercial abattoir on d 104. Overall (d 0 to 104), pigs using the wet-dry feeder had greater (P < 0.001) ADG, ADFI, and final weight compared with those using the conventional dry feeder. However, pigs using the wet-dry feeder had poorer F/G and increased feed cost per pig (P < 0.002) than pigs using the conventional dry feeder. Carcass yield, fat free lean index, premium per pig, and live value/cwt were increased, whereas average back fat depth was decreased (P < 0.03) for pigs using the conventional dry feeder compared with pigs using the wet-dry feeder. The combination of these effects resulted in a numerically lower net income per pig for pigs fed with the wet-dry feeder. These experiments demonstrate that growth performance of finishing pigs was improved with a wet-dry feeder compared with a conventional dry feeder. However, because carcasses of pigs fed with a wet-dry feeder yielded less and were fatter, more research is required to understand the dynamics among feeder design, feed intake, and economic return.

Key words: feeders, pig

Introduction

Because finishing feed costs represent roughly 50% of the cost of production, swine

[1] Appreciation is expressed to New Horizon Farms for use of pigs and facilities and Richard Brobjorg, Scott Heidebrink, and Marty Heintz for technical assistance.

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

producers are continually evaluating technologies that may improve the growth performance of finishing pigs and reduce feed cost per pound of gain. Additionally, increasing costs associated with waste handling provide an incentive to reduce water usage (slurry volume). Previous research at Kansas State University (KSU) has demonstrated that using a wet-dry feeder may improve the growth rate and feed efficiency and reduce water disappearance of finishing pigs. These previous studies evaluated the differences between a wet-dry feeder and a conventional dry feeder with water provided separately via a nipple waterer. However, studies comparing the effects of various feeder designs on the growth performance of finishing pigs in a modern, commercial finishing facility are scarce. Many barns are now equipped with feeders that present dry feed to the pigs with some sort of cup or trough located in close (horizontal) proximity as a water source. With a wet-dry feeder, the water is provided by a nipple in the feed pan. Therefore, the objective of this research was to determine whether use of a wet-dry feeder would improve performance and profitability of finishing pigs housed in commercial conditions.

Procedures

Procedures used in the experiment were approved by the KSU Institutional Animal Care and Use Committee. The experiment was conducted in a commercial research finishing facility in southwest 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 1 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).

Although the pens equipped with a wet-dry feeder contained a cup waterer (Figure 2), waterers were shut off during the experiments. Therefore, the only source of water for pigs in these pens was through the wet-dry feeder. In addition, water was delivered to all of the pens of each feeder type independently, and each of the 2 water lines was equipped with a single water meter to monitor total daily water disappearance for each feeder type.

In Exp. 1, 1,186 pigs were weighed and allotted to the 2 feeder types. There were 22 pens per treatment. Each pen contained 26 to 28 pigs with the average number of gilts and barrows per pen and initial weight (70.8 lb) balanced across treatments. All pigs were fed the same sequence of diets with 4 dietary phases (d 0 to 10, 10 to 28, 28 to 50, and 50 to 69; Table 1). On d 14, 28, 42, 56, and 69, pigs were weighed and feed disappearance was measured to determine ADG, ADFI, and F/G. This experiment was conducted from December 20, 2007, to February 27, 2008.

In Exp. 2, 1,236 pigs were weighed and allotted to the 2 feeder types. There were 23 pens per treatment. Each pen contained 25 to 28 pigs with the average number of gilts and barrows per pen and initial weight (63.2 lb) balanced across treatments. Unlike Exp. 1, all pigs were fed by using a feed budget (diet 1 = 59 lb/pig, diet 2 = 88 lb/pig, diet 3 = 121 lb/pig, and diet 4 = 130 lb/pig; Table 2). On d 84, the 3 largest pigs per pen were marketed. Afterward, all the remaining pigs were fed a fifth diet containing Paylean (Elanco Animal Health, Indianapolis IN) until d 104. On d 0, 14, 28, 42, 56, 70, 84, and 104, pigs were weighed and feed disappearance was measured to determine ADG, ADFI, and F/G. After transportation to a commercial abattoir on d 104, carcass measurements were obtained from 494 of the remaining pigs (11 pens per feeder type). Total feed cost per pig and total revenue per pig were determined, and an

initial pig cost ($50/pig) and facility and labor cost ($10.40/pig) were also used to determine net income per pig. This experiment was conducted from April 8, 2008, to July 21, 2008.

Data were analyzed as a completely randomized design by using the PROC MIXED procedure of SAS with pen as the experimental unit.

Results

In Exp. 1, overall (d 0 to 69) ADG, ADFI, and final weight were greater ($P < 0.001$) for pigs fed using a wet-dry feeder than for those fed using the conventional dry feeder (Table 3). Feed efficiency was not different between pigs fed with either feeder type. Water usage per pig averaged 1.38 and 1.44 gal/d for pigs fed using the conventional dry feeder and wet-dry feeder, respectively.

In Exp. 2, overall (d 0 to 104) ADG, ADFI, and final weight were increased ($P < 0.001$), but F/G was poorer ($P < 0.002$) for pigs fed using the wet-dry feeders (Table 4). Water usage per pig averaged 1.68 and 1.48 gal/d for pigs fed using the conventional dry feeder and wet-dry feeder, respectively.

At the conclusion of the study, pigs were marketed and carcass data were obtained from 494 of the pigs (11 pens per feeder type, Table 5). Hot carcass weight tended ($P < 0.06$) to be greater for pigs fed using the wet-dry feeders; however, carcass yield, fat free lean index, premium per pig, and live value per cwt were decreased ($P < 0.03$). Average backfat depth was also greater ($P < 0.002$) for pigs fed using wet-dry feeders. The combination of these responses resulted in a similar total revenue per pig, although total revenue for pigs fed with wet-dry feeders was numerically greater than for those fed using the conventional dry feeder. Because pigs fed with wet-dry feeders grew faster, they also consumed more feed and had a greater ($P < 0.001$) feed cost per pig than those fed using the conventional dry feeder. Therefore, the net income per pig was numerically greater for pigs fed using the conventional dry feeders.

In conclusion, these experiments demonstrate that growth performance is improved when pigs are offered feed and water ad libitum via a wet-dry feeder rather than a conventional dry feeder and drinker bowl. Because carcasses of pigs fed with a wet-dry feeder yielded less and were fatter, the use of wet-dry feeders may not be justified with some carcass incentive programs. More research is required to understand the reason for the decreased yield of pigs fed with the wet-dry feeders and to further determine the effect of feeder type on economic return to different production systems.

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, Exp. 1[1]

	Dietary phase			
Ingredient, %	d 0 to 10	d 10 to 28	d 28 to 50	d 50 to 69
Corn	58.88	52.09	55.31	57.93
Soybean meal (46.5% CP)	22.25	18.95	15.92	13.20
DDGS[2]	9.00	20.00	20.00	20.00
Bakery by-product	5.00	5.00	5.00	5.00
Choice white grease	2.55	2.05	2.10	2.25
Monocalcium P (21% P)	0.25	---	---	---
Limestone	0.80	0.80	0.80	0.80
Vitamins, minerals, AA/phytase/etc.	1.27	1.11	0.87	0.82
Total	100.00	100.00	100.00	100.00
Calculated analysis				
Standardized ileal digestible (SID) amino acids				
Lysine, %	1.11	1.05	0.95	0.86
Isoleucine:lysine ratio, %	59	63	64	66
Leucine:lysine ratio, %	138	158	168	177
Methionine:lysine ratio, %	32	31	30	31
Met & Cys:lysine ratio, %	58	60	60	64
Threonine:lysine ratio, %	62	62	64	63
Tryptophan:lysine ratio, %	16	16	16	16
Valine:lysine ratio, %	68	74	77	79
CP, %	18.9	19.7	18.5	17.4
Total lysine, %	1.24	1.20	1.09	0.99
ME, kcal/lb	1,585	1,580	1,581	1,585
SID lysine:ME ratio, g/Mcal	3.19	3.02	2.72	2.46
Ca, %	0.45	0.40	0.39	0.38
P, %	0.45	0.43	0.42	0.41
Available P, %	0.26	0.26	0.25	0.25

[1] Each dietary phase was fed to both feeder types during the periods described in the table.
[2] Dried distillers grains with solubles.

Table 2. Diet composition, Exp. 2

	Dietary Phase[1]				
Ingredient, %	1	2	3	4	5 (with Paylean)
Corn	61.60	54.56	50.05	52.76	59.61
Soybean meal (46.5% CP)	21.60	18.55	13.10	10.45	16.45
DDGS[2]	9.00	20.00	30.00	30.00	17.00
Bakery by-product	5.00	5.00	5.00	5.00	5.00
Choice white grease	0.65	---	---	---	---
Monocalcium P (21% P)	0.13	---	---	---	---
Limestone	0.80	0.85	0.85	0.85	0.80
Vitamins, minerals, AA/phytase/etc.	1.22	1.04	1.00	0.94	1.14
Total	100.00	100.00	100.00	100.00	100.00
Feed budget, lb/pig	59	88	121	130	to d 104
Calculated analysis					
Standardized ileal digestible amino (SID) acids					
Lysine, %	1.11	1.05	0.90	0.81	0.94
Isoleucine:lysine ratio, %	59	63	69	71	65
Leucine:lysine ratio, %	139	159	190	204	167
Methionine:lysine ratio, %	32	30	33	35	32
Met & Cys:lysine ratio, %	59	60	68	72	62
Threonine:lysine ratio, %	62	62	64	66	65
Tryptophan:lysine ratio, %	16	16	17	17	17
Valine:lysine ratio, %	68	74	84	87	77
CP, %	18.9	19.7	19.4	18.4	18.3
Total lysine, %	1.24	1.20	1.06	0.97	1.08
ME, kcal/lb	1,547	1,537	1,538	1,539	1,538
SID lysine:ME ratio, g/Mcal	3.25	3.10	2.66	2.39	2.77
Ca, %	0.42	0.41	0.40	0.39	0.39
P, %	0.42	0.44	0.46	0.45	0.41
Available P, %	0.23	0.26	0.31	0.30	0.24

[1] Each dietary phase was fed to pigs using both feeder types in the sequence and according to the budget outlined in the table.
[2] Dried distillers grains with solubles.

Table 3. The effects of feeder design on the growth performance of finishing pigs – Exp. 1[1]

	Feeder type			
Item	Conventional dry	Wet-dry	SE	Probability, P <
d 0 to 69				
ADG, lb	2.10	2.26	0.01	0.001
ADFI, lb	5.13	5.58	0.03	0.001
F/G	2.44	2.47	0.01	---
d 69 avg wt, lb	216.35	227.30	1.04	0.001
Water use, gal/d per pig	1.38	1.44		
Water use, gal/lb gain	0.66	0.64		

[1] A total of 1,186 pigs (PIC 337 × 1050) with 26 to 28 pigs per pen and 22 pens per treatment were used in a 69-d experiment to compare the growth performance of pigs fed from either a conventional dry feeder with a cup waterer or a wet-dry feeder.

Table 4. The effects of feeder design on the growth performance of finishing pigs – Exp. 2[1]

	Feeder type			
Item	Conventional dry	Wet-dry	SE	Probability, P <
d 0 to 104				
ADG, lb	1.90	2.01	0.01	0.001
ADFI, lb	4.96	5.40	0.03	0.001
F/G	2.62	2.68	0.01	0.002
d 104 avg wt, lb	261.35	272.80	1.52	0.001
Water use, gal/d per pig	1.68	1.48		
Water use, gal/lb gain	0.89	0.73		

[1] A total of 1,236 pigs (PIC 337 × 1050) with 25 to 28 pigs per pen and 23 pens per treatment were used in a 104-d experiment to compare the growth performance of pigs fed from either a conventional dry feeder with a cup waterer or a wet-dry feeder.

Table 5. The effects of feeder design on the carcass characteristics of finishing pigs and economic return – Exp. 2[1]

	Feeder type			
Item	Conventional dry	Wet-dry	SE	Probability, P <
Plant live wt, lb	253.7	265.9	2.34	0.002
HCW, lb	194.9	200.0	1.77	0.06
Yield, %	76.86	75.21	0.43	0.02
Avg backfat depth, in.	0.64	0.70	0.01	0.002
Loin depth, in.	2.41	2.45	0.04	---
Lean, %	57.10	55.89	0.48	0.10
Fat free lean index	50.48	49.94	0.16	0.03
Premium/pig, $	8.67	5.26	1.02	0.03
Value/cwt (live), $	56.28	54.83	0.39	0.02
Total revenue/pig, $[2]	142.78	145.80	1.70	---
Feed cost/pig, $	56.23	61.12	0.68	0.001
Feed, $/cwt gain	28.43	29.17	0.32	0.13
Net income/pig, $	26.15	24.28	1.40	0.36

[1] Carcass data from 494 pigs (11 pens/feeder-type) were obtained for the comparison of carcass data and economic evaluation.

[2] Base carcass price of $71.43/cwt as used to calculate total revenue. Facility cost of $10.40/pig and initial pig cost of $50.00/pig were used to calculate net income per pig.

EFFECTS OF FEEDER ADJUSTMENT ON GROWTH PERFORMANCE OF GROWING AND FINISHING PIGS[1]

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Summary

Two studies were conducted to determine the effects of feeder adjustment on growth performance of growing and finishing pigs. Both experiments were conducted at a commercial swine research facility in southwest Minnesota. In Exp. 1, a total of 1,170 barrows and gilts (PIC, initially 129.0 lb) were used in a 70-d study. Pigs were blocked by weight and randomly allotted to 1 of 5 treatments with 9 replications per treatment. The treatments were feeder settings of 1, 2, 3, 4, or 5, based on settings at the top of the STACO stainless steel dry feeders. Pigs were fed corn-soybean meal-based diets. From d 0 to 28, pigs fed from feeders with increasing feeder openings had increased (linear, $P < 0.04$) ADG and ADFI. For d 28 to 70, increasing feeder setting did not affect ($P > 0.10$) any growth performance traits. Overall (d 0 to 70), pigs fed from feeders with increasing feeder openings had increased (linear, $P < 0.03$) ADFI. Changing feeder setting did not affect ($P > 0.18$) ADG or F/G. In Exp. 2, a total of 1,250 barrows and gilts (PIC, initially 77.3 lb) were used in a 69-d study to determine the effect of feeder setting and diet type on growth performance of growing and finishing pigs. Pigs were blocked by weight and randomly allotted to 1 of 6 treatments with 8 replications per treatment. The treatments were arranged in a 3 × 2 factorial with main effects of STACO stainless steel dry feeder setting (1, 3, or 5) and diet type (corn-soybean meal- or by-product-based (15% DDGS and 5% bakery by-product). Overall (d 0 to 69), there were no feeder setting × diet type interactions ($P > 0.31$) for growth performance. Diet type did not affect ($P > 0.75$) growth performance. Increasing feeder openings increased ADG (quadratic, $P < 0.03$) and ADFI (linear, $P < 0.01$). Feeder setting tended to influence (quadratic, $P > 0.08$) F/G with the best F/G at feeder setting of 3. In conclusion, feeding pigs from feeders with a more open feeder setting increased ADG and ADFI and tended to improve F/G at middle feeder settings compared with more closed feeder settings. With the dry feeders used in this study, feed should cover slightly more than half of the feed pan to avoid limiting pig performance.

Key words: by-product, dried distillers grains with solubles, feeder adjustment, finishing pigs

Introduction

Because of the increase in commodity and feed ingredient prices, more emphasis has been put on improving efficiency of growing

[1] Appreciation is expressed to New Horizon Farms for use of pigs and facilities and Richard Brobjorg, Scott Heidebrink, and Marty Heintz for technical assistance.

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and finishing pigs. Proper feeder adjustment is often an area of focus for improvement in many production systems. Having feeder openings too wide can lead to feed wastage. Operating feeders too tight leads to more plugged feeders and out-of-feed events that could adversely affect performance.

Therefore, the objective of these trials was to determine the effect of different feeder settings on growth performance of growing and finishing pigs and whether diet type influenced the optimal feeder setting.

Procedures

Procedures used in these experiments were approved by the Kansas State University Institutional Animal Care and Use Committee. The experiment was conducted at a commercial research facility in southwest Minnesota. The facility had a totally slatted floor, and each pen was equipped with a STACO (Schaefferstown, PA) stainless steel dry self-feeder and 1 cup waterer. The STACO stainless steel dry self-feeder is a 5-hole single sided feeder with a feed pan dimension of 60-in. × 7-in. × 5.75-in. (length × width × height).

Feeder settings were based on the factory-cut holes in the side of the feeder (Figure 1). Moving a dial from one hole to the next adjusted the feeder gate via a rod that connected the dial to the agitation gate in the feed pan. The feeders had 10 possible feeder settings. Feeder setting 1 was the most open feeder setting. Feeder setting 5 was the most closed feeder setting used in our trials.

The facility was a double-curtain-sided deep-pit barn that operated on mechanical ventilation during the summer and automatic ventilation during the winter. Exp. 1 was conducted in late spring and early summer of 2007, and Exp. 2 was conducted in late spring of 2008.

Experiment 1. A total of 1,170 barrows and gilts (PIC 337 × 1050, initially 129.0 lb) were used in a 70-d study. Pigs were blocked by weight and randomly allotted to 1 of 5 treatments with 9 replications per treatment. Each pen contained 23 to 28 pigs with an equal distribution of barrows and gilts. Pigs were fed corn-soybean meal-based experimental diets (Table 1) in meal form. For the 5 experimental treatments, feeder settings were set at 1, 2, 3, 4, or 5. Feeder settings were left at their respective setting for the duration of the trial.

Pigs and feeders were weighed on d 0, 14, 28, 50, and 70 to determine the response criteria of ADG, ADFI, and F/G. On d 50, the barn was "topped" to simulate normal pig marketing under commercial production practices. The 2 heaviest pigs from all pens were visually selected, removed, and marketed. The remaining pigs were marketed on d 70.

During the week of each weigh day (wk 2, 4, 7, and 10), a digital photo of each feed pan was taken (Figures 2 to 4). The pictures were analyzed separately by a trained panel of 6 people; every picture was scored individually for pan coverage percentage.

After the trial was started, the distance between the feeder trough and the top of the feed plate was measured on both the left and right side of the feeder. The width of the feed plate (3.625 in.) was subtracted from the height measurement to determine gap opening. The feed gate was designed to have some "give" or "play" in the feed gate to allow for feed agitation. Thus, the gap opening of the feeder had a low and high position. The gap opening was measured when the feed plate was in both the lowest and highest position possible. Thus, 2 measurements (right and left side of feeder) of gap opening were obtained and averaged for each respective position (low or high) for each feeder. The high gap opening measurements and percentage of pan coverage were plotted, and the resulting graph was used to develop a regression equation. With this regression equation, it is possible to estimate the pan coverage at any feeder gap opening.

Experiment 2. A total of 1,250 barrows and gilts (PIC 337 × 1050, initially 77.3 lb) were used in a 69-d study. Pigs were blocked by weight and randomly allotted to 1 of 6 treatments with 8 replications per treatment. Each pen contained 27 to 28 pigs with an equal distribution of barrows and gilts. The treatments were arranged in a 2 × 3 factorial with main effects of STACO stainless steel dry feeder setting (1, 3, 5) and diet type (corn-soybean meal- or by-product based (15% DDGS and 5% bakery by-product; Table 2). Similar to Exp. 1, feeder settings remained at their respective setting for the duration of the trial. Pigs and feeders were weighed on d 0, 15, 30, 42, 55, and 69 to determine the response criteria of ADG, ADFI, and F/G.

During weeks 2 and 6 of the trial, a digital photo of each feed pan was taken. As in Exp. 1, all pictures were analyzed separately by a trained panel of 6 people; every picture was scored individually for pan coverage percentage. Also, after the trial was started, gap opening was measured using the same procedures as in Exp. 1. High gap opening was also graphed using the same procedures as in Exp. 1.

Statistical analysis. Data were analyzed as a randomized complete block design by using the PROC MIXED procedure of SAS with pen as the experimental unit.

Results

Experiment 1. From d 0 to 28, pigs fed from feeders with increasing feeder openings had increased (linear, $P < 0.01$) ADG and increased (linear, $P < 0.04$) ADFI (Table 3). For d 28 to 70, increasing feeder setting did not affect ($P > 0.10$) any growth performance traits. Overall (d 0 to 70), pigs fed from feeders with increasing feeder openings had increased (linear, $P < 0.03$) ADFI. Changing feeder setting did not affect ($P > 0.18$) ADG or F/G.

The range in feeder settings provided a wide range of feeder gap openings and corresponding pan coverage (Figure 5). As feeder setting increased from 1 to 5 (or tighten down), low and high gap opening decreased (linear, $P < 0.01$) as expected (Table 4). Furthermore, as feeder setting increased (or feeder gap opening decreased), feeder pan coverage percentage decreased (linear, $P < 0.01$) for wk 2, 4, 7, and 10 of the trial (Table 5).

Experiment 2. From d 0 to 30 and d 30 to 69, pigs fed from feeders with increasing feeder openings had increased (linear, $P < 0.01$) ADG and ADFI (Table 6). Overall (d 0 to 69), there were no feeder setting × diet type interactions ($P > 0.31$) for growth performance. Diet type did not affect ($P > 0.75$) growth performance (Table 7). Pigs fed from feeders with increasing feeder openings had increased (quadratic, $P < 0.03$) ADG. The pigs on feeder setting 1 grew the fastest; there was a slight reduction in growth rate for pigs fed with feeders on setting 3 and a large decrease in ADG as feeder setting was increased from 3 to 5. Pigs fed from feeders with increasing feeder openings had increased (linear, $P < 0.01$) ADFI. Feeder setting tended to influence (quadratic, $P > 0.08$) F/G; optimal F/G occurred when feeders were on setting 3.

As expected, as feeder setting increased (linear, $P < 0.01$), low gap opening and high gap opening decreased (Table 8). As feeder setting increased (or feeder gap opening decreased), feeder pan coverage percentage decreased for wk 2 (linear, $P < 0.01$) and 6 (quadratic, $P < 0.01$) of the trial (Table 9). Feed pan coverage at each gap opening was similar to coverage in Exp. 1; approximately 50% of the feed pan was covered with a high gap opening of 1.15 in. (Figure 6).

Discussion

Our data show that feed intake and daily gain increased as feeder opening increased, whereas feed efficiency improved at the middle feeder adjustment setting. These differ-

ences may be explained by increased feed wastage at a very open setting and restricted feed intake resulting in poorer ADG and F/G when feeders are adjusted too tightly.

These trials illustrate the importance of proper feeder management and adjustment. In both trials, feeder setting 3 appeared to be optimal for the feeder studied. However, to apply this data to other dry feeder types, feeder gap opening was measured. The average gap opening for feeder setting 3 from the feed trough to the bottom of the feed plate when the feed plate was in the high position was approximately 1.15 in. The amount of feed covering the bottom surface of the feeder pan for this setting averaged 61%. However, the range for individual feeders on this adjustment setting was large with a range of 14 to 93%. On the basis of this data, our recommendation is for feeders to be adjusted to allow feed to cover slightly more than half of the feed pan without feed accumulating in the corners.

Figure 1. Example of STACO stainless steel dry feeder on feeder setting 3.

Figure 2. Example of pan coverage for feeder setting 5.

Figure 3. Example of pan coverage for feeder setting 3.

Figure 4. Example of pan coverage for feeder setting 1.

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

Ingredient, %	Phase 1	Phase 2	Phase 3
Corn	68.74	72.49	65.10
Soybean meal (46.5% CP)	23.30	19.65	26.90
Choice white grease	6.00	6.00	6.00
Monocalcium phosphate (21% P)	0.45	0.40	0.55
Limestone	0.85	0.80	0.80
Salt	0.35	0.35	0.35
Vitamin premix	0.06	0.06	0.03
Trace mineral premix	0.07	0.07	0.04
Optiphos 2000[2]	0.03	0.03	0.03
L-lysine HCl	0.15	0.15	0.15
L-threonine	---	---	0.03
Paylean, 9 g/lb	---	---	0.03
Total	100.00	100.00	100.00
Calculated analysis			
SID[3] amino acids, %			
Lysine	0.90	0.81	0.97
Methionine:lysine	27%	28%	27%
Met & Cys:lysine	57%	59%	56%
Threonine:lysine	60%	60%	64%
Tryptophan:lysine	19%	19%	20%
SID Lysine:calorie ratio, g/Mcal of ME	2.48	2.23	2.68
ME, kcal/lb	1,644	1,646	1,643
Total lysine, %	1.00	0.90	1.10
CP, %	16.82	15.44	18.21
Ca, %	0.51	0.47	0.52
P, %	0.45	0.42	0.48
Available P, %[4]	0.25	0.23	0.23
Avail P:calorie ratio, g/mcal of ME	0.68	0.64	0.64

[1] Phase 1 fed from 208 to 259 lb, phase 2 fed from 170 to 222 lb, phase 3 fed from 222 to 253 lb.
[2] Provided per pound of diet: 227 phytase units of phytase.
[3] Standardized ileal digestible.
[4] Includes expected P release of 0.07% from added phytase.

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

	Phase 1		Phase 2		Phase 3	
Ingredient, %	Corn-soy	By-product	Corn-soy	By-product	Corn-soy	By-product
Corn	69.38	52.69	73.73	57.06	78.80	61.96
Soybean meal (46.5% CP)	25.05	22.04	20.99	17.86	16.11	13.14
Dried distillers grains with solubles	---	15.00	---	15.00	---	15.00
Bakery by-product	---	5.00	---	5.00	---	5.00
Choice white grease	3.00	3.00	3.00	3.00	3.00	3.00
Monocalcium phosphate (21% P)	0.55	0.20	0.40	0.05	0.35	0.03
Limestone	0.90	1.00	0.88	1.05	0.80	0.95
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.15	0.15	0.13	0.13	0.10	0.10
Trace mineral premix	0.15	0.15	0.13	0.13	0.10	0.10
Optiphos 2000[2]	0.03	0.03	0.03	0.03	0.03	0.03
L-lysine HCl	0.30	0.35	0.28	0.33	0.27	0.31
DL-methionine	0.06	---	0.04	---	0.02	---
L-threonine	0.09	0.05	0.07	0.04	0.07	0.04
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis						
SID[3] amino acids, %						
Lysine	1.06	1.06	0.94	0.94	0.81	0.81
Methionine:lysine	30%	27%	29%	29%	29%	31%
Met & Cys:lysine	56%	56%	56%	59%	58%	63%
Threonine:lysine	62%	62%	62%	62%	64%	64%
Tryptophan:lysine	17%	17%	17%	17%	17%	17%
SID Lysine:calorie ratio,						
g/Mcal of ME	3.04	3.04	2.70	2.68	2.32	2.30
ME, kcal/lb	1,578	1,588	1,581	1,591	1,585	1,594
Total lysine, %	1.17	1.21	1.05	1.07	0.90	0.93
CP, %	17.93	19.72	16.36	18.11	14.51	16.32
Ca, %	0.55	0.52	0.50	0.50	0.45	0.44
P, %	0.48	0.46	0.44	0.41	0.41	0.39
Available P, %[4]	0.18	0.18	0.25	0.25	0.23	0.24

[1] Phase 1 fed from 77 to 125 lb, phase 2 fed from 125 to 175 lb, phase 3 fed from 175 to 219 lb.
[2] Provided per pound of diet: 227 phytase units of phytase.
[3] Standardized ileal digestible.
[4] Includes expected P release of 0.07% from added phytase.

Table 3. Influence of feeder adjustment on growing-finishing pig performance (Exp. 1)[1]

	Feeder Setting						Probability, *P* <		
Item	1	2	3	4	5	SE	Treatment	Linear	Quadratic
d 0 to 28									
Initial wt, lb	129.0	129.2	128.4	128.7	129.7	1.54	0.97	0.82	0.60
ADG, lb	1.85	1.84	1.80	1.80	1.78	0.03	0.29	0.04	0.92
ADFI, lb	4.51	4.46	4.32	4.30	4.30	0.06	0.02	0.01	0.32
F/G	2.45	2.43	2.41	2.39	2.42	0.03	0.64	0.28	0.40
d 28 to 70									
ADG, lb	1.72	1.78	1.81	1.73	1.74	0.04	0.27	0.80	0.10
ADFI, lb	4.85	4.93	4.88	4.73	4.76	0.10	0.58	0.23	0.57
F/G	2.81	2.78	2.69	2.75	2.73	0.05	0.49	0.22	0.36
d 0 to 70									
ADG, lb	1.77	1.80	1.81	1.76	1.75	0.02	0.33	0.22	0.18
ADFI, lb	4.71	4.74	4.65	4.55	4.56	0.07	0.18	0.03	0.84
F/G	2.65	2.63	2.57	2.59	2.60	0.04	0.48	0.18	0.30
Final wt, lb	251.6	253.7	256.5	251.6	252.5	2.23	0.45	0.96	0.21

[1] A total of 1,170 pigs (PIC, initially 129.0 lb) were used in a 70-d experiment with 23 to 28 pigs per pen and 9 pens per treatment.

Table 4. Influence of feeder adjustment on feeder gap opening (Exp. 1)[1]

	Feeder Setting						Probability, *P* <		
Gap opening, in.[2]	1	2	3	4	5	SE	Treatment	Linear	Quadratic
Low	1.14	1.04	0.90	0.79	0.68	0.03	0.01	0.01	0.92
High	1.42	1.30	1.16	1.05	0.87	0.03	0.01	0.01	0.45

[1] A total of 1,170 pigs (PIC, initially 129.0 lb) were used in a 70-d experiment with 23 to 28 pigs per pen and 9 pens per treatment.
[2] Measured from the bottom of the feed pan to the bottom of the feed plate with the feed plate at the lowest (low) and highest (high) possible positions.

Table 5. Influence of feeder adjustment on feeder pan coverage (Exp. 1)[1]

	Feeder setting						Probability, *P* <		
Pan coverage, %	1	2	3	4	5	SE	Treatment	Linear	Quadratic
wk 2	74.0	71.3	57.0	34.3	20.6	4.63	0.01	0.01	0.09
wk 4	73.1	65.9	62.9	41.9	24.9	4.28	0.01	0.01	0.03
wk 7	78.0	67.0	63.7	46.3	24.8	3.39	0.01	0.01	0.01
wk 10	78.9	73.9	64.6	45.2	26.1	3.04	0.01	0.01	0.01

[1] A total of 1,170 pigs (PIC, initially 129.0 lb) were used in a 70-d experiment with 23 to 28 pigs per pen and 9 pens per treatment.

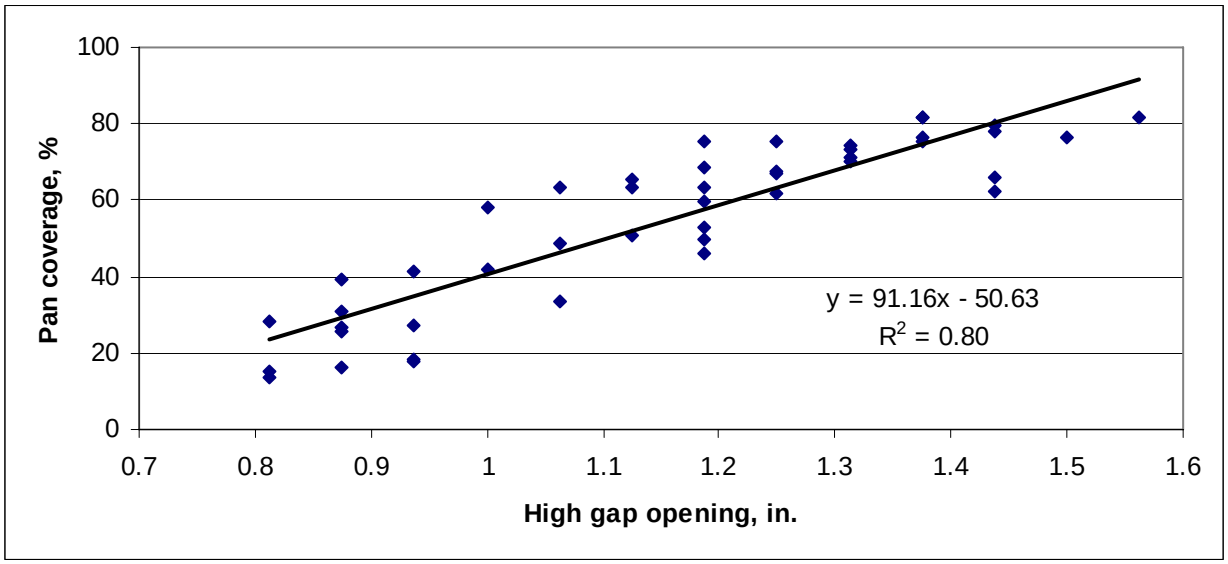

Figure 5. Percentage of pan covered with feed at different high gap opening measurements (Exp. 1).

High gap opening is the maximum distance from the feed pan to the bottom of the feeder agitation gate.

Table 6. Influence of feeder adjustment and diet type on growing-finishing pig performance (Exp. 2)[1]

	Corn-soybean meal			By-product							Probability *P*<	
	Feeder setting			Feeder setting							Feeder setting	
Item	1	3	5	1	3	5	SE	Diet × Feeder setting	Diet	Feeder setting	Linear	Quadratic
d 0 to 30												
Initial wt, lb	77.4	77.5	77.2	77.2	77.5	77.1	0.04	1.00	0.97	0.99	0.93	0.89
ADG, lb	2.09	2.04	1.91	2.01	2.04	1.97	0.04	0.22	0.92	0.01	0.01	0.16
ADFI, lb	4.35	4.16	4.03	4.36	4.29	4.05	0.08	0.68	0.42	0.01	0.01	0.70
F/G	2.07	2.06	2.14	2.19	2.09	2.06	0.05	0.13	0.63	0.46	0.55	0.29
d 30 to 69												
ADG, lb	2.11	2.06	1.94	2.09	2.07	1.94	0.03	0.90	0.97	0.01	0.01	0.08
ADFI, lb	5.49	5.25	5.03	5.43	5.26	5.04	0.07	0.86	0.81	0.01	0.01	0.83
F/G	2.60	2.55	2.60	2.60	2.55	2.60	0.04	1.00	0.88	0.26	0.99	0.10
d 0 to 69												
ADG, lb	2.10	2.05	1.92	2.06	2.05	1.95	0.02	0.37	0.87	0.01	0.01	0.03
ADFI, lb	4.99	4.77	4.59	4.95	4.84	4.61	0.06	0.74	0.75	0.01	0.01	0.69
F/G	2.37	2.34	2.40	2.42	2.34	2.35	0.03	0.31	0.87	0.19	0.67	0.08
Final wt, lb	223.5	220.6	212.1	221.4	220.3	214.2	3.27	0.81	0.97	0.02	0.01	0.33

[1] A total of 1,250 pigs (PIC, initially 77.3 lb) were used in a 69-d experiment with 27 to 28 pigs per pen and 8 pens per treatment for the treatments of feeder setting 1 and 3 for both diet types and 7 pens per treatment for the treatments of feeder setting 5 for both diet types.

Table 7. Main effects of feeder adjustment on growing-finishing pig performance (Exp. 2)[1]

					Probability, *P* <	
	Feeder setting				Feeder setting	
Item	1	3	*5*	SE	Linear	Quadratic
d 0 to 30						
Initial wt, lb	77.3	77.5	77.1	1.57	0.93	0.89
ADG, lb	2.05	2.04	1.94	0.03	0.01	0.16
ADFI, lb	4.35	4.22	4.04	0.05	0.01	0.70
F/G	2.13	2.07	2.10	0.04	0.55	0.29
d 30 to 69						
ADG, lb	2.10	2.06	1.94	0.02	0.01	0.08
ADFI, lb	5.46	5.26	5.03	0.05	0.01	0.83
F/G	2.60	2.55	2.60	0.03	0.99	0.10
d 0 to 69						
ADG, lb	2.08	2.05	1.94	0.02	0.01	0.03
ADFI, lb	4.97	4.80	4.60	0.05	0.01	0.69
F/G	2.39	2.34	2.38	0.03	0.67	0.08
Final wt, lb	222.5	220.4	213.2	2.31	0.01	0.33

[1] A total of 1,250 pigs (PIC, initially 77.3 lb) were used in a 69-d experiment with 27 to 28 pigs per pen and 8 pens per treatment for the treatments of feeder setting 1 and 3 for both diet types and 7 pens per treatment for the treatments of feeder setting 5 for both diet types.

Table 8. Influence of feeder adjustment on gap opening (Exp. 2)[1]

					Probability, *P* <	
	Feeder setting				Feeder setting	
Gap opening, in.[2]	1	3	5	SE	Linear	Quadratic
Low	1.13	0.86	0.62	0.02	0.01	0.50
High	1.42	1.14	0.87	0.02	0.01	0.83

[1] A total of 1,250 pigs (PIC, initially 77.3 lb) were used in a 69-d experiment with 27 to 28 pigs per pen and 8 pens per treatment for the treatments of feeder setting 1 and 3 for both diet types and 7 pens per treatment for the treatments of feeder setting 5 for both diet types.
[2] Measured from the bottom of the feed pan to the bottom of the feed plate with the feed plate at the lowest (low) and highest (high) possible positions.

Table 9. Influence of feeder adjustment and diet type on feeder pan coverage (Exp. 2)[1]

	Corn-soybean meal			By-product							Probability, *P* <	
	Feeder setting			Feeder Setting				Diet × Feeder setting		Feeder setting	Feeder setting	
Feeder pan coverage, %	1	3	5	1	3	5	SE		Diet		Linear	Quadratic
wk 2	73.3	46.9	19.4	85.5	63.2	17.8	6.87	0.37	0.10	0.01	0.01	0.28
wk 6	74.7	53.3	25.9	85.3	70.3	22.4	6.34	0.17	0.10	0.01	0.01	0.04

[1] A total of 1,250 pigs (PIC, initially 77.3 lb) were used in a 69-d experiment with 27 to 28 pigs per pen and 8 pens per treatment for the treatments of feeder setting 1 and 3 for both diet types and 7 pens per treatment for the treatments of feeder setting 5 for both diet types.

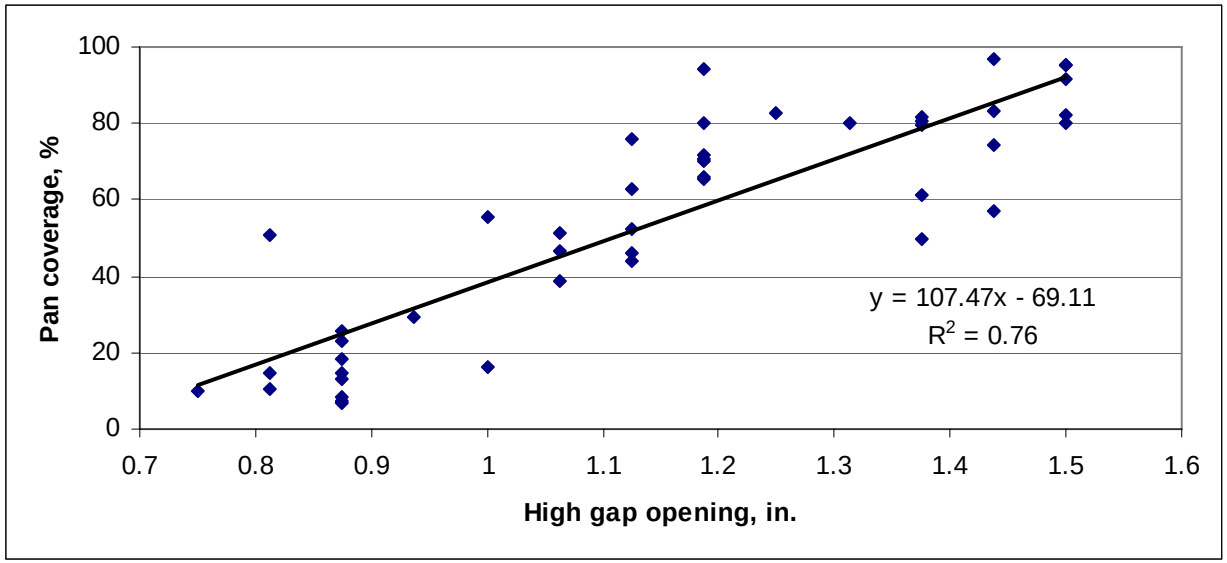

Figure 6. Percentage of pan covered with feed at different high gap opening measurements (Exp. 2).
High gap opening is the maximum distance from the feed pan to the bottom of the feeder agitation gate.

DIET PREFERENCE AND GROWTH PERFORMANCE IN WEANLING PIGS FED DIETS WITH *Morinda citrifolia* (NONI)

C. Feoli, J. D. Hancock, and K. C. Behnke[1]

Summary

Two experiments were conducted to determine the effects of adding 5% *Morinda citrifolia* (noni; Morinda Agricultural Products, Orem, UT) to diets for weanling pigs. In Exp. 1, 48 pigs (initially 9.3 lb) were used in a 29-d preference study. There were 6 pigs per pen and 8 pens total. The pens were equipped with 2 identical feeders (for diets without and with noni puree), and position of the feeders was switched each afternoon to prevent feeder location from affecting diet consumption. The diets were corn-soybean meal-based, pelleted, and had 1.8% lysine for d 0 to 5, 1.6% lysine for d 5 to 15, and 1.4% lysine for d 15 to 29. Feed and water were consumed on an ad libitum basis. No differences were noted among diets without and with noni for pelleting ease and pellet durability index (PDI). Feed intake was increased for d 0 to 5 (0.11 vs. 0.23 lb/d, $P < 0.05$) and d 0 to 15 (0.15 vs. 0.37 lb/d, $P < 0.006$) when noni was added to the diets. However, this effect disappeared for d 15 to 29 so that overall feed intake was not different (0.40 vs. 0.50 lb/d, $P > 0.39$) for d 0 to 29. In Exp. 2, 96 pigs (initially 14.8 lb) were used in a 29-d growth assay. There were 6 pigs per pen and 8 pens per treatment. The diets were the same as those used in the first experiment. Results indicated no differences ($P > 0.29$) in ADG, ADFI, and F/G for d 0 to 5 and 0 to 15 between pigs fed diets without and with noni. However, for d 15 to 29 and overall (d 0 to 29), ADG and ADFI were decreased ($P < 0.04$) for pigs fed diets with noni compared with the control. In conclusion, there was a preference for diets with noni for the first 15 d of the preference study. In the growth assay, prolonged feeding of diets with noni resulted in reduced feed intake and, ultimately, decreased rate of gain.

Key words: diet preference, *Morinda citrifolia*, noni, weanling pigs

Introduction

Morinda citrifolia (noni) has been used in Polynesian folk remedies form more than 2,000 years. It is thought to have antioxidant, antibiotic, bactericidal, and anticarcinogenic properties and contains phytochemicals that have been suggested to be biologically active (e.g., enhanced immune function, antibiotic-like functions, and decreased potential for cancer in laboratory rats). Swine producers always are searching for means to improve productivity of their pigs and profitability of their operations. Because the use of noni in diets for pigs is a relatively new research area, we designed 2 experiments to determine the effects of noni on feed preference and growth performance in weanling pigs.

Procedures

For Exp. 1, 48 weanling pigs (initially 9.3 lb) were used in a 29-d preference study. The pigs were blocked by weight and sorted into

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pens on the basis of gender and ancestry. There were 6 pigs per pen and 8 pens total in the environmentally controlled nursery room. Each 4-ft × 4-ft pen was equipped with woven-wire flooring, 2 identical feeders (for diets without and with noni puree), and 1 nipple waterer. Feeder positions were switched each afternoon to ensure that any preference for one diet vs. the other would not be affected by familiarity with a feeder's location.

The diets (Table 1) were corn-soybean meal-based and formulated to 1.8% lysine for d 0 to 5, 1.6 % lysine for d 5 to 15, and 1.4% lysine for d 15 to 29. Treatments were 5% test premix (80% water and 20% corn) for the control vs. 5% noni (Morinda Agricultural Products, Orem, UT). The diets for d 0 to 5 and 5 to 15 were steam conditioned at 140ºF for approximately 20 sec before passing into a pelleting press (CPM Master Model HD) equipped with a 1¼-in.-thick die having 5/32-in. openings. The diets for d 15 to 29 were steam conditioned at 180ºF and pelleted through the same press but with a 7/8-in.-thick die. Samples of the processed diets were collected, and pellet durability index (PDI) was determined by using the tumbling-box technique. Additionally, the PDI procedure was modified to induce more stress on the pellets by adding 5 hexagonal nuts into the tumbling box.

The pigs were allowed to consume feed and water on an ad libitum basis. Feeder weights were collected on d 0, 5, 15, and 29 of the experiment to allow calculation of ADFI. All data were analyzed by using the MIXED procedure of SAS with pen as the blocking criterion and feeder as the experimental unit. A significant F test was considered sufficient to declare a difference among treatment means.

For Exp. 2, 96 weanling pigs (initially 14.8 lb) were used in a 29-d growth assay. There were 6 pigs per pen and 8 pens per treatment. The pigs were sorted and housed as in Exp. 1 except that the pens had only 1 feeder. Diets (Table 1) were the same as those used in Exp. 1 (without and with noni), and feed and water were consumed on an ad libitum basis.

Pig and feeder weights were collected on d 0, 5, 15, and 29 of the experiment to allow calculation of ADG, ADFI, and F/G. All data were analyzed by using the MIXED procedure of SAS with initial weight as the blocking criterion and pen as the experimental unit. A significant F test was considered sufficient to declare a difference among treatment means.

Results and Discussion

In Exp. 1 (Table 2), observations made during feed processing indicated that all diets pelleted with ease and with only slight improvements (2 to 4%) in PDI for diets with noni. Pigs fed the control ate less for d 0 to 5 (0.11 vs. 0.23 lb/d, $P < 0.05$) and d 0 to 15 (0.15 vs. 0.37 lb/d, $P < 0.006$) than pigs fed diets with noni. However, preference for diets with noni disappeared during d 15 to 29 so that overall feed intake (d 0 to 29) was not different (0.40 vs. 0.50 lb/d, $P > 0.39$) for the control vs. noni treatments. The loss of the preference response could have resulted from prolonged consumption of the diets with a high concentration (5%) of noni. Alternatively, it could be that extended storage (2 to 4 weeks) of diets with noni lead to development of anti-palatability factors. Regardless what factors eventually led to loss of preference, our data demonstrate that piglets preferred diets with 5% noni for the first 2 wk after weaning.

In Exp. 2 (Table 3), when the same feed used in the preference determination was used in a growth assay, there were no differences ($P > 0.29$) in ADG, ADFI, and F/G for d 0 to 5 and 0 to 15 between pigs fed diets without and with noni. Overall (d 0 to 29), ADG ($P < 0.04$) and ADFI ($P < 0.02$) were decreased for pigs fed diets with noni. Thus, results of the

gowth assay tend to support those of the preference determination in that diets with a high concentration of noni that are fed for a prolonged period may begin to adversely affect feed intake and, thus, rate of gain.

In conclusion, there was a preference for diets with noni for the first 15 d of the preference study. In the growth assay, prolonged feeding of diets with noni resulted in reduced feed intake and, ultimately, decreased rate of gain.

Table 1. Composition of diets

Ingredient, %	d 0 to 5	d 5 to 15	d 15 to 29
Corn	22.97	42.57	58.19
Soybean meal (47.5% CP)	27.10	29.15	33.00
Whey	20.00	15.00	---
Lactose	10.00	---	---
Soy oil	2.00	---	---
Test premix [1]	5.00	5.00	5.00
Spray-dried plasma	5.00	2.50	
Fish meal	5.00	3.00	
Monocalcium phosphate (21% P)	0.80	0.66	1.30
Limestone	0.69	0.85	1.11
L-lysine HCl	0.21	0.21	0.32
DL-methionine	0.19	0.14	0.14
L-threonine	0.05	0.03	0.10
Salt	0.20	0.30	0.35
Vitamin premix	0.25	0.25	0.25
Mineral premix	0.15	0.15	0.15
Copper sulfate	---	---	0.09
Zinc oxide	0.39	0.19	---
Calculated analysis			
Lysine, %	1.80	1.60	1.40
Ca, %	0.90	0.80	0.75
Total P, %	0.80	0.70	0.67

[1] *Morinda citrifolia* (noni) was used to replace the test premix that was 80% water and 20% corn.

Table 2. Effects of diets without and with *Morinda citrifolia* (noni) on pellet quality and diet preference in weanling pigs (Exp. 1)[1]

Item	Control	Noni	SE	*P* value
PDI, %[2]				
d 0 to 5	97	99	N/A	N/A
d 5 to 15	90	94	N/A	N/A
Modified PDI, %[3]				
d 0 to 5	95	98	N/A	N/A
d 5 to 15	88	92	N/A	N/A
ADFI, lb				
d 0 to 5	0.11	0.23	0.03	0.05
d 5 to 15	0.15	0.37	0.04	0.006
d 0 to 29	0.40	0.50	0.07	---[4]

[1] A total of 48 weanling pigs (6 pigs/pen and 8 pens total) with an initial weight of 9.3 lb.
[2] Pellet durability index (ASAE, 1991).
[3] Modified by adding 5 hexagonal nuts (0.5-in. diameter) to the tumbling box.
[4] Dashes indicate $P > 0.15$.

Table 3. Effects of diets without and with *Morinda citrifolia* (noni) on growth performance of weanling pigs (Exp. 2)[1]

Item	Control	Noni	SE	*P* value
d 0 to 5				
ADG, lb	0.39	0.42	0.14	---[2]
ADFI, lb	0.40	0.40	0.02	---
F/G	1.03	0.95	0.50	---
d 0 to 15				
ADG, lb	0.49	0.46	0.02	---
ADFI, lb	0.62	0.58	0.09	---
F/G	1.27	1.26	0.18	---
d 0 to 29				
ADG, lb	0.86	0.80	0.03	0.04
ADFI, lb	1.12	1.03	0.11	0.02
F/G	1.30	1.29	0.09	---

[1] A total of 96 weanling pigs (6 pigs per pen and 8 pens per treatment) with an initial weight of 14.8 lb.
[2] Dashes indicate $P > 0.15$.

EFFECTS OF *Morinda citrifolia* (NONI) AND DIET COMPLEXITY ON GROWTH PERFORMANCE IN WEANLING PIGS

C. Feoli, J. D. Hancock, and K. C. Behnke[1]

Summary

Two experiments were conducted to determine the effects of concentration (0, 0.75, 1.5, 3.0, and 6.0%) of *Morinda citrifolia* (noni; Morinda Agricultural Products, Orem, UT) and diet complexity in weanling pigs. In Exp. 1, 210 pigs (initially 13.4 lb) were used in a 35-d growth assay; there were 7 pigs per pen and 6 pens per treatment. Diets were corn-soybean meal-based, and lysine concentrations were 1.8% for d 0 to 7, 1.6% for d 7 to 21, and 1.4% for d 21 to 35 with feed and water consumed on an ad libitum basis. Increasing the concentration of noni in the diet from 0 to 3% had no effects on pellet durability index (PDI) for the d 0 to 7 and 7 to 21 diets. Average daily gain (quadratic effect, $P < 0.03$) and F/G (quadratic effect, $P < 0.10$) for d 0 to 7 and F/G for d 0 to 21 (quadratic effect, $P < 0.04$) improved as noni concentration in the diet was increased from 0 to 0.75%. However, no treatment effects were observed overall (d 0 to 35). For Exp. 2, 168 pigs (initially 13.9 lb) were used in a 35-d growth assay; there were 6 pigs per pen and 7 pens per treatment. Treatments were arranged as a 2 × 2 factorial with main effects of diet formulation (simple vs. complex) and noni addition (0 vs. 3%). Simple diets had the same minimum nutrient specifications as complex diets but had no added lactose or spray-dried animal plasma for d 0 to 7 and only 10% added whey for d 7 to 21. Pelleting data indicated improved PDI with no additional energy inputs when noni was added to the simple diets (for d 21 to 35). Pigs fed simple diets had lower ADG ($P < 0.06$) for d 0 to 7 and lower ADG and ADFI ($P < 0.06$) for d 0 to 21 than pigs fed complex diets. During d 0 to 35 for ADG and d 0 to 21 for F/G, addition of noni to the simple diets had negative effects (diet complexity × noni interaction, $P < 0.02$). In conclusion, adding 0.75 to 3% noni to complex diets improved growth performance early in a titration experiment but had negative effects when added to the simple diet formulations used in a second experiment.

Key words: diet complexity, dose titration, *Morinda citrifolia*, noni

Introduction

In previous research conducted at Kansas State University and in Japan, there appeared to be an aversion that developed over time to diets with high inclusion of *Morinda citrifolia* (noni). Because noni was just recently considered a potential feed ingredient in diets for pigs, experiments should be conducted to determine the most appropriate dose × duration combination that will ensure ingestion of sufficient noni to have the desired biological effects. In addition, it is possible that noni might be able to replace some of the expensive ingredients often included in diets for weanling pigs (e.g., spray-dried animal plasma, milk products, specialized fish meals, and antibiotics), thereby becoming a preferred ingredient

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in diets for weanling pigs worldwide. Thus, we designed 2 experiments to determine the ideal concentration of noni in diets for weaned piglets and the effects of noni in simple and complex diets for weanling pigs.

Procedures

For the first experiment, 210 weanling pigs (initially 13.4 lb) were used in a 35-d titration experiment. The pigs were blocked by weight and sorted into pens on the basis of gender and ancestry. There were 7 pigs per pen and 6 pens per treatment in the environmentally controlled nursery room. Each pen was 4 ft × 4 ft and equipped with woven-wire flooring and 1 self-feeder and 1 nipple waterer to allow ad libitum consumption of feed and water.

The diets (Table 1) were corn-soybean meal based and formulated to 1.8% lysine for d 0 to 7, 1.6 % lysine for d 7 to 21, and 1.4% lysine for d 21 to 35. Treatments were 6% test premix (90% water and 10% corn) for the control vs. 0.75, 1.5, 3.0, and 6.0% noni (Morinda Agricultural Products, Orem, UT) added at the expense of the test premix. The diets were not steam conditioned before being passed into a pelleting press (CPM Master Model HD) equipped with a 1¼-in.-thick die having 5/32-in. openings. Samples of the processed diets were collected, and pellet durability index (PDI) was determined by using the tumbling-box technique. Additionally, the PDI procedure was modified to induce more stress on the pellets by adding 5 hexagonal nuts into the tumbling box.

Pig and feeder weights were collected on d 0, 7, 21, and 35 to allow calculation of ADG, ADFI, and F/G. All data were analyzed by using the MIXED procedure of SAS with initial weight as the blocking criterion and pen as the experimental unit. Polynomial regression was used to describe the shape of the response to increasing concentration of noni in the diets.

For the second experiment, 168 weanling pigs (initially 13.9 lb) were used in a 35-d growth assay. There were 6 pigs per pen and 7 pens per treatment. The pigs were sorted and housed as in Exp. 1 with feed and water consumed on an ad libitum basis.

The diets (Table 2) were corn-soybean meal based and formulated to 1.8% lysine for d 0 to 7, 1.6 % lysine for d 7 to 21, and 1.4% lysine for d 21 to 35. Treatments were arranged as a 2 × 2 factorial with main effects of diet formulation (simple vs. complex) and noni addition (0 vs 3%). Simple diets had the same minimum nutrient specifications as complex diets but had no added lactose or spray-dried animal plasma for d 0 to 7 and only 10% added whey for d 7 to 21. The diets for d 0 to 7 and 7 to 21 were steam conditioned at 140ºF for approximately 20 seconds before passing into a pelleting press (CPM Master Model HD) equipped with a 1¼-in.-thick die having 5/32-in. openings. The diets for d 21 to 35 were steam conditioned at 180ºF and pelleted through the same press and die used for the other diets. Samples of the pelleted diets were collected, and PDI was determined.

Pig and feeder weights were collected on d 0, 7, 21, and 35 to allow calculation of ADG, ADFI, F/G and variation (CV) in BW. All data were analyzed by using the MIXED procedure of SAS with initial weight as the blocking criterion and pen as the experimental unit. Orthogonal contrasts for a 2 × 2 factorial were used to separate treatment means with comparisons of (1) effect of diet formulation, (2) effect of noni addition, and (3) diet formulation × noni addition.

Results and Discussion

In Exp. 1 (Table 3), increasing the concentration of noni in the diet from 0 to 3% had no effects on PDI for d 0 to 7 and 7 to 21 diets. However, there appeared to be some slippage of PDI with 6% added noni. Pig growth data (Table 4) indicated that for d 0 to 7 there was

a quadratic improvement in ADG ($P < 0.03$) and F/G ($P < 0.10$) as noni concentration in the diet was increased from 0 to 0.75%, a plateau as noni concentration increased to 3%, and a decrease as noni concretion was increased further to 6%. The same response was observed for F/G during d 0 to 21 ($P < 0.04$). There was no overall effect (i.e., d 0 to 35) of adding noni to diets for nursery pigs.

In Exp. 2 (Table 5), pelleting data indicated improved PDI with no additional energy inputs when noni was added to the simplest diets (for d 21 to 35). For growth performance (Table 6), ADG was improved for d 0 to 7 ($P < 0.06$) and d 0 to 21 ($P < 0.02$) when pigs were given complex diets. However, the effects of diet complexity were not independent of noni addition as F/G for d 0 to 21 (diet complexity × noni interaction, $P < 0.02$) increased as noni was added to simple diets and decreased when noni was added to complex diets. For d 0 to 35, ADG and F/G were negatively affected (diet complexity × noni interaction, $P < 0.09$) when noni was added to simple diets but did not show any numerical difference when noni was added to complex diets. On d 35, CV showed greater ($P < 0.02$) weight variation among pigs within a pen for pigs fed simple diets compared with pigs fed complex diets. However, there was a trend ($P < 0.10$) for an interaction, suggesting that when noni was added, pens treated with the simple diets had a decrease in weight uniformity but pens treated with the complex diets had an improvement in weight uniformity.

In conclusion, our experiments suggested a small but positive effect of noni on pellet quality over and above simply adding water into the mixer. Adding 0.75 to 3% noni to complex diets improved growth performance early in a titration experiment but had negative effects when added to the simple diet formulations used in a second experiment.

Table 1. Composition of diets for Exp. 1

Ingredient, %	d 0 to 7	d 7 to 21	d 21 to 35
Corn	22.84	38.08	51.49
Soybean meal (47.5% CP)	27.24	29.60	33.65
Whey	20.00	15.00	---
Lactose	10.00	---	---
Soy oil	1.00	3.00	5.00
Test premix[1]	6.00	6.00	6.00
Spray-dried plasma	5.00	2.50	---
Fish meal	5.00	3.00	---
Monocalcium phosphate (21% P)	0.79	0.71	1.31
Limestone	0.69	0.83	1.11
L-lysine HCl	0.21	0.20	0.32
DL-methionine	0.19	0.15	0.15
L-threonine	0.05	0.04	0.11
Salt	0.20	0.30	0.37
Vitamin premix	0.25	0.25	0.25
Mineral premix	0.15	0.15	0.15
Copper sulfate	---	---	0.09
Zinc oxide	0.39	0.19	---
Calculated analysis			
Lysine, %	1.80	1.60	1.40
Ca, %	0.90	0.80	0.75
Total P, %	0.80	0.70	0.65

[1] *Morinda citrifolia* (noni) was used to replace the test premix that was 90% water and 10% corn.

Table 2. Composition of diets for Exp. 2

	d 0 to 7		d 7 to 21		
Ingredient, %	Simple	Complex	Simple	Complex	d 21 to 35
Corn	31.53	26.58	42.23	41.42	54.76
Soybean meal (47.5% CP)	36.45	26.49	35.80	29.30	33.40
Whey	20.00	20.00	10.00	15.00	---
Lactose	---	10.00	---	---	---
Soy oil	1.00	1.00	3.00	3.00	5.00
Test premix[1]	3.00	3.00	3.00	3.00	3.00
Spray-dried plasma	---	5.00	---	2.50	---
Fish meal	5.00	5.00	3.00	3.00	---
Monocalcium phosphate (21% P)	0.94	0.77	0.81	0.67	1.31
Limestone	0.55	0.71	0.83	0.84	1.11
L-lysine HCl	0.25	0.22	0.23	0.21	0.32
DL-methionine	0.20	0.19	0.15	0.14	0.14
L-threonine	0.09	0.05	0.06	0.03	0.10
Salt	0.20	0.20	0.30	0.30	0.37
Vitamin premix	0.25	0.25	0.25	0.25	0.25
Mineral premix	0.15	0.15	0.15	0.15	0.15
Copper sulfate	---	---	---	---	0.09
Zinc oxide	0.39	0.39	0.19	0.19	---
Calculated analysis					
Lysine, %	1.80	1.80	1.60	1.60	1.40
Ca, %	0.90	0.90	0.80	0.80	0.75
Total P, %	0.80	0.80	0.70	0.70	0.66

[1] *Morinda citrifolia* (noni) was used to replace the test premix that was 90% water and 10% corn.

Table 3. Effects of diets with increasing concentration of *Morinda citrifolia* (noni) on pellet quality (Exp. 1)

	noni, %				
Item	0	0.75	1.5	3.0	6.0
d 0 to 7					
PDI, %[1]	97.9	98.0	98.0	98.5	96.3
Mod PDI, %[2]	97.4	97.7	97.7	98.3	95.6
d 7 to 21					
PDI, %	95.9	96.0	96.4	94.2	96.9
Mod PDI, %	93.4	94.2	94.6	91.5	94.8

[1] Pellet durability index (ASAE 1991).
[2] Modified by adding 5 hexagonal nuts (0.5-in. diameter) to the tumbling box.

Table 4. Ideal concentration of *Morinda citrifolia* (noni) in diets for weanling pigs (Exp. 1)[1]

	Noni, %						*P* value			
Item	0	0.75	1.5	3.0	6.0	SE	Lin	Quad	Cubic	Quartic
d 0 to 7										
ADG, lb	0.43	0.49	0.44	0.50	0.39	0.03	0.13	0.03	---[2]	0.07
ADFI, lb	0.42	0.42	0.38	0.44	0.38	0.02	---	---	0.14	0.14
F/G	0.98	0.86	0.86	0.88	0.97	0.05	---	0.10	---	---
d 0 to 21										
ADG, lb	0.72	0.73	0.68	0.75	0.65	0.03	0.11	---	---	---
ADFI, lb	0.81	0.79	0.76	0.82	0.74	0.03	---	---	0.10	---
F/G	1.13	1.08	1.12	1.09	1.14	0.01	0.15	0.04	---	0.03
d 0 to 35										
ADG, lb	0.95	0.95	0.93	0.97	0.92	0.03	---	---	---	---
ADFI, lb	1.17	1.13	1.12	1.16	1.10	0.04	---	---	---	---
F/G	1.23	1.19	1.20	1.20	1.20	0.02	---	---	---	---

[1] A total of 210 weanling pigs (7 pigs per pen and 6 pens per treatment) with an initial weight of 13.4 lb.
[2] Dashes indicate $P > 0.15$.

Table 5. Effects of *Morinda citrifolia* (noni) on pellet quality in simple and complex diets (Exp. 2)

	Simple		Complex	
Item	Without noni	With noni	Without noni	With noni
d 0 to 7				
PDI, %[1]	96.85	96.71	96.47	97.94
Mod PDI, %[2]	95.91	95.70	95.24	97.35
d 7 to 21				
PDI, %	91.21	90.99	94.12	94.33
Mod PDI, %	86.13	86.39	91.62	91.04
d 21 to 35				
PDI, %	72.87	85.69	---[3]	---
Mod PDI, %	61.22	81.37	---	---
Net electrical energy, kWh/t	2.3	2.4	---	---

[1] Pellet durability index (ASAE).
[2] Modified by adding 5 hexagonal nuts (0.5-in. diameter) to the tumbling box.
[3] For d 21 to 35, the simple formulation was used either without or with noni for all pigs.

Table 6. Effects of *Morinda citrifolia* (noni) in simple and complex diets for weanling pigs[1]

	Simple		Complex			*P* value		
Item	Without noni	With noni	Without noni	With noni	SE	Diet effect	Noni effect	D × N
d 0 to 7								
ADG, lb	0.37	0.28	0.39	0.38	0.03	0.06	0.14	---[2]
ADFI, lb	0.39	0.32	0.39	0.39	0.02	0.15	0.14	---
F/G	1.05	1.14	1.00	1.03	0.13	---	---	---
CV d 7, % 3	7.9	6.5	6.8	6.0	0.9	---	---	---
d 0 to 21								
ADG, lb	0.59	0.53	0.61	0.62	0.02	0.02	---	0.13
ADFI, lb	0.69	0.66	0.73	0.72	0.03	0.06	---	---
F/G	1.17	1.25	1.20	1.16	0.02	---	---	0.02
CV d 21, %	10.3	11.0	9.4	9.8	1.3	---	---	---
d 0 to 35								
ADG, lb	0.87	0.80	0.85	0.85	0.02	---	0.05	0.02
ADFI, lb	1.08	1.01	1.06	1.06	0.03	---	0.11	0.15
F/G	1.24	1.26	1.25	1.25	0.01	---	---	0.09
CV d 35, %	11.1	14.5	9.8	8.1	1.4	0.02	---	0.10

[1] A total of 168 weanling pigs (6 pigs per pen and 7 pens per treatment) with an initial weight of 13.9 lb.
[2] Dashes indicate $P > 0.15$.
[3] The pigs were sorted by weight to begin the experiment, and the initial CV was 2.1 to 2.2% for all treatments.

EFFECTS OF 200 PPB ADDED CHROMIUM FROM CHROMIUM PROPIONATE ON THE GROWTH PERFORMANCE AND CARCASS CHARACTERISTICS OF FINISHING PIGS[1,2]

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

Summary

A total of 1,207 pigs (PIC 337 × 1050) were used in a 103-d experiment in a commercial research barn to evaluate the growth performance and carcass characteristics of finishing pigs fed 200 ppb chromium propionate. There were 22 replicate pens per treatment with 25 to 28 pigs per pen for the evaluation of chromium propionate from d 0 to 84 and 11 replicates per treatment for evaluating chromium propionate (0 and 200 ppb) and Paylean (0 and 9 g/ton) in a split-plot arrangement from d 84 to 103. Pigs were weighed (avg. 67.7 lb) and randomly allotted to 2 corn-soybean meal-based dietary treatments, a control diet and the control diet with 200 ppb chromium from chromium propionate. The treatments were fed through three 4-wk dietary phases (d 0 to 28, d 28 to 56, and d 56 to 84). On d 84, pigs fed the control or chromium treatment were allotted to a fourth dietary phase containing either 0 or 9 g/ton Paylean, resulting in a split-plot design. For the overall period (d 0 to 84), growth performance of pigs fed the control or 200 ppb chromium propionate was not different. From d 84 to 103 and overall (d 0 to 103), pigs fed diets containing Paylean had increased ($P < 0.01$) ADG and final weight. However, a chromium propionate × Paylean interaction ($P < 0.04$) was observed for ADFI and F/G from d 84 to 103 and overall (d 0 to 103) F/G. The reason for the interaction was that the magnitude of response to Paylean was slightly greater in pigs fed the control than in pigs fed chromium. Regardless, the F/G of pigs fed Paylean was considerably better ($P < 0.01$) from d 84 to 103 (2.43 vs. 2.89) and overall (d 0 to 103, 2.50 vs. 2.56) than that of those not fed Paylean. Carcass data from 500 of the pigs were available for comparison of carcass characteristics. Pigs fed Paylean had greater ($P < 0.05$) plant live weight than pigs not fed Paylean. Chromium propionate did not influence any of the carcass characteristics measured. This experiment provides further evidence that Paylean improves late-finishing growth performance. In this trial, growing and finishing pigs did not respond to the dietary inclusion of chromium from chromium propionate.

Key words: chromium, lysine, ractopamine HCl

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[1] Appreciation is expressed to Kemin AgriFoods North America for providing the KemTrace chromium propionate and funding of the 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.
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Introduction

Chromium is a micromineral that enhances insulin sensitivity and glucose uptake by cells. Some research with growing and finishing pigs has demonstrated that organic chromium may increase muscling and decrease fatness of pigs. Much of the early research utilized chromium picolinate as the chromium source. Chromium propionate also has been demonstrated to be a bioavailable source of chromium and was approved by the FDA for use in pigs.

Few studies, however, have evaluated chromium supplementation with chromium propionate in growing and finishing pigs. Therefore, our objective was to evaluate the effects of 200 ppb supplemental chromium from chromium propionate on the growth performance and carcass characteristics of growing and finishing pigs reared in commercial conditions. Additionally, we were interested in determining whether chromium supplementation would provide further performance and carcass benefits for pigs fed Paylean (Elanco Animal Health, Indianapolis, IN) for 19 d preslaughter.

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 southwest 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 18 ft × 10 ft. Each pen contained 1 self-feeder and 1 cup waterer.

A total of 1,207 pigs were weighed and allotted to 1 of 2 dietary treatments. There were 22 replicate pens per treatment. Each pen contained 25 to 28 pigs; average pig number per pen and weight were balanced across dietary treatment. The 2 dietary treatments consisted of a corn-soybean meal-based control diet and the control diet with 200 ppb chromium from chromium propionate (Table 1). Diets were fed through three 4-wk dietary phases (d 0 to 28, d 28 to 56, and d 56 to 84). On d 84, pigs fed the control or chromium treatment were allotted to a fourth dietary phase containing either 0 or 9 g/ton Paylean, resulting in a split-plot design. Pigs were weighed and feeder measurements were taken on d 0, 14, 28, 42, 56, 70, 84, 98, and 103 to determine ADG, ADFI, and F/G. On d 103, pigs were individually tattooed by pen number and transported to Swift and Co. (Worthington, MN) for the collection of carcass data on the following day.

Data were analyzed as a split-plot completely randomized design by using the PROC MIXED procedure of SAS with chromium treatment as the whole plot and Paylean treatment as the subplot.

Results

For the period from d 0 to 84, growth performance of pigs fed the control or 200 ppb chromium propionate was not different ($P > 0.85$; Tables 2 and 3).

From d 84 to 103 and overall (d 0 to 103), pigs fed diets containing Paylean had improved ($P < 0.01$) ADG and final weight. However, a chromium propionate × Paylean interaction ($P < 0.04$) was observed for ADFI and F/G from d 84 to 103 and overall (d 0 to 103) F/G. This occurred because pigs fed chromium propionate in the absence of Paylean had numerically lower ADFI and F/G than pigs fed the control diet, whereas pigs fed chromium propionate in the presence of Paylean had numerically greater ADFI and F/G than pigs fed Paylean only. Regardless, F/G of pigs fed Paylean was considerably better ($P < 0.01$) from d 84 to 103 (2.43 vs. 2.89) and overall (d 0 to 103, 2.50 vs. 2.56) than that of those not fed Paylean.

Carcass data from 500 of the pigs were available for comparison of carcass characteristics. Pigs fed Paylean had greater ($P < 0.05$) plant live weight than those not fed Paylean. Chromium propionate did not influence any of the carcass characteristics measured.

In conclusion, this experiment provides further evidence that Paylean improves late-finishing pig growth performance. However, growing and finishing pigs did not respond to the dietary inclusion of chromium from chromium propionate.

Table 1. Diet composition[1,2]

	Dietary Phase			
Ingredient, %	1 (d 0 to 28)	2 (d 28 to 56)	3 (d 56 to 84)	4[3] (d 84 to 103)
Corn	65.84	73.87	79.02	69.57
Soybean meal (46.5% CP)	29.00	21.05	15.90	25.45
Choice white grease	3.00	3.00	3.00	3.00
Monocalcium P (21% P)	0.63	0.50	0.55	0.45
Limestone	0.90	0.90	0.90	0.90
Salt	0.35	0.35	0.35	0.35
L-lysine HCl	0.10	0.15	0.15	0.15
Vitamin premix with phytase	0.08	0.08	0.05	0.05
Trace mineral premix	0.10	0.10	0.08	0.08
Total	100.00	100.00	100.00	100.00
Calculated analysis				
Standardized ileal digestible (SID) amino acids				
Lysine, %	1.00	0.84	0.72	0.95
Isoleucine:lysine ratio, %	72	70	70	69
Leucine:lysine ratio, %	154	162	173	154
Methionine:lysine ratio, %	28	29	31	28
Met & Cys:lysine ratio, %	57	59	63	57
Threonine:lysine ratio, %	62	61	62	60
Tryptophan:lysine ratio, %	20	19	19	19
Valine:lysine ratio, %	80	80	82	78
Protein, %	19.2	16.2	14.4	17.9
Total lysine, %	1.13	0.95	0.81	1.07
ME, kcal/lb	1,576	1,580	1,581	1,580
SIDlysine:ME ratio, g/Mcal	2.88	2.41	2.07	2.73
Ca, %	0.58	0.53	0.52	0.53
P, %	0.52	0.46	0.45	0.46
Available P, %	0.26	0.23	0.21	0.20

[1] Experimental control diets fed from d 0 to 103 before slaughter.
[2] Chromium propionate was added at the expense of corn in the control diets to achieve the 200 ppb chromium from chromium propionate treatment.
[3] Paylean (9 g/ton) was added at the expense of corn in the phase 4 (d 84 to 103) control diet to achieve the Paylean treatments during this phase.

Table 2. Effects of 200 ppb chromium from chromium propionate on growth performance and carcass characteristics with or without Paylean for 19-d preslaughter—interactive means[1]

	0 ppb chromium		200 ppb chromium			Probability, $P <$		
Item	0 g/ton Paylean	9 g/ton Paylean	0 g/ton Paylean	9 g/ton Paylean	SE Mean	Chromium × Paylean	Chromium	Paylean
Growth performance								
d 0 to 84								
D 0 wt, lb	67.5	---	67.7	---	0.66	---	---	---
ADG, lb	2.02	---	2.02	---	0.01	---	---	---
ADFI, lb	5.06	---	5.07	---	0.04	---	---	---
F/G	2.51	---	2.51	---	0.01	---	---	---
d 84 to 103								
D 84 wt, lb	237.5	238.6	238.2	239.6	1.81	---	---	---
ADG, lb	2.13	2.49	2.14	2.55	0.04	---	---	0.01
ADFI, lb	6.24	5.98	6.05	6.27	0.09	0.02	---	-
F/G	2.94	2.40	2.83	2.47	0.04	0.04	---	0.01
d 0 to 103								
ADG, lb	2.03	2.10	2.05	2.10	0.02	---	---	0.01
ADFI, lb	5.24	5.21	5.21	5.28	0.06	---	---	---
F/G	2.58	2.48	2.55	2.52	0.01	0.02	---	0.01
Final wt, lb	274.0	282.7	273.9	283.3	2.43	---	---	0.01
Carcass characteristics[2]								
Plant live wt, lb	271.5	278.7	268.7	279.6	3.47	---	---	0.05
HCW, lb	206.1	211.7	204.8	211.0	3.43	---	---	---
Yield, %	75.8	76.0	76.3	75.5	0.01	---	---	---
Backfat – 10th rib, in.	0.69	0.67	0.70	0.70	0.02	---	---	---
Loin depth, in.	2.46	2.50	2.38	2.55	0.06	---	---	---
Percent lean	55.6	55.2	55.2	55.8	0.62	---	---	---
Fat free lean index,%	50.3	50.6	50.1	50.4	0.24	---	---	---

[1] A total of 1,207 pigs (PIC 337 × 1050), with 25 to 28 pigs per pen and 22 pens per treatment, were used in a 103-d experiment to evaluate the growth performance of pigs fed 200 ppb chromium from chromium propionate; 11 pens per treatment from d 84 to 103 were used to evaluate feeding chromium propionate with or without Paylean (9 g/ton).

[2] Carcass data from 500 of the pigs were available for comparison of carcass characteristics.

Table 3. Effects of 200 ppb chromium from chromium propionate on growth performance and carcass characteristics with or without Paylean for 19-d preslaughter—main effects[1]

						Probability, $P <$		
	Chromium, ppb		Paylean, g/ton		SE	Chromium		
Item	0	200	0	9	Mean	× Paylean	Chromium	Paylean
Growth Performance								
d 0 to 84								
D 0 wt, lb	67.5	67.7	-	-	0.66	---	---	---
ADG, lb	2.02	2.02	-	-	0.01	---	---	---
ADFI, lb	5.06	5.07	-	-	0.04	---	---	---
F/G	2.51	2.51	-	-	0.01	---	---	---
d 84 to 103								
D 84 wt, lb	238.0	238.9	237.8	239.1	1.81	---	---	---
ADG, lb	2.31	2.34	2.13	2.52	0.04	---	---	0.01
ADFI, lb	6.11	6.16	6.15	6.12	0.09	0.02	---	---
F/G	2.67	2.65	2.89	2.43	0.04	0.04	---	0.01
d 0 to 103								
ADG, lb	2.06	2.07	2.04	2.10	0.02	---	---	0.01
ADFI, lb	5.23	5.24	5.22	5.25	0.06	---	---	---
F/G	2.53	2.53	2.56	2.50	0.01	0.02	---	0.01
Final wt, lb	278.3	278.6	273.9	283.0	2.43	---	---	0.01
Carcass characteristics[2]								
Plant live wt, lb	275.1	274.1	270.1	279.1	3.47	---	---	0.05
HCW, lb	208.9	207.9	205.5	211.3	3.43	---	---	---
Yield, %	75.9	75.9	76.0	75.8	0.01	---	---	---
Backfat – 10th rib, in.	0.68	0.70	0.70	0.68	0.02	---	---	---
Loin depth, in.	2.48	2.47	2.42	2.52	0.06	---	---	---
Percent lean	55.4	55.5	55.4	55.5	0.62	---	---	---
Fat free lean index, %	50.4	50.2	50.2	50.5	0.24	---	---	---

[1] A total of 1,207 pigs (PIC 337 × 1050), with 25 to 28 pigs per pen and 22 pens per treatment, were used in a 103-d experiment to evaluate the growth performance of pigs fed 200 ppb chromium from chromium propionate; 11 pens per treatment from d 84 to 103 were used to evaluate feeding chromium propionate with or without Paylean (9 g/ton).

[2] Carcass data from 500 of the pigs were available for comparison of carcass characteristics.

EFFECTS OF RACTOPAMINE HCL (PAYLEAN) AND α-LIPOIC ACID ON THE GROWTH PERFORMANCE AND CARCASS CHARACTERISTICS OF FINISHING PIGS

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Summary

A total of 48 gilts (initially 211 lb) were used to evaluate the effects of ractopamine HCl and α-lipoic acid on finishing pig performance and carcass characteristics. Pigs were blocked by weight and randomly allotted to 1 of 4 dietary treatments in a 22-d experiment. Pigs were fed corn-soybean meal-based diets. Treatments were arranged as a 2 × 2 factorial with main effects of ractopamine HCl (0 or 9 g/ton) and α-lipoic acid (0 or 300 ppm). For overall growth performance (d 0 to 22), ADG tended ($P < 0.09$) to be greater for pigs fed ractopamine HCl. Although F/G improved ($P < 0.01$) for pigs fed ractopamine HCl, there was a trend ($P < 0.07$) for an interaction between ractopamine HCl and α-lipoic acid. For pigs fed diets without ractopamine HCl, added α-lipoic acid numerically improved F/G, whereas in pigs fed ractopamine HCl, added α-lipoic acid numerically worsened F/G. Average final weight tended ($P < 0.06$) to be greater for pigs fed ractopamine HCl. No other differences in growth performance were observed. For the comparison of carcass characteristics, average live weight, HCW, yield, loin eye area at the 10th rib, and standardized fat-free lean were increased ($P < 0.04$) for pigs fed ractopamine HCl. Average backfat thickness tended ($P < 0.06$) to decrease for pigs fed ractopamine HCl. Tenth-rib backfat increased ($P < 0.05$) for pigs fed α-lipoic acid, and the percent fat-free lean of pigs fed α-lipoic acid tended ($P < 0.10$) to decrease as a result. In conclusion, the growth performance and carcass characteristics of pigs fed ractopamine HCl were improved. Feeding 300 ppm of α-lipoic acid did not affect growth performance but did tend to increase carcass fat content.

Key words: carcass characteristics, finishing pigs, ractopamine HCl

Introduction

Ractopamine HCl (Paylean, Elanco Animal Health, Indianapolis, IN) is commonly fed to late-finishing pigs to improve growth rate, feed efficiency, and carcass lean. A vast amount of research and field data supports the appropriate use of this compound in feeding programs.

Alpha-lipoic acid is an antioxidant compound that has been demonstrated to reduce carcass fat in male mice and increase muscle pH values 20 min and 24 h postmortem. Similar improvements in postmortem muscle pH have been reported for pigs. This probably occurs because α-lipoic acid enhances the action of insulin, which increases the intramus-

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cular uptake of glucose that can be stored as glycogen. Thus, recent studies in pigs have demonstrated the potential of α-lipoic acid to enhance pork quality. Supplemental α-lipoic acid could potentially enhance amino acid deposition in muscle as well, resulting in improvements in the proportion and quality of lean in pork. Studies to evaluate the potential effects of supplemental α-lipoic acid on the growth performance and carcass characteristics of pigs are lacking.

Therefore, our objective was to evaluate the effects of feeding α-lipoic acid to finishing pigs for 22 d prior to slaughter on growth performance and carcass characteristics. Additionally, we hoped to determine whether an independent response to α-lipoic acid would result in an additive or synergistic benefit to ractopamine HCl.

Procedures

Procedures used in this experiment were approved by the Kansas State University (KSU) Institutional Animal Care and Use Committee. The project was conducted at the KSU 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 per pig. Each pen was equipped with a dry self-feeder and 1 nipple waterer, providing ad libitum access to feed and water. The facility was a mechanically ventilated room with a pull-plug manure storage pit.

Forty-eight gilts (PIC TR4 × C22) averaging 211 lb were used in this study. Pigs were blocked by weight and randomly allotted to 1 of 4 dietary treatments. There were 2 pigs per pen and 6 pens per treatment. Experimental diets were fed in meal form with 9 g/ton ractopamine HCl, 300 ppm α-lipoic acid, or both added to a control diet at the expense of corn starch to achieve the dietary treatments (Table 1). This provided a 2 × 2 factorial arrangement of treatments. Pigs and feeders were weighed on d 0, 7, 14, and 22 to determine the growth performance criteria of ADG, ADFI, and F/G.

Table 1. Diet composition[1,2]

Ingredient	%
Corn	72.17
Soybean meal (46.5% CP)	25.22
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
Corn starch	0.65
Total	100.00
Calculated analysis	
Standardized ileal digestible amino acids	
Lysine, %	0.95
Isoleucine:lysine ratio, %	70
Leucine:lysine ratio, %	156
Methionine:lysine ratio, %	28
Met & Cys:lysine ratio, %	57
Threonine:lysine ratio, %	61
Tryptophan:lysine ratio, %	19
Valine:lysine ratio, %	79
Lysine:ME ratio, g/Mcal	2.84
CP, %	18.0
Total lysine, %	1.07
ME, kcal/lb	1,519
Ca, %	0.51
P, %	0.47
Available P, %	0.16

[1] Experimental diets fed for 22 d before slaughter.
[2] 0.05% Paylean (ractopamine HCL), 0.60% of a 5% α-lipoic acid premix containing wheat-midds, or their combination replaced corn starch in the control diet to achieve the dietary treatments.

On d 23, 1 pig per pen was transported to the KSU meats lab for humane slaughter and collection of carcass data. Hot carcass weights were collected immediately after evisceration. First-rib, tenth-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.

Data were analyzed as a randomized complete block design by using the PROC MIXED procedure of SAS with pen as the ex-

perimental unit. Least squares means were used to determine the differences and possible interactions among treatments.

Results and Discussion

For overall growth performance (d 0 to 22), ADG tended ($P < 0.09$) to be greater for pigs fed ractopamine HCl (Tables 2 and 3). Although F/G improved ($P < 0.01$) for pigs fed ractopamine HCl, there was a trend ($P < 0.07$) for an interaction between ractopamine HCl and α-lipoic acid. Pigs fed the α-lipoic acid diet without ractopamine HCl had numerically better F/G than pigs fed the control, but pigs fed α-lipoic acid with ractopamine HCl had numerically poorer F/G than pigs fed ractopamine HCl only. Average final weight tended ($P < 0.06$) to be greater for pigs fed ractopamine HCl. No other differences in growth performance were observed.

For the comparison of carcass characteristics, average live weight, HCW, yield, loin eye area at the 10th rib, and standardized fat-free lean were increased ($P < 0.04$) for pigs fed ractopamine HCl. Average backfat depth tended ($P < 0.06$) to decrease for pigs fed ractopamine HCl. Tenth-rib backfat increased ($P < 0.05$) for pigs fed α-lipoic acid, and the percent fat-free lean of pigs fed α-lipoic acid tended ($P < 0.10$) to decrease as a result.

In conclusion, the improved performance and carcass characteristics observed for pigs fed ractopamine HCl agree with previous research. Feeding 300 ppm of α-lipoic acid did not affect growth performance but did tend to increase carcass fat content.

Table 2. Growth performance and carcass characteristics of pigs fed ractopamine HCl (Paylean) and α-lipoic acid—interactive means[1]

	0 g/ton Paylean		9 g/ton Paylean			Probability, $P <$		
Item	0 ppm α-lipoic acid	300 ppm α-lipoic acid	0 ppm α-lipoic acid	300 ppm α-lipoic acid	SE Mean	Paylean × α-Lipoic acid	Paylean	α-Lipoic acid
Growth performance, d 0 to 22								
Initial wt, lb	211	211	211	211	3.00	---	---	---
ADG, lb	1.99	2.22	2.48	2.35	0.16	---	0.09	---
ADFI, lb	5.61	6.08	5.89	5.81	0.31	---	---	---
F/G	2.84	2.70	2.33	2.52	0.10	0.07	0.01	---
Final wt, lb	256	261	269	264	4.46	---	0.06	---
Carcass characteristics								
Live wt, lb	255	260	265	266	3.99	---	0.04	---
HCW, lb	179	184	190	194	2.94	---	0.01	---
Yield, %	70.4	70.8	71.7	72.9	0.64	---	0.02	---
Average backfat thickness, in.	0.86	0.89	0.72	0.83	0.05	---	0.06	---
10th rib fat depth, in.	0.57	0.73	0.50	0.61	0.06	---	---	0.05
Loin eye area, in.^{2}	7.58	7.28	8.32	8.30	0.35	---	0.03	---
Standardized fat-free lean, lb	102	100	111	110	1.96	---	0.01	---
Fat-free lean index, %	57.1	54.4	58.5	57.0	1.15	---	---	0.10

[1] A total of 48 gilts (PIC TR4 × C22), with 2 pigs per pen and 2 pens per treatment, were used for comparing growth performance. Carcass data were obtained from 1 pig per pen for the determination of carcass characteristics.

Table 3. Growth performance and carcass characteristics of pigs fed ractopamine HCl (Paylean) and α-lipoic acid—main effects[1]

	Paylean, g/ton		α-lipoic acid, ppm			Probability *P* <		
Item	0	9	0	300	SE Mean	Paylean × α-Lipoic acid	Paylean	α-Lipoic acid
Growth performance, d 0 to 22								
Initial wt, lb	211	211	211	211	3.00	---	---	---
ADG, lb	2.11	2.42	2.24	2.29	0.16	---	0.09	---
ADFI, lb	5.85	5.85	5.75	5.95	0.31	---	---	---
F/G	2.77	2.43	2.59	2.61	0.10	0.07	0.01	---
Final wt, lb	259	267	263	263	4.46	---	0.06	---
Carcass characteristics								
Live wt, lb	258	266	260	263	3.99	---	0.04	---
HCW, lb	182	192	185	189	2.94	---	0.01	---
Yield, %	70.6	72.3	71.1	71.9	0.64	---	0.02	---
Average backfat thickness, in.	0.88	0.78	0.79	0.86	0.05	---	0.06	---
10th rib fat depth, in.	0.65	0.56	0.54	0.67	0.06	---	---	0.05
Loin eye area, in.^{2}	7.43	8.31	7.95	7.79	0.35	---	0.03	---
Standardized fat-free lean, lb	101	111	107	105	1.96	---	0.01	---
Fat-free lean index, %	55.8	57.8	57.8	55.7	1.15	---	---	0.10

[1] A total of 48 gilts (PIC TR4 × C22), with 2 pigs per pen and 2 pens per treatment, were used for comparing growth performance. Carcass data were obtained from 1 pig per pen for the determination of carcass characteristics.

EFFECTS OF GLYCEROL AND RACTOPAMINE HCL (PAYLEAN) ON GROWTH PERFORMANCE, CARCASS CHARACTERISTICS, AND LOIN QUALITY OF FINISHING PIGS[1,2]

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Summary

A total of 1,054 barrows and gilts (PIC, initially 207.8 lb) were used in a 28-d study to determine the influence of glycerol and ractopamine HCl (Paylean) on growing-finishing pig performance, carcass characteristics, and loin quality. The experiment was conducted in a commercial swine research facility in southwest Minnesota. 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 with main effects of glycerol (0 or 5%) and ractopamine HCl (0 or 6.75 g/ton). Overall (d 0 to 28), there were no glycerol × ractopamine HCl interactions ($P > 0.10$) observed for growth performance. Pigs fed dietary glycerol had improved ($P < 0.04$) F/G, but ADG and ADFI ($P > 0.40$) were not affected. Pigs fed diets with added ractopamine HCl had improved ($P < 0.01$) ADG and F/G with a tendency ($P > 0.08$) for lower ADFI than pigs fed diets with no ractopamine HCl. For carcass characteristics, there were glycerol × ractopamine HCl interactions observed ($P < 0.05$) for percent yield and fat free lean index (FFLI). Adding either ractopamine HCl or glycerol to the control diet increased yield and FFLI; however, there were no additive effects when the combination of glycerol and ractopamine HCl was fed. Pigs fed ractopamine HCl had increased ($P < 0.04$) HCW, yield, loin depth, and FFLI. There was a glycerol × ractopamine HCl interaction ($P < 0.01$) observed for loin chop drip loss. Loin chop drip loss was numerically improved when glycerol and ractopamine HCl were added separately to the control diet; however, loin chop drip loss numerically decreased when the combination of glycerol and ractopamine HCl was fed. Glycerol did not affect ($P > 0.22$) loin characteristics. Ractopamine HCl tended to improve ($P < 0.08$) sirloin chop a* (redness) color. Neither ractopamine HCl nor glycerol influenced iodine value of belly fat, jowl fat, or backfat. In conclusion, pigs fed 5% glycerol had improved F/G, whereas pigs fed ractopamine HCl had improved growth and carcass characteristics and a tendency for improved loin a* color.

Key words: finishing pigs, glycerol, ractopamine HCl

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Introduction

According to the National Biodiesel Board, in October 2007, there were 105 biodiesel production facilities operating and 77 facilities in the planning or construction stage in the United States. If all these facilities were operational, the estimated U.S. biodiesel production capacity would exceed 2.5 billon gal. This level of production would produce nearly 1.3 million tons of glycerol, the primary coproduct of biodiesel production. There has been much interest in utilizing crude glycerol as a feed ingredient in livestock diets. However, little is known about glycerol's nutritional value and its effect on carcass characteristics. Previous research from Europe has shown that water holding capacity is increased and the unsaturation index of carcass fat can be reduced when pigs are fed glycerol.

Ractopamine HCl (marketed as Paylean, Elanco Animal Health, Indianapolis, IN) is often fed to finishing pigs just before marketing to improve growth rate, F/G, yield, loin depth, and fat free lean index (FFLI). These improvements in growth and carcass traits are supported by a large number of studies evaluating the use of ractopamine HCl in finisher diets. The increased use of glycerol in swine diets coupled with the common practice of feeding ractopamine HCl to finishing pigs warrants evaluation of these ingredients together. Therefore, the objective of this trial was to evaluate the effect of dietary glycerol and ractopamine HCl on finishing pig performance, carcass characteristics, loin quality, and iodine value of belly fat, jowl fat, and backfat.

Procedures

Procedures used in these experiments were approved by the Kansas State University Institutional Animal Care and Use Committee. The experiment was conducted at a commercial research facility in southwest Minnesota. The facility had a totally slatted floor, and each pen was equipped with a 4-hole dry self-feeder and 1 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 7 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 with main effects of glycerol (0 or 5%) and ractopamine HCl (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 (SID) lysine:ME ratio within those treatments that included or did not include ractopamine HCl. For glycerol, the NRC (1998) ME value of corn (1,551 kcal/lb) was used in diet formulation

Pigs and feeders were weighed on d 0, 7, 14, 21, and 28 to determine the response criteria of ADG, ADFI, and F/G. 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 JBS Swift & Company processing plant (Worthington, MN), where standard carcass criteria of carcass weight, loin and backfat depth, HCW, lean percentage,

and yield were collected. Fat-free lean index was also measured by using the equation 50.767 + (0.035 × HCW) – (8.979 × backfat).

Whole loins, jowl, backfat, and belly samples were collected on 1 barrow and 1 gilt randomly chosen from each pen from the d 28 marketing group for loin quality evaluation and fatty acid analysis. Jowl, backfat, and belly samples were collected and frozen until further processing and analysis.

After slaughter and for chilling 24 h, the loins were transported and stored at the Kansas State University Meat Laboratory at 32 to 38°F. Purge loss was measured 10 d postmortem by weighing the whole loin in the packaging material, removing the loin and blotting it dry, and reweighing the loin and dried packaging material. Purge loss was then calculated by subtracting the final loin weight from the initial loin weight. The value was then divided by the initial loin weight and multiplied by 100 to determine the percentage of purge loss. Loins were fabricated into 1-in. chops and allowed to bloom for at least 1 h prior to instrumental and visual color measurement. Color and pH measurements were taken on the *longissimus dorsi* muscle at 3 sections of the loin: the second chop anterior to the blade end, the center loin immediately posterior to the end of the *spinalis dorsi* muscle, and the second chop anterior to the sirloin end. Instrumental color was measured by using a Hunter Lab mini-scan colorimeter (Hunter Associated Laboratories Inc., Reston, VA.,) and reported as L* (lightness), a* (redness), and b* (yellowness). Visual color and marbling were evaluated by using the National Pork Producers Council's color and marbling standards (NPPC, 1998). Drip loss was conducted by utilizing a single 1-in. center cut chop from each loin. Each chop was weighed and placed into a plastic bag immediately following fabrication. This chop was then placed into refrigerated storage (32 to 38°F) for 24 h then reweighed to determine the amount of purge loss accumulation for the preceding 24-hour period. Loin pH was measured by utilizing an Accumet Basic pH Meter (Fisher Scientific, Waltham, MA, with a Pinnacle Series Gel Spear Point Electrode from Nova Analytics Corporation, Woburn, MA).

Fat samples were dissected from the jowl, loin, and backfat to analyze fatty acid composition. Iodine value was calculated from the following equation according to AOCS (1998) procedures:

C16:1(0.95)+C18:1(0.86)+C18:2(1.732)+C18:3(2.616)+C20:1(0.785)+C22:1(0.723).

The fatty acids results are represented as a percentage of the total fatty acids in the sample.

Data were analyzed as a randomized complete block design by using the PROC MIXED procedure of SAS with pen as the experimental unit. Main effects and interactions between pigs fed glycerol and ractopamine HCl were tested.

Results and Discussion

Overall (d 0 to 28), there were no glycerol × ractopamine HCl interactions ($P > 0.10$) observed for growth performance (Table 2). Pigs fed dietary glycerol had improved ($P < 0.04$) F/G, but there was no effect on ($P > 0.14$) ADG or ADFI. Pigs fed diets with added ractopamine HCl had improved ($P < 0.01$) ADG and F/G and tended ($P > 0.08$) to have lower ADFI than pigs fed diets with no ractopamine HCl. For carcass characteristics, there were glycerol × ractopamine HCl interactions ($P < 0.05$) observed for percent yield and FFLI. Percent yield and FFLI were numerically improved when glycerol and ractopamine HCl were added separately to the control diet; however, no additive effects were found when the combination of glycerol and ractopamine HCl was fed. Feeding dietary glycerol did not influence ($P > 0.27$) any other carcass characteristics. Pigs fed ractopamine HCl had increased ($P < 0.04$) HCW, yield,

loin depth, and FFLI than pigs not fed ractopamine HCl.

For loin quality characteristics, there was a glycerol × ractopamine HCl interaction ($P < 0.01$) observed for loin chop drip loss (Table 3). Loin chop drip loss was numerically improved when glycerol and ractopamine HCl were added separately to the control diet; however, when the combination of glycerol and ractopamine HCl was fed, loin chop drip loss numerically decreased. Glycerol did not affect ($P > 0.22$) other loin quality characteristics. Ractopamine HCl tended to improve ($P < 0.08$) sirloin chop a* color, indicating the loin had more redness when ractopamine HCl was included in the diet.

For carcass fat quality, there tended to be a glycerol × ractopamine HCl interaction ($P < 0.07$) for total monounsaturated fatty acids at the jowl location (Table 4). Feeding dietary glycerol and ractopamine HCl did not influence ($P > 0.17$) jowl fat, belly fat, or backfat iodine value (Tables 5 and 6). Pigs fed diets with added ractopamine HCl tended to have increased ($P < 0.07$) total *trans* fatty acids at the jowl and backfat locations. Feeding dietary glycerol or ractopamine HCl did not influence ($P > 0.14$) saturated fatty acids, total polyunsaturated fatty acids, unsaturated fatty acid:saturated fatty acid, and polyunsaturated fatty acid:saturated fatty acid at the locations measured.

Because glycerol has been reported to have ME content similar to that of corn, we did not expect that adding up to 5% glycerol to the diet would influence growth performance. Thus, the improvement in F/G when glycerol was added to the diet was unexpected. The improvement in F/G was primarily due to the response to adding glycerol to the diet containing ractopamine HCl. We speculate that perhaps glycerol is a more available energy source than corn, resulting in more efficient tissue deposition than diets not containing added glycerol.

There is considerable data reporting the benefits of adding ractopamine HCl to late-finishing pig diets. These benefits include increased ADG and final BW and improved F/G in addition to increased percent yield, loin depth, and FFLI. Thus, the ractopamine HCl response in this study is consistent with previous research.

Feeding glycerol and ractopamine HCl in conjunction did improve loin chop drip loss more than feeding each ingredient separately. This finding warrants further research.

In conclusion, feeding pigs 5% glycerol improved F/G in pigs fed ractopamine HCl. As expected, pigs fed ractopamine HCl had improved growth and carcass characteristics and a tendency for improved sirloin chop a* color. Neither ractopamine HCl nor glycerol influenced iodine value at the locations measured.

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
Optiphos 2000[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	31.37	30.54	30.36	29.71
Met & Cys:lysine	64.71	62.99	60.53	59.20
Threonine:lysine	64.23	63.67	64.27	63.84
Tryptophan:lysine	18.70	18.64	19.27	19.22
SID lysine:calorie ratio, g/Mcal of ME	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, %	14.27	14.00	17.32	17.05
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] Provided per pound of diet: 227 phytase units of phytase.
[3] Standardized ileal digestible.
[4] Includes expected P release of .07% from added phytase.

Table 2. Influence of crude glycerol and ractopamine HCl on finishing pig performance and carcass 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
d 0 to 28								
ADG, lb	1.93	1.93	2.15	2.22	0.05	0.38	0.01	0.40
ADFI, lb	6.50	6.46	6.35	6.27	0.12	0.82	0.08	0.51
F/G	3.37	3.35	2.96	2.82	0.05	0.10	0.01	0.04
Final wt, lb	256.4	256.2	261.7	263.7	2.63	0.68	0.02	0.72
HCW, lb[2]	189.3	192.0	199.5	199.2	1.95	0.46	0.01	0.53
Yield, %	74.63	75.85	76.26	75.91	0.37	0.05	0.04	0.27
Backfat depth, in.	0.71	0.70	0.67	0.70	0.01	0.06	0.17	0.34
Loin depth, in.	2.27	2.31	2.41	2.42	0.04	0.68	0.01	0.56
FFLI, %[3]	49.47	49.67	50.25	49.87	0.14	0.05	0.01	0.53
Lean, %	54.59	54.62	54.99	55.05	0.42	0.96	0.33	0.93

[1] A total of 1,054 pigs (initially BW, 207.8 lb) were used in a 28-d experiment with 25 to 27 pigs per pen with 10 pens per treatment.
[2] A total of 854 pigs were marketed on d 28 with 19 to 23 pigs per pen.
[3] Fat-free lean index.

Table 3. Influence of 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
Loin purge loss, %	0.13	0.15	0.16	0.15	0.02	0.65	0.46	0.77
Loin chop drip loss, %	1.89	2.61	2.47	2.03	0.18	0.01	0.99	0.45
NPPC marbling standard score[2]	1.50	1.70	1.45	1.42	0.12	0.33	0.17	0.48
NPPC color standard score[3]	3.10	3.13	3.15	3.36	0.09	0.34	0.14	0.22
Loin chop pH								
Blade	5.89	5.92	5.89	5.85	0.05	0.41	0.41	0.90
Middle	5.70	5.67	5.66	5.67	0.03	0.52	0.60	0.65
Sirloin	5.70	5.71	5.69	5.68	0.02	0.76	0.40	0.93
Center cut chop color								
L*[4]	55.45	56.03	55.54	54.54	0.62	0.15	0.20	0.70
a*[5]	9.54	9.73	10.20	9.66	0.34	0.28	0.37	0.60
b*[6]	14.41	14.56	14.72	14.16	0.39	0.38	0.90	0.62
Sirloin chop color								
L*	58.78	59.51	59.29	58.10	0.56	0.10	0.43	0.68
a*	9.32	9.04	9.78	9.71	0.31	0.74	0.08	0.59
b*	14.59	14.69	14.84	14.44	0.38	0.51	0.99	0.69

[1] A total of 80 loins were used in the experiment with 2 loins per pen and 10 pens per treatment.
[2] 1 = pale pinkish grapy to white, 2 = grayish pink, 3 = reddish pink, 4 = dark reddish pink, 5 = purplish red, 6 = dark purplish red (NPPC, 1999).
[3] Visual scale, which approximates the percentage of intramuscular fat content (NPPC, 1999).
[4] L*, 0 = black and 100 = perfect white.
[5] Positive a* indicates increasing redness.
[6] Positive b* indicates increasing yellowness.

Table 4. Influence of glycerol and ractopamine HCl on finishing pig jowl fat quality[1,2]

	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
Myristic acid (14:0), %	1.35	1.38	1.39	1.34	0.03	0.18	0.82	0.76
Palmitic acid (16:0), %	21.90	22.00	21.89	21.52	0.25	0.36	0.33	0.58
Palmitoleic acid (16:1), %	2.73	2.76	2.87	2.72	0.08	0.26	0.57	0.49
Margaric acid (17:0), %	0.48	0.51	0.48	0.49	0.02	0.65	0.62	0.24
Stearic acid (18:0), %	9.24	9.48	9.08	9.08	0.22	0.57	0.22	0.59
Oleic acid (18:1c9), %	41.98	41.96	41.86	41.89	0.30	0.94	0.75	0.99
Vaccenic acid (18:1n7), %	3.64	3.74	3.79	3.63	0.12	0.11	0.78	0.68
Linoleic acid (18:2n6), %	14.38	13.97	14.37	15.03	0.40	0.19	0.20	0.75
α-linolenic acid (18:3n3), %	0.62	0.60	0.62	0.64	0.02	0.28	0.15	0.93
γ-linolenic acid (18:3n6), %	0.62	0.60	0.62	0.64	0.02	0.28	0.15	0.93
Arachidic acid (20:0), %	0.20	0.20	0.20	0.18	0.01	0.29	0.15	0.66
Eicosadienoic acid (20:2), %	0.85	0.83	0.86	0.88	0.02	0.47	0.20	0.89
Arachidonic acid (20:4n6), %	0.11	0.10	0.11	0.11	0.01	1.00	0.29	0.35
Other fatty acids, %	2.45	2.39	2.40	2.43	0.05	0.32	0.97	0.74
Total SFA, %[3]	33.57	33.99	33.44	33.03	0.43	0.34	0.21	1.00
Total MUFA, %[4]	50.03	50.11	50.16	49.87	0.35	0.61	0.88	0.76
Total PUFA, %[5]	16.39	15.91	16.40	17.10	0.44	0.18	0.18	0.80
Total *trans* fatty acids, %[6]	41.03	40.95	42.16	42.81	0.80	0.65	0.07	0.73
UFA:SFA ratio[7]	1.98	1.95	1.99	2.03	0.04	0.33	0.21	0.98
PUFA:SFA ratio[8]	0.49	0.47	0.49	0.52	0.02	0.21	0.18	0.81
Iodine value, g/100 g[9]	69.6	68.9	69.7	70.7	0.7	0.22	0.17	0.87

[1] A total of 1,054 pigs (initially BW, 207.8 lb) were used in a 28-d experiment with 25 to 27 pigs per pen and 10 pens per treatment.
[2] A total of 854 pigs were marketed on d 28 with 19 to 23 pigs 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).
[3] Total saturated fatty acids (SFA) = {[C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]}, where the brackets indicate concentration.
[4] Total monounsaturated fatty acids (MUFA) = {[C14:1] + [C16:1] + [C18:1c9] + [C18:1n7] + [C20:1] + [C24:1]}, where the brackets indicate concentration.
[5] Total polyunsaturated fatty acids (PUFA) = {[C18:2n6] + [C18:3n3] + [C18:3n6] + [C20:2] + [C20:4n6]}, where the brackets indicate concentration.
[6] Total *trans* fatty acids = {[C18:1t] + [C18:2t] + [C18:3t]}, where the brackets indicate concentration.
[7] Unsaturated fatty acids (UFA):SFA ratio = [Total MUFA + Total PUFA] / Total SFA.
[8] PUFA:SFA ratio = Total PUFA / Total SFA.
[9] Calculated as IV = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 +[C18:3] × 2.616 + [C20:1] × 0.785+[C22:1] × 0.723, where the brackets indicate concentration (AOCS, 1998).

Table 5. Influence of glycerol and ractopamine HCl on finishing pig belly fat quality[1,2]

	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
Myristic acid (14:0), %	1.29	1.30	1.32	1.30	0.04	0.65	0.82	0.89
Palmitic acid (16:0), %	22.73	22.16	22.53	22.26	0.50	0.72	0.90	0.33
Palmitoleic acid (16:1), %	1.99	2.27	2.30	2.24	0.11	0.07	0.14	0.22
Margaric acid (17:0), %	0.61	0.55	0.46	0.58	0.04	0.03	0.10	0.35
Stearic acid (18:0), %	11.45	10.43	10.47	10.74	0.58	0.20	0.49	0.45
Oleic acid (18:1c9), %	38.63	39.63	39.60	39.24	0.65	0.22	0.58	0.55
Vaccenic acid (18:1n7), %	2.70	3.11	3.18	3.04	0.14	0.01	0.02	0.11
Linoleic acid (18:2n6), %	16.29	16.27	15.99	16.35	0.80	0.78	0.88	0.80
α-linolenic acid (18:3n3), %	0.67	0.68	0.66	0.66	0.03	0.91	0.65	0.95
γ-linolenic acid (18:3n6), %	0.67	0.68	0.66	0.66	0.03	0.91	0.65	0.95
Arachidic acid (20:0), %	0.26	0.23	0.23	0.22	0.02	0.70	0.19	0.22
Eicosadienoic acid (20:2), %	0.88	0.89	0.87	0.90	0.04	0.87	0.98	0.61
Arachidonic acid (20:4n6), %	0.10	0.09	0.11	0.11	0.02	0.80	0.33	0.63
Other fatty acids, %	2.29	2.31	2.29	2.31	0.06	0.90	0.96	0.58
Total SFA, %[3]	36.72	35.11	35.40	35.49	1.05	0.34	0.60	0.40
Total MUFA, %[4]	44.85	46.56	46.59	46.06	0.77	0.07	0.29	0.32
Total PUFA, %[5]	18.34	18.34	18.00	18.45	0.86	0.76	0.88	0.76
Total *trans* fatty acids, %[6]	44.56	45.13	48.01	44.94	1.67	0.21	0.26	0.38
UFA:SFA ratio[7]	1.73	1.85	1.83	1.83	0.08	0.37	0.60	0.39
PUFA:SFA ratio[8]	0.50	0.53	0.51	0.52	0.04	0.84	0.97	0.57
Iodine value, g/100 g[9]	68.6	70.0	69.6	69.7	1.49	0.62	0.80	0.54

[1] A total of 1,054 pigs (initially BW, 207.8 lb) were used in a 28-d experiment with 25 to 27 pigs per pen and 10 pens per treatment.
[2] A total of 854 pigs were marketed on d 28 with 19 to 23 pigs 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).
[3] Total saturated fatty acids (SFA) = {[C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]}, where the brackets indicate concentration.
[4] Total monounsaturated fatty acids (MUFA)= {[C14:1] + [C16:1] + [C18:1c9] + [C18:1n7] + [C20:1] + [C24:1]}, where the brackets indicate concentration.
[5] Total polyunsaturated fatty acids (PUFA) = {[C18:2n6] + [C18:3n3] + [C18:3n6] + [C20:2] + [C20:4n6]}, where the brackets indicate concentration.
[6] Total *trans* fatty acids = {[C18:1t] + [C18:2t] + [C18:3t]}, where the brackets indicate concentration.
[7] Unsaturated fatty acids (UFA):SFA ratio = [Total MUFA + Total PUFA] / Total SFA.
[8] PUFA:SFA ratio = Total PUFA / Total SFA.
[9] Calculated as IV = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 +[C18:3] × 2.616 + [C20:1] × 0.785+[C22:1] × 0.723, where the brackets indicate concentration (AOCS, 1998).

Table 6. Influence of glycerol and ractopamine HCl on finishing pig backfat quality[1,2]

	Ractopamine HCl, g/ton							
	0 g/ton		6.75 g/ton			Probability, *P* <		
Item	0% glycerol	5% glycerol	0% glycerol	5% glycerol	SE	Ractopamine HCl × Glycerol	Ractopamine HCl	Glycerol
Myristic acid (14:0), %	1.30	1.37	1.35	1.31	0.03	0.09	0.83	0.67
Palmitic acid (16:0), %	22.83	23.21	23.31	23.08	0.28	0.28	0.52	0.79
Palmitoleic acid (16:1), %	2.08	2.22	2.25	2.11	0.10	0.12	0.75	0.94
Margaric acid (17:0), %	0.60	0.59	0.56	0.58	0.03	0.57	0.30	0.92
Stearic acid (18:0), %	11.36	11.56	11.44	11.71	0.27	0.91	0.68	0.40
Oleic acid (18:1c9), %	38.05	38.05	38.24	38.04	0.33	0.77	0.79	0.76
Vaccenic acid (18:1n7), %	2.85	2.95	2.99	2.86	0.13	0.17	0.79	0.83
Linoleic acid (18:2n6), %	16.73	15.97	15.85	16.37	0.43	0.14	0.58	0.79
α-linolenic acid (18:3n3), %	0.68	0.66	0.64	0.66	0.02	0.35	0.35	0.85
γ-linolenic acid (18:3n6), %	0.68	0.66	0.64	0.66	0.02	0.35	0.35	0.85
Arachidic acid (20:0), %	0.24	0.26	0.24	0.22	0.01	0.09	0.11	0.83
Eicosadienoic acid (20:2), %	0.84	0.79	0.81	0.80	0.02	0.51	0.68	0.13
Arachidonic acid (20:4n6), %	0.11	0.09	0.10	0.09	0.01	0.51	0.29	0.12
Other fatty acids, %	2.26	2.20	2.16	2.11	0.04	0.89	0.02	0.16
Total SFA, %[3]	36.75	37.45	37.30	37.27	0.48	0.45	0.69	0.48
Total MUFA, %[4]	44.49	44.64	44.94	44.41	0.42	0.43	0.80	0.67
Total PUFA, %[5]	18.76	17.91	17.77	18.32	0.46	0.14	0.53	0.74
Total *trans* fatty acids, %[6]	42.45	41.90	44.43	42.59	0.69	0.36	0.06	0.10
UFA:SFA ratio[7]	1.73	1.67	1.68	1.69	0.03	0.41	0.70	0.48
PUFA:SFA ratio[8]	0.51	0.48	0.48	0.49	0.02	0.17	0.54	0.66
Iodine value, g/100 g[9]	69.0	67.8	67.8	68.3	0.70	0.23	0.61	0.64

[1] A total of 1,054 pigs (initially BW, 207.8 lb) were used in a 28-d experiment with 25 to 27 pigs per pen and 10 pens per treatment.

[2] A total of 854 pigs were marketed on d 28 with 19 to 23 pigs 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).

[3] Total saturated fatty acids (SFA) = {[C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]}, where the brackets indicate concentration.

[4] Total monounsaturated fatty acids (MUFA) = {[C14:1] + [C16:1] + [C18:1c9] + [C18:1n7] + [C20:1] + [C24:1]}, where the brackets indicate concentration.

[5] Total polyunsaturated fatty acids (PUFA) = {[C18:2n6] + [C18:3n3] + [C18:3n6] + [C20:2] + [C20:4n6]}, where the brackets indicate concentration.

[6] Total *trans* fatty acids = {[C18:1t] + [C18:2t] + [C18:3t]}, where the brackets indicate concentration.

[7] Unsaturated fatty acids (UFA):SFA ratio = [Total MUFA + Total PUFA] / Total SFA.

[8] PUFA:SFA ratio = Total PUFA / Total SFA.

[9] Calculated as IV= [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 +[C18:3] × 2.616 + [C20:1] × 0.785+[C22:1] × 0.723, where the brackets indicate concentration (AOCS, 1998).

INDEX OF KEY WORDS

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