FOREWORD

It is with great pleasure that we present to you the 2007 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.

Editors, 2007 Swine Day Report of Progress,

Bob Goodband Mike Tokach Steve Dritz Joel DeRouchey

ABBREVIATIONS USED IN THIS REPORT

ADG	=	average daily gain	Gal	=	gallon(s)	mo	=	month(s)
ADFI	=	average daily feed intake	GE	=	gross energy	Fg	=	microgram(s)
avg	=	average	h	=	hour(s)		=	.001 mg
BW	=	body weight	in	=	inch(es)	N	=	nitrogen
cm	=	centimeter(s)	IU	=	international unit(s)	ng	=	nanogram(s)
CP	=	crude protein	kg	=	kilogram(s)		=	.001 Fg
CV	=	coefficient of variation	Kcal	=	kilocalorie(s)	no.	=	number
cwt	=	100 lb	lb	=	pound(s)	ppm	=	parts per million
d	=	day(s)	Mcal	=	megacalorie(s)	sec	=	second(s)
DM	=	dry matter	ME	=	metabolizable energy	SEW	=	segregated early weaning
EF	=	Fahrenheit	mEq	=	milliequivalent(s)			
F/G	=	feed efficiency	min	=	minute(s)	wk	=	week(s)
ft	=	foot(feet)	mg	=	milligram(s)	wt	=	weight(s)
ft^2	=	square foot(feet)	ml	=	cc (cubic centimeters)	yr	=	year(s)
g	=	gram(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 lb 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 lb of premix contains vitamin A, 2,000,000 IU; vitamin D_3, 300,000 IU; vitamin E, 8,000 IU; menadione, 800 mg; riboflavin, 1,500 mg; pantothenic acid, 5,000 mg; niacin, 9,000 mg; and vitamin B_{12}, 7 mg.

Sow add pack: each lb of premix contains choline, 100,000 mg; biotin, 40 mg; folic acid, 300 mg; and pyridoxine, 900 mg.

NOTICE

Trade names are used to identify products. No endorsement is intended, nor is any criticism implied of similar products not named.

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.

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Growing-Finishing Management

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BIOLOGICAL VARIABILITY AND CHANCES OF ERROR

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

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

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

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

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

EFFECTS OF PCV2 VACCINE ON THE GROWTH PERFORMANCE OF PIGS AND MORTALITY RATE IN A PCV2-POSITIVE COMMERCIAL SWINE HERD

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Summary

A total of 1,470 pigs were used to study a commercial sow herd with a history of Porcine Circovirus Disease (PCVD). The objective was to evaluate the effect of two commercially available Porcine Circovirus Type 2 (PCV2) vaccines on growth and mortality rates. The first vaccine was administered one week after weaning (1-dose) while the second was administered at weaning and repeated three weeks later (2-dose). A third group of unvaccinated pigs served as a control group. Pigs were individually weighed at weaning (d 0), d 113, 143, and just prior to market. On d 113, pigs on the 2-dose treatment were heavier (P<0.05) than the control group, and the 1-dose treatment pigs were intermediate. At d 143, just prior to when the first pigs were marketed, both the 1-dose and the 2-dose pigs were heavier than the control pigs by 7.6 and 10.2 lb (P<0.05), respectively, and there were no significant differences in weights between the two vaccinated groups. However, differences in weights between the vaccinated and the control pigs were smaller at off-test compared to differences at d 143 due to a wider variability in on-test days as a result of multiple marketing days prior to end of the trial. Although there were no significant differences between the two vaccinated groups, ADG was greater (P<0.05) in all vaccinated pigs compared to non-vaccinated control pigs from d 0 to d 113, d 143, and at off-test. From d 113 to 143 and until the day they were taken off test, there were no differences in ADG, regardless of treatment. This suggests that the increase in growth rate in vaccinated pigs occurred during the period d 0 to 113. Barrows consistently exhibited greater ADG and heavier weights (P<0.05) than gilts throughout the trial. No significant differences in mortality rate between treatments were observed but both vaccinated groups had mortality rates that were 3% lower than the non-vaccinated control pigs. Based on these results, both commercial vaccines were effective in mitigating the effects of PCV2 virus and improving the growth performance of pigs in a PCV2 positive herd.

(Key words: health, PCVAD, PCV2.)

Introduction

Porcine Circovirus Diseases (PCVD) is considered a disease of major economic importance because of its ability to cause high death loss and poor growth performance. The disease is caused by Porcine Circovirus Type 2 (PCV2) and the condition is usually non-responsive to antibiotic treatment due to the viral cause. Clinical signs of the disease include poor body condition with varying degrees of muscle wasting, labored breathing, and enlarged lymph nodes. Death loss can be as high as 40% in severely affected herds. The

[1]Food Animal Health and Management Center, College of Veterinary Medicine.

PCV2 virus is very stable and resistant to inactivation. Preventing or minimizing the chances of infection requires exceptionally good husbandry practices. Although researchers have confirmed PCV2 as the main infectious agent to trigger the disease, PCVD may require other factors or agents for clinical signs and lesions to appear. Positive responses and initial field results with the use of recently developed vaccines have further confirmed the major role PCV2 plays in the development of the disease. These results have been very promising; however, most of these were reported in terms of mortality reduction and very little study has been done with the vaccine in terms of growth performance. Therefore, the objective of this trial was to compare the effects of two commercially available PCV2 vaccines (1- or 2-dose) on growth rate and mortality.

Procedures

The experiment was conducted in a 2,000-sow commercial farm in Northeastern Kansas with a history of PCVD. A total of 1,470 weaned pigs (825 barrows and 645 gilts) were ear-tagged for identification and randomly allotted to one of three treatments with gilts and barrows equally allocated to each treatment group. Pigs were placed on test from three different weaning groups and weaning group was considered a block. All pigs were free of any physical defect and in good body condition. The treatments included a negative control (non-vaccinated), 1-dose-vaccinated, and 2-dose vaccinated pigs. The 1-dose pigs were vaccinated one week after weaning while 2-dose pigs were vaccinated at weaning and repeated three weeks later. The vaccines were commercially available (1-dose: Fort Dodge, 2-dose: Intervet) and administered according to label instructions.

Each weaning group was initially housed in three separate mechanically ventilated nursery rooms and were then transferred to open-sided, naturally ventilated buildings during the growing to finishing phase. All on-test pigs were weighed on days 0, 113, and 143 and just prior to market to determine average daily gain. Weighing of pigs just prior to market was done in several batches for each group as part of the topping-out procedure of the farm. Thus, heavier pigs were weighed earlier than the rest of the pigs if they already weighed at least 270 lb before the scheduled weigh date for each block. Average daily gain was analyzed from only those pigs that were marketed. Only weight gains of pigs marketed were used for the calculation of ADG and weight gains of dead pigs were not used in the calculation for ADG.

On-test pigs that died were recorded and mortality rate was calculated as number of deaths divided by the initial number of pigs placed on test. A total of 15 pigs (5 nursery and 10 finishing) with clinical signs indicative of PCVD were submitted to the KSU Diagnostic Laboratory for necropsy and histopathological examination to confirm the presence of PCV2 infection.

Data were analyzed as a 3 × 2 factorial randomized complete block design using the MIXED procedure of SAS. The fixed effects were vaccine treatment (control, 1-dose, and 2-dose) and sex (barrow or gilt) with the random effect of wean group.

Results and Discussion

Histopathologic lesions associated with PCV2 infection were noted in pigs necropsied from each of the three weaning groups. Average weight of pigs given the 2-dose vaccine was greater ($P<0.05$) than the control pigs at mid-finishing (d 113 on-test) but not different from pigs that were given the 1-dose vaccine, which were intermediate. At day 143 on-test, no significant difference in average pig weight

was observed between the two vaccinated groups. However, the 1-dose vaccinated and 2-dose vaccinated groups were heavier by 7.6 and 10.2 lb ($P<0.05$), respectively, than the control groups. This is demonstrated by the greater number of pigs weighing 260 lb or more in the vaccinated groups compared to the control group at d 143 (Figure 1). Pigs on the 2-dose treatment had heavier ($P<0.05$) off-test weights than did non-vaccinated pigs, and 1-dose treated pigs were intermediate. However, weight differences between the vaccinated groups and the control group was noticeably smaller at off-test compared to differences at d 143. This may be explained by the fact that all groups were topped out several days before they were taken off test leaving the rest of the pigs within close weight range across all groups.

Also, the control group was on test longer compared to the two groups, which allowed them to gain more weight and close the weight gap. There were no sex by treatment interactions observed, but as expected, barrows were significantly heavier ($P<0.05$) than gilts on d 113 up to market.

There was no significant difference in ADG among the pigs from the 1-dose and 2-dose vaccinated groups from d 0 to 113, 143, or off-test. However, on all occasions both vaccinated groups exhibited greater ADG ($P<0.05$) compared to the control group. This explains the widening gap in average weights between the vaccinated groups and control group at d 113 and 143 on-test. All groups did not exhibit any significant difference in ADG from Day 113 to Day 143 and at off-test, which indicates that significant difference in growth rates occurs between d 0 and 113.

No differences in mortality rate were noted between any of the treatment groups. However, the two vaccinated groups had 3% lower mortality compared to the control group (7.7 and 7.8% vs. 11.0%, respectively). We believe that the absence of statistical difference among the treatments is due to the greater variability as a result of a respiratory disease outbreak during the trial. A clinical outbreak of bacterial disease due to *Haemophilus parasuis* was noted in two nursery groups. Additionally, an outbreak of respiratory disease due to *Actinobacillus pleuropneumoniae* was noted in one finisher group.

In conclusion, both commercial PCV2 vaccines were effective in improving the growth performance of pigs from weaning to finishing as shown by heavier weights and greater ADG of the vaccinated groups. There were no statistically significant differences between the two vaccines in terms of the parameters measured. However, pigs given the 2-dose vaccine were 2.6 lb heavier than those given the 1-dose vaccine at d 143 after weaning.

Table 1. Effects of PCV2 Vaccine on Growth Performance and Mortality Rate[1]

Item	Vaccine Main Effect			Sex Main Effect		*P*-values	
	Control	1-dose[2]	2-dose[3]	Barrows	Gilts	Vaccine	Sex
Weight, lb							
D 0	19.1	19.6	19.3	19.3	19.4	0.24	0.50
D 113	181.8[a]	188.2[ab]	190.7[b]	190.3	183.5	0.04	<0.0001
D 143	237.3[a]	244.8[b]	247.4[b]	248.7	237.6	0.03	<0.0001
Off-test	256.7[a]	261.8[ab]	265.0[b]	265.3	257.1	0.05	<0.0001
Days On-test	153.2	151.8	151.9	151.2	153.3	0.08	<0.0001
ADG, lb							
D 0 to 113	1.44[a]	1.49[b]	1.52[b]	1.51	1.45	0.02	<0.0001
D 0 to 143	1.53[a]	1.58[b]	1.60[b]	1.61	1.53	0.02	<0.0001
D 0 to Market	1.55[a]	1.60[b]	1.62[b]	1.63	1.55	0.02	<0.0001
D 113 to D 143	1.89	1.91	1.94	2.00	1.84	0.39	<0.0001
D113 to Market	1.89	1.93	1.95	2.00	1.84	0.25	<0.0001
Mortality, %	11.0	7.8	7.7	8.7	9.0	0.42	0.86

[a,b]Means within the vaccine main effect lacking a common superscript differ $P<0.05$.

[1]A total of 1,470 pigs were randomly assigned at weaning (d 0) to one of the three vaccine treatments within barrows and gilts.

[2]1-dose was the PCV2 vaccine available from Fort Dodge administered one week after weaning .

[3]2-dose was the commercially available vaccine from Intervet administered at weaning and 3 weeks later.

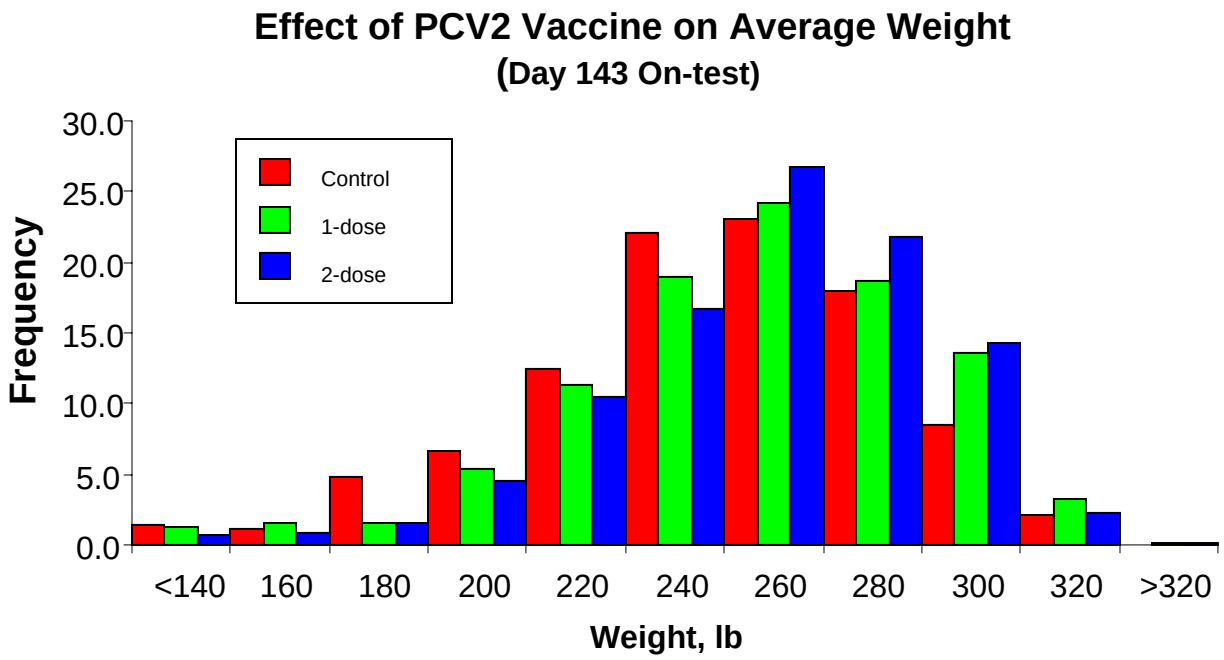

Figure 1. Comparative Weight Distribution of Treatment Groups at Day 143 on-Test.

EVALUATION OF A PCV2 VACCINE ON FINISHING PIG GROWTH PERFORMANCE AND MORTALITY RATE[1]

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Summary

A total of 2,553 pigs (PIC L337 × C22) were used in two experiments in a commercial research barn to evaluate the effects of a commercially available Porcine Circovirus Type 2 (PCV2) vaccine on finisher pig growth rate, feed efficiency, and mortality rate. Pigs in Exp. 1 were vaccinated at 9 and 11 wk of age while pigs in Exp. 2 were vaccinated earlier at 5 and 7 wk of age. In Exp. 1, 1,300 pigs were individually weighed and the vaccine treatment administered 15 and 1 d before being placed on test in the finisher. In Exp. 2 1,253 pigs were used and randomly allotted based on nursery pen average pig weight and the vaccine treatment administered 41 and 27 d before being placed on test in the finisher. Pen weights were obtained on d 0 and every 2 weeks until the end of the trial. Feed intake was recorded on a pen basis. In Exp 1, growth rate, feed intake, feed efficiency, and mortality were improved ($P<0.05$) in vaccinated pigs compared to unvaccinated pigs. In Exp. 2, there was a vaccine by sex interaction ($P<0.01$) for ADG 2. The interaction was the result of the vaccine increasing ADG to a greater extent in barrows than in gilts. The interaction for ADG resulted in a vaccine by sex interaction for market weight ($P<0.05$). Vaccinated barrows were 10.6 lb heavier compared to unvaccinated control barrows while vaccinated gilts were only 2.1 lb heavier than unvaccinated gilts at market. In Exp. 2, ADFI and F/G were numerically better and mortality rate was decreased for vaccinated pigs compared to control pigs. In both experiments, mortality rates were lower ($P<0.05$) in vaccinated pigs. Vaccinated pigs had 2.6 and 5.9% less mortality than non-vaccinated pigs in Exp. 1 and 2, respectively. The commercial PCV2 vaccine used in this study was effective at reducing mortality and increasing growth rate in finisher pigs with histopathologic lesions suggestive of Porcine Circoviral Disease (PCVD).

(Key words: health, PCVD, PCV2.)

Introduction

Porcine Circovirus Disease (PCVD) is an emerging disease in the US and KS that principally affects finishing pigs. The disease was first described in Canada 10 years ago. Porcine Circovirus 2 (PCV2), the causative agent, is very difficult to control and is present in almost every pig production facility. Clinical disease leads to high death loss, and increased cull rates in growing and finishing pigs but was not thought to greatly affect growth performance in pigs with subclinical infection.

[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.

Fortunately, three commercial PCV2 vaccines have become available in the US in the last year. A two-dose PCV2 vaccine was introduced by Intervet in 2006 but in very limited supply. Thus, very limited data exist that document its efficacy under field conditions to quantify its impact on finishing pig performance. Therefore, this trial was conducted to evaluate the effects of a 2-dose PCV2 vaccine on growth performance, feed efficiency, and mortality in a commercial finishing facility.

Procedures

General. All experimental procedures used in these studies were approved by the Kansas State University Institutional Animal Care and Use Committee.

A total of 1,300 (initially 53.5 lb) and 1,253 (initially 12.1 lb) pigs were used in Exp. 1 and 2, respectively. Only pigs that were free of any defect and in good body condition were included at the time of allotment in both experiments. In Exp. 1, pigs were individually weighed, ear tagged for identification, and randomly allotted to one of two treatments with gilts and barrows equally allocated to each treatment group. Thus, average weight was identical between vaccinated pigs and control pigs prior to vaccination. Two doses of vaccine (2 ml per dose, Intervet®) were then administered at 9 and 11 weeks of age (15 and 1 day before being placed on-test). In Exp 2, pens in the nursery were weighed and pens were randomly allotted to one of two treatments to have the same starting weight for both treatments. The vaccinated pigs were given two doses (2 ml per dose) of a commercially available vaccine (Intervet®) administered at 5 and 7 weeks of age (d 41 and 27 prior to being placed on-test). Gilts and barrows were equally allocated in separate pens. The on-test period consisted of the last 96 days in Exp 1 and 105 days in Exp 2 of the finishing period. Pigs were weighed every two weeks of the finishing phase to determine ADG, ADFI, and F/G.

Both experiments were conducted in a commercial research finishing barn in southwestern Minnesota and used similar genetics (PIC L337 × C22). Pens were 18 × 10 feet. The barns were double curtain sided, with completely slatted flooring and a deep pit for manure storage. Each pen contained one self-feeder and one cup waterer. All pigs in both treatments in each of the two experiments were fed similar diets based on corn-soybean meal in a phase feeding scheme. Ractopamine HCl (Paylean) was added to the diet from d 84 to 98 in Exp. 2. Feed was provided with a robotic feeding system to provide feed intake on an individual pen basis. During the on-test finisher phase, pen weights and inventories were obtained every two weeks. Seven days prior to the end of the test period the same number of pigs (3 in Exp. 1 and 2 in Exp. 2) were weighed and sold, similar to normal procedures in commercial production.

On-test pigs that died during the finishing phase were recorded and mortality rate was calculated as the number of deaths divided by the initial number of pigs placed on test in each pen. Samples of clinically affected pigs indicative of PCVD were necropsied and tissue samples were submitted to a diagnostic laboratory to document PCVD associated lesions and PCV2 infection.

Data were analyzed as a 2 × 2 factorial in a randomized complete block design. Analysis of variance was conducted on all data by using the GLIMIX procedure of SAS and pen was used as the experimental unit. The fixed effects were vaccine treatment (non-vaccinated control or vaccinated) and sex (barrow or gilt).

Results and Discussion

Experiment 1. Clinical signs and histopathologic lesions consistent with PCVD were noted in pigs necropsied from the experiment. There were no sex by treatment interaction for any response criteria, but as expected, barrows

were heavier ($P<0.05$) than the gilts at the end of the trial (Table 1). The barrows also exhibited greater ($P<0.05$) ADG and feed intake but poorer ($P<0.05$) feed efficiency than gilts.

Pigs were put on test in the finisher just after administration of the second dose of vaccine. Vaccinated pigs were 3.21 lb heavier than the control pigs at d 89 even though they were 1.9 lighter when placed on test. It should be noted that the timing of vaccination was at an older age than recommended. At market, vaccinated pigs were 2.9 lb heavier per pig than the pigs that were not vaccinated. The heaviest pigs in each pen (3 pigs per pen) were sold 7 days earlier than the rest of the pigs, which were weighed at the end of the trial. This explains the smaller difference in weights at the end of the trial compared to d 89. The differences in final weight were due to the faster growth rate ($P<0.05$) of the vaccinated pigs during the test period. The vaccinated pigs also had increased ($P<0.05$) feed intake and feed efficiency compared to the non-vaccinated pigs. For a similar weight gain, the vaccinated pigs would require 9.4 lb less feed than the non-vaccinated pigs.

Mortality rate was significantly reduced ($P<0.05$) in the vaccinated group compared to the non-vaccinated group. There was no difference in mortality rates between gilts and barrows although barrow mortality was numerically greater.

Experiment 2. Clinical signs and histopathologic lesions consistent with PCVD were noted in pigs necropsied from the experiment.

There was a vaccine by sex interaction ($P<0.01$) for ADG. The interaction was the result of the vaccine causing a greater increase in ADG in barrows than in gilts (Table 2). The interaction for ADG resulted in a vaccine by sex interaction for average weight on d 98 and market weight ($P<0.05$). Vaccinated barrows were 11.1 lb heavier than unvaccinated control barrows while vaccinated gilts were only 2.6 lb heavier than unvaccinated gilts at market. No significant interactions were observed for ADFI, F/G, or mortality. However, magnitude of mortality in barrows was greater than in gilts (Table 3).

There were no significant differences in feed intake and feed efficiency between vaccinated and non-vaccinated groups. Barrows, as expected, had greater feed intake but poorer feed efficiency compared to gilts ($P<0.01$), and tended to have higher mortality ($P = 0.08$) compared to gilts.

The effect of the vaccine on ADG through time indicates that growth rate differences between control and vaccinated pigs peaked between the second and sixth week on-test (Figure 1). Paylean was introduced in the diet during the d 84 to 98 period. The decrease in ADG in unvaccinated pigs preceded the observed rise in mortality. The greatest difference in cumulative mortality between vaccinated and unvaccinated pigs was noted between the sixth and twelfth week on-test (Figure 2).

In conclusion, the PCV2 vaccine used in the experiments was effective in decreasing mortality rate and improving the growth performance of pigs in a PCV2-infected herd as indicated by heavier weights of the vaccinated group. Vaccinated pigs had greater ADG in both experiments, significantly improved feed efficiency in Exp 1 and numerically improved efficiency in Exp 2.

Table 1. Effects of a PCV2 Vaccine[a] on Growth Performance and Mortality Rate (Exp 1)[b]

	Vaccine Main Effect			Sex Main Effect			*P*-values		
Item	Control	Vaccine	SE	Barrow	Gilt	SE	Vaccine	Sex	Vaccine × Sex
Weight, lb									
D 0	79.0	77.1	0.6	77.9	78.1	0.6	0.02	0.76	0.52
D 89[c]	257.8	261.0	1.2	262.4	256.5	1.2	0.06	0.001	0.69
Market[d]	259.9	262.8	1.1	264.2	258.5	1.1	0.07	0.0004	0.84
D 0 to 96									
ADG, lb	2.03	2.10	0.01	2.10	2.03	0.01	<.0001	<.0001	1.00
ADFI, lb	5.21	5.30	0.03	5.44	5.06	0.03	0.03	<.0001	0.90
F/G	2.57	2.52	0.01	2.59	2.50	0.01	0.01	<.0001	0.85
Mortality, %	5.6	3.0	0.90	4.4	3.8	0.80	0.02	0.62	0.35

[a]Commercial PCV2 vaccine (Intervet; 2 ml per dose) administered at 9 and 11 weeks of age to the vaccine treatment (15 and 1 d prior to being placed on-test in the finisher) .

[b]Total of 1,300 pigs were individually weighed and randomly assigned to one of the two treatments within barrows and gilts prior to administration of the first vaccine dose. Thus, average weight (53.5 lb) was identical between vaccinated pigs and control pigs prior to vaccination.

[c]Day 89 was the last day that all pigs remained in the pen prior to topping the heaviest 3 pigs in each pen.

[d]Market weight was the average weight of the three pigs topped 7 days before the end of the trial (d 89) and the pigs remaining at the end of the trial (d 96).

Table 2. Effects of Gender on the Efficacy of a PCV2 Vaccine[ab] (Exp. 2)

Item	Control		Vaccine			*P*-values
	Barrow	Gilt	Barrow	Gilt	SE	Vaccine×sex
Weight, lb						
D 0	57.5	57.8	56.4	56.6	0.7	0.96
D 98	250.6[d]	248.2[d]	260.4[e]	250.0[d]	2.0	0.05
Market[c]	264.4[d]	261.8[d]	275.0[e]	263.9[d]	1.0	0.04
D 0 to 105						
ADG, lb	1.97[d]	1.94[d]	2.08[e]	1.97[d]	0.01	0.01
ADFI, lb	5.10	4.82	5.25	4.82	0.07	0.27
F/G	2.59	2.48	2.52	2.45	0.03	0.68
Mortality, %	12.1	6.5	3.3	2.6	0.15	0.45

[a]Commercial PCV2 vaccine (Intervet; 2 ml per dose) administered at 5 and 7 weeks of age to the vaccine treatement (41 and 27 d prior to being placed on-test in the finisher).
[b]A total of 1,253 pigs (initially 12.1 lb) were randomly assigned by nursery pen average weight to one of the two treatments within barrows and gilts prior to administration of the first vaccine dose.
[c]Market weight was the average weight of pigs topped 7 days before the end (d 98) of the trial and the pigs remaining at the end of the trial (d 105).
[d,e]Means in the same row with different superscripts differ ($P<0.05$).

Table 3. Main Effects of a PCV2 Vaccine[a] on Growth Performance and Mortality Rate[b] (Exp. 2)

Item	Vaccine main effect			Sex main effect			*P*-values	
	Control	Vaccine	SE	Barrow	Gilt	SE	Vaccine	Sex
Weight, lb								
D 0	57.6	56.5	0.7	57.0	57.2	0.7	0.28	0.84
D 98	249.4	255.2	1.4	255.5	249.2	1.4	0.005	0.003
Market[c]	263.1	269.4	1.4	269.7	262.8	1.4	0.004	0.002
D 0 to 105								
ADG, lb	1.96	2.03	0.01	2.03	1.96	0.01	<.0001	0.0001
ADFI, lb	4.96	5.04	0.05	5.18	4.82	0.05	0.28	<.0001
F/G	2.54	2.48	0.025	2.56	2.46	0.025	0.14	0.01
Mortality, %	8.9	3.0	0.1	6.5	4.1	0.1	<.0001	0.08

[a]Commercial PCV2 vaccine (Intervet; 2 ml per dose) administered at 5 and 7 weeks of age to the vaccine treatment (41 and 27 d prior to being placed on-test in the finisher).
[b]A total of 1,253 pigs (initially 12.1 lb) were randomly assigned by nursery pen average weight to one of the two treatments within barrows and gilts prior to administration of the first vaccine dose.
[c]Market weight was the average weight of pigs topped 7 days before the end (d 98) of the trial and the pigs remaining at the end of the trial (d 105).

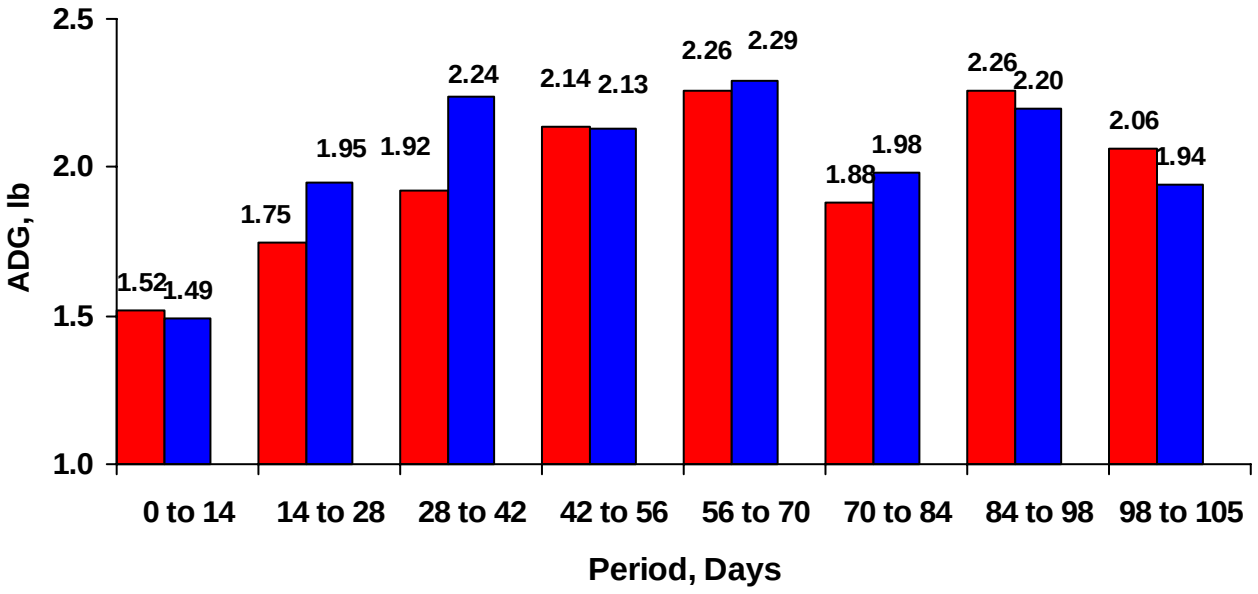

Figure 1. Growth Rate During Each Period for Unvaccinated Pigs ( ) Compared to PCV2 Vaccinated Pigs ( ) Over Time (Exp. 2; d 0 to 105).

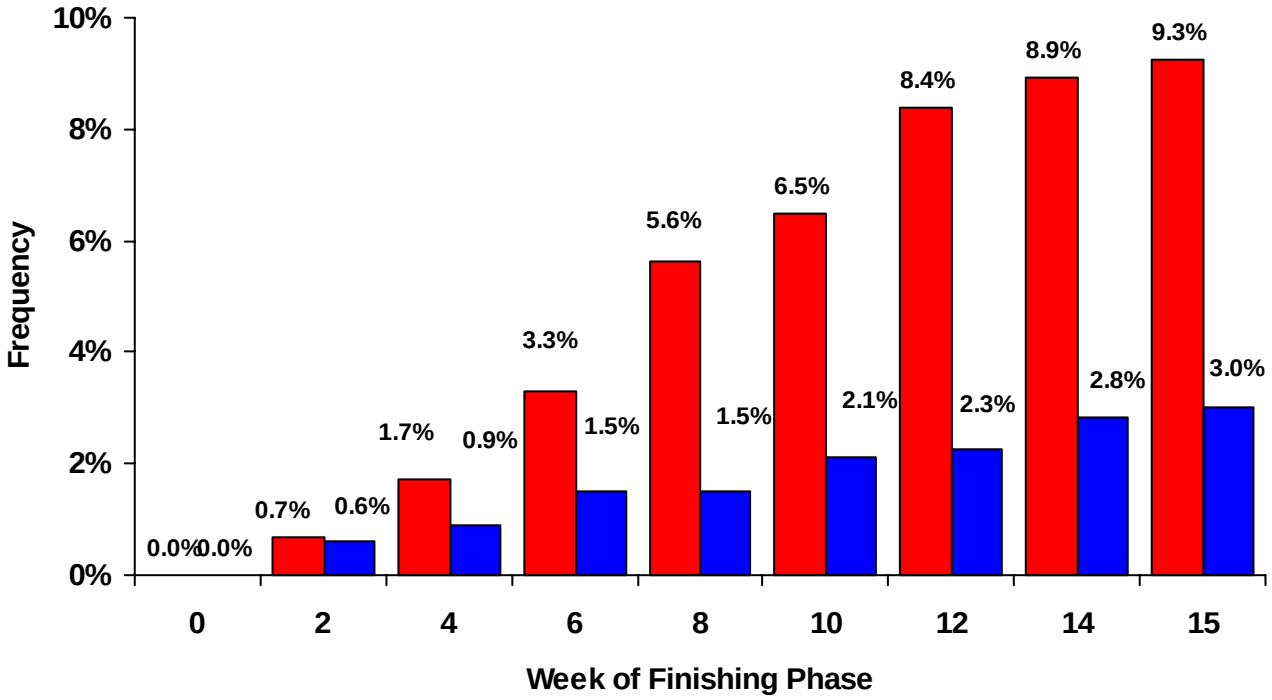

Figure 2. Effect of PCV2 Vaccination on Cumulative Mortality Rate in Non-vaccinated Pigs ( ) and Vaccinated Pigs ( ) from D 0 to 105 on-Test (Exp. 2).

OMEGA-3 FATTY ACID SUPPLEMENTATION AND THE INSULIN-LIKE GROWTH FACTOR (IGF) SYSTEM IN EARLY PREGNANCY IN PIGS

A. Brazle, T. Rathbun, B. Johnson, and D. Davis

Summary

The IGF system of growth factors, receptors and binding proteins functions from early in pregnancy. Recent evidence indicates improved embryo survival in gilts fed supplemental omega-3 fatty acids beginning before conception. Here we report effects of supplementing a corn-soybean meal diet (control) with a marine source of protected omega-3 fatty acids (PFA, 1.5% of diet) on mRNA expression for IGF-I, IGF-II, IGF Binding Protein-3 (IGFBP-3) and IGFBP-5 in the porcine gravid uterus. The PFA (Gromage™) contained equal amounts of eicosapentanoic (EPA) and docosahexanoic (DHA) acids and replaced corn in the diet beginning when gilts were approximately 170 d old (n = 13/treatment).

Gilts were artificially inseminated at approximately 205 d of age. Conceptus and endometrial samples were collected on d 11, 15, and 19 of gestation. All gilts were pregnant.

In the conceptus, message for IGF-II and IGFBP-3 increased (P<0.001) from d 15 to d 19, while there was an increase (P < 0.001) in IGF-I and IGFBP-5 from d 11 to 15 and a decrease (P<0.001) to d 19. In the endometrium, message for IGF-I was stable over the interval, but message for IGF-II and IGFBP-5 were increased by d 15 and IGFBP-3 by d 19 (P<0.01). There were trends for omega-3 fatty acid supplementation to increase endometrial IGF-II (P = 0.09) and IGFBP-5 (P = 0.12) on d 15. In the d-19 conceptus, embryonic but not extraembryonic IGF-I mRNA tended to be greater (P = 0.13) for PFA compared to control gilts. During d 11 to 19 the conceptus is elongating, attaching to the uterus, and the embryonic disc is differentiating from a homogenous tissue to form the tissues and organs of the adult. One mechanism for omega-3 fatty acid effects in early pregnancy could involve epigenetic effects on mRNA expression for the IGF and IGFBP proteins.

(Key words: reproduction, IGF, omega-3 fatty acids.)

Introduction

Published research indicates that the insulin-like growth factor system includes three hormones, IGF-I, IGF-II, and insulin, and six binding proteins, IGFBP-1 through IGFBP-6. Insulin-like growth factor (IGF)–I and –II are proteins that are important regulators of fetal and postnatal growth.

IGF-I is present in most fetal tissues as early as the embryonic stage. IGF-II is the prominent growth factor during fetal growth and development. IGFBP-3 is the most abundant binding protein, and it binds approximately 90% of the IGFs in circulation. IGFBP-5 is the most conserved binding protein across species and is an essential regulator of physiological processes.

Materials and Methods

At 150 d of age, 26 gilts (PIC 327MQ × 1050; BW = 131 kg) were exposed to boars to induce puberty. At 170 d of age, gilts were moved to gestation stalls and dietary treatments were initiated.

Gilts were randomly assigned to one of two dietary treatments. The control treatment consisted of a typical corn-soybean meal diet. The treatment called PFA was the control diet with an added protected fish source of omega-3 fatty acids. This product, Gromega™, was added at 1.5 percent of the diet in place of corn.

At approximately d 190, a 14-d Matrix® treatment was applied for estrus synchronization. After the Matrix® treatment and upon heat detection, gilts were artificially inseminated with semen from the PIC line 1050 boars. Dietary treatments continued until days eleven, fifteen, and nineteen of gestation (d 0 = onset of estrus) when gilts underwent surgery to remove embryos and tissue samples. Prior to the trial, gilts were pen fed, *ad libitum*. Once moved to gestation stalls, gilts were fed 5 lb per day for the remainder of the trial.

Thirteen gilts were allotted per treatment. All were pregnant at surgery and provided samples for mRNA measurement. Total RNA was isolated from endometrium, extraembryonic membrane, and embryos by using the RNeasy Mini Kit (Qiagen; Valencia, CA). The concentration of RNA was determined by absorbance at 260 nm. Electrophoresis of total RNA through a 1% agarose-formaldehyde gel followed by ethidium bromide staining allowed visualization of 28S and 18S ribosomal RNA (rRNA) and was used to assess the integrity of RNA. One microgram of total RNA was reverse-transcribed to produce the first-strand complementary DNA (cDNA) using TaqMan reverse transcriptase (Applied Biosystems, Foster City, CA) following the protocol recommended by the manufacturer.

Real-time quantitative-PCR was used to measure the quantity of mRNA for IGF-I, IGF-II, IGFBP-3, and IGFBP-5 and 18S rRNA in total RNA isolated from endometrium, extraembryonic membranes, and embryos. Measurement of the relative quantity of cDNA was carried out using TaqMan Universal PCR Master Mix (Applied Biosystems), 900 n*M* of the appropriate forward and reverse primers, 200 n*M* of the appropriate TaqMan detection probe, and 1 µL (0.5 µg cDNA) of the cDNA mixture. Commercially available eukaryotic 18S rRNA primers and probes were used as an endogenous control (Applied Biosystems; Genbank Accession no. X03205). Assays were preformed in an ABI Prism 7000 sequence detection system (Applied Biosystems) using thermal cycling parameters recommended by the manufacturer (50 cycles of 15 sec at 95ºC and 1 min at 60ºC). Relative expressions of mRNA of IGF-I, IGF-II, IGFBP-3, and IGFBP-5 were normalized to the 18S rRNA endogenous control and expressed in arbitrary units. Primers and probes were used for the real-time quantitative-PCR.

Data were analyzed using the MIXED procedure of SAS (SAS, 2000; SAS Inst. Inc., the Satterthwaite degrees of freedom).

Results

In the endometrium, as day of gestation increased, the mRNA for all of the IGF proteins except IGF-I increased. Within the conceptus, the mRNAs for all the IGF proteins increased ($P < 0.001$) with increasing day of gestation. Within the conceptus on d 19 of gestation, the embryo contained more ($P = 0.056$) IGF-I mRNA than the extraembryonic tissue, and there was a trend for a tissue by treatment interaction ($P = 0.13$) because PFA tended to increase IGF-I message in the embryo but not in the extraembryonic tissue. There was also a tendency ($P<0.09$) for the extraembryonic membranes to contain more IGFBP-3 message (30.2 ± 5.6) than the embryo (15.6 ± 5.6).

In the endometrium, IGF-II message was greater ($P<0.05$) on d 15 and d 19 than on d

11, and there was a tendency ($P = 0.09$) for a d × treatment interaction because PFA tended to increase IGF-II message on d 15 but not on other days. In the endometrium IGFBP-5 mRNA was greater ($P<0.05$) on d 15 and d 19 than on d 11, and a trend for a treatment × day effect ($P<0.12$) because PFA tended to increase IGFBP-5 mRNA on d 15 but decrease its message on d 19.

Discussion

There were no strong treatment effects of omega-3 fatty acid supplementation on IGF-I, IGF-II, IGFBP-3, or IGFBP-5 in the endometrium; however, tendencies for d × treatment interactions for IGF-II and IGFBP-5 occurred because PFA tended to increase their mRNAs on d 15 but not other days. Because the mRNA for these two proteins also increased on d 15 it may be that this period of transition is responsive to omega-3 fatty acid supplementation. There was also a tendency for PFA to increase IGF-I mRNA in the embryo on d 19. The dietary fatty acid fed to the sow could have impacted the fetuses' rate of transcription of mRNA stability of the IGF mRNA by increasing its half-life.

There were day effects detected in the endometrium and conceptus for all the IGF genes studied. In particular the interval from d 11 to d 15 seems to be a period when the IGF system is upregulated in these tissues. In the conceptus IGF-II and IGFBP-3 continued to increase to d 19, while IGFBP-3 showed a similar but less dramatic increase from d 15 to d 19 in the endometrium. These changes occur during a period of blastocyst elongation and attachment, embryogenesis and growth of tissues.

It is important to determine whether maternal fatty acid supplementation can modulate IGF signaling during this critical period of pregnancy. More data on protein expression and potentially including samples for the individual days from d 11 to 19 would expand our ability to evaluate this possibility. It will ultimately be important to evaluate downstream physiologies such as steroid synthesis.

NEONATAL FC RECEPTOR mRNA EXPRESSION IN GASTROINTESTINAL TISSUES FROM PIGS FED MEAL OR PELLETED DIETS WITH OR WITHOUT IRRADIATED AND NON-IRRADIATED SPRAY-DRIED ANIMAL PLASMA

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Summary

The neonatal Fc receptor (FcRn) participates in intracellular trafficking of IgG and the maintenance of circulating IgG. The relationship between the FcRn and IgG may also augment host defense immunosurveillance. The current studies evaluated FcRn mRNA from intestinal tissues in fetal pigs and FcRn mRNA in weaned pigs fed meal or pelleted diets with or without irradiated or non-irradiated spray-dried animal plasma.

In Exp. 1, fetal pigs were obtained at d 55 and 70 of gestation (n = 5 fetuses/gestational age) and total RNA was isolated from intestinal tissues for quantitative real-time PCR (qPCR) to determine mRNA for FcRn. The FcRn transcripts were observed in all samples, and greater levels of FcRn mRNA were observed in d 55 fetuses compared to d 70 fetuses.

In Exp. 2, weaned pigs were used in an 11-d growth assay to determine the effects of feeding meal and pelleted diets with irradiated or non-irradiated spray-dried animal plasma (AP 920) on FcRn expression in intestinal tissues.

Pigs were blocked by weight and randomly allotted in a 2 × 2 factorial to one of four dietary treatments. Main effects were diet form (meal or pellet) and either irradiated or non-irradiated spray-dried animal plasma. Jejunal, ileal, and cecal tissues were collected from 24 pigs at the conclusion of the growth assay. Total RNA was isolated to quantify relative mRNA expression of FcRn. The FcRn mRNA transcripts were observed in all tissues. The FcRn mRNA was more abundant ($P<0.02$) in pigs fed the non-irradiated plasma compared with the pigs fed irradiated plasma. The FcRn mRNA was more abundant ($P<0.05$) in pigs fed the meal diets compared with the pigs fed pelleted diets.

In conclusion, these data suggest that fetal and weanling pig tissues have FcRn mRNA present in the jejunal, ileal, and cecal sections of the small intestine. These data also indicate that FcRn varies with age in pigs. Diet form (meal or pellet) and irradiation of spray-dried animal plasma affects the expression of FcRn in weanling pigs.

(Key words: feed manufacturing, Fc receptor, gestation.)

Introduction

The classic role of the neonatal Fc receptor (FcRn) is to transport IgG from milk across intestinal epithelial cells in newborns. The re-

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ceptor also has been implicated in extending the half-life of circulating IgG. The neonatal Fc receptor, FcRn, is a heterologous macromolecule, structurally similar to MHC class-I, consisting of a triplet of Ig-like α chains associated with β-2-microglobulin. The neonatal Fc receptor participates in intracellular trafficking of IgG and the maintenance of circulating IgG. Evidence from the human and murine experiments suggests that the relationship between the FcRn and IgG may augment host defense immunosurveillance. FcRn was detected by immunostaining on the apical surface of human fetal small intestine and was found to be equally distributed among stomach, ileal, and colonic epithelium. However, the intestinal expression of FcRn has not been evaluated in domestic pigs. Therefore, the objective of Exp. 1 was to evaluate the presence and relative abundance of FcRn mRNA from intestinal tissue in fetal pigs. Experiment 2 further evaluated the presence and relative abundance of FcRn mRNA in intestinal tissues of weaned pigs fed meal or pelleted diets with or without irradiated or non-irradiated spray-dried animal plasma.

Materials and Methods

Experiment 1. Fetal pigs were surgically removed from three sows at d 55 and three sows at d 70 of gestation with one or two fetuses collected per sow (5 fetuses/gestational age). Intestinal tissues were collected from fetuses and total RNA was isolated for quantitative real-time PCR (qPCR) to determine expression of FcRn mRNA.

Experiment 2. A total of 48 pigs (PIC; Initial BW 5.2 kg) were used in an 11-d growth assay. Pigs were blocked by weight, and randomly allotted in a 2 × 2 factorial to one of four dietary treatments (Table 1). Main effects were diet form (meal or pellet) and either irradiated or non-irradiated spray-dried animal plasma. Twenty-four pigs were randomly selected and euthanized on d 11. An incision was made down the abdominal midline, and the ileocecal junction was immediately located. The jejunal, ileal, and cecal sections were immediately clamped off and digestive contents and section tissues samples were collected in 1.5 mL microcentrifuge tubes. All samples were snap frozen in liquid nitrogen and remained frozen at -80°C until assayed. Tissues were homogenized and genomic DNA was extracted from both tissues and contents using the MO BIO Laboratories, Inc. UltraClean™ Fecal DNA Kit (Carlsbad, California). The isolated DNA was used for quantitative real-time PCR (qPCR) to determine expression of FcRn mRNA.

Statistical analysis was performed using the MIXED procedures in SAS. Pig was used as the experimental unit.

Results and Discussion

Experiment 1. The FcRn transcripts were observed in all fetuses (Figure 1). Relative abundance of FcRn was lower in the d 70 fetuses compared to the d 55 fetuses. This is an indication that the FcRn may be more important earlier in the life of the pig, and may decrease rapidly as the pig ages. Due to the small number of observations in the study it is difficult to draw a strong conclusion about the differences in expression between d 70 and 55 fetuses. However, this data confirms the presence of the FcRn in the gastrointestinal tract of pigs.

Experiment 2. The FcRn transcripts were observed in all tissue samples (Figure 2), indicating the presence of the FcRn mRNA in pigs. The FcRn mRNA was more abundant ($P < 0.02$) in pigs fed the non-irradiated spray-dried animal plasma compared with the pigs fed irradiated animal plasma. The FcRn mRNA was more abundant ($P < 0.05$) in pigs fed the meal diets compared with the pigs fed pelleted diets. This may indicate that pigs fed the meal diet and the diet containing non-irradiated spray-dried animal plasma may have a greater need for IgG absorption for

immune status or defense mechanism. However, it is not clear if an increase in FcRn mRNA expression in pigs alters IgG status as mRNA presence is not a direct indicator of the function protein.

These data suggest that fetal and weanling pig tissues have FcRn mRNA present in the jejunal, ileal, and cecal sections of the small intestine. These data also may imply that FcRn mRNA may vary with age, but more research is required to determine if this is a true response. Diet form (meal or pellet) and irradiation of spray-dried animal plasma affects the expression of FcRn mRNA in weanling pigs. These data suggest that dietary manipulation may alter the receptor mRNA expression and may lead to changes in IgG absorption status of the pig. However, additional research would be required to determine changes in IgG status, as an indication of changes or enhanced immune function.

Table 1. Composition of Diets, As-Fed Basis (Experiment 2)

Item, %	d 0 to 11[a]
Corn	44.01
Soybean meal (46.5% CP)	19.40
Spray dried whey	20.00
Spray dried animal plasma	5.00
Menhaden fish meal	5.00
Soy oil	3.00
Monocalcium P (21% P)	0.75
Limestone	0.65
Salt	0.25
Vitamin premix	0.25
Trace mineral premix	0.15
Antibiotic[b]	0.70
Zinc oxide	0.38
L-Threonine	0.08
L-Lysine HCl	0.23
DL-Methionine	0.15
	100.00
Calculated analysis	
Total lysine, %	1.50
ME, kcal/lb	1,552
Protein, %	22.6
Ca, %	0.88
P, %	0.80
Available P, %	0.57
Lysine:calorie ratio, g/Mcal	4.38

[a]The phase 1 (d 0 to 11) diet was feed in either meal or pelleted form with irradiated spray dried animal plasma or non-irradiated spray dried animal plasma.
[b]Provided 140g Neomycin sulfate and 140g Oxytetracycline HCl per ton of feed.

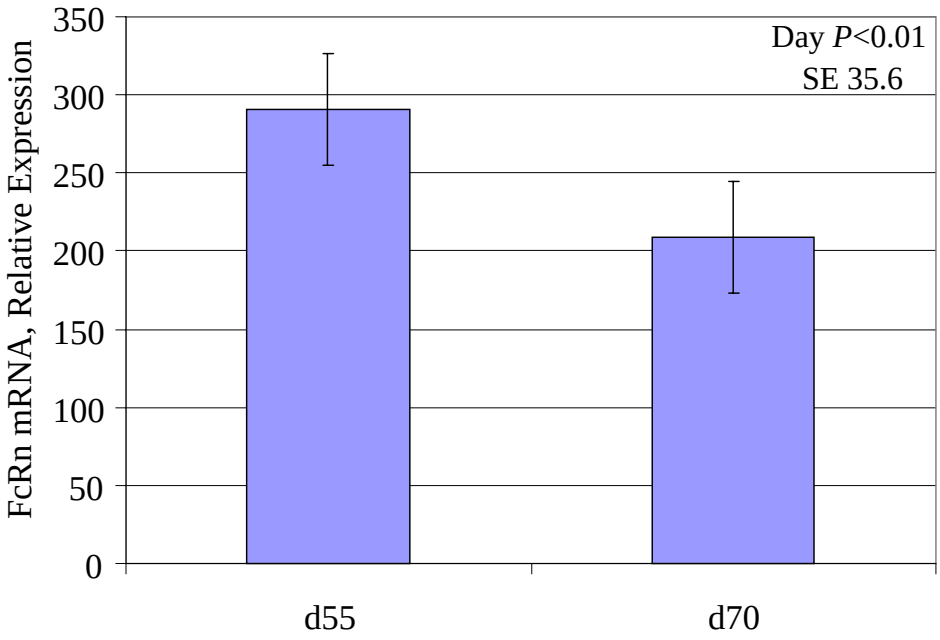

Figure 1. The Relative Expression of FcRn mRNA in Fetal Pig Intestinal Tissues Collected at D 55 and D 70 of Gestation. The Fc receptor transcripts were observed in all fetuses. Relative abundance of FcRn was lower in the d 70 fetuses compared to the d 55 fetuses.

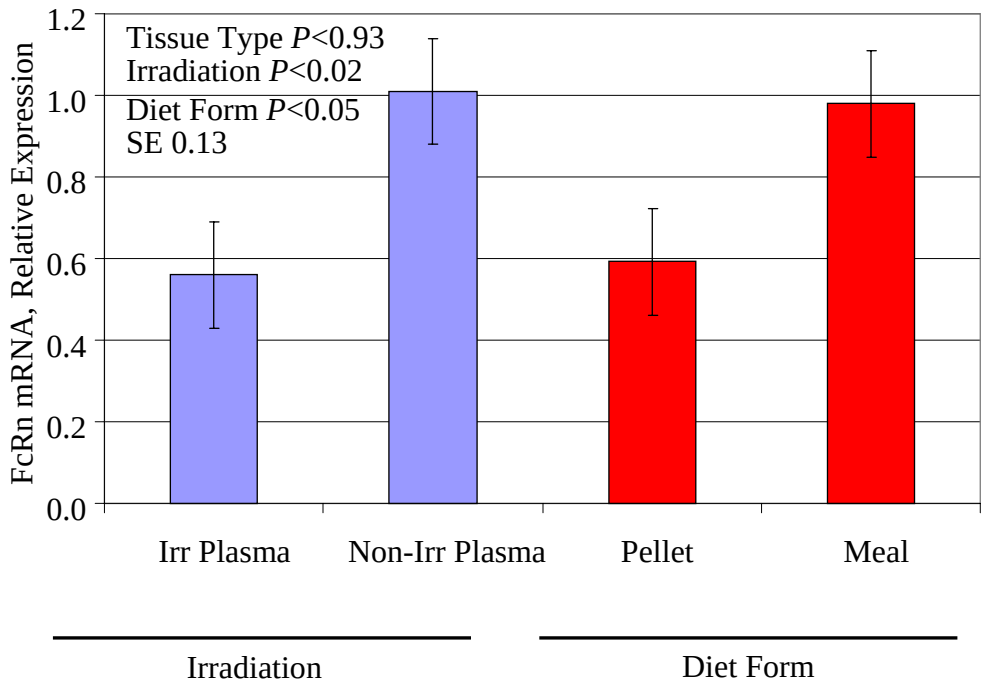

Figure 2. The Effects of Plasma Irradiation (Irr) and Diet Form on the Relative Abundance of the FcRn in Weanling Pigs. The FcRn mRNA was more abundant ($P<0.02$) in pigs fed the non-irradiated plasma compared with the pigs fed irradiated plasma. The FcRn mRNA was more abundant ($P < 0.05$) in pigs fed the meal diets compared with the pigs fed pelleted diets.

EFFECTS OF LACTATION FEED INTAKE AND CREEP FEEDING ON SOW AND PIGLET PERFORMANCE

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Summary

A total of 84 sows (PIC, Line 1050) and their litters were used to determine the effects of lactation and creep feeding on sow and piglet performance. Three groups of sows were blocked according to day of farrowing and parity and allotted to four treatments in a 2 × 2 factorial with lactation feed intake (*ad libitum* vs. restricted) and creep feeding (none vs. creep) as factors. Piglets were cross-fostered within each block to standardize litter weights and litter size (>11 pigs). A common lactation diet (1,586 kcal ME/lb, 0.97% TID Lys) was used in the study. From d 3 of lactation, *ad libitum* sows were allowed free access to feed while restricted sows were fed 25% less than those fed *ad libitum*. A pelleted creep diet (1,585 ME/lb, 1.56% TID Lys) with 1.0% chromium oxide was offered to creep-fed pigs from d 3 to weaning (d 21). Piglets were weighed individually at d 3, 7, 14, and 21. Amount of creep feed consumed was determined daily. Fecal samples from all creep-fed pigs were taken on d 7, 14, and 21 and fecal color was assessed to categorize pigs as eaters or non-eaters. Sow weight and P2 backfat thickness (6.5 cm from the midline over the last rib) were measured after farrowing and at weaning. There was no interaction between lactation feed intake and creep feeding. *Ad libitum* feeding of sows reduced BW loss (-33.0 vs. -52.9 lb; $P<0.01$), improved total ($P<0.04$) and daily ($P<0.04$) gains of litters, and increased (90 vs. 71%; $P<0.03$) the percentage of sows returning to estrus by d 14 compared with limit-fed sows. Creep feeding did not affect ($P>0.30$) sow BW and backfat loss, but increased days to estrus (5.4 vs. 4.9 d; $P<0.03$) for sows that returned to heat by 14 d. Creep feeding tended to improve litter weaning weights (132.7 vs. 124.9 lb/d; $P<0.09$) by reducing mortality rate after cross-fostering (3.9 vs. 7.3%; $P<0.06$). Total creep feed intake of litters did not differ (2.24 vs. 2.28 lb/litter; $P<0.93$) between *ad libitum* and limit-fed sows. About 60% of the creep-fed pigs were categorized as eaters. Of those identified as eaters, 23, 20, and 57% began consuming creep feeding from d 3 to 7, 7 to 14, and 14 to 21, respectively. From d 0 to 28 post-weaning, there was no effect of creep feeding on d 28 weights ($P<0.93$), ADG ($P<0.86$), ADFI ($P<0.93$), and F/G ($P<0.95$) compared to non-creep fed pigs. Eaters tended to be heavier until d 28 post-weaning ($P<0.16$) and had greater ($P<0.06$) ADG and total gains than non-eaters and no creep pigs. In conclusion, creep feeding improved survivability, but had no effects on pre-weaning gain and sow performance. Low feed intake during lactation negatively affected both sow and litter performance. Creating more eaters in whole litters may be beneficial in improving post-weaning performance.

(Key words: creep feeding, feed management, lactation.)

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Introduction

Numerous studies have demonstrated a positive relationship between pre-weaning growth and post-weaning performance. Increased nutrient availability to suckling piglets is considered a major determinant of birth-to-weaning growth rate, which can be provided either by improving the sow's milk output using nutrient-dense lactation diets or providing highly digestible creep feed to piglets during the suckling period. The effect of lactation feed intake and creep feeding on pre- and post-weaning performance have been evaluated independently in previous studies; however, there has been no work done on the effect of these two nutritional regimens in a single study. In addition, creep feeding has been suggested to reduce the nutritional load in lactating sows especially with large litters, which may have positive benefits in reducing lactation weight loss and weaning-to-estrus interval. However, there has been no study at present to support this claim. Therefore, the objectives of this experiment were to evaluate the effect of lactation feed intake and creep feeding on pre- and post-weaning performance, and to determine the effect of creep feeding on body weight loss, back fat thickness, and weaning-to-estrus interval in sows.

Procedures

A total of 84 sows (PIC, Line 1050) and their litters were used in this study conducted at the Kansas State University Swine Research and Teaching Center farrowing facilities. Sows used in this experiment were from three batches of sows farrowed in August, October, and November 2006, with 28 experimental sows included from each batch. Sows were blocked according to parity and date of farrowing and were allotted to four experimental treatments using a randomized complete block design in a 2 × 2 factorial with lactation feed intake (*ad libitum* vs. restricted) and creep feeding (none vs. creep) as factors. Piglets were cross-fostered within each block to standardize litter weights and litter size (>11 pigs). The sow or litter was the experimental unit with 21 replicates per treatment.

A common lactation diet (1,586 kcal ME/lb, 0.97% TID Lys) was used in the study (Table 1). From d 3 of lactation, *ad libitum* sows were allowed free access to feed while restricted sows were fed 25% lower than those fed *ad libitum*. In the creep-fed treatments, a creep diet (1,585 kcal ME/lb, 1.56% TID Lys) with 1.0% chromium oxide was offered *ad libitum* at d 3 until weaning (d 21). The creep diet was in pellet form (2-mm pellets) and was fed using a rotary creep feeder with hopper (Rotecna® Mini Hopper Pan, Rotecna SA, Spain).

Piglets were weighed individually at d 3, 7, 14, and 21 (weaning). Amount of creep feed consumed was determined daily. Fecal samples from all creep-fed pigs were taken using sterile swabs once per sampling day on d 7, 14, and 21. The cotton-tipped swab was inserted into the anal opening in a clockwise motion for about 2 inches and pulled slowly for fecal collection. Fecal color was assessed to categorize piglets as eaters or non-eaters of creep feed. Piglets were categorized as eaters when the fecal sample was colored green at least once on any of the three sampling days. Non-eaters were creep-fed piglets that never showed green-colored feces. Pigs that were not provided with creep feed were designated as no creep pigs. At weaning, 624 out of 819 pigs were blocked according to initial weight and creep feeding (no vs. yes) and were used in three different nursery trials. Extra pigs (n=195) were also housed in the nursery facility and fed a common diet. Pigs and feeders were weighed weekly until d 28 post-weaning to calculate for average daily gain, average daily feed intake, and feed to gain ratio.

Weekly feed intake of the sows was recorded to calculate total and average daily feed intake. Sows were weighed and P2 backfat thickness (6.5 cm from the midline over

the last rib) were measured post-farrowing and at weaning. Estrus detection using back pressure test were performed twice a day from weaning until 14 d after weaning to determine days to estrus and percentage of sows returning to estrus within 14 d. In this study, six sows were removed from the test due to either poor daily feed intake or death of the sow. 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 using heat lamps when needed.

Periodic and cumulative average daily gain and creep feed intake were calculated for each treatment group. Pre-weaning mortality was also calculated. The coefficient of variation for pig weights within each litter was determined at d 3 and 21. Sow body weight loss, change in P2 back fat thickness, and weaning-to-estrus interval were calculated. Data were analyzed as a randomized complete block design using PROC MIXED of SAS. Regression models for daily litter creep feed intake were developed using PROC REG of SAS. Logistic regression curves were also developed using PROC LOGISTIC of SAS to determine estimated probabilities of changes in the proportion of eaters as determined by weights on d 0 (birth), d 3, and at weaning.

Results and Discussion

The effects of lactation feeding level and creep feeding on sow performance are shown in Tables 2 and 3. Sows had an average parity of 1.6 ± 0.7 and lactation length of 21.1 ± 1.9 d. There was no significant interaction between lactation feeding level and creep feeding on any of the performance parameters measured; therefore, only main effects will be discussed. *Ad libitum*-fed sows had 32 and 26% greater total (219.2 vs. 149.6 lb, $P<0.0001$) and daily (10.8 vs. 8.0 lb, $P<0.0001$) feed intake than restricted-fed sows, respectively. There were no differences in post-farrowing ($P<0.37$) and weaning ($P<0.23$) weights of *ad libitum* and restricted-fed sows. However, *ad libitum* feeding of sows reduced lactation weight loss (-33.0 vs. -52.9 lb; $P<0.01$) compared to limit-fed sows. Backfat thickness after farrowing ($P<0.84$) and at weaning ($P<0.44$) were also similar; likewise, backfat loss throughout lactation did not differ ($P<0.27$) between *ad libitum* and limit-fed sows. Days to estrus for sows that returned to estrus by d 14 after weaning were similar ($P<0.83$) between *ad libitum* and restricted-fed sows. However, *ad libitum* feeding increased (90 vs. 71%, $P<0.03$) the percentage of sows returning to estrus by d 14.

These results conform with similar studies investigating the effects of energy restriction during lactation or effects of high ambient temperature in lactating sows. Sows with restricted energy intakes lost more weight and backfat during lactation than sows allowed *ad libitum* intake. One response that was different from previous studies was that differences in backfat loss were not observed in this study. In previous studies, daily energy intake was restricted to a level (33 to 50%) greater than the feed restriction in this study (26% of *ad libitum* intake), which may help explain the differences in results. The higher rate of sows failing to exhibit estrus within 14 d demonstrates the detrimental effects of limit feeding in sows during lactation. Low feed intake during lactation has been previously shown to depress luteinizing hormone (LH) secretion, which is required for the release of eggs from follicles into the ovary and commence another reproductive stage.

Providing litters with creep feed did not affect total ($P<0.56$) and daily ($P<0.57$) feed intake of sows. Likewise, there were no differences in sow weights after farrowing ($P<0.27$) and at weaning ($P<0.48$), or in weight loss ($P<0.75$) between sows with litters provided with and without creep feed. The same effect was observed in backfat thickness after farrowing ($P<0.14$) and at weaning

(P<0.21), and in backfat loss (P<0.34). However, creep feeding increased days to estrus (5.4 vs. 4.9 d; P<0.03) for sows that returned to heat by 14 d. There were no differences (P<0.77) in the proportion of sows which returned to estrus within 14 d between sows with creep and non-creep fed litters. There has been no previous study evaluating the effects of creep feeding on sow performance, although claims have been made on some potential benefits of the practice. Creep feeding was thought to reduce the nutritional load in lactating sows especially with large litters, which may have corollary effects in reducing lactation weight loss and weaning-to-estrus interval. These were not observed in this study where creep feeding for 18 d did not have any effect on sow performance except for increasing days to estrus. The amount of litter creep feed intake observed in this study was too small (3.65 Mcal; 1.26% of total energy intake of the sows) to generate any appreciable, nutritional savings to lactating sows that may merit a reduction in mobilized body reserves or improve their metabolic state. The impact of creep feeding on reducing nutrition requirements of the sow may be greater with older weaning ages, but does not appear to be beneficial in a 21-d lactation period.

The effects of lactation feeding level and creep feeding on pig and litter performance are shown in Tables 4 and 5. Lactation feeding level had no effect on litter size at weaning (P<0.93) and pre-weaning mortality rate (P<0.76). *Ad libitum* feeding of sows improved total (P<0.04) and daily (P<0.04) gains of litters and tended to increase litter weaning weights (P<0.10) compared to limit-fed sows. Likewise, total gain (P<0.04), daily gain (P<0.03), and weaning weights (P<0.06) of individual pigs were higher in *ad libitum*-fed sows. These results conform with other studies, which demonstrate the benefits of high lactation feed intake on pre-weaning growth rate. The coefficient of variation (CV) in litters of sows fed *ad libitum* and restricted were similar at weaning (P<0.22); likewise, there were no differences (P<0.78) in litter CV change between the two levels of lactation feeding.

Creep feeding increased litter size at weaning by 0.4 pig per litter; however, this difference was not significant (P<0.19). The increase in litter size was mainly due to a reduction in pre-weaning mortality rate after cross-fostering (3.9 vs. 7.3%; P<0.06) with creep feeding. There were no differences in total gains (P<0.55), daily gains (P<0.53), and weaning weights (P<0.54) of pigs at weaning between creep and non-creep fed litters. Total (P<0.17) and daily (P<0.16) gains of litters were also unaffected by creep feeding; however, litter weaning weights tended to be greater (P<0.09) in creep-fed litters due to reduced mortality rates after cross-fostering and greater (P<0.04) litter weights at the start of creep feeding (d 3). There were no differences in litter CV at weaning (P<0.25) and CV change throughout lactation (P<0.49), which indicates the lack of effect of creep feeding in improving litter uniformity.

Litters of restricted-fed sows had 33% greater (0.12 vs. 0.09 lb; P<0.02) creep feed intake than litters of *ad libitum* fed sows from d 3 to 7 (Figure 1). However, no differences (P<0.41) in litter creep feed intake were observed in other periods. Overall, total creep feed intake was highly variable between litters, ranging from 0.58 to 5.18 lb/litter throughout the 18 d period that creep feed was provided. Total creep feed intake of litters did not differ (2.24 vs. 2.28 lb/litter; P<0.93) between *ad libitum* and restricted-fed sows, which suggests that a limited nutrient supply to both sows and litters did not drive piglets to consume more creep feed. About 72 and 77% of the total creep feed intake of litters of restricted and *ad libitum*-fed sows was consumed in the last week prior to weaning. The daily creep feed intake of litters increased quadratically (R^2=0.22; P<0.0001) from d 3 to weaning; however, intakes greater than 0.1 lb per litter were attained only from d 13 before weaning (Figure 2). About 59 and 41% of the

creep-fed piglets were categorized as eaters and non-eaters (Figure 3). Of pigs identified as eaters, 23, 20, and 57% were positive for creep feed consumption on d 7, 14, and 21, respectively (Figure 4). The higher intake and percentage of eaters created in the last week prior to weaning indicate that piglets more readily accept and consume greater amounts of creep feed at an older age. Thus, creep feed consumption seems to be more related to the maturity of the piglets rather than the age of induction of creep feeding.

Logistic regression curves showed a positive relationship between birth weight ($P<0.03$) and a tendency for a positive relationship with d 3 weights ($P<0.17$) and the proportion of eaters and non-eaters among litters. There was no relationship ($P<0.94$) between d 21 and creep feed consumption category. The estimated probability of the changes in the proportion of non-eaters in creep-fed litters increased from 41 to 86% as pig birth weight increased from 1.2 to 5.6 lb (Figure 5). Based on the logistic model, birth weights of less than 2 lb have more than 50% probability of becoming eaters. This indicates that smaller pigs at birth have a higher probability of becoming eaters of creep feed while heavier pigs tend more to become non-eaters. This suggests differences in their consumption patterns and the value of creep feeding within whole litters. Larger pigs have greater ability to compete for prime suckling positions in the udder, and given the choice, seemed to prefer milk over the creep feed. Creep feed then provides an alternative nutritional source to smaller, less competitive piglets.

From d 0 to 28 post-weaning, there was no effect of creep feeding on d 28 weights ($P<0.93$), ADG ($P<0.86$), ADFI ($P<0.93$), and F/G ($P<0.95$) compared to non-creep fed pigs (Table 6). However, when pigs were categorized based on creep feed consumption category, eaters tended to be heavier until d 28 post-weaning (Figure 6; $P<0.16$) and had higher ($P<0.06$) ADG and total gains than non-eaters and no creep pigs (Figure 7). Eaters and non-eaters were mixed at weaning, which may explain the lack of differences between creep and non-creep fed pigs. The differences in post-weaning gain also agree with previous studies, where eaters, non-eaters, and non-creep fed pigs were compared. These studies have attributed these differences in post-weaning growth efficiency to shorter latency time (interval between weaning and first feed intake) and greater post-weaning feed intake in eaters. A recent study using segment perfusion tests also showed greater net absorption in the small intestine of eaters compared to non-eaters, though some studies have reported no effect of pre-weaning eating activity on gut morphology.

In conclusion, low feed intake during lactation negatively affected both sow and litter performance. Creep feeding tended to improve litter weaning weights due to higher survivability, but had no effects on pre-weaning gain and sow performance. When pigs were categorized based on creep feed consumption category, eaters had greater post-weaning gains and weights than non-eaters and non-creep fed pigs. Creating more eaters in whole litters may be beneficial in improving post-weaning performance. Thus, factors, whether dietary or non-dietary, which can enhance the proportion of eaters in litters, should be investigated.

Table 1. Diet Composition (as-fed basis)

Ingredient, %	Creep[a]	Lactation[b]
Corn	6.15	60.00
Soybean meal (46.5% CP)	2.32	31.20
Spray dried whey	25.00	-
Fine ground oat groats	30.00	-
Extruded soy protein concentrate	10.00	-
Spray-dried animal plasma	6.00	-
Select menhaden fish meal	6.00	-
Lactose	5.00	-
Choice white grease	5.00	5.00
Monocalcium P (21% P)	0.35	1.45
Chromium oxide	1.00	-
Antibiotic	1.00	
Limestone	0.45	1.20
Zinc oxide	0.38	-
Salt	0.30	0.50
L-Lysine HCl	0.15	-
DL-methionine	0.15	-
Trace mineral premix	0.15	0.15
Vitamin premix	0.25	0.25
Sow add pack	-	0.25
Acidifier	0.20	-
Flavor	0.10	-
Vitamin E, 20,000 IU	0.05	-
Total	100.00	100.00
Calculated analysis		
Crude protein, %	23.9	19.6
TID Lysine, %	1.56	0.97
ME, kcal/lb	1,585	1,589
Ca, %	0.79	0.87
Available P, %	0.56	0.38
TID Lysine:ME ratio, g/Mcal	4.47	2.77

[a]Diet fed in pellet form.
[b]Diet fed in meal form throughout lactation.

Table 2. Effects of Lactation Feeding Level and Creep Feeding on Sow Performance (Interactive Effects)[ab]

	Lactation Feeding Level × Creep Feeding					Probability, *P*<		
	Restricted		*Ad libitum*					
Item	No	Yes	No	Yes	SED	Lactation	Creep	Lactation × Creep
No. of sows	19	19	20	20	-	-	-	-
Lactation length, d	21.0	21.1	20.9	21.1	0.1	0.39	0.25	0.89
Average parity	1.5	1.6	1.5	1.6	0.1	0.56	0.21	0.95
Lactation feed intake, lb								
Total, d 0 - 21	151.1	148.1	221.3	217.1	6.5	<0.0001	0.56	0.86
ADFI	8.0	7.9	10.9	10.6	0.3	<0.0001	0.57	0.79
Sow weight, lb								
Post-farrowing	475.6	487.0	463.8	478.2	15.9	0.37	0.27	0.90
Weaning	422.4	428.3	433.8	443.1	147	0.23	0.48	0.87
Change	-53.9	-51.8	-30.8	-35.3	5.2	<0.0001	0.75	0.38
Backfat, mm								
Post-farrowing	17.8	15.8	17.1	16.2	1.4	0.84	0.14	0.56
Weaning	12.6	12.1	13.4	12.3	0.9	0.44	0.21	0.63
Change	-5.3	-3.7	-3.6	-3.9	0.9	0.27	0.34	0.17
Days to estrus[g]	4.7	5.7	5.1	5.2	0.3	0.83	0.03	0.15
Return to estrus, %[h,i]	73.7	68.4	90.0	90.0	-	0.03	0.77	-

[a]Three groups of sows (total = 78, PIC Line 1050) were blocked according to day of farrowing and parity and allotted to four treatments in a 2 x 2 factorial with lactation feeding level (Restricted vs. *Ad libitum*) and creep feeding (No vs. Yes) as factors.
[b]There was no significant interaction ($P>0.10$) between lactation feeding level and creep feeding on any parameter measured.
[c]Sows on the restricted feeding program were fed 25% lower than those fed *ad libitum*.
[d]Creep feed with 1.0% chromium oxide was offered ad libitum from d 3 to weaning (21 ± 0.1 d).
[e,f]Means in the same row with different superscript differ ($P<0.05$).
[g]For sows returning to estrus within 14 d post-weaning.
[h]Percentage of sows returning to estrus within 14 d post-weaning.
[i]Means evaluated using a chi-square test.

Table 3. Effects of Lactation Feeding Level and Creep Feeding on Sow Performance (Main Effects)[ab]

	Lactation Feeding[c]		Creep Feeding[d]			Probability, *P*<		
Item	Restricted	*Ad libitum*	No	Yes	SED	Lactation	Creep	Lactation × Creep
No. of sows	38	40	39	39	-	-	-	-
Lactation length, d	21.1	21.0	21.0	21.1	0.1	0.39	0.25	0.89
Average parity	1.6	1.5	1.5	1.6	0.1	0.56	0.21	0.95
Lactation feed intake, lb								
Total, d 0 - 21	149.6[e]	219.2[f]	185.9	182.9	5.2	<0.0001	0.56	0.86
ADFI	8.0[e]	10.8[f]	9.4	9.3	0.1	<0.0001	0.57	0.79
Sow weight, lb								
Post-farrowing	481.3	471.0	469.7	482.6	11.6	0.37	0.27	0.90
Weaning	425.4	438.5	428.1	435.7	10.7	0.23	0.48	0.87
Change	-52.9[e]	-33.0[f]	-42.4	-43.5	3.8	<0.0001	0.75	0.38
Backfat, mm								
Post-farrowing	16.8	16.6	17.5	16.0	1.0	0.84	0.14	0.56
Weaning	12.4	12.9	13.0	12.2	0.7	0.44	0.21	0.63
Change	-4.5	-3.8	-4.5	-3.8	0.7	0.27	0.34	0.17
Days to estrus[g]	5.2	5.1	4.9[e]	5.4[f]	0.2	0.83	0.03	0.15
Return to estrus, %[h,i]	71.0[e]	90.0[f]	82.1	79.5	-	0.03	0.77	-

[a]Three groups of sows (total = 78, PIC Line 1050) were blocked according to day of farrowing and parity and allotted to four treatments in a 2 x 2 factorial with lactation feeding level (Restricted vs. *Ad libitum*) and creep feeding (No vs. Yes) as factors.
[b]There was no significant interaction ($P>0.10$) between lactation feeding level and creep feeding on any parameter measured; means of main effects are reported.
[c]Sows on the restricted feeding program were fed 25% lower than those fed *ad libitum*.
[d]Creep feed with 1.0% chromium oxide was offered *ad libitum* from d 3 to weaning (21 ± 0.1 d).
[e,f]Means in the same row with different superscript differ ($P<0.05$).
[g]For sows returning to estrus within 14 d post-weaning.
[h]Percentage of sows returning to estrus within 14 d post-weaning.
[i]Means evaluated using a chi-square test.

Table 4. Effects of Lactation Feeding Level and Creep Feeding on Litter and Pig Performance (Interactive Effects)[ab]

	Lactation Feeding Level × Creep Feeding					Probability, *P*<		
	Restricted		*Ad libitum*					
Item	No	Yes	No	Yes	SED	Lactation	Creep	Lactation × Creep
No. of litters	19	19	20	20	-	-	-	-
Pigs/litter								
d 3 (start creep)	11.1	10.9	10.8	11.1	0.3	0.75	0.99	0.32
d 21	10.3	10.5	10.1	10.7	0.4	0.93	0.19	0.59
Mortality, %	7.5	4.3	7.1	3.6	2.5	0.76	0.06	0.92
Litter weight, lb								
d 3 (start creep)	38.2	40.3	36.5	40.2	1.9	0.53	0.04	0.56
d 21	123.9	126.2	126.0	139.2	6.3	0.10	0.09	0.23
Litter BW gain, lb								
Total	94.6	94.8	97.6	108.2	5.4	0.04	0.17	0.19
ADG	5.20	5.20	5.34	5.94	0.29	0.04	0.16	0.17
Pig weight, lb								
d 3 (start creep)	3.8	3.8	3.7	3.8	0.1	0.66	0.45	0.88
d 21	12.1	12.0	12.5	13.1	0.4	0.06	0.54	0.30
Pig BW gain, lb								
Total	9.2	9.0	9.6	10.2	0.5	0.04	0.55	0.25
ADG	0.52	0.51	0.54	0.58	0.03	0.03	0.53	0.22
Litter CV, %[g]								
d 3 (start creep)	20.4	20.4	19.5	16.9	1.6	0.05	0.25	0.24
d 21	19.4	19.2	17.7	17.3	2.1	0.22	0.84	0.97
Change	-1.0	-1.2	-1.8	0.4	2.1	0.78	0.49	0.39

[a]Three groups of sows (total = 78, PIC Line 1050) were blocked according to day of farrowing and parity and allotted to four treatments in a 2 x 2 factorial with lactation feeding level (Restricted vs. *Ad libitum*) and creep feeding (No vs. Yes) as factors.
[b]There was no significant interaction ($P>0.10$) between lactation feeding level and creep feeding on any parameter measured.
[c]Sows on the restricted feeding program were fed 25% lower than those fed *ad libitum*.
[d]Creep feed with 1.0% chromium oxide was offered *ad libitum* from d 3 to weaning (21 ± 0.1 d).
[e,f]Means in the same row with different superscript differ ($P<0.05$).
[g]CV = coefficient of variation; values were determined from piglet weights within a litter.

Table 5. Effects of Lactation Feeding Level and Creep feeding on Litter and Pig Performance (Main Effects)[ab]

Item	Lactation Feeding[c]		Creep Feeding[d]			Probability, *P*<		
	Restricted	*Ad libitum*	No	Yes	SED	Lactation	Creep	Lactation × Creep
No. of litters	38	40	39	39	-	-	-	-
Pigs/litter								
d 3 (start creep)	11.0	10.9	11.0	11.0	0.3	0.75	0.99	0.32
d 21	10.4	10.4	10.2	10.6	0.3	0.93	0.19	0.59
Mortality, %	5.9	5.3	7.3[e]	3.9[f]	1.8	0.76	0.06	0.92
Litter weight, lb								
d 3 (start creep)	39.3	38.6	37.4[e]	40.3[f]	1.4	0.53	0.04	0.56
d 21	125.1[e]	132.6[f]	124.9[e]	132.7[f]	4.5	0.10	0.09	0.23
Litter BW gain, lb								
Total	94.7[e]	102.9[f]	96.1	101.5	3.9	0.04	0.17	0.19
ADG	5.20[e]	5.64[f]	5.27	5.57	0.21	0.04	0.16	0.17
Pig weight, lb								
d 3 (start creep)	3.8	3.8	3.7	3.8	0.1	0.66	0.45	0.88
d 21	12.0[e]	12.8[f]	12.3	12.5	0.4	0.06	0.54	0.30
Pig BW gain, lb								
Total	9.1[e]	9.9[f]	9.4	9.6	0.4	0.04	0.55	0.25
ADG	0.52[e]	0.56[f]	0.53	0.55	0.02	0.03	0.53	0.22
Litter CV, %[g]								
d 3 (start creep)	20.4[e]	18.2[f]	20.0	18.7	1.1	0.05	0.25	0.24
d 21	19.3	17.5	18.6	18.3	1.5	0.22	0.84	0.97
Change	1.1	0.7	1.4	0.4	1.5	0.78	0.49	0.39

[a]Three groups of sows (total = 78, PIC Line 1050) were blocked according to day of farrowing and parity and allotted to four treatments in a 2 x 2 factorial with lactation feeding level (Restricted vs. *Ad libitum*) and creep feeding (No vs. Yes) as factors.
[b]There was no significant interaction ($P>0.10$) between lactation feeding level and creep feeding on any parameter measured; means of main effects are reported.
[c]Sows on the restricted feeding program were fed 25% lower than those fed *ad libitum*.
[d]Creep feed with 1.0% chromium oxide was offered *ad libitum* from d 3 to weaning (21 ± 0.1 d).
[e,f]Means in the same row with different superscript differ ($P<0.05$).
[g]CV = coefficient of variation; values were determined from piglet weights within a litter.

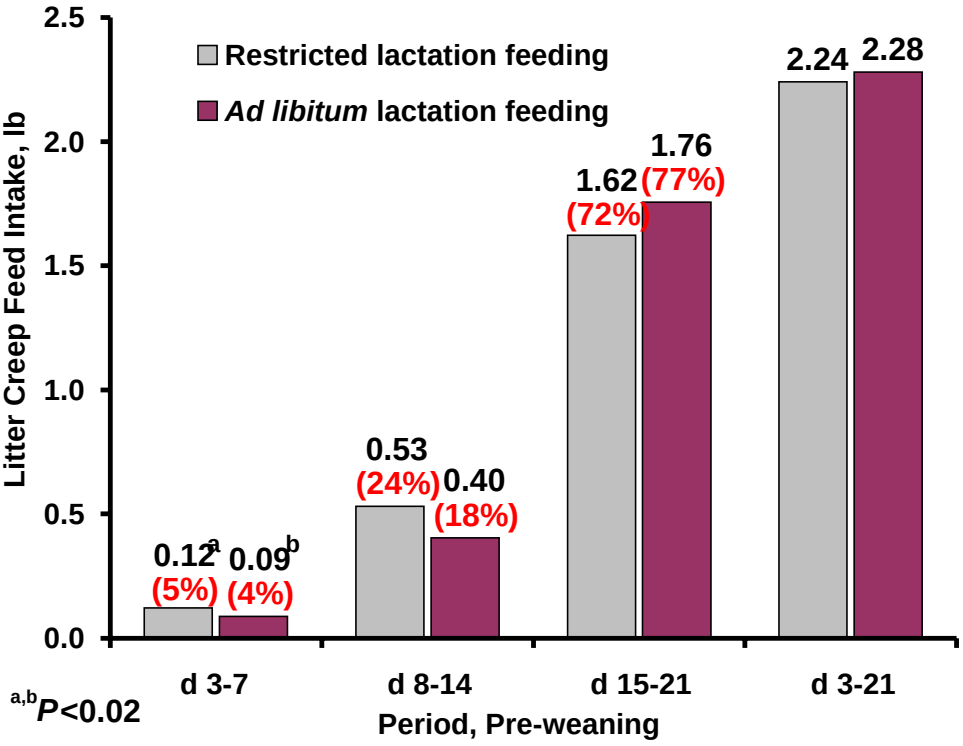

Figure 1. Effects of Lactation Feeding Level on Litter Creep Feed Intake (% of total litter creep feed intake in parentheses).

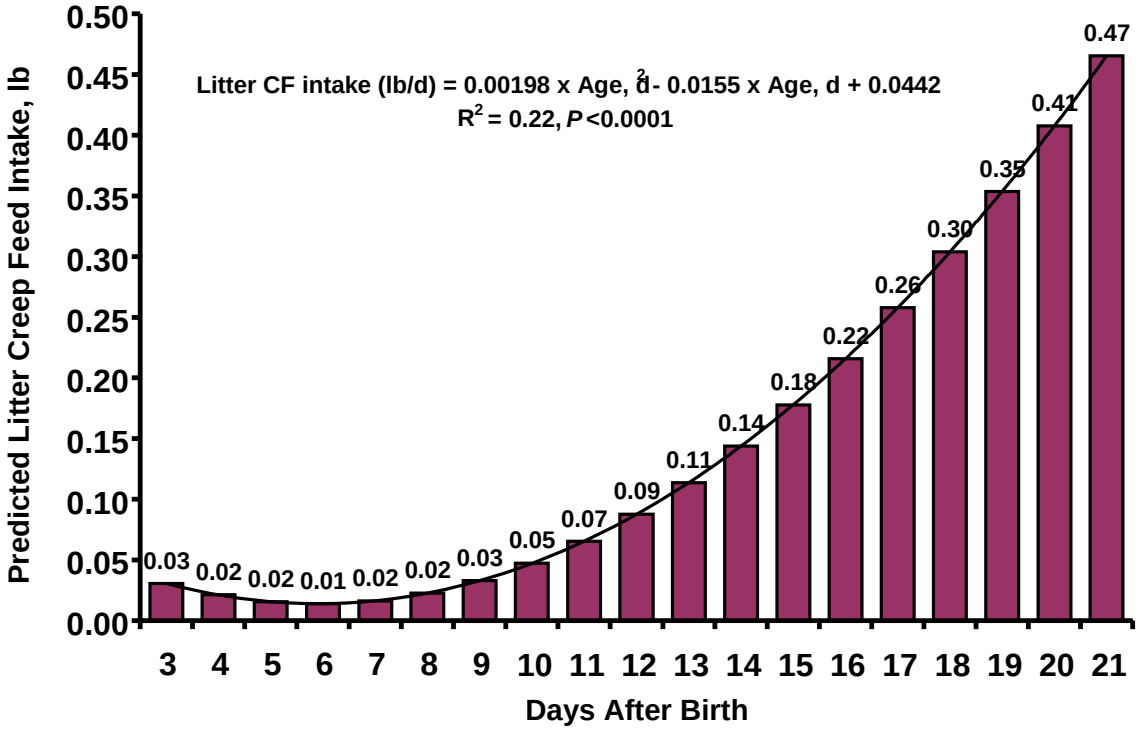

Figure 2. Predicted Daily Litter Creep Feed Intake (from 39 litters).

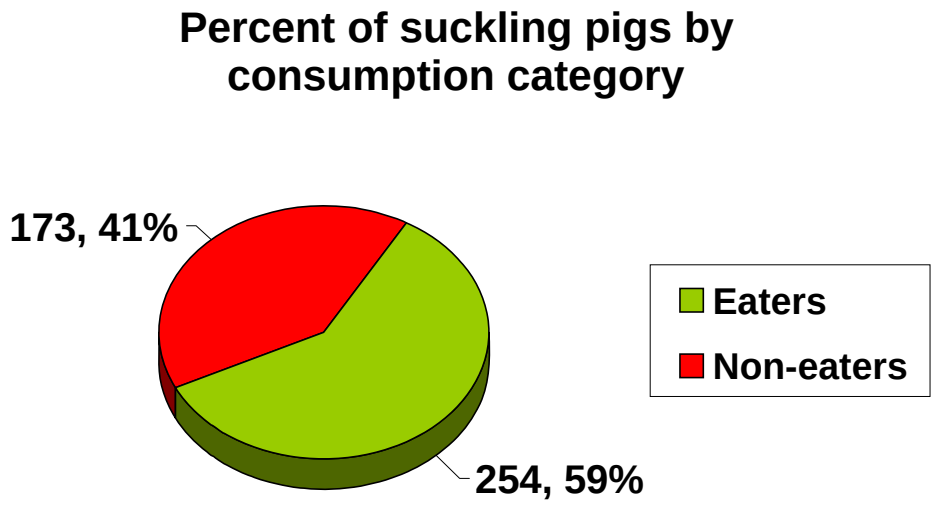

Figure 3. Characterization of Piglets Provided with Creep Feed Based on Consumption Category.

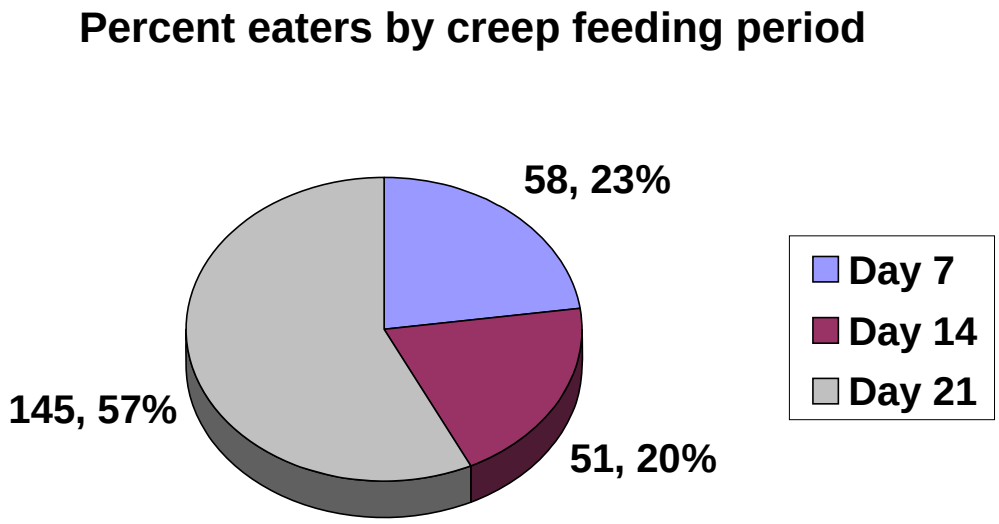

Figure 4. Frequency and Percentage of Pigs Identified as Eaters on D 7, 14, and 21.

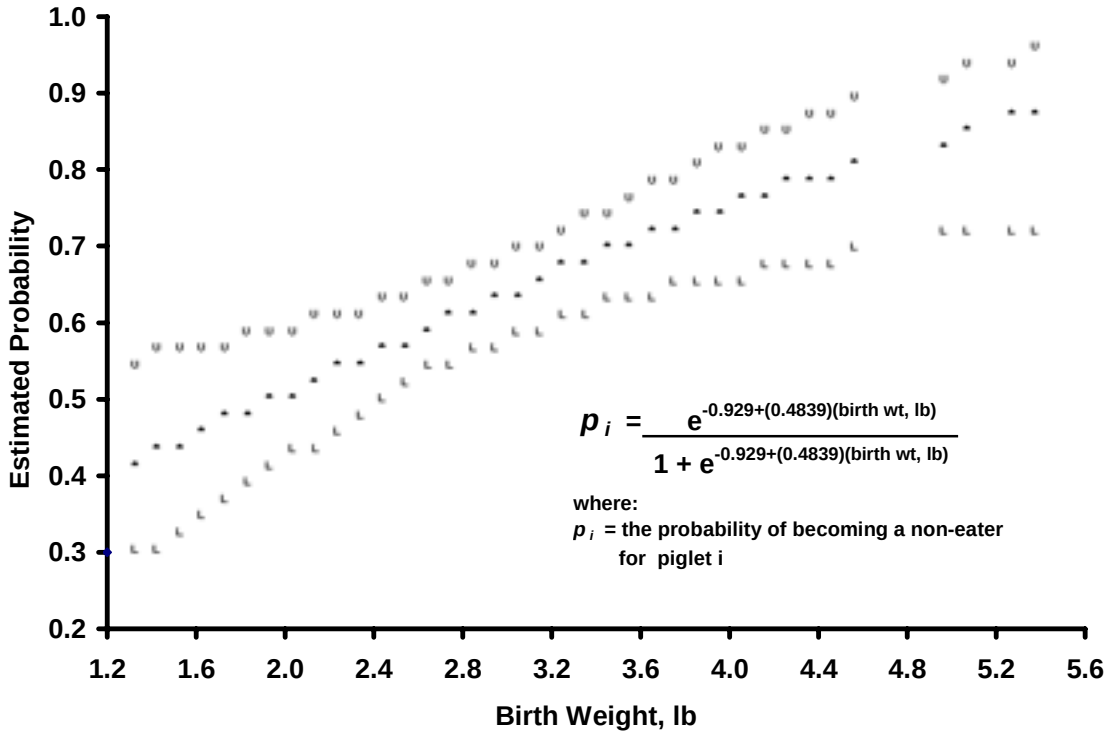

Figure 5. Logistic Curve of Changes in Proportion of Non-eaters as Affected by Changes in Birth Weight (U=Upper Limit, L=Lower Limit)

Table 5. Effects of Creep Feeding on Post-weaning Growth Performance[a]

Item	Creep Feeding		SED	Probability, *P*<
	No	Yes		
No. of pens	52	52	-	-
Pig weights, lb				
D 0	13.56	13.23	0.92	0.71
D 14	20.57	20.62	1.22	0.97
D 21	28.33	28.57	1.51	0.87
D 28	38.82	38.64	1.98	0.93
D 0 to 14				
ADG, lb	0.50	0.53	0.03	0.25
ADFI, lb	0.56	0.61	0.03	0.15
F/G	1.14	1.18	0.04	0.31
D 0 to 21				
ADG, lb	1.37	1.36	0.04	0.79
ADFI, lb	1.73	1.71	0.08	0.82
F/G	1.26	1.26	0.05	0.92
D 0 to 28				
ADG, lb	0.98	0.99	0.04	0.86
ADFI, lb	1.22	1.22	0.08	0.93
F/G	1.24	1.23	0.04	0.95

[a]A total of 624 out of 819 pigs (PIC L337 x C22) were blocked according to initial weight and creep feeding (no vs. yes); values are means of 52 pens of 6 pigs each, respectively

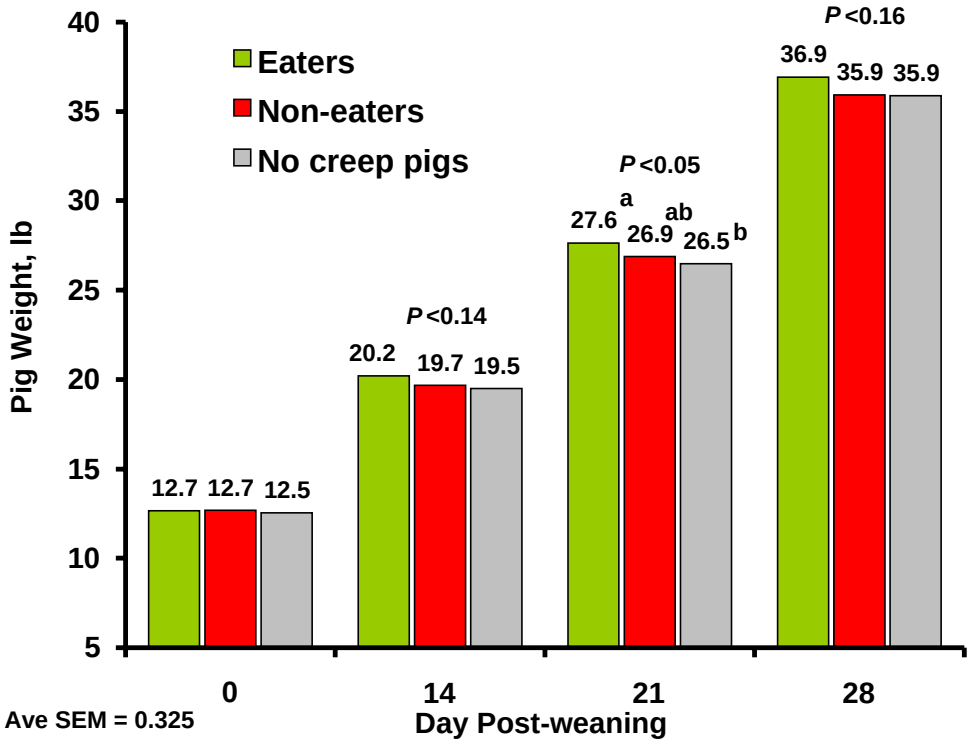

Figure 6. Post-weaning Live Weight Trends of Piglets According to Creep Feed Consumption Category (n = 819).

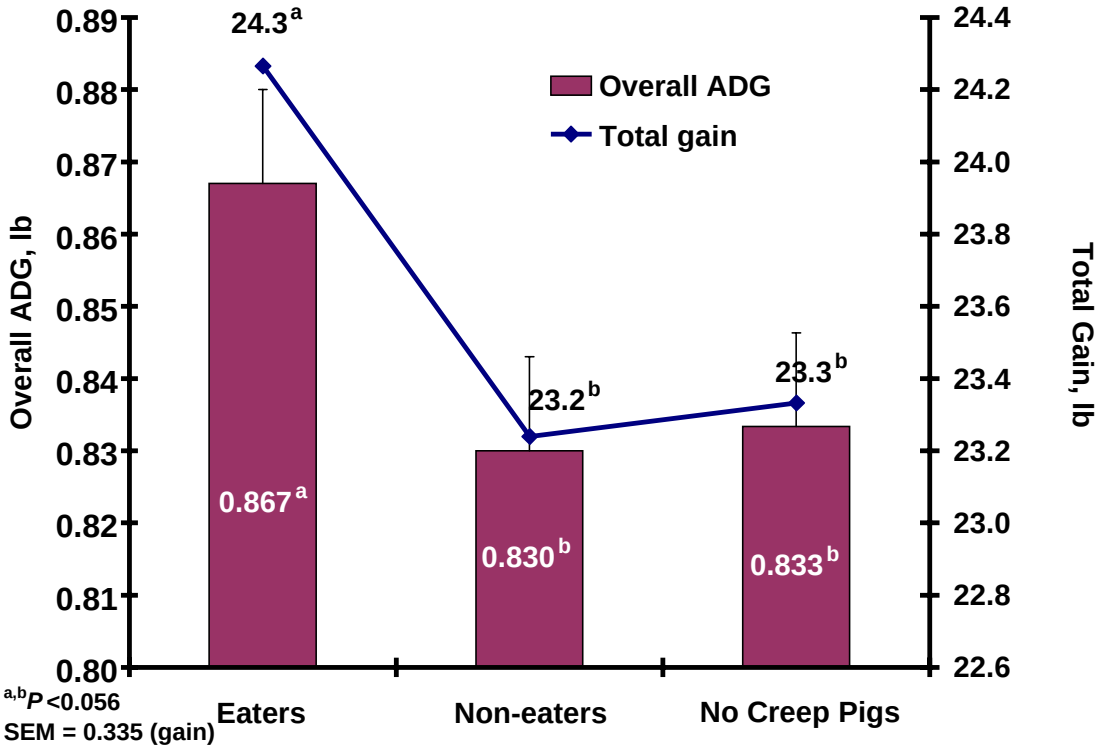

Figure 7. Overall Post-weaning ADG and Total Gain (d 0 – 28) of Piglets According to Creep Feed Consumption Category (n = 819).

EFFECTS OF VARYING CREEP FEEDING DURATION ON PROPORTION OF PIGS CONSUMING CREEP FEED AND PRE-WEANING PERFORMANCE

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Summary

A total of 54 sows (PIC Line 1050) and their litters were used in this study to determine the effects of varying durations of creep feeding on the rate of pigs consuming creep feed (eaters) and pre-weaning performance. Two groups of sows were blocked according to parity and date of farrowing and allotted to three experimental treatments using a randomized complete block design. Creep feeding was initiated at d 7, 14, and 18 from birth for a duration of 13, 6, and 2 d of creep feeding. A creep diet (1,585 kcal ME/lb, 1.56% TID Lys) with 1.0% chromium oxide was offered *ad libitum* until weaning (d 20) using a rotary creep feeder with hopper. A single lactation diet (1,586 kcal ME/lb, 0.97% TID Lys) was used where sows were allowed free access to feed throughout lactation. Piglets were weighed individually at d 0 (birth), 7, 14, 18, and 20 to calculate total and daily gains. Daily creep feed intake per litter was recorded and calculated. Fecal samples from all piglets were taken twice per sampling day using sterile swabs at d 14, 18, and 20 for Treatment 1; at d 18 and 20 for Treatment 2; and d 20 for Treatment 3. Piglets were categorized as 'eaters' when fecal sample was colored green at least once on any of the sampling days. Overall, there were no differences in weaning weights ($P<0.61$), total gain ($P<0.38$), and daily gain ($P<0.38$) among pigs and litters fed creep for different durations. Total creep feed intake of litters fed creep for 13 and 6 d were greater ($P<0.0001$) than those litters provided creep feed for 2 d. There were no differences ($P<0.69$) in overall creep intake between litters fed for 13 and 6 d. Litters provided with creep feed for 13 d produced 10% more (80 vs. 70%; $P<0.03$) eaters than litters fed creep for both 6 and 2 d. There were no differences ($P<0.98$) in the percentage of eaters between litters fed creep for 6 and 2 d. In conclusion, longer durations of creep feeding did not affect pre-weaning gain and weaning weights but did increase the proportion of eaters in whole litters; however, a relatively high percentage of pigs (70%) were classified as eaters by providing creep feed for only 2 d prior to weaning.

(Key words: feed management, creep feeding, feeding duration.)

Introduction

The plethora of evidence on the benefits of creep feeding has been limiting and equivocal, especially for weaning ages less than four weeks. However, recent studies where piglets were categorized into eaters and non-eaters of

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creep feed have provided some new insights on the value of creep feeding. Research at Kansas State University has shown that creep feeding for 18 d improved piglet survivability but did not improve pre-weaning gains or weaning weights at d 20. When whole litters where divided based on creep feed consumption category, piglets designated as eaters had better post-weaning gains and d 28 weights compared to non-eaters and non-creep fed pigs. In this study, about 60% of the creep-fed pigs were categorized as eaters while 75% of creep feed intake was consumed in the last week prior to weaning. It is not known if providing creep feed at varying durations will create more eaters or affect pre-weaning performance. Therefore, the objective of this experiment was to determine the effects of varying durations of creep feeding on the rate of creating eaters and pre-weaning performance.

Procedures

A total of 54 sows (PIC Line 1050) and their litters were used in this study conducted at the Kansas State University Swine Research and Teaching Center farrowing facilities. Sows used in this experiment were from two batches of sows farrowed in April and May, 2007, with 27 experimental sows included from each batch. Sows were blocked according to parity and date of farrowing and allotted to three experimental treatments using a randomized complete block design. Cross-fostering was performed within 48 h post-farrowing to standardize litter weights and litter size (>12 pigs). The sow or litter was the experimental unit with 18 replicates per treatment group.

There were three experimental treatments in this study according to the duration of creep feeding. Creep feeding was initiated at d 7, 14, and 18 from birth for Treatments 1, 2, and 3, respectively. These corresponded to durations of 13, 6, and 2 d of creep feeding. A creep diet (1,585 kcal ME/lb, 1.56% TID Lys; Table 1) with 1.0% chromium oxide was offered *ad libitum* until weaning using a rotary creep feeder (Rotecna® Mini Hopper Pan, Rotecna SA, Spain). The feeder is equipped with a 6-liter capacity hopper, which is adjustable to five different settings of feeder gaps to allow *ad libitum* feeding. The creep diet was in pellet form (2-mm pellets). A single lactation diet (1,586 kcal ME/lb, 0.97% TID Lys) was used in the experiment. Sows were allowed free access to feed throughout lactation. Water was made available at all times for both sows and their litters using nipple drinkers and bowls, respectively.

Piglets were weighed individually at d 0 (birth), 7, 14, 18, and 20 (weaning). Creep feeders were weighed daily. Daily creep feed consumption per litter was computed as the difference in feeder weights between consecutive days. Fecal samples from all piglets were taken using sterile swabs at d 14, 18, and 20 for Treatment 1; at d 18 and 20 for Treatment 2; and d 20 for Treatment 3. The color of each fecal sample was visually determined. Fecal sampling was performed twice per sampling day. Piglets that tested negative on the first fecal sampling were re-sampled after 9 to 12 h. Piglets were categorized as 'eaters' when fecal color was green at least once on any of the sampling days.

Sows were weighed after farrowing and at weaning. Weekly feed intake of the sows was recorded to calculate total and average daily feed intake. In this study, two sows from Treatment 3 were removed from the test due to death of the sow. 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 using heat lamps when needed.

Periodic and cumulative average daily gain and creep feed intake were calculated for each treatment group. Pre-weaning mortality was also calculated. Data were analyzed as a randomized complete block design using

PROC MIXED of SAS. The effect of varying creep feeding durations on percentage of eaters was analyzed using the Chi-square test in SAS.

Results and Discussion

The effect of varying creep feeding durations on sow performance is shown in Table 2. Sows had an average parity of 2.1 ± 0.2 and lactation length of 19.9 ± 0.3 d. Varying the duration of creep feeding had no effect on total (P<0.76) or daily feed intake (P<0.53) of sows during lactation. Likewise, there were no differences in post-farrowing weight (P<0.98), weaning weight (P<0.74), and lactation weight loss (P<0.67) among the treatments. Litter size at weaning (P<0.98) and mortality from d 2 to weaning (P<0.93) was also similar across the treatments.

Overall, differences in litter weaning weights (P<0.80), total gain (P<0.50), and daily gain (P<0.52) among litters fed creep for different durations were not significant (Table 3). For individual pigs, differences in weaning weight (P<0.61), total gain (P<0.38), and average daily gain (P<0.38) among creep-fed litters for different durations were also not significant (Table 4). These results suggest that the availability of creep feed for longer durations did not improve weaning weights and weight gains of both pigs and litters. This may be due to the relatively small creep feed intake during the first week of creep feeding; intake may have been insufficient to generate any differences in growth performance.

From d 8 to 14, litters offered creep feed for 13 d had a total intake of 0.36 lb (Figure 1). From d 15 to 20, litters fed creep for 6 d had a higher (P<0.02) total creep intake than litters fed creep for 13 d. Likewise, litters provided with creep feed for 6 and 2 d also tended (P<0.09) to have higher total creep intake than litters fed creep for 13 d. Overall, the total creep feed intake of litters fed for 13 and 6 d were greater (P<0.0001) than those litters provided creep feed for only 2 d (Figure 1). There were no differences (P<0.69) in total creep intake between those fed for 13 and 6 d. These results suggest that initiating creep feeding at a later age does not detrimentally affect creep intake; instead, older piglets readily accept creep feed and consume the same or more feed than piglets started on creep feed at an earlier age. Thus, litter creep intake seems to be more related to the maturity of piglets rather than the period of induction of creep feeding.

The duration of creep feeding influenced (P<0.03) the proportion of eaters in creep-fed litters (Figure 2). Litters provided with creep feed for 13 d produced 10% more (P<0.03) eaters than litters fed creep for both 6 and 2 d. There were no differences (P<0.98) in the percentage of eaters between litters fed creep for 6 and 2 d. The higher rate of eaters suggests that the longer availability of creep feed to litters helps stimulate more piglets to consume creep feed and improves the average creep consumption of piglets categorized as eaters. However, a 10% difference in eaters also indicates that the additional 7 to 11 d of creep feeding generated only 1 more eater per litter (for a litter of at least 10 piglets). Therefore, the benefit of longer durations of creep feeding should be weighed based on the economic value of creating more eaters in whole litters.

In conclusion, longer durations of creep feeding do not affect pre-weaning gain and weaning weights but can increase the proportion of eaters in whole litters. The adoption of longer creep feeding durations should be evaluated based on practicality and the economic benefits of improved piglet performance attributed to eaters post-weaning.

Table 1. Diet Composition (as-fed basis)

Ingredient, %	Creep[a]	Lactation[b]
Corn	6.15	60.00
Soybean meal (46.5% CP)	2.32	31.20
Spray dried whey	25.00	-
Fine ground oat groats	30.00	-
Extruded soy protein concentrate	10.00	
Spray-dried animal plasma	6.00	-
Select menhaden fish meal	6.00	-
Lactose	5.00	
Choice white grease	5.00	5.00
Monocalcium P (21% P)	0.35	1.45
Chromium oxide	1.00	-
Antibiotic	1.00	
Limestone	0.45	1.20
Zinc oxide	0.38	-
Salt	0.30	0.50
L-Lysine HCl	0.15	-
DL-methionine	0.15	-
Trace mineral premix	0.15	0.15
Vitamin premix	0.25	0.25
Sow add pack	-	0.25
Acidifier	0.20	-
Flavor	0.10	-
Vitamin E, 20,000 IU	0.05	-
Total	100.00	100.00
Calculated analysis		
Crude protein, %	23.9	19.6
TID Lysine, %	1.56	0.97
ME, kcal/lb	1,585	1,589
Calcium, %	0.79	0.87
Available P, %	0.56	0.38
TID Lysine:ME ratio, g/Mcal	4.47	2.77

[a]Diet fed in pellet form.
[b]Diet fed in meal form throughout lactation.

Table 2. Effects of Varying Creep Feeding Durations on Sow Performance[ab]

Item	Creep Feeding Duration, d			SED	Probability, *P*<
	13	6	2		
No. of sows	18	18	16	-	-
Lactation length, d	19.7	19.9	20.0	0.2	0.33
Average parity	2.1	2.1	2.2	0.2	0.95
Lactation feed intake, lb					
Total (d 0 to 20)	225	223	231	14.5	0.76
ADFI	11.4	11.2	11.5	0.7	0.53
Sow weight, lb					
Post-farrowing	480	482	482	14.5	0.98
Weaning	445	450	456	14.5	0.74
Change	-34.7	-32.1	-27.7	7.9	0.67
No. of pigs/litter					
Post-fostering	12.2	12.3	12.2	0.1	0.51
D 20 (weaning)	11.2	11.3	11.2	0.3	0.98
Mortality (d 2 to 20), %	7.7	7.9	8.6	2.3	0.93

[a]Two groups of sows (total =52, PIC Line 1050) were blocked according to day of farrowing and parity and allotted to three treatments (13, 6, and 2 d creep feeding durations).
[b]Creep feed with 1.0% chromium oxide was offered *ad libitum* from d 7, 14, and 18 to weaning (20 d).

Table 3. Effects of Varying Creep Feeding Durations on Litter Performance[ab]

Item	Creep Feeding Duration, d			SED	Probability, *P*<
	13	6	2		
No. of litters	18	18	16	-	-
No. of pigs	219	221	197	-	-
Litter weight, lb					
Post-fostering	34.0	34.2	33.9	1.0	0.97
D 7	60.4	60.8	60.6	2.7	0.99
D 14	102.0	100.1	99.8	5.1	0.89
D 18	129.0	127.1	125.7	6.1	0.86
At weaning	141.2	138.1	137.0	6.6	0.80
Litter BW gain, lb					
D 8 to 14	41.7	39.4	38.9	2.8	0.55
D 15 to 18	27.0	27.0	25.9	1.6	0.75
D 19 to 20	12.2	11.0	11.2	1.0	0.41
D 15 to 20	39.2	38.0	37.2	2.2	0.65
D 8 to 20	80.9	77.3	76.0	4.4	0.50
Litter ADG, lb					
D 8 to 14	5.96	5.62	5.55	0.40	0.55
D 15 to 18	6.75	6.76	6.45	0.41	0.75
D 19 to 20	6.56	6.33	6.20	0.37	0.62
D 15 to 20	6.14	5.51	5.65	0.50	0.41
D 8 to 20	6.22	5.96	5.85	0.34	0.52

[a]Two groups of sows (total =52, PIC Line 1050) were blocked according to day of farrowing and parity and allotted to three treatments (13, 6, and 2 d creep feeding durations).
[b]Creep feed with 1.0% chromium oxide was offered ad libitum from d 7, 14, and 18 to weaning (d 20).

Table 4. Effects of Varying Creep Feeding Durations on Pig Performance[ab]

Item	Creep Feeding Duration, d			SED	Probability, *P*<
	13	6	2		
No. of litters	18	18	16	-	-
No. of pigs	219	221	197	-	-
Pig weight, lb					
Post-fostering	3.05	3.04	3.04	0.07	0.97
D 7	5.40	5.40	5.40	0.17	0.99
D 14	9.13	8.89	8.94	0.36	0.78
D 18	11.55	11.29	11.24	0.44	0.75
At weaning	12.66	12.26	12.26	0.47	0.61
Pig BW gain, lb					
D 8 to 14	3.73	3.49	3.54	0.22	0.49
D 15 to 18	2.42	2.39	2.3	0.14	0.68
D 19 to 20	1.11	0.97	1.02	0.08	0.19
D 15 to 20	3.53	3.37	3.32	0.18	0.46
D 8 to 20	7.26	6.86	6.86	0.34	0.38
Pig ADG, lb					
D 8 to 14	0.533	0.499	0.506	0.031	0.49
D 15 to 18	0.605	0.598	0.574	0.036	0.68
D 19 to 20	0.556	0.487	0.511	0.039	0.19
D 15 to 20	0.589	0.561	0.553	0.030	0.46
D 8 to 20	0.559	0.527	0.528	0.026	0.38

[a]Two groups of sows (total =52, PIC Line 1050) were blocked according to day of farrowing and parity and allotted to three treatments (13, 6, and 2 d creep feeding durations).
[b]Creep feed with 1.0% chromium oxide was offered ad libitum from d 7, 14, and 18 to weaning (d 20).

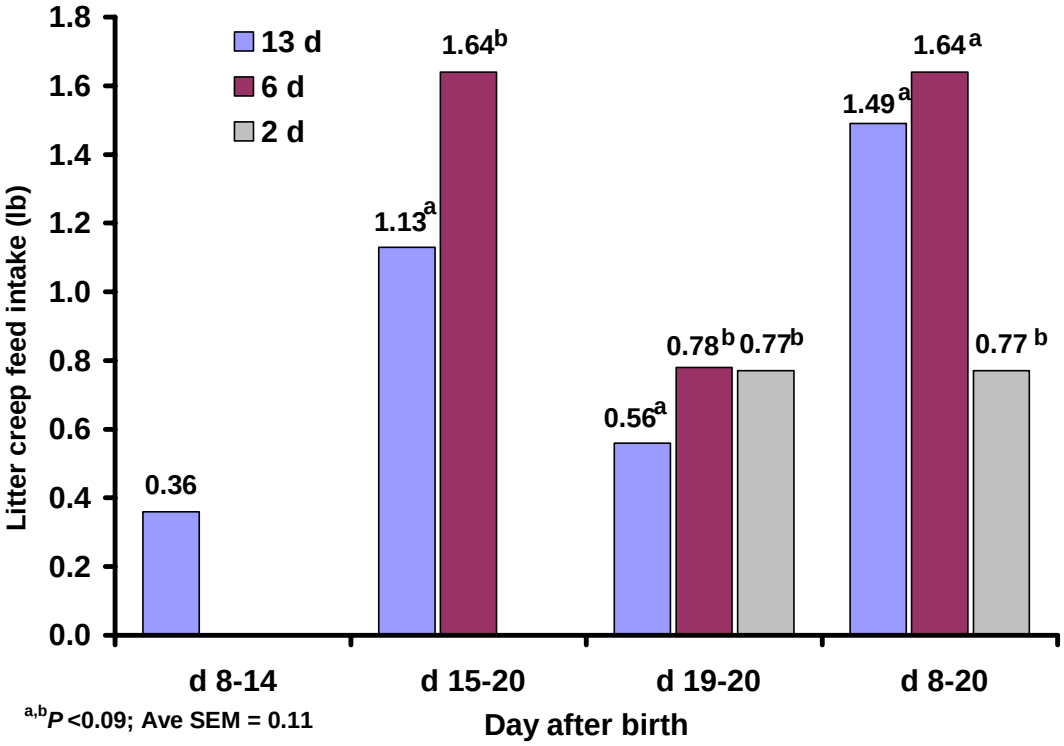

Figure 1. Effect of Varying Creep Feeding Durations on Total Litter Creep Feed Intake.

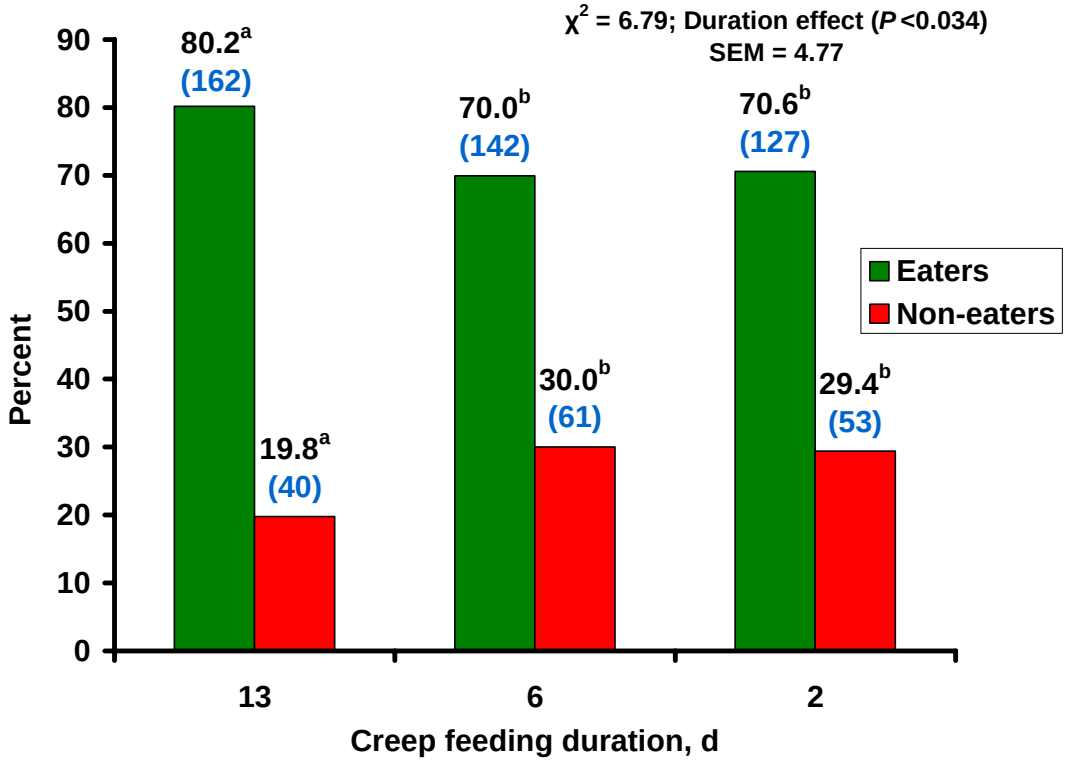

Figure 2. Effect of Varying Creep Feeding Durations on Percentage of Eaters (number of pigs in parentheses).

EFFECTS OF DIFFERENT CREEP FEEDER DESIGNS AND FEED ACCESSIBILITY ON CREEP FEED CONSUMPTION AND LITTER PERFORMANCE[1]

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Summary

The objective of this experiment was to determine the effects of different creep feeder designs and increased feed accessibility on creep feed consumption and pre-weaning performance. A total of 54 sows (PIC Line 1050) and their litters were used in this study. Two groups of sows were blocked according to parity and date of farrowing using a randomized complete block design and allotted to three experimental treatments: Treatment 1 – rotary feeder with hopper (Control), Treatment 2 – rotary feeder without hopper, and Treatment 3 – pan feeder. A creep diet (1,585 kcal ME/lb, 1.56% TID Lys) with 1.0% chromium oxide was offered *ad libitum* at d 18 until weaning (d 21). A single lactation diet (1,586 kcal ME/lb, 0.97% TID Lys) was used, where sows were allowed free access to feed throughout lactation. Piglets were weighed individually at d 0 (birth), 18, and 21 (weaning) to calculate total and daily gains. Litter creep feed intake as feed disappearance was also calculated. Fecal samples from all piglets were taken twice using sterile swabs between 3 and 12 h before weaning for all treatments. Piglets were categorized as 'eaters' when the fecal sample was colored green at least once on any of the two samplings. Results showed no differences in pig ($P<0.18$) and litter ($P<0.51$) weights at weaning among litters using the different types of creep feeder. Total and daily gains of pigs ($P<0.20$) and litters ($P<0.31$) were also similar across treatments. Litters using the rotary feeder without the hopper or the pan feeder had 2.7 times greater ($P<0.0001$) total creep disappearance than those using the rotary feeder with the hopper. The average feeding frequency was 1, 2.3, and 4.2 times per 12 h for the rotary feeder with and without the hopper, and the pan feeder, respectively. Creep feeder design influenced ($P<0.0001$) the proportion of eaters created among piglets provided with creep feed. There were 69, 47, and 42% eaters in creep-fed litters using the rotary feeder with a hopper, rotary feeder without hopper, and pan feeder, respectively. In conclusion, the proportion of eaters in creep-fed litters can be influenced by non-dietary factors, such as creep feeder design.

(Key words: feed management, creep feed, feeder design.)

Introduction

Previous studies have shown that suckling piglets categorized as eaters have higher intakes and better growth performance immediately post-weaning than non-eaters of creep feed. If creep feeding behavior can be encouraged and more eaters can be created within a litter, then post-weaning performance can be improved. Very few studies have evaluated the effect of different creep feeder designs and

[1]Appreciation is expressed to TechMix, Inc., Stewart, Minnesota, for donation of a portion of the feeders used in this experiment.

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creep feed accessibility on feeding behavior, intake, and performance of suckling piglets. Some of these studies have shown positive improvements on feeder visiting time and intakes of suckling pigs by using a familiar trough or when feeding space was increased. However, these studies evaluated whole litters and did not differentiate between eaters and non-eaters within a litter. Moreover, the effects of different types of creep feeders on creating eaters have never been evaluated. Therefore, the objective of this experiment was to determine the effects of different creep feeder designs and increasing creep feed accessibility on the rate of creating piglet eaters and pre-weaning performance.

Procedures

A total of 54 sows (PIC Line 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 two batches of sows farrowed in June and July 2007, with 27 experimental sows included from each batch. Sows were blocked according to parity and date of farrowing and were allotted to three experimental treatments using a randomized complete block design. Cross-fostering was performed within 48 h post-farrowing to standardize litter weights and litter size (>10 pigs). The sow or litter was the experimental unit with 18 replicates per treatment group.

There were three types of creep feeder designs tested in this study. Treatment 1 used a rotary creep feeder (Rotecna® Mini Hopper Pan, Rotecna SA, Spain), which is 10.6 inches in diameter, 34 inches in linear feeding space, and 2.1 inches deep (Figure 1). It is designed to accommodate 5 pigs per feeding time. This feeder design is equipped with a 6-liter capacity hopper, which is adjustable to five different settings of feeder gaps to allow *ad libitum* feeding. The hopper also has a curved rim and wings that helps separate piglets while feeding and to minimize feed wastage. The feeder can also be latched to the flooring of the pen and fixed on a specific location within the farrowing crate. This feeder was used in our previous creep feeding studies, and, therefore, served as the control treatment in this study. In past studies, 70% of piglets were categorized as eaters using this feeder. For Treatment 2, a rotary creep feeder without a hopper (Rotecna® Mini Pan, Rotecna SA, Spain) was used (Figure 2). This feeder design has the same dimensions as the feeder in Treatment 1, and can also be latched on a specific location within the farrowing crate. This feeder represents conventional bowl feeders that are commonly used in the industry. For Treatment 3, a stainless pan feeder was used (Figure 3). This feeder is 40.2 inches long, 5.3 inches wide, and 1 inch deep. The feeder is placed in between the divider of two farrowing crates, which provides two feeding troughs per feeder with a 1.1 inch width per trough. The rotary creep feeder (Treatment 1 and 2) was placed in a location where it was most accessible to piglets, sows could not urinate or defecate in it, or the side opposite of the udder area of the sow. This was chosen to ensure creep feed accessibility, prevent soiling of the creep feed, and allow unhindered suckling of piglets to the sow.

A creep diet (1,585 kcal ME/lb, 1.56% TID Lys) with 1.0% chromium oxide was offered *ad libitum* at d 18 until weaning on d 21 (Table 1). The creep diet was in pellet form (2-mm pellets). For Treatment 1, sufficient amounts of creep feed were placed in the hopper to ensure that feed was always available. The adjustment of the hopper was checked daily to allow *ad libitum* feeding and control feed wastage. For Treatments 2 and 3, small amounts of creep feed were placed on the feeder whenever the feeder was empty. The feeders were checked every 2 h for 12 h each day. In every crate, the daily frequency of adding creep feed was recorded. A single lactation diet (1,586 kcal ME/lb, 0.97% TID Lys) was used in the experiment. Sows were allowed free access to feed throughout lactation.

Water was made available at all times for both sows and their litters using nipple drinkers and bowls, respectively.

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 were collected using a Mini Shop-Vac® 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 that tested negative on the first fecal sampling were re-sampled 9 to 12 h after the first sampling. Piglets were categorized as 'eaters' when the fecal sample was colored green at least once on any of the two samplings.

Sows were weighed post-farrowing and at weaning. Weekly feed intake of the sows was recorded to calculate total and average daily 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 using heat lamps when needed.

Periodic and cumulative average daily gain and creep feed intake as feed disappearance were calculated for each treatment group. Data were analyzed as a randomized complete block design using PROC MIXED of SAS. The effect of different creep feeder designs on percentage of eaters was analyzed using the Chi-square test in SAS.

Results and Discussion

The technical parameters and performance of lactating sows used in this study is shown in Table 2. Experimental sows had an average parity of 2.1 ± 0.2 and lactation length of 21.1 ± 0.3 d. There were no differences in post-farrowing weight (P<0.90), weaning weight (P<0.90), and lactation weight loss (P<0.56) among the treatments. Total and average daily feed intake of sows throughout lactation was also similar (P<0.30) among the treatments.

The effect of different creep feeder designs on pig and litter performance is shown in Table 3. There were no differences in pig (P<0.18) and litter (P<0.51) weights at weaning among litters using the different types of creep feeder. Total and daily gains of pig (P<0.20) and litters (P<0.31) were also similar across treatments. However, litters using the rotary feeder without the hopper or the pan feeder had 2.7 times greater (P<0.0001) total creep disappearance than those using the rotary feeder with the hopper. (Figure 4).

The lack of differences in pig and litter growth rates among the treatments suggest that a large proportion of creep feed offered to litters using the rotary feeder without the hopper and the pan feeder were not consumed but wasted. The design of these two feeders is more open and creep feed is more accessible to piglets compared to the feeder with the hopper. However, these feeders also allowed some piglets to root, lie in, and push feed out of the feeder, which eventually reduced the availability and accessibility of creep feed to other piglets. The higher creep feed disappearance with the pan feeder also confirmed results of other studies where increased access to creep feed was provided. The pan feeder in this study was designed to provide more feeding spaces than the rotary feeder, but piglets more often approach and consume creep feed with their bodies parallel to the feeder rather than pigs eating side by side (Figure 3).

The addition of the hopper to the rotary feeder reduced total creep disappearance without affecting growth performance. This feeder design was used in our previous creep feeding trials and was shown to measure none to very small amounts of creep intake for whole litters, indicating its ability to control feed wastage. It can be assumed that the total creep disappearance measured in this study

with this feeder is close to the true intake of creep feed by the litter. There are aspects of the design of this feeder that may help explain the lower creep disappearance. The conical shape as well as the curved rim and wings at the bottom of the hopper prevented piglets from rooting, standing over, or pushing creep feed out of the troughs. The hopper was also adjusted daily to manage the amount of feed that flowed out of the gap, which controlled the level of feed in the trough.

The average feeding frequency was 1, 2, 3, and 4.2 times per 12 h for the rotary feeder with and without the hopper, and the pan feeder, respectively. Though the rotary feeder with hopper allowed *ad libitum* feeding, the daily weighing and re-introduction of the feeder to the litter was counted as one feeding per day. The higher feeding frequency for both the rotary feeder without the hopper and the pan feeder were facilitated to minimize feed wastage. In creep feeding, the typical recommendation is to feed small amounts frequently to stimulate intake and manage feed wastage. However, the practice still allowed higher creep disappearance than the feeder with the hopper. This also demonstrated the extra effort needed to manage these creep feeders, which in the end, did not provide any positive returns.

In terms of creating eaters, the type of creep feeder influenced ($P<0.0001$) the proportion of eaters created among piglets provided with creep feed (Figure 5). In litters using the rotary feeder with the hopper, 69 and 31% of suckling piglets were categorized as eaters and non-eaters at weaning, respectively. These proportions were consistent with our previous creep feeding studies using the same feeder and creep diet. On the other hand, litters on the rotary feeder without the hopper had 22% fewer eaters ($P<0.0001$) than with litters on the rotary feeder with the hopper. Likewise, litters using the pan feeder had 27% less eaters ($P<0.0001$) than litters on the rotary feeder with the hopper.

The higher proportion of eaters created using the rotary feeder with the hopper may be a function of both feeder design and piglet creep consumption. The addition of the hopper to the rotary feeder significantly increased the percentage of eaters, which may be partially attributed to its design. This feeder design staves off piglets from wasting feed and provides continuous availability of feed in the troughs. In a recent study evaluating Cr_2O_3 as a marker for identifying creep feed-eating piglets, eaters were identified as piglets consuming Cr_2O_3-containing creep feed in appreciable amounts or in multiple days. Therefore, this feeder enabled more piglets in the litter to consume significant amounts of creep feed. This finding further supports the assumption that creep feed disappearance using this feeder is close to the true value of litter creep intake.

The lower proportion of eaters generated from litters using the rotary feeder without the hopper and the pan feeder also supports the notion that more creep feed was wasted than consumed. Greater accessibility and increased feeding spaces resulted to higher creep disappearance, but did not produce more eaters within the litter. This is contrary to the assumption of previous studies, where increased feeding space and accessibility was thought to encourage more piglets to imitate others at the feeder and stimulate initial intake of creep feed. The fewer number of eaters in this study suggest that less creep feed was available in these feeders for piglets to consume in appreciable amounts. Moreover, the rate of feed wastage due to physical activity of piglets on the feeder may be faster than their rate of consumption.

In conclusion, the type of creep feeder may influence the proportion of eaters in creep-fed litters. Increasing feeding space and feed accessibility led to higher feed disappearance, but did not necessarily generate more eaters in whole litters. The rotary feeder with the hopper achieved a lower creep feed disap-

pearance, but created the most eaters. Thus, the proper choice of creep feeder is essential to manage creep feeding and to maximize the number of eaters in the litter.

Figure 1. Rotary Feeder With Hopper (Control).

Figure 2. Rotary Feeder Without Hopper.

Figure 3. Pan Feeder.

Table 1. Diet Composition (as-fed basis)

Ingredient, %	Creep[a]	Lactation[b]
Corn	6.15	60.00
Soybean meal (46.5% CP)	2.32	31.20
Spray dried whey	25.00	-
Fine ground oat groats	30.00	-
Extruded soy protein concentrate	10.00	
Spray-dried animal plasma	6.00	-
Select menhaden fish meal	6.00	-
Lactose	5.00	
Choice white grease	5.00	5.00
Monocalcium P (21% P)	0.35	1.45
Chromium oxide	1.00	-
Antibiotic	1.00	
Limestone	0.45	1.20
Zinc oxide	0.38	-
Salt	0.30	0.50
L-Lysine HCl	0.15	-
DL-methionine	0.15	-
Trace mineral premix	0.15	0.15
Vitamin premix	0.15	0.25
Sow add pack	-	0.25
Acidifier	0.20	-
Flavor	0.05	-
Vitamin E, 20,000 IU	0.05	-
Total	100.00	100.00
Calculated analysis		
Crude protein, %	23.9	19.6
TID Lysine, %	1.56	0.97
ME, kcal/lb	1,585	1,589
Calcium, %	0.79	0.87
Available P, %	0.56	0.38
TID Lysine:ME ratio, g/Mcal	4.47	2.77

[a]Diet fed in pellet form.
[b]Diet fed in meal form throughout lactation.

Table 2. Sow Technical Parameters[ab]

Treatment	Feeder Design			SED	Probability, *P*<
	Rotary feeder with hopper	Rotary feeder without hopper	Pan feeder		
No. of litters	18	18	18	-	-
No. of pigs	189	188	185	-	-
Average parity	2.1	2.2	2.0	0.13	0.23
Lactation length, d	21.1	21.2	21.2	0.17	0.60
Sow weight, lb					
Post-farrowing	504	511	503	19.1	0.90
Weaning	478	485	484	17.2	0.90
Change	-26	-26	-19	5.6	0.56
Lactation feed intake, lb					
Total	227.4	232	246.5	12.6	0.30
ADFI	11.3	11.5	12.2	0.64	0.35

[a]Two groups of sows (total =54, PIC Line 1050) were blocked according to day of farrowing and parity and allotted to the three treatments.
[b]Creep feed with 1.0% chromium oxide was offered *ad libitum* from d 18 to weaning (20 d).

Table 3. Effects of Different Creep Feeder Designs on Pig and Litter Performance[ab]

Treatment	Feeder Design			SED	Probability, *P*<
	Rotary feeder with hopper	Rotary feeder without hopper	Pan feeder		
No. of litters	18	18	18	-	-
No. of pigs/litter					
D 18 (start creep)	10.5	10.4	10.3	0.27	0.70
D 21 (weaning)	10.5	10.4	10.3	0.27	0.70
Pig weights, lb					
Post-fostering	3.0	3.0	3.0	0.06	0.96
D 18 (start creep)	10.8	11.3	11.4	0.37	0.21
D 21 (weaning)	12.4	13.1	13.1	0.43	0.18
Total gain (d 18 to 21), lb	1.6	1.8	1.7	0.09	0.20
Daily gain (d 18 to 21), lb	0.54	0.59	0.58	0.03	0.20
Litter weights, lb					
Post-fostering	31.6	31.4	31.0	0.69	0.66
D 18 (start creep)	113.4	117.6	117.3	4.48	0.58
D 21 (weaning)	130.3	135.9	135.2	5.23	0.51
Total gain (d 18 to 21), lb	16.9	18.4	17.9	1.0	0.31
Daily gain (d 18 to 21), lb	5.64	6.12	5.96	0.32	0.31

[a]Two groups of sows (total =54, PIC Line 1050) were blocked according to day of farrowing and parity and allotted to the three treatments.
[b]Creep feed with 1.0% chromium oxide was offered *ad libitum* from d 18 to weaning (20 d).

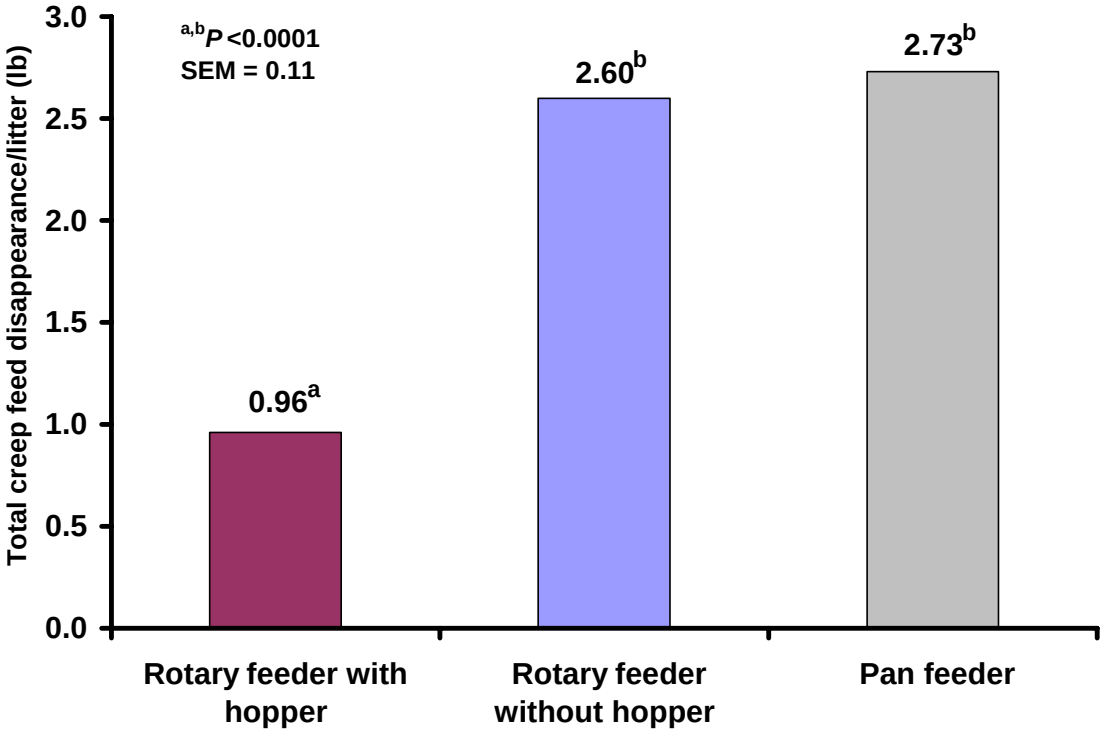

Figure 4. Total Creep Feed Disappearance Between Different Creep Feeder Designs.

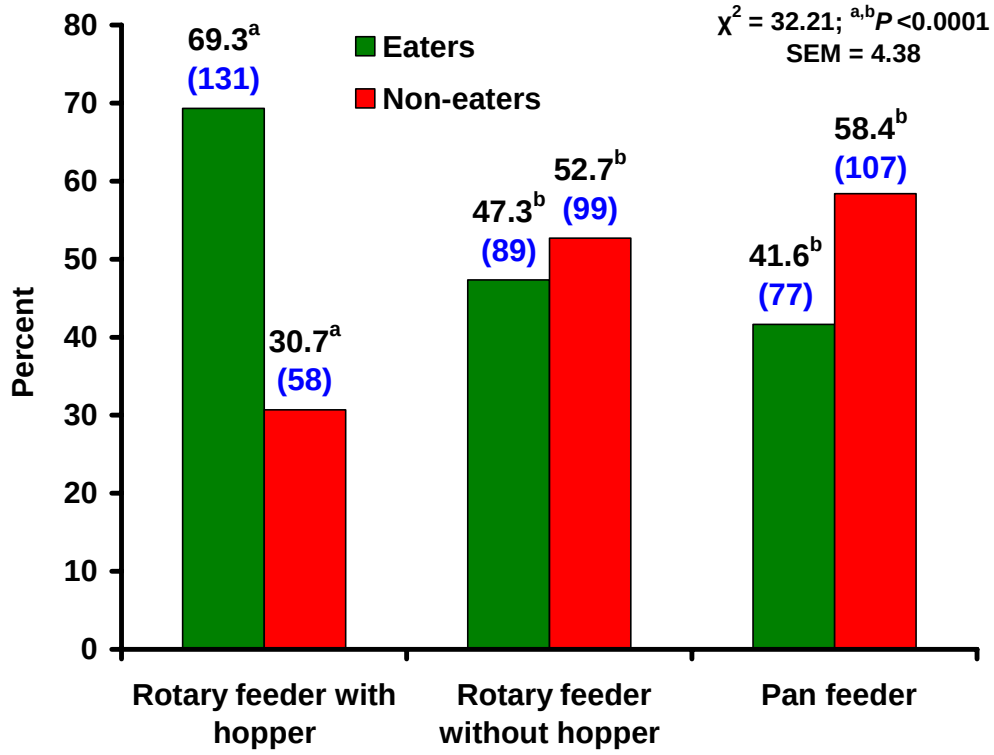

Figure 5. Effect of Creep Feeder Design on Creating Eaters (number of pigs in parentheses).

VALIDATION OF FLANK-TO-FLANK ALLOMETRIC EQUATIONS IN PREDICTING WEIGHT OF LACTATING SOWS AND LACTATION WEIGHT CHANGE

R. C. Sulabo, M. D. Tokach, S. S. Dritz[1], E. J. Wiedemann, R. D. Goodband, J. M. DeRouchey, and J. L. Nelssen

Summary

The objectives of this study were to validate the use of flank-to-flank measurement in predicting weight of lactating sows and to determine the accuracy of the developed models in estimating lactation weight change. A total of 70 lactating sows (PIC Line 1050) were used in this study. Flank-to-flank measurement and body weight were measured on each individual sow after farrowing and at weaning. Flank-to-flank measurement and weight of lactating sows was positively correlated (R^2 = 0.61; P<.0001) with the following equation: $BW^{0.33}$, kg = 0.0371 x Flank-to-flank (cm) + 2.161. Weights of sows post-farrowing and at weaning were lower (P<0.03) when predicted with the previous allometric model developed from growing pigs and sows than their actual weights or weights predicted using the lactating sow model. Likewise, absolute residuals for post-farrowing and weaning weights using a previous allometric model developed from growing pigs and gestating sows were greater (P<0.02) than those of the lactating sow model. There were no differences (P<0.89) between the predicted weights using the lactating sow model and their actual weights. There also were no differences between the actual average weight loss (P<0.14) and the predicted loss using the lactating sow model. Using the model previously developed with growing pigs and gestating sows resulted in 15.5 lb (P<0.007) greater than the actual average weight loss. In conclusion, flank-to-flank measurement can be used as a predictor of weight of lactating sows, with the relationship having less accuracy than those used for growing-finishing pigs, gestating sows, and boars. The pig allometric equation cannot be used to estimate weights of lactating sows and lactation weight change. The developed lactating sow model was more appropriate in estimating weights and weight loss at the herd level, but needs to be validated on other sows before use can be recommended.

(Key words: lactating sows, flank-to-flank, allometric equations, weight.)

Introduction

Kansas State University researchers have developed an allometric equation that uses flank-to-flank measurement as a valid predictor of pig body weight (Figure 1). This model encompassed a wide range of weights (150 to 800 lb) and was developed in numerous genetic lines and both sexes of pigs. The ability to predict pig body weight accurately within the weight range provides numerous potential applications. In sows, this provided a simple yet more accurate method of categorizing sows into weight categories that can be useful in developing feeding programs, especially during gestation. Some pig producers have

[1]Food Animal Health and Management Center, College of Veterinary Medicine.

also applied this model in estimating weight of lactating sows and used these estimates to determine weight change during lactation. However, the model has not been tested in lactating sows for its validity in estimating changes in weight. Therefore, the objective of this study was to validate the use of flank-to-flank measurement in predicting weight of lactating sows in different physiological stages and to determine the accuracy of the sow models in estimating lactation weight change.

Procedures

A total of 70 lactating sows (PIC Line 1050) at the Kansas State University Swine Research and Teaching Center were used in this study. Sows were weighed using a platform scale after farrowing and at weaning. Then using a cloth tape measure, flank-to-flank measurement was taken immediately in front of the hind legs of the sow. Measurement was from the bottom of the flank on one side to the bottom of the flank on the other side, with the cloth tape being placed over the top of the hip. The date of measurement, sow ID, parity, body weight (BW), and flank-to-flank measurement were recorded.

The weights of the sows post-farrowing and at weaning were estimated using two equations: Equation 1 – the original growing pig and gestating sow allometric model, and Equation 2 – the lactating sow model with BW expressed as $BW^{0.33}$ developed from the sows in this experiment. The model to predict weight of lactating sows using flank-to-flank measurement was developed using PROC REG of SAS. To improve the accuracy of the developed model, all observations were analyzed for influential outliers using multiple criteria, including studentized residuals, h value, DFITTS, DFBETAS, Cook's D, and CovRatio. Observations with values from the SAS output that exceeded the calculated critical value for three of the six criteria were removed from the model. A total of four sows were considered influential outliers and were excluded in the analysis. Residuals were used to estimate the accuracy of the equations in estimating post-farrowing and weaning weights. The residuals were calculated as the absolute value of the difference between predicted weight using the two allometric equations and actual weight measured. Lactation weight change was measured as the difference between the weight of the sow at weaning and its post-farrowing weight. Differences between the actual and predicted values for post-farrowing weight, weaning weight, absolute residuals, and lactation weight change were compared and analyzed using PROC GLM of SAS with the individual sow as the experimental unit.

Results and Discussion

The relationship between flank-to-flank measurement and weight of lactating sows expressed on an allometric basis ($BW^{0.33}$) is shown in Figure 2. Flank-to-flank measurement and weight of lactating sows was positively correlated ($R^2 = 0.61$; $P<.0001$) with the following equation: $BW^{0.33}$, kg = 0.0371 × flank-to-flank (cm) + 2.161. This result agrees with previous work on growing-finishing pigs, gestating sows, and boars and indicates that flank-to-flank measurement can also be used to estimate weight of lactating sows. However, the developed lactating sow model only explains 61% of the variation in sow weights, which is considerably lower than the original pig and gestating sow model (96%) and the boar model (86%).

Using the pig model, the predicted weights of sows post-farrowing and at weaning were 24 ($P<0.03$) and 40 lb ($P<0.0001$) lower than their actual weights, respectively (Figure 3). These estimates were also lower ($P<0.01$) than the predicted weights using the lactating sow model. Likewise, absolute residuals for post-farrowing and weaning weights using the pig allometric equation were 9.2 ($P<0.02$) and 16 lb ($P<0.0008$) greater than those of the lactating sow model (Figure 4). There were no

differences ($P<0.89$) between the predicted weights using the lactating sow model and their actual weights. This is expected as the lactating sow model was developed from the same group of sows as used to test the accuracy; however, the growing pig and gestating sow model did not accurately predict the weight of lactating sows at any physiological stage. This did not conform with previous work on adult, working boars, where the growing pig and gestation sow allometric equation fit the boar data as well as the developed boar equation. This suggests that there are more variations in body shape or differences in body volume of lactating sows that cannot be explained solely by linear body dimensions. The underestimation of weights may also be partially explained by the unaccounted contribution of mammary gland growth throughout lactation. University of Illinois researchers previously determined the compositional changes of suckled mammary glands from d 5 to 28 of lactation. Wet weights of a suckled mammary gland increased linearly from 0.84 lb/suckled gland at d 5 to 1.30 lb/suckled gland at d 21 of lactation. If the sow is suckling at least 10 pigs, then the unaccounted weight will be 8.4 and 13.1 lb at d 5 and 21, respectively. Changes in other mammary tissues and body stores throughout lactation may also contribute to the underestimation.

At the individual sow level, the predicted weight change using the pig model and the lactating sow model with the actual lactation weight change was highly variable. For example, both models predicted a positive weight gain in only one out of six sows that actually gained weight during lactation. There were also two sows that were predicted to have had a positive weight gain, when both actually lost weight. At the herd level, the predicted weight loss using the pig model was 15.5 lb ($P<0.007$) greater than the actual average weight loss, and the predicted weight loss using the lactating sow model was intermediate (Figure 5). There were no differences between the actual average weight loss ($P<0.14$) and the predicted loss using the lactating sow model. These illustrate the inability of either model to accurately estimate lactation weight change at the individual sow level. However, the lactating sow model was more accurate in estimating lactation weight loss than the pig model at the herd level. These results negate the potential usefulness of this method in estimating weight loss of individual lactating sows. The potential application of this model may be in performing experiments that will create differences and require the determination of weights and weight changes of groups of sows during lactation. The model measures the average sow weight loss of a group of sows more accurately than the loss of a particular sow. However, the validity of the lactating sow model on other data sets needs to be verified.

In conclusion, flank-to-flank measurement can be used as a predictor of weight of lactating sows, with the relationship having less accuracy than those in growing-finishing pigs, gestating sows, and boars. The allometric equation developed from growing pigs and gestating sows cannot be used to estimate weights of lactating sows and lactation weight change. The developed lactating sow model was more appropriate in estimating weights and weight loss at the herd level.

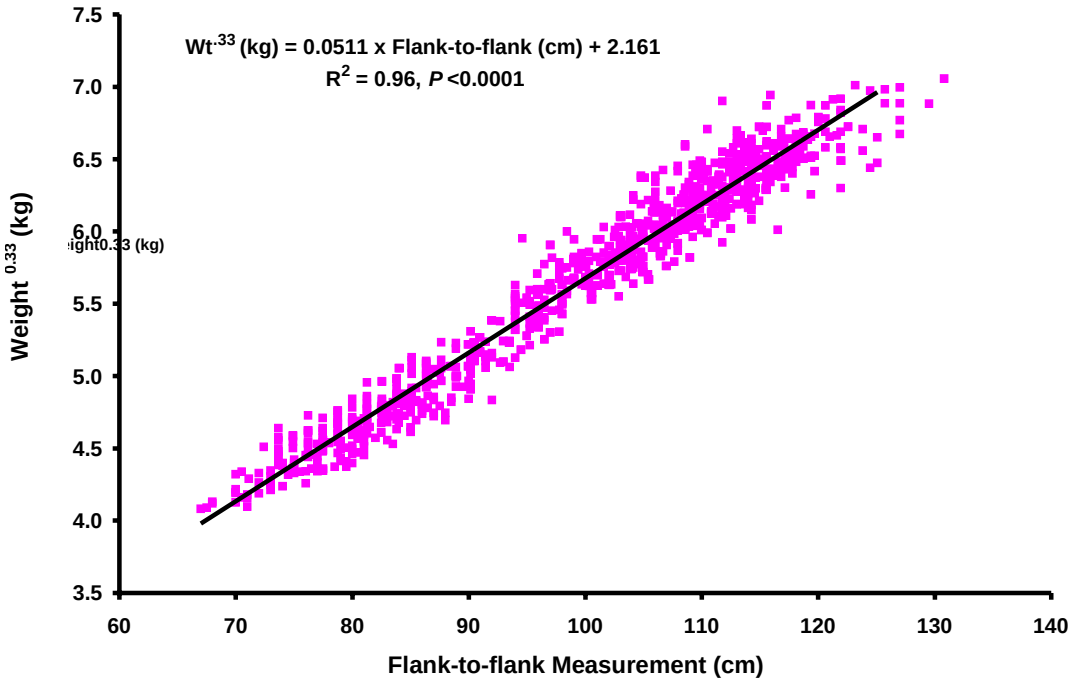

Figure 1. Relationship Between Flank-to-flank Measurement and Pig Body Weight Expressed on an Allometric Basis. This equation was developed in previous experiments (Sulabo et al., 2007).

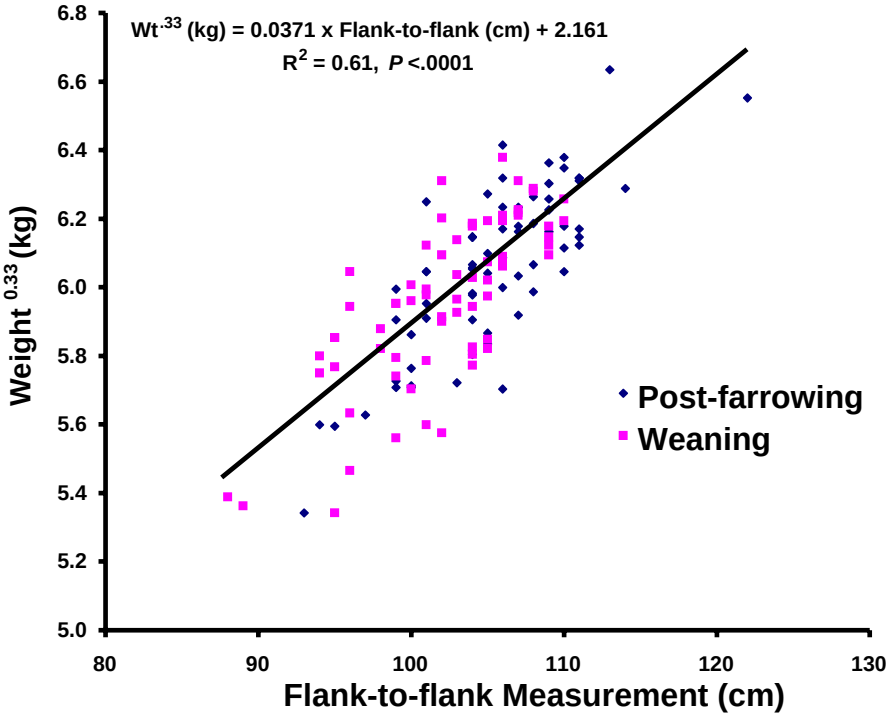

Figure 2. Relationship Between Flank-to-flank Measurement and Weight of Lactating Sows Expressed on an Allometric Basis (66 sows).

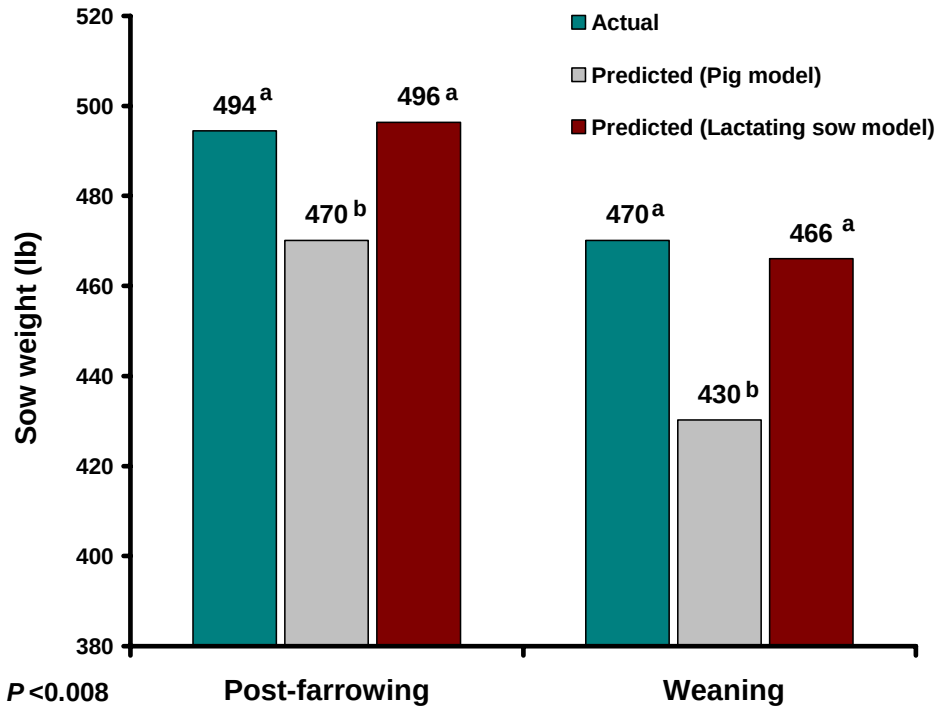

Figure 3. Actual and Predicted Weight of Lactating Sows at Post-farrowing and Weaning Using the Growing Pig and Gestating Sow Model and the Lactating Sow Model.

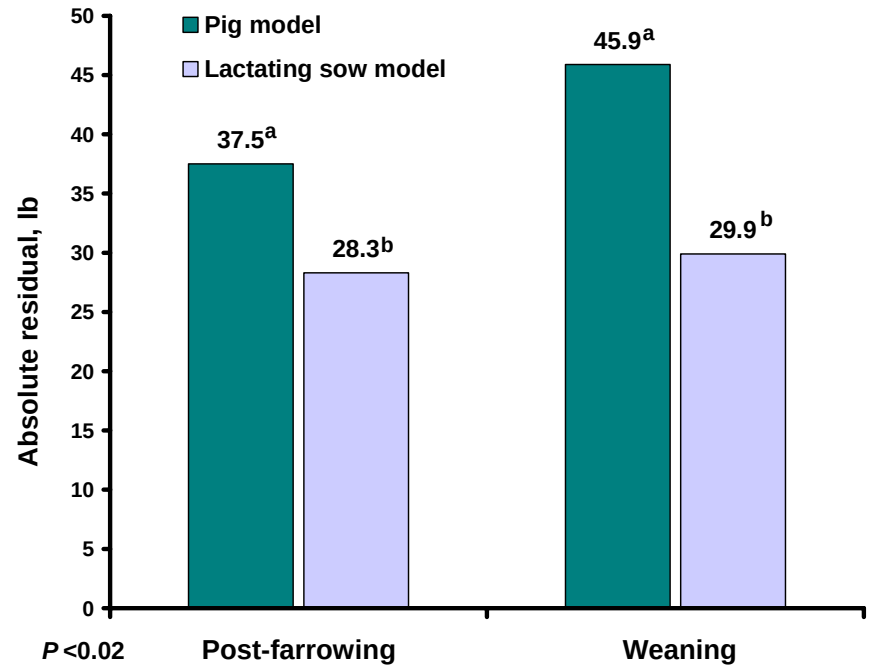

Figure 4. Absolute Residuals Using the Growing Pig and Gestating Sow Model and Lactating Sow Model for Estimating Post-farrowing and Weaning Weights.

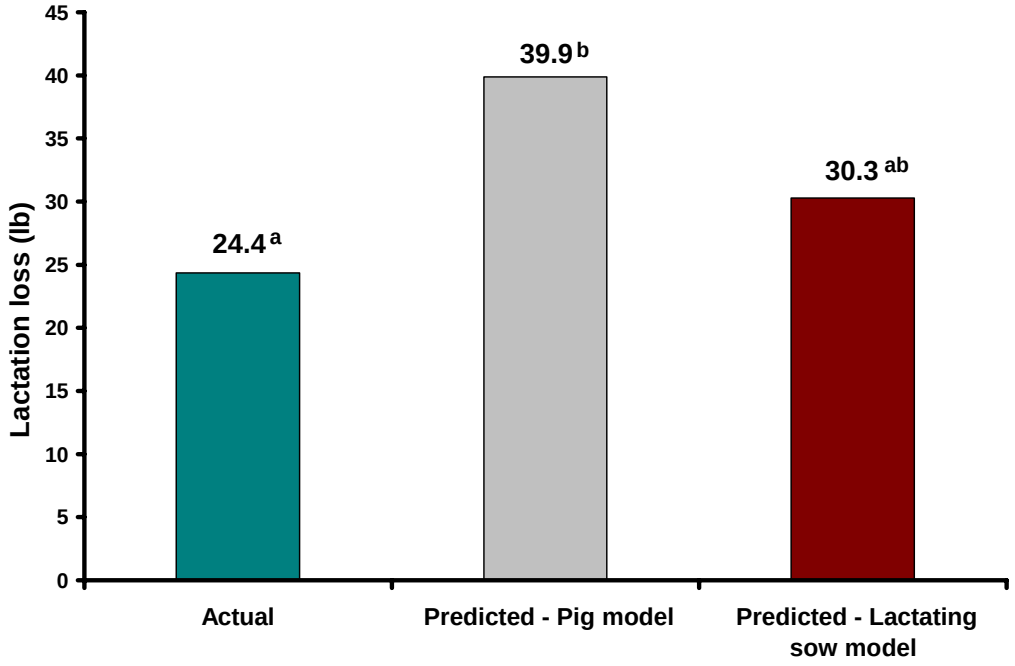

Figure 5. Actual and Predicted Values for Average Lactation Weight Loss Using the Pig Model and Lactating Sow Model.

AN EVALUATION OF DEXTROSE, LACTOSE, AND WHEY SOURCES IN PHASE 2 STARTER DIETS FOR WEANLING PIGS[1]

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Summary

Two experiments were conducted to evaluate the effects of various dextrose, lactose, and whey sources on weanling pig performance. In Exp. 1, a total of 228 pigs (initially 17.1 lb) were used in a 14-d experiment. There were six treatments consisting of a control (corn-soybean meal diet) or the control diet with 7.2% lactose, 7.2% dextrose anhydrous, 7.2% dextrose monohydrate, 10% feed-grade whey, or 10% food-grade whey. Pigs were blocked by weight and randomly allotted to treatment after being fed SEW and Transition diets for the first seven days post-weaning. Overall, ADG and d 14 weight were improved ($P<0.05$) for pigs fed lactose or food-grade whey when compared to pigs fed feed-grade whey. There were no other differences in ADG or d 14 weights among the treatments. Average daily feed intake was improved ($P<0.05$) for pigs fed lactose, dextrose monohydrate, or food-grade whey when compared to those fed feed-grade whey. Feed efficiency was improved ($P<0.05$) for pigs fed food-grade whey rather than dextrose monohydrate. For the economic analysis, pigs fed the control diet had the lowest ($P<0.01$) cost per pound of gain, followed by pigs fed dextrose monohydrate, dextrose anhydrous, feed-grade whey, lactose, and food-grade whey. Margin-over-feed cost was improved ($P<0.05$) for pigs fed the control diet rather than the diets containing lactose, dextrose anhydrous, or either whey source.

In Exp. 2, a total of 352 pigs (initially 17.1 lb) were used in a 14-d experiment to evaluate seven commercial whey sources. There were eight treatments consisting of a corn-soybean meal-based control diet and seven diets containing 10% whey, each of a different whey source. Pigs were blocked by weight and randomly allotted to treatment after being fed SEW and Transition diets for the first five days post-weaning. Overall, ADG and d 14 weight were improved ($P<0.05$) for pigs fed whey sources A and E when compared to the control and sources B and D. Pigs fed whey sources C, F, and G had intermediate ADG. Average daily feed intake was greater ($P<0.05$) for pigs fed whey source E rather than the control or whey sources B, C, D, and G. Feed efficiency was improved ($P<0.05$) for pigs fed whey source A rather than the control. Pigs fed the remaining whey sources had intermediate F/G. For the economic analysis, pigs fed the control diet had the lowest cost per pound of gain ($P<0.01$). Margin-over-feed cost was improved ($P<0.05$) for pigs fed the control diet rather than the diets containing whey sources B, D, and G. Pigs fed whey

[1]Appreciation is expressed to Denny McKilligan of TechMix, Inc., for providing the lactose, dextrose monohydrate, and dextrose anhydrous for a portion of this research.

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

source A had intermediate MOF that was also greater ($P<0.05$) than that of pigs fed whey sources B and D.

In conclusion, differences in the growth performance of pigs fed various whey (or lactose) and dextrose sources exist. The quality, cost, and relative feeding value of lactose sources should be considered when formulating diets for nursery pigs. In some cases, especially with the current high price of dried whey, feeding a Phase 2 diet containing no added source of lactose may be a more economical option despite the slight reduction in growth performance.

(Key words: feed ingredients, lactose, dextrose, whey.)

Introduction

Lactose and/or whey are important dietary components in many commercial pig starter diets because they provide an easily digestible source of energy for pigs immediately post-weaning. Spray-dried whey also provides a highly digestible source of essential amino acids. Both have also been demonstrated to stimulate feed intake in the weanling pig, making the adaptation to a dry, cereal-based diet easier.

Recent increases in the market price of whey and lactose have stimulated interest in determining the feeding value of alternative feedstuffs that may stimulate feed intake and provide digestible energy and/or amino acids for young pigs. Research from Ohio State University has reported that pigs fed diets containing dextrose performed equally to those fed diets containing lactose. More research is needed, however, to evaluate the suitability of dextrose replacement for lactose in commercial-type, pig-starter diets.

The increased demand for lactose and food-grade whey is responsible for much of the recent increase in cost of these ingredients. As a consequence, whey sources not previously utilized by feed manufacturers are finding a place in the market because they are available and may be less expensive. However, differences in quality among the various whey sources currently being used in piglet diets may exist. Previous research has demonstrated such differences.

The objective of these experiments was to compare various commercially available lactose, whey, or "replacement" products in pig starter diets and determine the economic impact of including these ingredients in Phase 2 diets.

Procedures

General. Procedures used in these experiments were approved by the Kansas State University Animal Care and Use Committee. Both projects were conducted at the KSU Segregated Early-Weaning Research Facility. Pens had steel "tri-bar" flooring, and provided approximately 3 ft^2 per pig. Each pen was equipped with a four-hole, dry, self-feeder and one cup waterer to provide *ad libitum* access to feed and water. The facility was a mechanically ventilated room with a pull-plug manure storage pit.

Experiment 1. A total of 228 pigs were weaned at 14.2 lb and 21 d of age and fed SEW and Transition diets for the first seven days post-weaning. Afterwards, pigs were blocked by weight and randomly allotted to one of the six dietary treatments with 8 pens per treatment. Each pen within 6 replications contained 5 pigs, and each pen within the remaining 2 replications contained 4 pigs. Experimental Phase 2 diets were fed for 14 d in meal form (Table 1). The control diet was a corn-soybean meal-based diet. Lactose, dextrose anhydrous, or dextrose monohydrate (7.2%) were added to the control diet at the expense of corn; or 10% feed-grade whey or food-grade whey were added at the expense of corn, select menhaden fish meal, spray-dried

blood cells, and salt to create the five additional treatments. Pigs and feeders were weighed on d 0, 7, and 14 to determine the response criteria of ADG, ADFI, and F/G.

Experiment 2. A total of 352 pigs were weaned at 15.2 lb and 21 d of age and fed SEW and Transition diets for the first five days post-weaning. Afterwards, pigs were blocked by weight and randomly allotted to one of the eight dietary treatments with 8 pens per treatment. Each pen within 4 replications contained 6 pigs, and each pen within the remaining 4 replications contained 5 pigs. Experimental Phase 2 diets were fed for 14 d in meal form (Table 1). The control diet was a corn-soybean meal-based diet. Seven different sources of commercial whey were each added to the control diet at 10% at the expense of corn, select menhaden fish meal, spray-dried blood cells, and salt to achieve the dietary treatments. Samples of each whey source were collected and analyzed for chemical composition (Table 2). Pigs and feeders were weighed on d 0, 7, and 14 to determine the response criteria of ADG, ADFI, and F/G.

Statistical Analysis. Data were analyzed as a randomized complete block design using the PROC MIXED procedure of SAS with pen as the experimental unit. Least squares means were used to determine differences among treatments.

Results

Experiment 1. For the overall 14-d trial, ADG and d 14 weight were improved ($P<0.05$) for pigs fed lactose or food-grade whey when compared to pigs fed feed-grade whey (Table 3). There were no other differences in ADG or d 14 weights among the treatments. Average daily feed intake was improved ($P<0.05$) for pigs fed lactose, dextrose monohydrate, or food-grade whey when compared to those fed feed-grade whey. Feed efficiency was improved ($P<0.05$) for pigs fed food-grade whey rather than dextrose monohydrate.

For the economic analysis, pigs fed the control diet had the lowest ($P<0.01$) cost per pound of gain, followed by pigs fed dextrose monohydrate, dextrose anhydrous, feed-grade whey, lactose, and food-grade whey. Margin-over-feed (MOF) cost was improved ($P<0.05$) for pigs fed the control diet rather than the diets containing lactose, dextrose anhydrous, or either whey source. Pigs fed dextrose monohydrate had intermediate MOF that was also higher ($P<0.05$) than that of pigs fed feed-grade whey.

Experiment 2. Throughout the entire 14-d trial, ADG and d 14 weight were improved ($P<0.05$) for pigs fed whey sources A and E when compared to the control and sources B and D (Table 4). Pigs fed whey sources C, F, and G had intermediate ADG. Average daily feed intake was greater ($P<0.05$) for pigs fed whey source E rather than the control or whey sources B, C, D, and G. Feed efficiency was improved ($P<0.05$) for pigs fed whey source A rather than the control. Pigs fed the remaining whey sources had intermediate F/G.

For the economic analysis, pigs fed the control diet had the lowest ($P<0.01$) cost per pound of gain. Margin-over-feed cost was improved ($P<0.05$) for pigs fed the control diet rather than the diets containing whey sources B, D, and G. Pigs fed whey source A had intermediate MOF that was also greater ($P<0.05$) than that of pigs fed whey sources B and D.

Discussion

These experiments demonstrate that not all sources of dextrose, lactose, and/or whey protein are created equal; it is important to use sources of known, high-quality whey in nursery diets. The performance of pigs fed feed-grade whey in Exp. 1 was similar to that of pigs fed the control diet, but was poorer than

that observed for pigs fed pure lactose or food-grade whey. In Exp. 2, there were only two sources of whey that resulted in growth performance superior to that of the controls. None of the criteria from the chemical analysis of the whey sources appear to explain the differences in pig performance.

Economic analysis using recent market prices indicates that none of the dextrose or lactose and/or whey protein sources evaluated may be justifiable in Phase 2 diets. While the inclusion of these ingredients may be necessary in diets fed immediately post-weaning, their use in later diets should be minimized to reduce the cost per pound of gain. The quality, cost, and relative feeding value of dietary lactose sources should be considered when formulating nursery pig diets for improved MOF. Also, guaranteed analysis is not necessarily a good indicator of whey quality for weanling pigs. Verification of the quality of a lactose source, and its impact on palatability and performance, is best determined through feeding trials.

Table 1. Composition of Experimental Diets (Experiments 1 and 2)

Ingredient	Negative control (Exp. 1 and 2)	7.2% Lactose or Dextrose (Exp. 1)	10% Dried Whey (Exp. 1 and 2)
Corn	64.10	56.65	55.50
Soybean meal (46.5% CP)	25.70	25.70	25.70
Select menhaden fish meal	3.29	3.49	2.50
Spray-dried blood cells	1.32	1.40	1.00
Lactose or dextrose	-	7.20	-
Spray-dried edible whey	-	-	10.00
Soybean oil	2.00	2.00	2.00
Monocalcium P (21% P)	1.20	1.20	1.00
Limestone	0.80	0.75	0.75
Salt	0.33	0.33	0.30
L-lysine HCl	0.30	0.30	0.30
DL-methionine	0.16	0.18	0.17
L-threonine	0.14	0.15	0.13
Vitamin premix	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15
Zinc oxide	0.25	0.25	0.25
Total	100.00	100.00	100.00
Calculated analysis			
Total lysine, %	1.45	1.45	1.45
True digestible amino acids			
Lysine, %	1.32	1.32	1.32
Isoleucine:lysine ratio, %	56	55	57
Leucine:lysine ratio, %	130	126	126
Methionine:lysine ratio, %	36	37	36
Met & Cys:lysine ratio, %	58	58	58
Threonine:lysine ratio, %	62	62	62
Tryptophan:lysine ratio, %	17	17	17
Valine:lysine ratio, %	70	69	68
Protein, %	21.2	20.7	20.9
ME, kcal/lb	1,545	1,546	1,540
TID lysine:ME ratio, g/Mcal	3.88	3.87	3.89
Ca, %	0.80	0.79	0.78
P, %	0.71	0.70	0.69
Available P, %	0.42	0.42	0.42

Table 2. Analyzed Composition of Various Whey Sources (Exp. 2)[a]

Item	Whey Source						
	A	B	C	D	E	F	G
Dry matter, %	96.38	95.21	94.46	94.14	93.27	n/a	95.66
Crude protein, %	12.50	12.70	12.20	12.80	13.60	n/a	12.10
Ca, %	0.35	0.45	0.56	0.57	0.51	n/a	0.39
P, %	0.62	0.67	0.66	0.67	0.67	n/a	0.60
Na, %	0.60	0.66	1.02	0.68	0.65	n/a	0.65
Salt, %	2.37	2.66	2.45	2.60	2.57	n/a	2.63
Cl, %	1.44	1.61	1.49	1.58	1.56	n/a	1.60
Ash, %	6.30	5.90	6.30	5.90	5.30	n/a	6.10
pH	7.19	8.02	8.80	8.11	7.94	n/a	7.56

[a]The chemical composition of whey source F was unavailable.

Table 3. Comparison of Dextrose and Lactose Sources in Phase 2 Nursery Diets (Exp. 1)[a]

Item	Control	Lactose	Dextrose Anhydrous	Dextrose Monohydrate	Feed-Grade Whey	Food-Grade Whey	SE Mean
D 0 to 14							
ADG, lb	0.79^{de}	0.84^{d}	0.79^{de}	0.80^{de}	0.73^{e}	0.83^{d}	0.05
ADFI, lb	0.99^{de}	1.02^{d}	1.00^{de}	1.02^{d}	0.92^{e}	1.02^{d}	0.07
F/G	1.26^{de}	1.22^{de}	1.26^{de}	1.27^{d}	1.26^{de}	1.22^{e}	0.02
Cost/lb gain, $[b]	0.15^{d}	0.21^{e}	0.19^{f}	0.18^{g}	0.20^{e}	0.22^{h}	0.003
Margin over feed, $[c]	3.85^{de}	3.43^{fg}	3.45^{fg}	3.62^{ef}	3.06^{g}	3.27^{fg}	0.24
Pig weight, lb							
D 0	17.0	17.1	17.0	17.1	17.0	17.1	1.11
D 14	28.0^{de}	28.9^{d}	28.1^{de}	28.3^{de}	27.3^{e}	28.7^{d}	1.80

[a]A total of 228 pigs were used in a 14-day, Phase 2 experiment with eight replications of 4 or 5 pigs per pen. Diets were fed from d 7 to 21 after weaning.
[b]Ingredient pricing used in this analysis included: corn, $118/ton; soybean meal, $207/ton; select menhaden fish meal and spray-dried blood cells, $1100/ton; lactose, $1680/ton; dextrose anhydrous, $1040/ton; dextrose monohydrate, $640/ton; feed-grade whey, $1100/ton; food-grade whey, $1400/ton; soy oil, $660/ton; mono-calcium phosphate, $332/ton; limestone, $30/ton; salt, $53/ton; and $15/ton processing and delivery fee.
[c]Based on market price of $0.50/lb. Calculated as gain × $0.50/lb, minus feed cost per pig.
[defgh]Means in the same row with different superscripts differ (P<0.05).

Table 4. Comparison of Whey Sources in Phase 2 Nursery Diets (Exp. 2)[a]

Item	Control	Whey Source							SE Mean
		A	B	C	D	E	F	G	
D 0 to 14									
ADG, lb	0.65^{d}	0.77^{e}	0.68^{d}	0.72^{de}	0.68^{d}	0.77^{e}	0.72^{de}	0.70^{de}	0.03
ADFI, lb	0.86^{de}	0.92^{def}	0.85^{e}	0.89^{de}	0.87^{de}	0.97^{f}	0.92^{def}	0.87^{de}	0.03
F/G	1.31^{d}	1.20^{e}	1.27^{de}	1.25^{de}	1.29^{de}	1.26^{de}	1.28^{de}	1.26^{de}	0.04
Cost/lb gain, $[b]	0.16^{d}	0.22^{e}	0.23^{e}	0.23^{e}	0.23^{e}	0.23^{e}	0.23^{e}	0.23^{e}	0.006
Margin over feed, $[c]	3.14^{d}	3.06^{de}	2.58^{f}	2.77^{def}	2.56^{f}	2.95^{def}	2.72^{def}	2.66^{ef}	0.16
Pig weight, lb									
D 0	17.1	17.2	17.1	17.1	17.1	17.2	17.1	17.1	0.81
D 14	26.3^{d}	27.9^{e}	26.7^{d}	27.2^{de}	26.6^{d}	27.9^{e}	27.2^{de}	26.9^{de}	0.43

[a]A total of 352 pigs were used in a 14-day, Phase 2 experiment with eight replications of 5 or 6 pigs per pen. Diets were fed from d 5 to 19 after weaning.
[b]Ingredient pricing used in this analysis included: corn, $118/ton; soybean meal, $207/ton; select menhaden fish meal and spray-dried blood cells, $1100/ton; lactose, $1680/ton; dextrose anhydrous, $1040/ton; dextrose monohydrate, $640/ton; feed-grade whey, $1100/ton; food-grade whey, $1400/ton; soy oil, $660/ton; mono-calcium phosphate, $332/ton; limestone, $30/ton; salt, $53/ton; and $15/ton processing and delivery fee.
[c]Based on market price of $0.50/lb. Calculated as gain × $0.50/lb, minus feed cost per pig.
[def]Means in the same row with different superscripts differ ($P<0.05$).

AN EVALUATION OF AN ENZYME BLEND (NATUZYME®) IN DIETS FOR WEANLING PIGS[1]

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Summary

Two experiments were conducted to evaluate the effects of an enzyme blend (Natuzyme®) on nursery pig growth performance. In Exp. 1, a total of 210 pigs (initially 13.6 lb) were used in a 35-d experiment to evaluate the effect of increasing levels of Natuzyme® (0, 0.035, and 0.05%) on weanling pig performance. Natuzyme® was added to either a negative or positive control diet as a 2 × 3 factorial to form six dietary treatments. The negative control diet was a corn-soybean meal-based diet containing 12.5% soy hulls and no antibiotics. The positive control diet was a corn-soybean meal-based diet without soy hulls, and contained a feed-grade antibiotic (Neo-Terramycin with 140 g of neomycin and 140 g of oxytetracycline per ton). Pigs were blocked by weight and randomly allotted to treatment at weaning. Diets were fed in two phases from d 0 to 14 and d 14 to 35. For d 0 to 14, ADG and d 14 weight tended to improve ($P<0.08$) by feeding the positive control diets with a feed-grade antibiotic. There were also trends for improved (quadratic, $P<0.09$) ADG, ADFI, and d 14 weight with increasing Natuzyme®. There were no differences in performance from d 14 to 35. For the overall trial (d 0 to 35), ADG and d 35 weight tended to be improved (linear, $P<0.09$; and quadratic, $P<0.07$; respectively) for pigs fed increasing Natuzyme® and for pigs fed the positive control diets ($P<0.07$ and $P<0.08$, respectively) compared with pigs fed the negative control.

In Exp. 2, a total of 180 pigs (initially 14.0 lb) were used in a 35-d experiment to further evaluate the effects of increasing Natuzyme® in diets with or without an antibiotic. Natuzyme® (0, 0.35, and 0.05%) was added to either a negative or positive control diet as a 2 × 3 factorial to form six dietary treatments. The negative control diet was a corn-soybean meal-based diet without a feed-grade antibiotic. The positive control diet was similar to that of the negative control diet, however, it contained a feed-grade antibiotic (Neo-Terramycin with 140 g of neomycin and 140 g of oxytetracycline per ton). Pigs were blocked by weight, and at weaning, randomly allotted to treatment with two dietary phases (d 0 to 14 and d 14 to 35). From d 0 to 14, pigs fed the positive control diet had improved ($P<0.01$) ADG, F/G, and d 14 weight compared to pigs fed the negative control. Average daily feed intake tended to be greater ($P<0.06$) for pigs fed the positive control diets. Also, pigs fed increasing Natuzyme® had improved ADG, F/G, and d 14 weight (linear, $P<0.05$). From d 14 to 35, pigs fed increasing Natuzyme® had poorer F/G (linear, $P<0.05$). Overall (d 0 to 35), ADG, ADFI, and d 35 weight were improved ($P<0.01$) for pigs fed the positive control compared to the negative control diet. When the observations for pigs fed the posi-

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tive control diets (diets containing feed-grade antibiotic) in both experiments were combined, ADG from d 14 to 35 was improved (linear, $P<0.06$ and quadratic, $P<0.02$) with increasing Natuzyme®. Also, pigs fed increasing Natuzyme® had improved ADFI from d 14 to 35 (linear, $P<0.03$ and quadratic, $P<0.01$). Overall (d 0 to 35), ADG, ADFI, and d 35 weight were improved (linear and quadratic, $P<0.05$) by including Natuzyme® in the diet.

In conclusion, pigs fed diets containing a feed-grade antibiotic had improved growth performance. The addition of Natuzyme® to corn-soybean meal-based diets also improved pig performance, particularly when included in diets containing a feed-grade antibiotic. However, in these studies, there did not appear to be a benefit to feeding more than 0.035% Natuzyme®.

(Key words: enzymes, antibiotics.)

Introduction

Recent increases in feed ingredient costs have motivated the swine industry to identify technologies that will improve feed utilization and reduce the cost per pound of gain. Since the mid-1980s, the addition of enzymes to animal feeds has been practiced in regions where wheat, rye, and barley are the primary feedstuffs. However, there have not been consistent improvements in growth or economic benefits to support supplementing corn-based diets with enzymes. Corn is a highly digestible energy source with relatively few antinutritional characteristics. However, continuing and intensive research and development of feed enzymes has the potential to increase their use in regions where corn is fed. In particular, the use of phytase enzyme in corn-based diets has become fairly common. The addition of phytase significantly reduces phosphorus excretion. Thus, the use of enzyme technology is improving nutrient utilization and the ability to manage nutrients in a manner that minimizes environmental impact.

Enzymes that assist animals in overcoming some of the species and/or age specific antinutritional characteristics of vegetable proteins (i.e., soybean meal) are also being developed. Therefore, products which contain a specific blend of enzymes may be able to provide multiple benefits. Natuzyme® is a commercially available enzyme blend containing α-amylase, xylanase, protease, and ß-glucanase enzymes. The objective of this experiment was to evaluate the effects of Natuzyme® on the growth performance of weanling pigs fed corn-soybean meal-based diets.

Procedures

Procedures used in both experiments were approved by the Kansas State University Animal Care and Use Committee.

Experiment 1. The experiment was conducted at the KSU Swine Teaching and Research Farm. Pens had a wire-mesh floor and provide approximately 3 ft^2 per pig. Each pen was equipped with a four-hole, dry, self-feeder and one nipple waterer to provide *ad libitum* access to feed and water. The facility was a mechanically ventilated room with a pull-plug manure storage pit.

A total of 210 pigs (initially 13.6 lb and 21 d of age) were weaned and used in a 35-d experiment to evaluate the effect of increasing Natuzyme® (0, 0.035, and 0.05%) on weanling pig performance. Pigs were blocked by weight and randomly allotted to one of six dietary treatments with five pens per treatment. Each pen contained 7 pigs. Two control diets were fed, which included a negative control diet containing 12.5% soy hulls and no feed-grade antibiotic, and a positive control diet without soy hulls that contained a feed-grade antibiotic (Neo-Terramycin with 140 g of neomycin and 140 g of oxytetracycline per ton). Natuzyme® (0, 0.035, and 0.05%) was added to each control diet at the expense of corn starch to achieve the six dietary treatments. Experimen-

tal diets were fed in meal form and fed in two dietary phases (Table 1). Phase 1 diets were fed from d 0 to 14 and Phase 2 diets were fed from d 14 to 35. Pigs and feeders were weighed on d 0, 7, 14, 21, 28, and 35 post-weaning to determine the response criteria of ADG, ADFI, and F/G.

Experiment 2. The experiment was conducted at the KSU Segregated Early-Weaning Facility. All pens had steel, "tri-bar" flooring and provided approximately 3 ft^2 per pig. Each pen was equipped with a four-hole, dry, self-feeder and one stainless-steel cup waterer to provide *ad libitum* access to feed and water. The facility was a mechanically ventilated room with a pull-plug manure storage pit.

A total of 180 pigs (initially 14.0 lb and 21 d of age) were weaned and used in a 35-d experiment to evaluate the effect of increasing levels of Natuzyme® (0, 0.035, and 0.05%) on weanling pig performance. Pigs were blocked by weight and randomly allotted to one of the six dietary treatments. Each treatment had six pens, and each pen contained 5 pigs. Two control diets were used. The negative control diet did not contain any feed-grade antibiotics, but was otherwise identical to the positive control diet in Exp. 1. The positive control diet was identical to that used in Exp. 1, and contained a feed-grade antibiotic (Neo-Terramycin with 140 g of neomycin and 140 g of oxytetracycline per ton). Natuzyme® (0, 0.035, and 0.05%) was added to each control diet at the expense of corn starch to achieve the six dietary treatments. Experimental diets were fed in meal form and maintained throughout two dietary phases (Table 2). Phase 1 diets were fed from d 0 to 14 and Phase 2 diets were fed from d 14 to 35. Pigs and feeders were weighed on d 0, 7, 14, 21, 28, and 35 post-weaning to determine the response criteria of ADG, ADFI, and F/G.

Statistical Analysis. Data in both experiments were analyzed as a randomized complete block design using the PROC MIXED procedure of SAS with pen as the experimental unit. Linear and quadratic polynomial contrasts were also used to determine the effects of increasing Natuzyme®. In addition, the data from pigs fed the positive control diets in both experiments were combined to analyze the overall effects of Natuzyme® in Phase 1 and Phase 2 diets that contained an antibiotic.

Results and Discussion

Experiment 1. There were no interactions observed ($P>0.15$) between pigs fed Natuzyme® and the those fed the control diet (Tables 3 and 4).

From d 0 to 14 (Phase 1), ADG and d 14 weight tended to be improved ($P<0.07$ and $P<0.08$, respectively) by feeding the positive control diets, and also tended to be improved (quadratic, $P<0.09$) by including Natuzyme® in the diet. Average daily feed intake also tended to be improved (quadratic, $P<0.06$) by including Natuzyme® in the diet. Feed efficiency was not influenced by dietary treatment.

There were no significant differences in performance for the Phase 2 period (d 14 to 35). Overall (d 0 to 35), pigs fed the positive control diets tended to have improved ADG ($P<0.07$) and d 35 wt ($P<0.08$). Adding Natuzyme® to the diets also tended to improve ADG (linear, $P<0.09$) and d 35 weight (quadratic, $P<0.07$). Feed efficiency was similar for all dietary treatments.

Experiment 2. For d 0 to 14, there was a trend ($P<0.08$) for a Control × Natuzyme® interaction for F/G. This resulted from the greater improvement observed when Natuzyme® was added to the negative control diet when compared to Natuzyme® addition to the positive control diet. Otherwise, ADG, F/G, and d 14 wt were improved ($P<0.01$) by feeding the positive control diets with a feed-grade antibiotic (Tables 5 and 6). Average

daily feed intake also tended to be greater ($P<0.06$) for pigs fed the positive control diets. There were also improvements (linear, $P<0.05$) in ADG, F/G, and d 14 wt associated with the inclusion of Natuzyme®.

From d 14 to 35, F/G was poorer (linear, $P<0.05$) for pigs fed Natuzyme®. For the overall trial (d 0 to 35), ADG, ADFI, and d 35 wt were increased ($P<0.01$) for pigs fed the positive control diets containing a feed-grade antibiotic.

Combined Data from Exp. 1 and 2 (Positive Controls). When the observations for the positive control diets in both experiments were combined, there were no differences in performance from d 0 to 14.

From d 14 to 35, ADG increased (linear, $P<0.06$ and quadratic, $P<0.02$) with increasing Natuzyme®. Likewise, ADFI was increased (linear, $P<0.03$ and quadratic, $P<0.01$) with increasing Natuzyme®.

Overall (d 0 to 35), ADG, ADFI, and d 35 wt were improved (linear and quadratic, $P<0.05$) by including Natuzyme® in the diet.

In summary, pigs had improved growth performance when fed diets containing a feed-grade antibiotic. Also, the addition of Natuzyme® to corn-soybean meal-based diets improved pig performance, particularly when included in a diet containing a feed-grade antibiotic. However, in these studies, there did not appear to be a benefit to feeding more than 0.035% Natuzyme®.

Table 1. Composition of Experimental Diets (Exp. 1)[a]

	Phase 1		Phase 2	
Ingredient	Negative control	Positive control	Negative control	Positive control
Corn	43.81	51.54	52.99	60.79
Soybean meal (46.5% CP)	26.21	30.14	31.09	35.00
Soy hulls	12.50	-	12.50	-
Select menhaden fish meal	3.75	3.75	-	-
Spray-dried edible whey	10.00	10.00	-	-
Corn starch	0.05	0.05	0.05	0.05
Soybean oil	1.00	1.00	-	-
Monocalcium P (21% P)	0.75	0.75	1.15	1.15
Limestone	0.60	0.75	0.90	1.00
Salt	0.35	0.35	0.35	0.35
L-lysine HCl	0.30	0.30	0.30	0.30
DL-methionine	0.14	0.13	0.14	0.13
L-threonine	0.14	0.14	0.13	0.13
Vitamin premix	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15
Antibiotic[b]	-	0.70	-	0.70
Total	100.00	100.00	100.00	100.00
Calculated analysis				
Total lysine, %	1.50	1.55	1.40	1.45
True digestible amino acids				
Lysine, %	1.34	1.41	1.24	1.31
Isoleucine:lysine ratio, %	59	60	62	63
Leucine:lysine ratio, %	117	121	126	129
Methionine:lysine ratio, %	34	33	34	33
Met & Cys:lysine ratio, %	56	56	58	58
Threonine:lysine ratio, %	63	63	63	64
Tryptophan:lysine ratio, %	17	17	18	18
Valine:lysine ratio, %	64	66	68	69
Protein, %	21.30	22.40	20.80	21.90
ME, kcal/lb	1,440	1,514	1,417	1,492
TID lysine: ME ratio, g/Mcal	4.22	4.22	3.98	3.98
Ca, %	0.81	0.81	0.74	0.73
P, %	0.67	0.70	0.62	0.65
Available P, %	0.40	0.40	0.32	0.32

[a]Natuzyme® (0, 0.035, and 0.05%) was added to the basal diets at the expense of corn starch.
[b]Provided 140 g/ton of Neomycin and 140 g/ton of Oxytetracycline.

Table 2. Composition of Experimental Diets (Exp. 2)[a]

	Phase 1		Phase 2	
Ingredient	Negative control	Positive control	Negative control	Positive control
Corn	51.54	51.54	60.79	60.79
Soybean meal (46.5% CP)	30.14	30.14	35.00	35.00
Select menhaden fish meal	3.75	3.75	-	-
Spray-dried edible whey	10.00	10.00	-	-
Corn starch	0.05	0.05	0.05	0.05
Soybean oil	1.00	1.00	-	-
Monocalcium P (21% P)	0.75	0.75	1.15	1.15
Limestone	0.75	0.75	1.00	1.00
Salt	0.35	0.35	0.35	0.35
L-lysine HCl	0.30	0.30	0.30	0.30
DL-methionine	0.13	0.13	0.13	0.13
L-threonine	0.14	0.14	0.13	0.13
Vitamin premix	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15
Antibiotic[b]	-	0.70	-	0.70
Total	100.00	100.00	100.00	100.00
Calculated analysis				
Total lysine, %	1.55	1.55	1.45	1.45
True digestible amino acids				
Lysine, %	1.41	1.41	1.31	1.31
Isoleucine:lysine ratio, %	60	60	63	63
Leucine:lysine ratio, %	121	121	129	129
Methionine:lysine ratio, %	33	33	33	33
Met & Cys:lysine ratio, %	56	56	58	58
Threonine:lysine ratio, %	63	63	64	64
Tryptophan:lysine ratio, %	17	17	18	18
Valine:lysine ratio, %	66	66	69	69
Protein, %	22.40	22.40	21.90	21.90
ME, kcal/lb	1,514	1,514	1,492	1,492
TID lysine: ME ratio, g/Mcal	4.22	4.22	3.98	3.98
Ca, %	0.81	0.81	0.73	0.73
P, %	0.70	0.70	0.65	0.65
Available P, %	0.40	0.40	0.32	0.32

[a]Natuzyme® (0, 0.035, and 0.05%) was added to the basal diets at the expense of corn starch.
[b]Provided 140 g/ton of Neomycin and 140 g/ton of Oxytetracycline.

Table 3. The Effect of Dietary Addition of Natuzyme® on Nursery Pig Growth Performance – Interactive Means (Exp. 1)[a]

								P <			
		Negative control [b]			Positive control [b]				Negative vs		Enzyme [c]	
Item	Natuzyme®, %	0	0.035	0.05	0	0.035	0.05	SE Mean	Positive	Enzyme	Linear	Quadratic
D 0 to 14												
ADG, lb		0.37	0.45	0.43	0.45	0.52	0.45	0.04	0.07	0.12	-	0.09
ADFI, lb		0.42	0.52	0.48	0.49	0.56	0.48	0.04	-	0.10	-	0.06
F/G		1.13	1.16	1.12	1.09	1.06	1.07	0.06	-	-	-	-
D 14 to 35												
ADG, lb		1.28	1.28	1.26	1.24	1.36	1.33	0.04	-	-	-	-
ADFI, lb		1.84	1.86	1.81	1.80	1.97	1.89	0.07	-	-	-	-
F/G		1.43	1.46	1.43	1.46	1.44	1.42	0.03	-	-	-	-
Overall, D 0 to 35												
ADG, lb		0.91	0.94	0.93	0.92	1.03	0.98	0.03	0.07	0.08	0.09	0.12
ADFI, lb		1.26	1.32	1.27	1.27	1.40	1.32	0.05	-	0.14	-	0.10
F/G		1.38	1.40	1.37	1.38	1.36	1.35	0.02	-	-	-	-
Pig weight, lb												
D 0 wt, lb		13.63	13.62	13.62	13.63	13.62	13.63	0.84	-	-	-	-
D 14 wt, lb		18.88	19.93	19.67	19.87	20.96	19.89	1.06	0.08	0.12	-	0.09
D 35 wt, lb		46.01	47.00	46.20	45.97	49.58	47.83	1.52	0.08	0.06	0.12	0.07

[a]A total of 210 pigs were used in a 35-day experiment with five replications and 7 pigs per pen. Diets were fed in two phases with phase 1 from d 0 to 14 after weaning, and phase 2 from d 14 to 35.
[b]The negative control diet contained 12.5% soy hulls and no feed-grade antibiotic. The positive control diet did not contain soy hulls, but did contain a feed-grade antibiotic (Neo-Terramycin with 140 g of neomycin and 140 g of oxytetracycline per ton).
[c]No Interactions, $P>0.15$.

Table 4. The Effect of Dietary Addition of Natuzyme® on Nursery Pig Growth Performance – Main Effects (Exp. 1) [a]

	Controls		Natuzyme®, %				*P* <			
						SE	Negative vs		Enzyme[c]	
Item	Negative[b]	Positive[b]	0	0.035	0.05	Mean	Positive	Enzyme	Linear	Quadratic
D 0 to 14										
ADG, lb	0.42	0.47	0.41	0.49	0.44	0.04	0.07	0.12	-	0.09
ADFI, lb	0.47	0.51	0.45	0.54	0.48	0.04	-	0.10	-	0.06
F/G	1.14	1.07	1.11	1.11	1.09	0.06	-	-	-	-
D 14 to 35										
ADG, lb	1.27	1.31	1.26	1.32	1.30	0.04	-	-	-	-
ADFI, lb	1.83	1.89	1.82	1.92	1.85	0.07	-	-	-	-
F/G	1.44	1.44	1.45	1.45	1.42	0.03	-	-	-	-
Overall, D 0 to 35										
ADG, lb	0.93	0.97	0.91	0.98	0.95	0.03	0.07	0.08	0.09	0.12
ADFI, lb	1.29	1.33	1.26	1.36	1.30	0.05	-	0.14	-	0.10
F/G	1.38	1.37	1.38	1.38	1.36	0.02	-	-	-	-
Pig weight, lb										
D 0 wt, lb	13.63	13.63	13.63	13.62	13.63	0.84	-	-	-	-
D 14 wt, lb	19.49	20.24	19.37	20.45	19.78	1.06	0.08	0.12	-	0.09
D 35 wt, lb	46.41	47.79	45.99	48.29	47.02	1.52	0.08	0.06	0.12	0.07

[a]A total of 210 pigs were used in a 35-day experiment with five replications and 7 pigs per pen. Diets were fed in two phases with phase 1 from d 0 to 14 after weaning, and phase 2 from d 14 to 35.
[b]The negative control diet contained 12.5% soy hulls and no feed-grade antibiotic. The positive control diet did not contain soy hulls, but did contain a feed-grade antibiotic (Neo-Terramycin with 140 g of neomycin and 140 g of oxytetracycline per ton).
[c]No Interactions, $P>0.15$.

Table 5. The Effect of Dietary Addition of Natuzyme® on Nursery Pig Growth Performance – Interactive Means (Exp. 2) [a]

								P <			
	Negative control [b]			Positive control [b]			SE	Negative vs		Enzyme[c]	
Item Natuzyme®, %	0	0.035	0.05	0	0.035	0.05	Mean	Positive	Enzyme	Linear	Quadratic
D 0 to 14											
ADG, lb	0.21	0.29	0.29	0.30	0.34	0.35	0.03	0.01	0.10	0.04	-
ADFI, lb	0.34	0.37	0.37	0.38	0.41	0.42	0.03	0.06	-	-	-
F/G	1.66	1.30	1.38	1.27	1.25	1.23	0.09	0.003	0.04	0.02	-
D 14 to 35											
ADG, lb	1.02	0.99	1.01	1.09	1.15	1.09	0.03	0.001	-	-	-
ADFI, lb	1.36	1.34	1.39	1.51	1.62	1.54	0.05	0.001	-	-	-
F/G	1.33	1.35	1.37	1.38	1.41	1.42	0.02	0.001	0.11	0.04	-
Overall, D 0 to 35											
ADG, lb	0.70	0.71	0.72	0.78	0.82	0.79	0.03	0.001	-	-	-
ADFI, lb	0.95	0.95	0.97	1.06	1.12	1.09	0.04	0.001	-	-	-
F/G	1.36	1.34	1.36	1.36	1.37	1.38	0.02	-	-	-	-
Pig weight, lb											
D 0 wt, lb	14.00	14.01	14.03	14.00	14.01	14.01	0.79	-	-	-	-
D 14 wt, lb	16.95	18.02	18.00	18.23	18.72	18.90	0.87	0.01	0.10	0.04	-
D 35 wt, lb	38.45	38.81	39.47	41.18	43.15	42.00	1.24	0.001	-	-	-

[a]A total of 180 pigs were weaned at an avg. 14.01 lb BW and used in a 35-day experiment with six replications and 5 pigs per pen. Diets were fed in two phases with phase 1 from d 0 to 14 after weaning, and phase 2 from d 14 to 35.

[b]The negative control diet did not contain a feed-grade antibiotic, and the positive control diet contained Neo-Terramycin at 140 g of neomycin and 140 g of oxytetracycline per ton.

[c]Tendency for an interaction ($P<0.08$) for D 0 to 14 F:G. All other, $P>0.15$.

Table 6. The Effect of Dietary Addition of Natuzyme® on Nursery Pig Growth Performance – Main Effects (Exp. 2) [a]

	Controls		Natuzyme®, %			SE	*P* <			
							Negative vs		Enzyme [c]	
Item	Negative[b]	Positive[b]	0	0.035	0.05	Mean	Positive	Enzyme	Linear	Quadratic
D 0 to 14										
ADG, lb	0.26	0.33	0.26	0.31	0.32	0.03	0.01	0.10	0.04	-
ADFI, lb	0.36	0.40	0.36	0.39	0.40	0.03	0.06	-	-	-
F/G	1.45	1.25	1.46	1.28	1.30	0.09	0.003	0.04	0.02	-
D 14 to 35										
ADG, lb	1.01	1.11	1.06	1.07	1.05	0.03	0.001	-	-	-
ADFI, lb	1.36	1.56	1.44	1.48	1.46	0.05	0.001	-	-	-
F/G	1.35	1.40	1.36	1.38	1.39	0.02	0.001	0.11	0.04	-
Overall, D 0 to 35										
ADG, lb	0.71	0.79	0.74	0.76	0.75	0.03	0.001	-	-	-
ADFI, lb	0.96	1.09	1.00	1.04	1.03	0.04	0.001	-	-	-
F/G	1.35	1.37	1.36	1.36	1.37	0.02	-	-	-	-
Pig weight, lb										
D 0 wt, lb	14.01	14.01	14.00	14.01	14.02	0.79	-	-	-	-
D 14 wt, lb	17.66	18.62	17.59	18.37	18.45	0.87	0.01	0.10	0.04	-
D 35 wt, lb	38.91	42.11	39.82	40.98	40.74	1.24	0.001	-	-	-

[a]A total of 180 pigs were weaned at an avg. 14.01 lb BW and used in a 35-day experiment with six replications and 5 pigs per pen. Diets were fed in two phases with phase 1 from d 0 to 14 after weaning, and phase 2 from d 14 to 35.

[b]The negative control diet did not contain a feed-grade antibiotic, and the positive control diet contained Neo-Terramycin at 140 g of neomycin and 140 g of oxytetracycline per ton.

[c]Tendency for an interaction ($P<0.08$) for D 0 to 14 F:G. All other, $P>0.15$.

Table 7. The Effect of Dietary Addition of Natuzyme® on Nursery Pig Growth Performance (Exp. 1 and 2 Combined, Positive Controls Only) [a]

	Natuzyme®, %				*P* <	
Item	0	0.035	0.05	SE Mean	Linear	Quadratic
D 0 to 14						
ADG, lb	0.37	0.42	0.39	0.03	-	-
ADFI, lb	0.43	0.47	0.45	0.03	-	-
F/G	1.19	1.17	1.15	0.05	-	-
D 14 to 35						
ADG, lb	1.16	1.25	1.20	0.04	0.06	0.02
ADFI, lb	1.64	1.78	1.70	0.06	0.03	0.005
F/G	1.42	1.42	1.42	0.02	-	-
Overall, D 0 to 35						
ADG, lb	0.84	0.91	0.87	0.03	0.04	0.02
ADFI, lb	1.15	1.25	1.19	0.04	0.05	0.01
F/G	1.37	1.37	1.37	0.01	-	-
Pig weight, lb						
D 0 wt, lb	13.83	13.83	13.84	0.55	-	-
D 14 wt, lb	18.97	19.74	19.35	0.67	-	-
D 35 wt, lb	43.36	46.07	44.65	1.15	0.007	0.003

[a]A total of 195 pigs were used from two 35-day experiments. The positive controls from Exp. 1 and 2 were combined to provide eleven replications and 65 pigs per treatment. Diets were fed in two phases with phase 1 from d 0 to 14 after weaning, and phase 2 from d 14 to 35.

AN EVALUATION OF ARABINOGALACTAN (LARAFEED® AG) AS A NUTRACEUTICAL GROWTH PROMOTER IN STARTER DIETS FOR WEANLING PIGS[1]

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

Summary

A nursery study was conducted at the KSU Segregated Early-Weaning Facility to evaluate the effect of dietary arabinogalactan on weanling pig performance. Arabinogalactan is a water-soluble proteoglycan/polysaccharide, most commonly harvested from the bark of the Western Larch (*Larix occidentalis)* tree, which has demonstrated neutraceutical properties in a limited number of studies with dogs and foals. A total of 288 pigs (initially 14.9 lb) were used in the 35-d experiment. Pigs were blocked by weight and randomly allotted to one of eight dietary treatments fed throughout Phase 1 (d 0 to 14) and Phase 2 (d 14 to 28), followed by a common diet during Phase 3 (d 28 to 35). Four levels of arabinogalactan (0, 0.05, 0.10, and 0.20%) were included in either a negative or positive control diet in a 2 × 4 factorial to form the eight dietary treatments. The negative control diet was a corn-soybean meal based diet without feed-grade antibiotics. The positive control diet was identical to the negative control, but contained a feed-grade antibiotic (Neo-Terramycin with 140 g of neomycin and 140 g of oxytetracycline per ton). The common diet fed during Phase 3 did not contain arabinogalactan, but did contain a feed-grade antibiotic (Neo-Terramycin). From d 0 to 14 (Phase 1), ADG, ADFI, and d 14 weight decreased (linear, $P<0.05$) with increasing level of arabinogalactan in the diet. Also, pigs fed the positive control diet were heavier ($P<0.05$) on d 14 than those fed the negative control. During Phase 2 (d 14 to 28) and for the overall treatment period (d 0 to 28), ADG, ADFI, and d 28 weight were improved ($P<0.01$) for pigs fed the positive control diet compared with pigs fed the negative control. Due to the reduction in ADFI at the highest level (0.20%) of arabinogalactan, ADFI decreased (linear, $P<0.05$) from d 0 to 28 with increasing arabinogalactan. From d 28 to 35 (Phase 3), when all pigs were fed a common diet, ADG and F/G were poorer for pigs previously fed the positive control. Overall (d 0 to 35), ADG tended to be improved ($P<0.07$), and ADFI and d 35 weight were improved ($P<0.05$) for pigs fed the positive control, but F/G was slightly poorer ($P<0.05$) than for pigs fed the negative control. A reduction (linear, $P<0.05$) in ADFI was observed for pigs fed increasing arabinogalactan. In conclusion, the addition of arabinogalactan to weanling pig diets did not improve growth performance with the high level (0.20%) resulting in reduced ADFI. However, ADG,

[1] Appreciation is expressed to Lonza, Inc., Allendale, NJ for providing the Larafeed® AG arabinogalactan, and for sponsorship of the trial

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

[3]Lonza, Inc., Allendale NJ.

ADFI, and d 35 weight were improved by including a feed-grade antibiotic in the Phase 1 and Phase 2 diets.

(Key words: antibiotics, arabinogalactan.)

Introduction

There is increasing public concern about the use of sub-therapeutic levels of feed-grade antibiotics in food animal production. The judicious use of sub-therapeutic (or more commonly "growth promoter") levels of antibiotics in food animal production has served to improve animal health, welfare, and performance/production efficiency. Most often, the use of these feed-grade antibiotics coincides with periods of increased stress, such as weaning.

As an alternative to feed-grade antibiotics, there is increasing interest in identifying suitable nutraceutical compounds. Nutricines are "natural" compounds found in various foodstuffs in trace amounts, with properties that may improve health and immune function but lack an established requirement. An increasing understanding of potential nutraceutical compounds that may enhance immunity and health, and improve the ability to cope with periods of increased stress has stimulated interest in identifying suitable antibiotic replacements. Few nutraceuticals, however, have been evaluated in studies measuring animal performance.

Arabinogalactan is a naturally occurring, water-soluble proteoglycan/polysaccharide that is not generally found in foodstuffs commonly fed to domesticated pigs. A few experiments with dogs and young foals have identified improvements in the digestive health and immune function of animals supplemented with arabinogalactan in their diet. Weanling pigs are particularly vulnerable to enteric diseases and digestive upset, and these contribute significantly to losses in growth performance during the nursery period. A large portion of the "growth promoter" levels of feed-grade antibiotics used in the swine industry are used during this period due to their demonstrated efficacy in nursery pigs. Therefore, the objective of this experiment was to evaluate the influence of dietary arabinogalactan on the growth performance of weanling pigs.

Procedures

Procedures used in this experiment were approved by the Kansas State University Animal Care and Use Committee. The project was conducted at the KSU Segregated Early-Weaning Facility. Pens had steel 'tri-bar' flooring and provided approximately 3 ft^2 per pig. Each pen was equipped with a four-hole, dry, self-feeder and one cup waterer, providing *ad libitum* access to feed and water. The facility was a mechanically ventilated room with a pull-plug manure storage pit underneath the pens' mesh flooring.

A total of 288 pigs were weaned at an average of 14.9 lb and 21 d of age. Pigs were blocked by weight and randomly allotted to one of the eight dietary treatments with eight pens per treatment. Each pen contained either 4 or 5 pigs. Two control diets were used. The negative control diet did not contain any feed-grade antibiotics, while the positive control diet contained a feed-grade antibiotic (Neo-Terramycin with 140 g of neomycin and 140 g of oxytetracycline per ton). Arabinogalactan (Larafeed® AG; to provide 0, 0.05, 0.10 and 0.20% arabinogalactan) was added to each control diet at the expense of corn starch to achieve the eight dietary treatments. Experimental diets were fed in meal form and maintained throughout two dietary phases (Table 1). Phase 1 diets were fed from d 0 to 14 and Phase 2 diets were fed from d 14 to 28. All pigs were fed a common diet that contained a feed-grade antibiotic (Neo-Terramycin with 140 g of neomycin and 140 g of oxytetracy-

cline per ton) during Phase 3 (d 28 to 35). Pigs and feeders were weighed on d 0, 7, 14, 21, 28, and 35 post-weaning to determine the response criteria of ADG, ADFI, and F/G.

Data were analyzed as a randomized complete block design using the PROC MIXED procedure of SAS with pen as the experimental unit. Linear and quadratic polynomial contrasts were used to determine the effects of increasing arabinogalactan.

Results

There were no interactions ($P>0.10$) between the control diet and arabinogalactan (Tables 2 and 3). For the d 0 to 14 (Phase 1) period, ADG, ADFI, and d 14 weight decreased (linear, $P<0.05$) with increasing arabinogalactan in the diet. This was primarily due to the large reductions observed at the highest level fed (0.20%). Also, pigs fed the positive control diet had heavier ($P<0.05$) d 14 weights than those fed the negative control.

During Phase 2 (d 14 to 28), ADG, ADFI, and d 28 weight of pigs fed the positive control diet were improved compared with pigs fed the negative control diet.

For the overall treatment period (d 0 to 28), ADG and ADFI were improved for pigs fed the positive control. Because of the lower ADFI for pigs fed the diet containing the highest level (0.20%) of arabinogalactan, ADFI decreased linearly ($P<0.05$) with increasing arabinogalactan.

From d 28 to 35 (Phase 3), when all pigs were fed a common diet, ADG and F/G were poorer ($P<0.01$) for pigs previously fed the positive control diet.

Overall (d 0 to 35), ADG tended to be improved ($P<0.07$) for pigs fed the positive control. Also, ADFI and d 35 weight were improved ($P<0.05$) for pigs fed the positive control, but F/G was slightly poorer ($P<0.05$). A reduction (linear, $P<0.05$) in ADFI was observed for pigs fed increasing arabinogalactan, primarily at the highest level (0.20%).

In conclusion, the addition of arabinogalactan to weanling pig diets did not improve growth performance. In fact, feeding the highest level (0.20%) resulted in reduced performance. However, ADG, ADFI, and d 35 weight were improved by including a feed-grade antibiotic in the Phase 1 and Phase 2 diets.

Table 1. Composition of Experimental Diets[a,b,c]

Ingredient	Phase 1 Negative Control	Phase 2 Negative Control	Phase 3 Common
Corn	50.67	59.85	58.01
Soybean meal (46.5% CP)	30.13	35.05	34.85
Select menhaden fish meal	3.75	-	-
Spray-dried edible whey	10.00	-	-
Corn starch	1.17	1.17	-
Soybean oil	1.00	-	3.00
Monocalcium P (21% P)	1.20	1.50	1.20
Limestone	0.75	1.10	0.93
Salt	0.35	0.35	0.35
L-lysine HCl	0.30	0.30	0.30
DL-methionine	0.13	0.13	0.15
L-threonine	0.15	0.15	0.11
Vitamin premix	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15
Antibiotic[c]	-	-	0.70
Total	100.00	100.00	100.00
Calculated analysis			
Total lysine, %	1.55	1.45	1.44
True digestible amino acids			
Lysine, %	1.41	1.31	1.30
Isoleucine:lysine ratio, %	60	63	62
Leucine:lysine ratio, %	121	129	128
Methionine:lysine ratio, %	33	33	35
Met & Cys:lysine ratio, %	56	58	59
Threonine:lysine ratio, %	63	64	62
Tryptophan:lysine ratio, %	17	18	18
Valine:lysine ratio, %	66	69	69
Protein, %	22.40	21.90	21.60
ME, kcal/lb	1,514	1,492	1,560
TID lysine: ME ratio, g/Mcal	4.22	3.98	3.78
Ca, %	0.81	0.73	0.71
P, %	0.70	0.65	0.65
Available P, %	0.40	0.32	0.33

[a]The positive control contained a feed-grade antibiotic (140 g/ton of Neomycin and 140 g/ton of Oxytetracycline) at the expense of corn starch, but was otherwise identical to the negative control.
[b]Larafeed® AG (to provide 0, 0.05, 0.10 and 0.20% arabinogalactan) was added to the basal diets at the expense of corn starch.
[c]Provided 140 g/ton of Neomycin and 140 g/ton of Oxytetracycline.

Table 2. Growth Performance of Nursery Pigs Fed Increasing Arabinogalactan – Interactive Means[a,b,c]

										P <			
	Negative Control				Positive Control					Negative vs		Arabinogalactan	
Item Arabinogalactan, %	0	0.05	0.10	0.20	0	0.05	0.10	0.20	SE Mean	Positive	Arabinogalactan	Linear	Quadratic
D 0 to 14													
ADG, lb	0.34	0.37	0.32	0.31	0.38	0.38	0.41	0.31	0.04	0.08	0.10	0.05	-
ADFI, lb	0.43	0.43	0.39	0.39	0.44	0.44	0.48	0.39	0.03	0.08	0.06	0.02	-
F/G	1.32	1.19	1.28	1.25	1.19	1.20	1.16	1.60	0.15	-	-	-	-
D 14 to 28													
ADG, lb	1.00	0.98	1.02	1.01	1.15	1.13	1.21	1.07	0.05	0.01	-	-	-
ADFI, lb	1.34	1.33	1.31	1.30	1.50	1.47	1.56	1.39	0.07	0.01	-	-	-
F/G	1.35	1.35	1.28	1.29	1.30	1.32	1.30	1.30	0.03	-	-	-	-
Overall, D 0 to 28													
ADG, lb	0.67	0.68	0.67	0.66	0.76	0.75	0.81	0.68	0.04	0.01	-	-	-
ADFI, lb	0.89	0.88	0.85	0.85	0.96	0.95	1.02	0.88	0.05	0.01	0.08	0.04	-
F/G	1.32	1.30	1.27	1.28	1.27	1.28	1.26	1.31	0.02	-	-	-	-
D 28 to 35 (common diet)													
ADG, lb	1.80	1.74	1.74	1.75	1.61	1.63	1.64	1.59	0.05	0.01	-	-	-
ADFI, lb	2.31	2.24	2.25	2.28	2.25	2.26	2.28	2.14	0.08	-	-	-	-
F/G	1.28	1.29	1.29	1.30	1.41	1.39	1.39	1.35	0.03	0.01	-	-	-
Overall, D 0 to 35													
ADG, lb	0.90	0.89	0.88	0.88	0.93	0.92	0.98	0.85	0.04	0.07	0.10	0.09	-
ADFI, lb	1.17	1.15	1.13	1.13	1.22	1.21	1.27	1.12	0.05	0.01	0.07	0.04	-
F/G	1.30	1.29	1.28	1.28	1.31	1.31	1.30	1.32	0.02	0.04	-	-	-
Pig Weights, lb													
D 0	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	0.70	-	-	-	-
D 14	19.7	20.1	19.3	19.3	20.3	20.2	20.6	19.3	1.04	0.05	0.13	0.05	-
D 28	33.7	33.8	33.6	33.5	36.5	36.4	37.5	35.1	1.62	0.01	-	-	-
D 35	46.3	46.0	45.8	45.7	47.7	47.8	49.0	46.2	1.81	0.01	-	-	-

[a]A total of 288 pigs were used in a 35-day experiment with eight replications and 4 or 5 pigs per pen. Experimental diets were fed in two phases, with phase 1 from d 0 to 14 after weaning and phase 2 from d 14 to 28. A common diet containing an antibiotic (Neo-Terramycin with 140 g of neomycin and 140 g of oxytetracycline per ton) was fed during the third phase from d 28 to 35.

[b]The negative control diet did not contain a feed-grade antibiotic. The positive control diet contained a feed-grade antibiotic (Neo-Terramycin with 140 g of neomycin and 140 g of oxytetracycline per ton).

[c]No interactions, $P>0.10$

Table 3. Growth Performance of Nursery Pigs Fed Increasing Arabinogalactan – Main Effects[a,b,c]

	Control		Arabinogalactan, %					*P* <			
								Negative vs		Arabinogalactan	
Item	Negative	Positive	0	0.05	0.10	0.20	SE Mean	Positive	Arabinogalactan	Linear	Quadratic
D 0 to 14											
ADG, lb	0.34	0.37	0.36	0.38	0.36	0.31	0.04	0.08	0.10	0.05	-
ADFI, lb	0.41	0.44	0.44	0.43	0.43	0.39	0.03	0.08	0.06	0.02	-
F/G	1.26	1.29	1.26	1.20	1.22	1.42	0.15	-	-	-	-
D 14 to 28											
ADG, lb	1.00	1.14	1.08	1.05	1.11	1.04	0.05	0.01	-	-	-
ADFI, lb	1.32	1.48	1.42	1.40	1.44	1.34	0.07	0.01	-	-	-
F/G	1.32	1.30	1.32	1.33	1.29	1.30	0.03	-	-	-	-
Overall, D 0 to 28											
ADG, lb	0.67	0.75	0.72	0.71	0.74	0.67	0.04	0.01	-	-	-
ADFI, lb	0.86	0.95	0.93	0.91	0.93	0.86	0.05	0.01	0.08	0.04	-
F/G	1.29	1.28	1.29	1.29	1.27	1.29	0.02	-	-	-	-
D 28 to 35 (common diet)											
ADG, lb	1.76	1.62	1.70	1.68	1.69	1.67	0.05	0.01	-	-	-
ADFI, lb	2.27	2.23	2.28	2.25	2.27	2.21	0.08	-	-	-	-
F/G	1.29	1.38	1.34	1.34	1.34	1.33	0.03	0.01	-	-	-
Overall, D 0 to 35											
ADG, lb	0.89	0.92	0.91	0.91	0.93	0.87	0.04	0.07	0.10	0.09	-
ADFI, lb	1.15	1.21	1.19	1.18	1.20	1.13	0.05	0.01	0.07	0.04	-
F/G	1.29	1.31	1.31	1.30	1.29	1.30	0.02	0.04	-	-	-
Pig Weights, lb											
D 0	14.9	14.9	14.9	14.9	14.9	14.9	0.70	-	-	-	-
D 14	19.6	20.1	20.0	20.1	20.0	19.3	1.04	0.05	0.13	0.05	-
D 28	33.7	36.4	35.1	35.1	35.6	34.3	1.62	0.01	-	-	-
D 35	46.0	47.7	47.0	46.9	47.4	46.0	1.81	0.01	-	-	-

[a]A total of 288 pigs were used in a 35-day experiment with eight replications and 4 or 5 pigs per pen. Experimental diets were fed in two phases, with phase 1 from d 0 to 14 after weaning and phase 2 from d 14 to 28. A common diet containing an antibiotic (Neo-Terramycin with 140 g of neomycin and 140 g of oxytetracycline per ton) was fed during the third phase from d 28 to 35.

[b]The negative control diet did not contain a feed-grade antibiotic. The positive control diet contained a feed-grade antibiotic (Neo-Terramycin with 140 g of neomycin and 140 g of oxytetracycline per ton).

[c]No interactions, $P>0.10$

AN EVALUATION OF ASTAXANTHIN AS A NUTRACEUTICAL GROWTH PROMOTER IN STARTER DIETS FOR WEANLING PIGS[1]

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Summary

A nursery study was conducted at the KSU Swine Teaching and Research Farm to evaluate the effect of increasing dietary astaxanthin (0, 5, 10, and 25 ppm) on weanling pig performance. Astaxanthin is a carotenoid found in various plants, algae, and seafood that exhibits antioxidant and potential anti-inflammatory properties that may be beneficial during times of stress and reduced immunity, such as weaning. A total of 210 pigs (initially 12.6 lb) were used in the 28-d experiment. Pigs were blocked by weight and randomly allotted to one of five dietary treatments. Pigs were fed simple corn-soybean meal-dried, whey-based diets during Phase 1 (d 0 to 14); and corn-soybean meal diets in Phase 2 (d 14 to 28). Treatments consisted of a basal diet for each phase without added feed-grade antibiotic, or the basal diet with 5, 10, or 25 ppm added astaxanthin without added feed-grade antibiotic; or the basal diet with a feed-grade antibiotic (Neo-Terramycin with 140 g of neomycin and 140 g of oxytetracycline per ton). For the d 0 to 14 (Phase 1) period, ADG and F/G were improved (P<0.05) by including a feed-grade antibiotic in the diet. Average daily gain and F/G of pigs fed astaxanthin was not different than control pigs. Pigs fed a feed-grade antibiotic during Phase 1 were heavier (P<0.05) on d 14 than were pigs fed 0, 5, or 10 ppm astaxanthin. They also tended to be heavier (P<0.10) than pigs fed 25 ppm astaxanthin. For the overall Phase 2 period (d 14 to 28), pigs fed antibiotic had greater (P < 0.05) ADG than pigs fed 0, 5, and 25 ppm astaxanthin; the pigs fed 10 ppm astaxanthin had intermediate ADG. Pigs fed antibiotic had greater (P<0.05) ADFI than pigs fed all other treatments. Feed efficiency was improved (quadratic, P<0.07) as the level of astaxanthin increased to 10 ppm and then returned to control values at the 25 ppm level. Pigs fed antibiotic had poorer (P<0.05) F/G than pigs fed 0, 5, or 10 ppm astaxanthin, and pigs fed 25 ppm astaxanthin had poorer (P<0.05) F/G than pigs fed 10 ppm astaxanthin. Overall (d 0 to 28), ADG, ADFI, and average weight on d 28 were improved (P<0.05) by including a feed-grade antibiotic in the diet. Pigs fed 25 ppm astaxanthin or a feed-grade antibiotic had poorer (P<0.05 and P<0.10, respectively) F/G than pigs fed 10 ppm astaxanthin. In conclusion, the growth performance of pigs receiving 5, 10, or 25 ppm of astaxanthin in the Phase 1 and Phase 2 diets was not different than that of pigs fed the negative control diet. However, ADG and ADFI were improved by including a feed-grade antibiotic in the Phase 1 and Phase 2 diets.

(Key words: antibiotics, astaxanthin.)

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[1]Appreciation is expressed to IGENE – Astaxanthin Partners, Ltd. for providing the Aquasta® astaxanthin, and for partial funding of the trial.

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

Introduction

There is increasing public concern about the use of sub-therapeutic levels of feed-grade antibiotics in food animal production. The judicious use of sub-therapeutic (or more commonly "growth promoter") levels of antibiotics in food animal production has served to improve animal health, welfare, and performance/production efficiency. Most often, the use of these feed-grade antibiotics coincides with periods of increased stress, such as weaning.

As a potential alternative to feed-grade antibiotics, there is increasing interest in identifying nutraceutical compounds. Nutricines are "natural" compounds found in various foodstuffs in trace amounts; they have properties that may improve health and immune function but lack an established requirement. An increasing understanding of potential nutraceutical compounds that may enhance immunity and health, and improve the ability to cope with periods of increased stress has stimulated interest in determining their suitability as antibiotic replacements. Few nutraceuticals, however, have been evaluated in studies measuring animal performance. Of these, few have consistently and scientifically been demonstrated to improve animal performance or successfully sustain a level of performance equal to that achieved with a feed-grade antibiotic.

Astaxanthin is used extensively in the aquaculture feed industry for its pigmentation characteristics. Astaxanthin is a carotenoid that also has potent antioxidant properties and exists naturally in various plants, algae, and seafood. Because of its antioxidant and potential anti-inflammatory characteristics, there is interest in evaluating astaxanthin as a nutraceutical in domestic animal species. These properties may be beneficial during times of stress and reduced immunity, such as weaning. Thus, the objective of this experiment was to determine the influence of astaxanthin on growth performance of weanling pigs.

Procedures

Procedures used in this experiment were approved by the Kansas State University Animal Care and Use Committee. The project was conducted at the KSU Swine Teaching and Research Farm. Pens had a wire-mesh floor and provide approximately 3 ft^2 per pig. Each pen was equipped with a four-hole, dry, self-feeder and one nipple waterer providing *ad libitum* access to feed and water. The facility was a mechanically ventilated room with a pull-plug manure storage pit.

A total of 210 pigs were weaned at an average of 12.6 lb and 21 d of age. Pigs were blocked by weight and randomly allotted to one of the five dietary treatments with six pens per treatment. Each pen contained seven pigs. Experimental diets were fed in meal form and maintained throughout two dietary phases (Table 1). The Phase 1 diet, fed from d 0 to 14, was a corn-soybean meal-based diet containing 10% dried whey and 3.75% fish meal. The Phase 2 diet was fed from d 14 to 28 and was a corn-soybean meal-based diet without specialty ingredients. Astaxanthin (0, 5, 10, and 25 ppm) or Neo-Terramycin (140 g/ton of neomycin and 140 g/ton of oxytetracycline) was added to the basal diets at the expense of corn starch to achieve the dietary treatments. Pigs and feeders were weighed on d 0, 7, 14, 21, and 28 post-weaning to determine the response criteria of ADG, ADFI, and F/G.

Data were analyzed as a randomized complete block design using the PROC MIXED procedure of SAS with pen as the experimental unit. Linear and quadratic polynomial contrasts were used to determine the effects of increasing astaxanthin.

Results and Discussion

The analyzed astaxanthin levels for the experimental diets containing added astaxanthin were 4.1, 9.6, and 23 ppm, similar to the targeted values of 5, 10, and 25 used in diet formulation.

For the d 0 to 14 (Phase 1) period, ADG and F/G were improved ($P<0.05$) by including a feed-grade antibiotic in the diet (Table 2). Pigs fed a feed-grade antibiotic were heavier ($P<0.05$) on d 14 than pigs fed 0, 5, or 10 ppm astaxanthin, and they tended to be heavier ($P<0.10$) than pigs fed 25 ppm astaxanthin. Pigs fed astaxanthin had similar performance to pigs fed the negative control diet.

For the Phase 2 period (d 14 to 28), ADG of pigs fed antibiotic was greater ($P<0.05$) than that of pigs fed 0, 5, and 25 ppm astaxanthin; pigs fed 10 ppm astaxanthin had intermediate ADG. Average daily feed intake was greater ($P<0.05$) for pigs fed antibiotic than for all other treatments. Feed efficiency was improved (quadratic, $P<0.07$) as astaxanthin increased to 10 ppm; it then became poorer at the 25 ppm level. Pigs fed antibiotic had poorer ($P<0.05$) F/G than pigs fed 0, 5, or 10 ppm astaxanthin, and pigs fed 25 ppm astaxanthin had poorer ($P<0.05$) F/G than pigs fed 10 ppm astaxanthin.

Overall (d 0 to 28), ADG, ADFI, and average weight on d 28 were improved ($P<0.05$) by including a feed-grade antibiotic in the diet. Pigs fed 25 ppm astaxanthin or a feed-grade antibiotic had poorer ($P<0.05$ and $P<0.10$, respectively) F/G than those fed 10 ppm astaxanthin.

In conclusion, the growth performance of pigs receiving 5, 10, or 25 ppm of astaxanthin in the Phase 1 and Phase 2 diets was not different than that of pigs receiving the negative control diet. Including a feed-grade antibiotic in the diet improved ADG and ADFI during both phases and for the overall experiment.

Table 1. Composition of Experimental Diets[a]

Ingredient	Phase 1	Phase 2
Corn	51.05	60.30
Soybean meal (46.5% CP)	30.15	35.00
Select menhaden fish meal	3.75	-
Spray-dried edible whey	10.00	-
Corn starch	0.77	0.77
Soybean oil	1.00	-
Monocalcium P (21% P)	1.20	1.50
Limestone	0.75	1.10
Salt	0.35	0.35
L-lysine HCl	0.30	0.30
DL-methionine	0.13	0.13
L-threonine	0.15	0.15
Vitamin premix	0.25	0.25
Trace mineral premix	0.15	0.15
Total	100.00	100.00
Calculated analysis		
Total lysine, %	1.55	1.45
True ileal digestible amino acids		
Lysine, %	1.41	1.31
Isoleucine:lysine ratio, %	60	63
Leucine:lysine ratio, %	121	129
Methionine:lysine ratio, %	33	33
Met & Cys:lysine ratio, %	56	58
Threonine:lysine ratio, %	64	65
Tryptophan:lysine ratio, %	17	18
Valine:lysine ratio, %	66	69
Protein, %	22.4	21.9
ME, kcal/lb	1,520	1,498
TID lysine:ME ratio, g/Mcal	4.20	3.97
Ca, %	0.90	0.83
P, %	0.79	0.73
Available P, %	0.40	0.32

[a]Astaxanthin (5, 10, or 25 ppm) or Neo-Terramycin (140g/ton Neomycin + 140g/ton oxytetracycline) was added to the basal diets at the expense of corn starch to achieve the dietary treatments.

Table 2. Growth Performance of Nursery Pigs Fed Increasing Astaxanthin or a Feed-Grade Antibiotic[a]

Item	Negative control	Added Astaxanthin, ppm			Positive control	SE Mean	$P \leq$ Astaxanthin	
		5	10	25			Linear	Quadratic
D 0 to 14								
Initial weight, lb	12.58	12.56	12.59	12.58	12.59	0.61	-	-
ADG, lb	0.29[b]	0.30[b]	0.30[b]	0.31[b]	0.37[c]	0.02	-	-
ADFI, lb	0.37	0.38	0.37	0.39	0.43	0.03	-	-
F/G	1.27	1.26	1.28	1.26	1.16	0.04	-	-
D 14 weight, lb	16.69[b]	16.77[b]	16.72[b]	16.85[bc]	17.79[c]	0.75	-	-
D 14 to 28								
ADG, lb	1.04[b]	1.02[b]	1.06[bc]	1.04[b]	1.13[c]	0.04	-	-
ADFI, lb	1.32[b]	1.29[b]	1.32[b]	1.34[b]	1.49[c]	0.04	-	-
F/G	1.27[bc]	1.27[bc]	1.24[b]	1.29[cd]	1.32[d]	0.01	-	0.064
Overall, D 0 to 28								
ADG, lb	0.67[b]	0.66[b]	0.68[b]	0.67[b]	0.75[c]	0.03	-	-
ADFI, lb	0.84[b]	0.84[b]	0.85[b]	0.86[b]	0.96[c]	0.03	-	-
F/G	1.27[bc]	1.27[bc]	1.25[b]	1.29[c]	1.28[bc]	0.01	-	-
D 28 weight, lb	31.22[b]	31.05[b]	31.59[b]	31.37[b]	33.56[c]	1.17	-	-

[a]A total of 210 pigs were used in a 28-day, two-phase experiment to evaluate the growth performance of pigs fed increasing levels of Aquasta® astaxanthin (0, 5, 10, and 25 ppm). A fifth treatment containing a growth-promotant level of a feed-grade antibiotic (Neo-Terramycin) was also included as a positive control. Six replications (pens) of 7 pigs per pen were utilized in a randomized complete block arrangement of treatments. Phase 1 diets were fed from d 0 to 14 and Phase 2 diets were fed from d 14 to 28 after weaning.

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

COMPARISON OF MODIFIED CONCEPT PR 100 AND SPRAY-DRIED ANIMAL PLASMA ON NURSERY PIG PERFORMANCE[1]

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Summary

One hundred eighty weanling pigs (initially 11.3 lb and 18 ± 2 d of age) were used in a 28-d growth assay to determine if Modified Concept PR 100 (MCNPR), a plant-based protein ingredient containing added synthetic amino acids and nucleic acids, can replace spray-dried animal plasma (SDAP) in nursery pig diets. The five experimental treatments were: 1) control (no specialty protein source); 2) 2.5% SDAP; 3) 5.0% SDAP; 4) 2.5% MCNPR; and 5) 5.0% MCNPR. Treatment diets were fed from d 0 to 14 post-weaning, with a common diet fed to all pigs from d 14 to 28 post-weaning. Analyzed values of MCNPR were noticeably lower than the manufacturer-provided values used in diet formulation. The difference in calculated and analyzed lysine values would decrease the total dietary lysine content by 0.027 and 0.056% for the 2.5 and 5.0% MCNPR, respectively.

From d 0 to 14, pigs fed increasing SDAP had improved (linear, $P<0.01$) ADG, ADFI, and F/G, which was primarily due to a large improvement from the 0 to 2.5% SDAP inclusion, with further increases when 5.0% was fed. In addition pigs fed increasing levels of MCNPR had improved (quadratic, $P<0.002$) feed efficiency, with pigs fed 2.5% MCNPR having the maximum response. While no statistical differences ($P>0.21$) were detected in ADG and ADFI for pigs fed increasing levels of MCNPR, there were improvements by approximately 21 and 11%, respectively, over the control diet. However, pigs fed SDAP had greater ($P<0.05$) ADG, ADFI, and BW at d 14 compared to pigs fed MCNPR.

Overall (d 0 to 28), pigs fed increasing SDAP from d 0 to 14 had greater ($P<0.03$) ADG and tended to have improved ($P<0.08$) ADFI and F/G. Also, pigs fed increasing MCNPR had improved (quadratic, $P<0.01$) feed efficiency, with pigs fed 2.5% MCNPR having the maximum response. While no statistical differences ($P>0.18$) were detected in ADG and ADFI for pigs previously fed increasing MCNPR, there were improvements by approximately 10 and 7%, respectively, over the control diet. Although the magnitude of difference between pigs fed SDAP and MCNPR was maintained to the end of the trial, there were no overall significant differences in growth between pigs fed SDAP and MCNPR ($P>0.21$). These results indicated that SDAP and MCNPR can effectively be used in nursery pig diets to improve growth performance when used as a partial replacement for soybean meal. However, pigs fed SDAP had greater performance than pigs fed

[1]Appreciation expressed to John Whitehead and Charles Schel, Concept Nutrition Ltd., for partial funding of this experiment.

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

MCNPR during the test period, but these differences were not found at the conclusion of the studies.

(Key words: feed ingredients, modified concept PR 100, spray-dried animal plasma.)

Introduction

Spray-dried animal plasma (SDAP) is commonly used in pelleted starter diets to increase daily gain and feed intake of newly weaned pigs. However, with increased consumer and regulatory pressure to remove animal protein sources from swine diets, effective alternatives must be developed and evaluated. In the 2006 KSU Swine Day Report, a newly developed product, Concept PR 100, which is a plant-based protein source, was evaluated to replace SDAP in nursery diets. This data showed that pigs fed diets with Concept PR 100 had improved growth post-weaning but did not equal the improvement shown with pigs fed SDAP. Because of the improvements in growth for pigs fed Concept PR 100, modifications to the existing formula were made by the manufacturer in an attempt to replace SDAP in diets for nursery pigs. Therefore, the objective of this study was to determine if a Modified Concept PR 100 (MCNPR) can fully replace SDAP in nursery pig diets.

Procedures

A total of 180 weanling pigs (initially 11.3 lb and 18 ± 2 d of age) were used in a 28-d growth assay. Pigs were blocked by weight and allotted to one of five dietary treatments. There were six pigs per pen and six pens per treatment. Each pen contained one self-feeder and one nipple waterer to provide *ad libitum* access to feed and water. Pigs were housed in the Kansas State University Swine Teaching and Research Center.

The five experimental treatments were: 1) control (no specialty protein source); 2) 2.5% SDAP; 3) 5.0% SDAP; 4) 2.5% MCNPR; and 5) 5.0% MCNPR. Treatment diets were fed from d 0 to 14 post-weaning, with a common diet fed to all pigs from d 14 to 28 post-weaning. All diets were fed in meal form. The MCNPR (Concept Nutrition Ltd., UK) is a proprietary blend of plant protein ingredients, synthetic amino acids, and nucleic acids which was substituted on a 1:1 basis with SDAP (APC 920; American Proteins Corp., Ankeny, IA). In experimental diet formulation, nutrient values from NRC (1998) were used for SDAP while nutrient values for MCNPR were provided by the manufacturer (Table 1). Experimental diets were formulated to contain 1.50% total lysine (Table 2). Analysis for crude protein and amino acids of SDAP and MCNPR were conducted at the conclusion of the experiment. All pigs were fed a common Phase 2 diet (without SDAP or MCNPR) from d 15 to 28. Average daily gain, ADFI, and F/G were determined by weighing pigs and measuring feed disappearance on d 7, 14, 21, and 28 post-weaning.

Data were analyzed as a randomized complete block design with pen as the experimental unit. Pigs were blocked based on weaning weight, and analysis of variance was performed using the MIXED procedure of SAS. Linear and quadratic polynomial contrasts were used to determine the effects of increasing SDAP or MCNPR in the diet. Also, a contrast comparing the mean of pigs fed SDAP and MCNPR was performed to determine differences between the two protein sources.

Results and Discussion

Crude protein and amino acid analyses of SDAP revealed similar levels as compared to those used in diet formulation (Table 1). However, analyzed values of MCNPR were noticeably lower than the manufacturer provided values used in diet formulation. The difference in calculated and analyzed lysine values would decrease the total dietary lysine

content by 0.027 and 0.056% for the 2.5 and 5.0% MCNPR, respectively.

From d 0 to 14, pigs fed increasing SDAP had improved (linear, $P<0.01$) ADG, ADFI, and F/G, which was primarily due to a large improvement from the 0 to 2.5% SDAP inclusion, with smaller increases when 5.0% was fed (Table 3). In addition, pigs fed increasing MCNPR had improved (quadratic, $P<0.002$) feed efficiency with pigs fed 2.5% having the maximum response. While no statistical differences ($P>0.21$) were detected in ADG and ADFI for pigs fed increasing MCNPR, there were improvements by approximately 21 and 11%, respectively, compared to the control diet. However, pigs fed SDAP had greater ($P<0.05$) ADG, ADFI, and BW at d 14 compared to pigs fed MCNPR.

From d 15 to 28 (common feeding period), there were no differences among pigs fed any of the dietary treatments ($P>0.15$).

Overall (d 0 to 28), pigs fed increasing SDAP from d 0 to 14 had greater (linear, $P<0.03$) ADG and tended to have improved (linear $P<0.08$) ADFI and F/G. Also, pigs fed increasing MCNPR had improved (quadratic, $P<0.01$) feed efficiency, with pigs fed 2.5% having the maximum response. While no statistical differences ($P>0.18$) were detected in ADG and ADFI for pigs fed increasing MCNPR, there were improvements by approximately 10 and 7%, respectively, compared to pigs fed the control diet. There were no overall differences in growth between pigs fed SDAP and MCNPR ($P>0.21$).

Results from this study indicate that nursery pig performance improved, as expected, when a specialty protein source was used as partial replacement for soybean meal in the diet. However, while the typical growth improvement was seen with the addition of SDAP, the inclusion of MCNPR did not improve growth performance to the extent of SDAP. This may be due to the lower analyzed crude protein and amino acids than were used in diet formulation. These lower values may have contributed to the inability of MCNPR to equal the response seen when pigs were fed SDAP.

These results indicate that SDAP and MCNPR can effectively be used in nursery pig diets to improve growth performance when used as a partial replacement for soybean meal. However, pigs fed SDAP had greater performance than pigs fed MCNPR during the test period, but these differences were not found at the conclusion of the study.

The use of MCNPR in nursery diets to provide a plant protein-based alternative to animal products needs to be further evaluated, based on improvements seen in this study and previously reported research.

Table 1. Analyzed Nutrient Composition of Specialty Ingredients (As-fed Basis)

	SDAP[1]		MCNPR[2]	
Nutrient	Formulated[3]	Analyzed[4]	Formulated[5]	Analyzed[4]
Crude Protein, %	78.00	79.25	67.79	62.17
Amino Acids, %:				
Arginine	4.55	4.67	4.70	3.86
Cysteine	2.63	2.56	0.92	0.74
Histidine	2.55	2.57	1.61	1.37
Isoleucine	2.71	2.88	2.89	2.40
Leucine	7.61	7.62	4.60	4.16
Lysine	6.84	6.90	6.85	5.76
Methionine	0.75	0.65	2.39	2.17
Threonine	4.72	4.48	4.64	4.03
Tryptophan	1.36	1.35	1.50	1.11
Valine	4.94	5.00	2.94	2.51

[1]Spray-dried animal plasma (APC 920; American Proteins Corp., Ankeny, IA).
[2]Modified Concept Nutrition Plasma Replacer 100 (Concept Nutrition Ltd., UK).
[3] Nutrient values from NRC (1998).
[4]Mean value of one sample analyzed in duplicate.
[5] Nutrient values provided by the manufacturer.

Table 2. Composition of Experimental Diets (as-fed basis)[1]

		SDAP[2]		MCNPR[3]		
Ingredient, %	Control	2.50%	5.00%	2.50%	5.00%	Phase 2
Corn	44.05	47.60	51.20	47.60	51.20	59.20
Soybean meal (46.5% CP)	37.50	31.50	25.50	31.50	25.50	34.75
Spray-dried animal plasma	-	2.50	5.00	-	-	-
Modified Concept PR 100	-	-	-	2.50	5.00	-
Dried whey	15.00	15.00	15.00	15.00	15.00	-
Soy oil	-	-	-	-	-	2.00
Monocalcium P (21 % P)	1.40	1.25	1.13	1.25	1.13	1.60
Limestone	1.00	1.10	1.20	1.10	1.20	1.10
Salt	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
Trace mineral premix	0.15	0.25	0.25	0.25	0.25	0.15
L-Lysine HCl	0.15	0.15	0.15	0.15	0.15	0.30
DL-Methionine	0.12	0.11	0.10	0.11	0.10	0.15
L-Threonine	0.07	0.05	0.03	0.05	0.03	0.15
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis:[4]						
Total Lysine, %	1.50	1.50	1.50	1.50	1.50	1.44
TID amino acids, %[5]						
Lysine	1.34	1.35	1.35	1.35	1.35	1.30
Methionine:lysine	32	31	29	31	29	35
Met & Cys:lysine	58	58	58	58	58	59
Threonine:lysine	64	64	64	64	64	65
Tryptophan:lysine	20	19	19	19	19	18
Isoleucine:lysine	67	64	60	64	60	62
Crude Protein, %	23.3	22.7	22.2	22.5	21.6	21.7
Ca, %	0.89	0.89	0.89	0.91	0.93	0.85
P, %	0.78	0.76	0.75	0.74	0.70	0.74

[1]Experimental diets fed from d 0 to 14 post-weaning and with all pigs fed a common diet from d 15 to 28 post-weaning.
[2]Spray-dried animal plasma (APC 920; American Proteins Corp., Ankeny, IA).
[3]Modified Concept Plasma Replacer 100 (Concept Nutrition Ltd., UK).
[4]Nutrient values from NRC (1998) were used for SDAP and nutrient values for MCNPR were provided by the manufacturer.
[5]True ileal digestible amino acids.

Table 3. Effect of Specialty Protein Source on Nursery Pig Performance[1]

							Probability, $P <$				
		SDAP[2]		MCNPR[3]			SDAP vs	SDAP		MCNPR	
Item	Control	2.5%	5.0%	2.5%	5.0%	SEM	MCNPR	Linear	Quadratic	Linear	Quadratic
D 0 to 14											
ADG, lb	0.35	0.49	0.52	0.43	0.42	0.04	0.04	0.003	0.24	0.21	0.29
ADFI, lb	0.46	0.58	0.61	0.50	0.52	0.04	0.03	0.01	0.38	0.26	0.90
F/G	1.33	1.19	1.18	1.15	1.26	0.03	0.62	0.01	0.12	0.15	0.002
D 15 to 28											
ADG, lb	0.99	1.04	1.06	1.02	1.06	0.05	0.87	0.23	0.85	0.23	0.95
ADFI, lb	1.31	1.36	1.40	1.35	1.43	0.08	0.85	0.29	0.94	0.15	0.74
F/G	1.32	1.31	1.31	1.31	1.35	0.02	0.33	0.78	0.72	0.29	0.27
D 0 to 28											
ADG, lb	0.67	0.76	0.79	0.73	0.74	0.04	0.24	0.03	0.50	0.21	0.61
ADFI, lb	0.88	0.97	1.01	0.92	0.97	0.06	0.42	0.08	0.69	0.18	0.90
F/G	1.32	1.27	1.27	1.26	1.32	0.02	0.21	0.06	0.27	0.85	0.01
Pig Weight, lb											
D 0	11.35	11.33	11.29	11.35	11.39	0.52	0.05	0.15	0.73	0.31	0.52
D 14	16.30	18.14	18.52	17.39	17.24	0.89	0.05	0.004	0.23	0.18	0.31
D 28	30.15	32.64	33.40	31.70	32.11	1.53	0.28	0.03	0.49	0.18	0.65

[1]A total of 180 pigs (six pigs per pen and six pens per treatment) with an initial BW of 11.3 lbs. Pigs were fed experimental diets from d 0 to 14 post-weaning, with all pigs fed a common diet from d 15 to 28 post-weaning.
[2]Spray-dried animal plasma (APC 920; American Proteins Corp., Ankeny, IA).
[3]Modified Concept Plasma Replacer 100 (Concept Nutrition Ltd., UK).

EFFECTS OF PHYTOBIOTICS (BIOMIN® P.E.P.) ON NURSERY PIG PERFORMANCE

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Summary

A total of 192 weanling pigs (initially weighing 12.9 lb and 22 ± 2 d of age, PIC) were used in a 42-d growth assay to determine the effects of phytobiotic (Biomin® P.E.P. 125 and 125T) addition to nursery pig diets on post-weaning growth performance. Pigs were blocked by initial weight and randomly allotted to one of four treatments: 1) negative control (feed containing no antibiotic or phytobiotic); 2) negative control + phytobiotic 1 (125 g/ton of Biomin® P.E.P. 125); 3) negative control + phytobiotic 2 (125 g/ton of Biomin® P.E.P. 125T), and 4) positive control (feed containing 140 g/ton of neomycin sulfate and 140 g/ton of oxytetracycline HCl; Neo/OTC). Each treatment had six pigs per pen and eight replications (pens).

Phase 1 and Phase 2 diets were fed from d 0 to 14 and d 14 to 42 post-weaning, respectively. Pigs were weighed and feed intake was determined weekly to calculate ADG, ADFI, and F/G. Data were analyzed as a randomized complete block design using the MIXED procedure of SAS with pen as experimental unit. Overall (d 0 to 42), pigs fed Neo/OTC had greater ADG ($P<0.03$) and ADFI ($P<0.01$) than pigs fed the negative control or diets with phytobiotics. Addition of phytobiotics to the nursery diet also increased ($P<0.02$) daily gains (5.3 to 6.1%) and reduced ($P<0.01$) F/G (3.5 to 4.0%) compared to pigs fed diets without antibiotics. No differences ($P>0.38$) were observed in ADFI between pigs fed the negative control diet and pigs fed either phytobiotic. Pigs fed diets containing either phytobiotic had improved ($P<0.01$) F/G compared with pigs fed diets with Neo/OTC. However, pigs fed diets with Neo/OTC had similar ($P=0.26$) F/G compared to pigs fed diets without antibiotics. No differences ($P>0.52$) were observed in ADG, ADFI, and F/G between pigs fed diets with phytobiotic 1 and 2. In conclusion, phytobiotics in nursery diets improved post-weaning growth performance compared to pigs fed diets without antibiotics. However, the improvement in growth rate was intermediate between diets fed with and without in-feed antibiotics. Further research is needed to elucidate specific modes of action that caused positive effects in post-weaning growth and efficiency.

(Key words: antibiotics, phytobiotics.)

Introduction

Phytobiotics, which are natural biologically active substances derived from herbs and spices, are one of the potential alternatives considered in the context of replacing in-feed antibiotics in swine diets. The viability of phytobiotic use in animal feeding stemmed from extensive clinical evidence of the potency of numerous plant extracts as antimicrobial agents. Potential effects of phytobiotics on

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[2]Bioman Inc., San Antonio, TX.

immune function can be mediated either by alterations of the composition of the gut microflora or by direct effects on the gut-associated or general immune system.

Biomin® P.E.P. is a combination of phytobiotics and fructo-oligosaccharides designed to stimulate the pig's appetite through its aromatic properties, optimize digestion, and enhance the immune system through its antimicrobial and antioxidative effects. A number of field tests comparing this phytogenic blend with antibiotic growth promoters in nursery diets have shown positive effects on growth performance, but controlled experiments have been lacking. Therefore, the objective of this experiment was to determine the effects of phytobiotic (Biomin® P.E.P. 125 and 125T) addition to nursery pig diets on post-weaning growth performance.

Procedures

A total of 192 weanling pigs (initially weighing 12.9 lb and 22 ± 2 d of age, PIC) were used in a 42-d growth assay. Pigs were blocked by initial weight and randomly allotted to one of four experimental treatments. Each treatment had six pigs per pen and eight replications (pens). Each pen contained one self-feeder and one nipple waterer to provide *ad libitum* access to feed and water. Pigs were housed in the Kansas State University Swine Teaching and Research Center.

The experimental treatments were: 1) negative control (feed containing no antibiotic or phytobiotic); 2) negative control + phytobiotic 1 (125 g/ton of Biomin® P.E.P. 125); 3) negative control + phytobiotic 2 (125 g/ton of Biomin® P.E.P. 125T), and 4) positive control (feed containing 140 g/ton of neomycin sulfate and 140 g/ton of oxytetracycline HCl; Neo/OTC). A two-phase diet series was used, with a Phase 1 diet fed from d 0 to 14 and a Phase 2 diet fed from d 14 to 42 after weaning. Biomin® P.E.P. 125, Biomin® P.E.P. 125T, or the antibiotic replaced corn in the negative control diets to form the experimental treatments (Table 1). All experimental diets were fed in meal form. Pigs and feeders were weighed on day 0, 7, 14, 21, 28, 35, and 42 post-weaning to calculate ADG, ADFI, and F/G. Data were analyzed as a randomized complete block design using the MIXED procedure of SAS with pen as experimental unit.

Results and Discussion

From d 0 to 7, pigs fed diets containing Neo/OTC had greater ($P<0.02$) ADG than pigs fed the negative control diet (Table 2). This improvement in gain resulted in heavier (15.07 vs. 14.55 lb; $P<0.02$) weights at d 7. Daily gains of pigs fed diets containing phytobiotics were intermediate and not different ($P>0.13$) from pigs fed diets with either Neo/OTC or without antibiotics. There were no differences in ADFI between treatments. Moreover, pigs fed diets with Neo/OTC had better ($P<0.03$) F/G than pigs fed diets without antibiotics. Likewise, pigs on diets containing phytobiotic 2 tended to have a better ($P<0.08$) F/G than pigs fed no antibiotics. Pigs fed diets with phytobiotic 1, however, had similar ($P>0.17$) F/G to those of other treatments.

From d 0 to 14, pigs fed diets with Neo/OTC had greater ($P<0.01$) daily gains compared to both the negative control-fed pigs and the pigs fed diets with phytobiotics. Pigs fed either of the phytobiotics also had a greater ($P<0.01$) ADG than the negative controls. Daily gains were similar ($P>0.17$) between pigs fed phytobiotic 1 and 2. There were no differences ($P>0.86$) in ADFI between the pigs fed the negative control diet and pigs fed diets with either of the phytobiotics. Pigs fed diets with phytobiotic 2, however, had decreased ($P<0.01$) ADFI compared to pigs fed Neo/OTC. Pigs fed diets containing Neo/OTC had the best ($P<0.03$) F/G; however, pigs fed diets with either of the phy-

tobiotics also had better ($P<0.01$) F/G than pigs fed the control diet with no antibiotics.

From d 14 to 42, pigs fed Neo/OTC tended to have greater ($P<0.08$) ADG than pigs fed the negative control diet, with phytobiotic-fed pigs being intermediate. Pigs fed Neo/OTC had greater ($P<0.01$) ADFI than pigs fed the negative control diet or diets with either phytobiotic. There were no differences ($P>0.32$) in ADFI between the negative control and pigs fed either phytobiotic. Pigs fed the control diet without antibiotics and either of the phytobiotics had better ($P>0.01$) F/G than pigs fed diets containing Neo/OTC. No differences in ADG, ADFI, and F/G were observed between phytobiotic 1 and 2.

Overall (d 0 to 42), pigs fed Neo/OTC had greater ($P<0.04$) daily gains than pigs fed diets with no antibiotics or with phytobiotic 2. In addition, pigs fed Neo/OTC tended to have greater ($P<0.07$) ADG than pigs fed diets with phytobiotic 1. Pigs fed phytobiotic 1 and 2 also had greater ($P<0.03$) ADG than pigs fed no antibiotics. As a result, pigs fed diets with Neo/OTC had the heaviest weight at d 42, weighing 4.6 lb more (59.5 vs. 54.9 lb; $P<0.01$) than the negative controls and at least 2 lb more ($P<0.03$) than either of the phytobiotic-fed pigs. Likewise, pigs fed either phytobiotic were 2.2 lb heavier ($P<0.02$) than pigs fed the negative control diet. Pigs fed Neo/OTC had greater ($P<0.01$) ADFI than pigs fed the negative control diet or a diet with either phytobiotic. No differences ($P>0.38$) were observed in ADFI between pigs fed the negative control diet and pigs fed either phytobiotic. Pigs fed diets containing either phytobiotic had improved ($P<0.01$) F/G compared with pigs fed diets with or without antibiotics. However, pigs fed diets with Neo/OTC had similar ($P=0.26$) F/G compared to pigs fed diets without antibiotics. No differences ($P>0.52$) were observed in ADG, ADFI, and F/G between pigs fed diets with phytobiotic 1 and 2.

Results of the study demonstrate the positive effect of antibiotics in promoting growth of nursery pigs. This is consistent with previous studies conducted at the Kansas State University research farm; where pigs fed nursery diets containing Neo/OTC had greater ADG and ADFI than pigs fed the control diet with no medication post-weaning. This experiment also found that both phytobiotics improved growth performance of nursery pigs compared to a diet without antibiotics. Overall, addition of phytobiotics improved daily gains by 5.3 to 6.1% and F/G by 3.5 to 4.0% compared to pigs fed diets with no antibiotics. Pigs fed diets with antibiotics had 4.5 to 5.3% higher daily gains than those fed diets with phytobiotics, but feed efficiency of phytobiotic-fed pigs was 2.4 to 3.0% better than that of the antibiotic-fed pigs. The improvement in daily gain for pigs on diets with Neo/OTC appears to be due to the increase in ADFI compared with pigs fed the other diets (9.7% higher ADFI than pigs fed no antibiotics). No differences in ADFI were observed between pigs fed diets containing phytobiotics and diets without antibiotics. This indicates that the positive improvement in growth performance related to phytobiotic addition to the diet is an efficiency response.

In conclusion, adding phytobiotics to nursery diets improved post-weaning growth performance and can be used effectively as growth promoters in diets that do not contain antibiotics. However, this improvement in growth rate was intermediate between diets fed with or without in-feed antibiotics. Further research is needed to elucidate specific modes of action that caused positive effects in post-weaning growth and efficiency. Because the growth response observed from antibiotics was largely driven by feed intake, and the phytobiotics resulted in an efficiency response, then it is speculated that the two have different modes of action and may potentially have additive effects.

Table 1. Diet Composition (As-fed Basis)

Ingredient, %	Phase 1[a]	Phase 2[b]
Corn	51.11	59.27
Soybean meal (46.5% CP)	30.16	35.10
Spray dried whey	10.00	---
Select menhaden fish meal	3.75	---
Soy oil	1.00	1.00
Monocalcium P (21% P)	1.20	0.50
Limestone	0.75	1.10
Salt	0.35	0.35
Vitamin premix	0.25	0.25
Trace mineral premix	0.15	0.15
L-Threonine	0.15	0.15
DL-Methionine	0.13	0.13
Lysine HCl	0.30	0.30
Corn starch	0.70	---
Antibiotic[c]	---	0.70
Total	100.00	100.00
Calculated analysis		
Total lysine, %	1.55	1.45
True digestible amino acids, %		
Lysine	1.41	1.31
Isoleucine:lysine ratio	60	62
Leucine:lysine ratio	122	129
Methionine:lysine ratio	32	32
Met & cys:lysine ratio	56	57
Threonine:lysine ratio	66	67
Tryptophan:lysine ratio	17	18
Valine:lysine ratio	68	71
ME, kcal/lb	1,493	1,494
CP, %	21.9	21.4
Ca, %	0.90	0.83
P, %	0.79	0.72
Available P, %	0.50	0.39

[a]Fed from d 0 to 14 post-weaning.
[b]Fed from d 14 to 42 post-weaning.
[c]Phytobiotic 1 (125 g of Biomin® P.E.P. 125), 2 (125 g of Biomin® P.E.P. 125 T), or antibiotic (140 g/ton neomycin sulfate, 140 g/ton oxytetracycline HCl) replaced cornstarch in the control diets to provide the additional dietary treatments.

Table 2. Effects of Phytobiotics on Nursery Pig Performance[1]

	Dietary Treatment					Probability, *P*<			
Item	Negative Control	Phytobiotic 1[2]	Phytobiotic 2[3]	Neo/OTC[4]	SEM	Negative vs Neo/OTC	Negative vs Phytobiotics	Neo/OTC vs Phytobiotics	Phytobiotic 1 vs 2
Pig weight, lb									
D 0	12.91	12.90	12.91	12.91	0.02	0.61	0.99	0.56	0.31
D 7	14.55	14.79	14.77	15.07	0.21	0.02	0.22	0.12	0.90
D 28	33.18	35.22	34.69	36.52	0.70	0.0001	0.008	0.02	0.46
D 42	54.86	57.44	57.08	59.44	1.05	0.0003	0.02	0.03	0.74
D 0 to 7									
ADG, lb	0.24	0.27	0.27	0.31	0.03	0.02	0.21	0.13	0.87
ADFI, lb	0.31	0.31	0.28	0.31	0.02	0.91	0.37	0.44	0.26
F/G	1.36	1.17	1.11	1.04	0.14	0.03	0.07	0.40	0.66
D 0 to 14									
ADG, lb	0.37	0.49	0.45	0.58	0.02	<.0001	0.0002	<.0001	0.17
ADFI, lb	0.54	0.56	0.51	0.59	0.02	0.05	0.86	0.02	0.06
F/G	1.45	1.15	1.15	1.02	0.06	<.0001	<.0001	0.03	0.94
D 14 to 42									
ADG, lb	1.31	1.35	1.35	1.37	0.03	0.08	0.21	0.42	0.90
ADFI, lb	1.86	1.90	1.89	2.04	0.04	0.0004	0.32	0.0009	0.87
F/G	1.41	1.41	1.40	1.48	0.02	0.001	0.55	<.0001	0.64
D 0 to 42									
ADG, lb	1.00	1.06	1.05	1.11	0.03	0.0003	0.02	0.03	0.73
ADFI, lb	1.42	1.45	1.43	1.55	0.02	0.0003	0.38	0.0004	0.52
F/G	1.42	1.37	1.36	1.40	0.02	0.26	0.0001	0.003	0.57

[1]A total of 192 pigs (initial wt of 12.9 lb and 22 ± 2 d of age, PIC), with 6 pigs per pen and 8 replications per treatment.
[2]Provided with 125 g of Biomin® P.E.P. 125 per ton of complete feed.
[3]Provided with 125 g of Biomin® P.E.P. 125 T per ton of complete feed.
[4]Provided with 140 g of neomycin sulfate and 140 g of oxytetracycline HCl per ton of complete feed.

EFFECTS OF CHOICE WHITE GREASE OR SOYBEAN OIL ON GROWTH PERFORMANCE AND CARCASS CHARACTERISTICS OF GROW-FINISH PIGS[1]

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Summary

A total of 144 barrows and gilts (PIC) with an initial BW of 97 lb were used to evaluate the effects of dietary fat source and duration of feeding on growth performance and carcass fat quality. Dietary treatments included a corn-soybean meal control diet with no added fat or a 2 × 4 factorial arrangement with 5% choice white grease (CWG) or soybean oil and withdrawal of the fat 0, 14, 28, or 56 days before market (82 days). At the end of each feeding duration, pigs were switched to the control diet. At the end of the study (d 82), jowl fat and backfat samples were collected. Lengthening the duration of feeding soybean oil increased (quadratic, $P<0.01$) ADG and improved F/G. Increasing the feeding duration of CWG had no effect on ADG, but improved (quadratic, $P<0.01$) F/G. Increasing the feeding duration of CWG or soybean oil increased (quadratic, $P<0.02$) dressing percentage with the improvement being greater ($P<0.06$) for pigs fed CWG compared to pigs fed soybean oil. Gilts had increased ($P<0.01$) iodine value (IV; more unsaturated fat) compared to barrows. Increasing feeding duration of either soybean oil or CWG increased (quadratic, $P<0.01$) IV compared to pigs fed the control diet. In summary, adding fat to the diet improved pig growth performance but increased jowl fat and backfat IV. Feeding fat during any stage influenced jowl IV at market with duration of feeding having the greatest response with soybean oil.

(Key words: fat, pork quality, iodine value.)

Introduction

Considerable research has shown improvements in feed efficiency and average daily gain from feeding added fat to finishing pigs. Carcass composition, however, can be altered when fat is included in diets, which may have implications from a processor acceptance standpoint. Iodine value is a measure of the level of unsaturation or softness of a fat. Feeding different fat sources for various time periods may influence carcass iodine value, which is an indicator of carcass firmness and quality. Currently, Triumph Foods, St. Joseph, MO has set a maximum jowl iodine value of 73. With this in mind, the objective of this trial was to evaluate the influence removing soybean oil or choice white grease from the diet at different times before market would have on growth performance, carcass characteristics, and carcass fat iodine values.

Procedures

One hundred forty-four crossbred barrows and gilts, (PIC 337 × C22) with an initial

[1]The authors thank the Kansas Corn Growers and Soybean Associations and the Kansas Pork Association for partial financial support.

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weight of 96.7 lb, were used in an 82 d experiment. Pigs were blocked by gender and weight and allotted to one of nine treatments with eight replicate pens per treatment. Pigs were housed two per pen in an environmentally controlled finishing barn with 4 ft × 4 ft totally slatted pens. Each pen was equipped with a one-hole dry self-feeder and nipple waterer to provide *ad libitum* access to feed and water.

Treatments were based on two different fat sources and fat withdrawal time before slaughter. The treatments included a control diet plus eight diets arranged in a 2 × 4 factorial based on fat source (choice white grease or soybean oil) and withdrawal time before market (0, 14, 28, or 56 days; Figure 1). The control diet was corn-soybean meal-based without added fat. Choice white grease (CWG) and soybean oil were added at 5% to the control diet. Prior to being placed on test, pigs had been fed a similar corn-soybean meal-based diet without added fat.

Diets were formulated to be fed in three phases from d 0 to 26, 26 to 54, and 54 to 82 to correspond with approximate weight ranges of 90 to 150, 150 to 210, and 210 to 270 lb (Tables 1 to 3). Either 5% choice white grease or soybean oil was added to each basal diet to form the experimental diets. A constant TID lysine:ME ratio was maintained by increasing the soybean meal level in the basal diet when adding the fat sources.

Pigs and feeders were weighed on d 12, 26, 40, 54, 68, and 82 to calculate ADG, ADFI, and F/G. Pigs were slaughtered at Triumph Foods of St. Joseph, MO at the end of the 82-d trial for collection of individual carcass data. The pigs were marked with an individual tattoo before marketing. At 24 h postmortem, jowl and backfat samples were collected and frozen until further processing and analysis for fatty acid profiles. Iodine value was calculated from 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).

The fatty acids are represented as a percentage of the total fatty acids in the sample. Data were analyzed in a randomized complete-block design with pen as the experimental unit. Analysis of variance was performed by using the MIXED procedure of SAS. Linear and quadratic contrasts were used to evaluate the effects of feeding duration of CWG and soybean oil on growth and carcass performance. Hot carcass weight was used as a covariate for last rib backfat, 10^{th} rib backfat, loin eye area, and percentage lean.

Results and Discussion

Barrows had increased ($P<0.03$) ADG, ADFI, and F/G compared with gilts. Increasing feeding duration of soybean oil improved (quadratic, $P<0.01$) ADG and F/G. Increasing feeding duration of CWG improved (quadratic, $P<0.02$) F/G. For both fat sources, growth performance appeared to be optimized with a feeding duration of 68 days. Barrows had increased ($P<0.04$) hot carcass weight, last rib backfat, and 10^{th} rib backfat, and decreased ($P<0.01$) loin depth and percentage lean compared with gilts. Increasing feeding duration of CWG and soybean oil increased (quadratic, $P<0.02$) hot carcass weight and dressing percentage with the yield improvement being greater ($P<0.06$) for pigs fed CWG than for pigs fed soybean oil.

Barrows had lower ($P<0.03$) iodine values for jowl fat and backfat and C 18:2 fatty acids than gilts. Barrows also had a greater ($P<0.04$) percentage of saturated fatty acids in the jowl fat and backfat than gilts. Increasing feeding duration of CWG and soybean oil increased (quadratic, $P<0.01$) iodine value of jowl fat and backfat, and C 18:2 fatty acids in jowl fat and backfat. Increasing feeding duration of CWG and soybean oil decreased (quadratic, $P<0.01$) saturated fatty acids in the jowl and backfat. Pigs fed soybean oil had increased

(quadratic, $P<0.01$) iodine values and C 18:2 fatty acids in jowl and backfat, and decreased (quadratic, $P<0.01$) saturated fatty acids in jowl fat and backfat compared with pigs fed CWG.

These results confirm that adding fat to finishing pig diets improves growth performance and feed efficiency. The results also confirm barrows have increased ADG, ADFI, F/G, and backfat, but decreased loin eye area and percentage lean compared with gilts. Increasing feeding duration of fat improves dressing percentage.

Feeding fat increased the softness of fat deposits as measured by iodine value and the percentage of C 18:2 fatty acids, with soybean oil having a more dramatic effect than CWG. Feeding 5% choice white grease, with the Midwestern source used in this trial, for the entire 82-d trial resulted in jowl iodine values acceptable for the Triumph Plant; however, feeding 5% soybean oil for as short of a period as 26 d resulted in jowl iodine value exceeding the maximum threshold even when it was removed from the diet at 56 d before market. Therefore, producers must monitor levels of unsaturated fatty acids in diets for market swine from all dietary sources. Further research evaluating feeding regimes to overcome the large increase in carcass IV when unsaturated fat sources are included in the diet is warranted.

Table 1. Phase 1 Diet Composition (d 0 to 26, as-fed basis)

Ingredients, %	Control	5% CWG	5% Soybean Oil
Corn	72.09	64.14	63.98
Soybean meal (46.5% CP)	25.16	28.11	28.27
Choice white grease	---	5.00	---
Soybean oil	---	---	5.00
Monocalcium P (21% P)	1.05	1.05	1.05
Limestone	0.90	0.90	0.90
Salt	0.35	0.35	0.35
Vitamin premix	0.15	0.15	0.15
Trace mineral premix	0.15	0.15	0.15
L-lysine HCl	0.15	0.15	0.15
Total	100.00	100.00	100.00
Calculated analysis			
Total lysine, %	1.07	1.13	1.14
True ileal digestible amino acids			
Lysine, %	0.95	1.01	1.02
Methionine:lysine ratio, %	28	27	27
Met & cys:lysine ratio, %	57	55	55
Threonine:lysine ratio, %	61	60	60
Tryptophan:lysine ratio, %	19	19	19
ME, kcal/lb	1,507	1,609	1,619
Crude fat, %	3.2	7.9	7.9
Ca, %	0.64	0.65	0.65
P, %	0.60	0.59	0.59
Available P, %	0.29	0.29	0.29
TID lysine:Calorie ratio, g/Mcal ME	2.58	2.58	2.58
Analyzed values			
Dietary fat IV	106.9	53.3	92.1
Dietary IV	34.2	42.1	72.8

Table 2. Phase 2 Diet Composition (d 26 to 54, as-fed basis)

Ingredients, %	Control	5% CWG	5% Soybean Oil
Corn	80.07	72.68	72.48
Soybean meal (46.5% CP)	17.28	19.67	19.87
Choice white grease		5.00	
Soybean oil			5.00
Monocalcium P (21% P)	1.00	1.00	1.00
Limestone	0.90	0.90	0.90
Salt	0.35	0.35	0.35
Vitamin premix	0.13	0.13	0.13
Trace mineral premix	0.13	0.13	0.13
L-lysine HCl	0.15	0.15	0.15
Total	100.00	100.00	100.00
Calculated analysis			
Total lysine, %	0.85	0.90	0.91
True ileal digestible amino acids			
Lysine, %	0.75	0.80	0.81
Methionine:lysine ratio, %	30	29	29
Met & cys:lysine ratio, %	63	60	59
Threonine:lysine ratio, %	62	61	61
Tryptophan:lysine ratio, %	19	19	19
ME, kcal/lb	1,510	1,612	1,622
Crude fat, %	3.4	8.1	8.1
Ca, %	0.61	0.62	0.62
P, %	0.55	0.55	0.55
Available P, %	0.27	0.27	0.27
TID lysine:calorie ratio, g/Mcal ME	2.14	2.14	2.14
Analyzed values			
Dietary fat IV	107.1	64.4	89.9
Dietary IV	36.4	52.2	72.9

Table 3. Phase 3 Diet Composition (d 54 to 82, as-fed basis)[a]

Ingredients, %	Control	5% CWG	5% Soybean Oil
Corn	84.18	77.11	76.87
Soybean meal (46.5% CP)	13.37	15.44	15.68
Choice white grease		5.00	
Soybean oil			5.00
Monocalcium P (21% P)	0.80	0.80	0.80
Limestone	0.90	0.90	0.90
Salt	0.35	0.35	0.35
Vitamin premix	0.13	0.13	0.13
Trace mineral premix	0.13	0.13	0.13
L-lysine HCl	0.15	0.15	0.15
Total	100.00	100.00	100.00
Calculated analysis			
Total lysine, %	0.74	0.78	0.79
True ileal digestible amino acids			
Lysine, %	0.65	0.69	0.70
Methionine:lysine ratio, %	32	31	30
Met & cys:lysine ratio, %	67	63	63
Threonine:lysine ratio, %	64	62	62
Tryptophan:lysine ratio, %	19	19	19
ME, kcal/lb	1,514	1,616	1,626
Crude fat, %	3.5	8.2	8.2
Ca, %	0.56	0.57	0.57
P, %	0.50	0.49	0.49
Available P, %	0.22	0.22	0.22
TID lysine:calorie ratio, g/Mcal ME	1.85	1.85	1.85
Analyzed values			
Dietary fat IV	106.6	60.9	85.2
Dietary IV	37.3	49.9	69.9

Figure 1. Treatment Structure

	Day of Trial			
Treatment	0 to 26	26 to 54	54 to 68	68 to 82
Control	Control	Control	Control	Control
CWG[1] d 0 to 26	5% CWG	Control	Control	Control
CWG d 0 to 54	5% CWG	5% CWG	Control	Control
CWG d 0 to 68	5% CWG	5% CWG	5% CWG	Control
CWG d 0 to 82	5% CWG	5% CWG	5% CWG	5% CWG
Soybean Oil d 0 to 26	5% Soy Oil	Control	Control	Control
Soybean Oil d 0 to 54	5% Soy Oil	5% Soy Oil	Control	Control
Soybean Oil d 0 to 68	5% Soy Oil	5% Soy Oil	5% Soy Oil	Control
Soybean Oil d 0 to 82	5% Soy Oil	5% Soy Oil	5% Soy Oil	5% Soy Oil

[1]Choice white grease.

Table 4. Effects of Choice White Grease and Soybean Oil and Feeding Duration on Growth Performance[a]

													Probability, *P*<					
														Feeding duration				
Fat source:	Control	5 % Choice white grease				5 % Soybean oil							Fat	CWG		Soybean oil	
Feeding duration, d:	0	26	54	68	82	26	54	68	82	Barrows	Gilts	SE	Gender	Source	Linear	Quad	Linear	Quad
D 0 to 82																		
ADG, lb	2.18	2.24	2.27	2.28	2.27	2.28	2.29	2.38	2.35	2.36	2.21	0.071	0.01	0.07	0.42	0.14	0.32	0.01
ADFI, lb	6.93	7.00	6.71	6.65	6.52	7.28	6.49	6.79	6.86	6.35	5.72	0.090	0.01	0.54	0.81	0.23	0.93	0.79
F/G	2.82	2.72	2.66	2.60	2.61	2.66	2.67	2.54	2.54	2.70	2.59	0.072	0.03	0.30	0.47	0.02	0.37	0.01

[a]Total of 144 pigs (initial weight 96.7 lbs) with 2 pigs per pen and eight replications per treatment.

Table 5. Effects of Choice White Grease and Soybean Oil and Feeding Duration on Carcass Characteristics[a]

													Probability, *P*<					
														Feeding duration				
Fat source:	Control	5 % Choice white grease				5 % Soybean oil							Fat	CWG		Soybean oil	
Feeding duration, d:	0	26	54	68	82	26	54	68	82	Barrows	Gilts	SE	Gender	Source	Linear	Quad	Linear	Quad
Carcass weight, lb	199.5	201.5	207.2	209.0	207.7	203.7	208.5	211.7	211.3	211.6	201.8	0.056	0.04	0.22	0.63	0.02	0.56	0.01
Yield, %	72.5	72.1	73.3	73.5	73.3	71.8	73.2	72.4	73.1	72.7	72.8	0.015	0.72	0.06	0.32	0.01	0.18	0.05
Last rib bf, in	0.96	0.91	0.91	1.06	0.88	0.90	0.87	0.93	1.04	1.02	0.86	0.204	0.04	0.80	0.64	0.99	0.12	0.58
10^{th} rib bf, in	0.70	0.69	0.70	0.72	0.70	0.69	0.73	0.68	0.79	0.79	0.63	0.167	0.01	0.43	0.72	0.72	0.24	0.97
Loin depth, in	2.22	2.37	2.29	2.36	2.37	2.26	2.29	2.43	2.36	2.28	2.29	0.079	0.01	0.51	0.30	0.84	0.95	0.17
Lean, %	54.5	55.5	55.0	54.9	55.2	55.1	54.7	55.7	53.7	53.6	56.4	0.037	0.01	0.35	0.46	0.69	0.31	0.58
Backfat IV	63.3	64.8	67.7	68.0	68.8	67.6	77.2	81.2	84.3	69.6	72.8	0.111	0.02	0.01	0.60	0.01	0.49	0.01
Jowl IV	67.1	68.8	70.3	70.2	71.5	73.3	79.1	80.9	82.0	72.8	74.3	0.077	0.03	0.01	0.56	0.01	0.01	0.01
Backfat 18:2, %	11.2	12.9	12.7	12.9	13.7	15.8	19.2	21.2	21.8	16.0	17.9	0.312	0.01	0.01	0.44	0.04	0.40	0.01
Jowl 18:2%	12.0	13.1	14.1	14.2	14.5	15.1	21.0	23.9	25.8	15.0	16.0	0.263	0.04	0.01	0.63	0.01	0.01	0.01
Backfat saturated, %	34.7	34.1	32.8	32.9	32.2	32.8	31.1	30.9	30.6	37.4	35.8	0.079	0.04	0.01	0.96	0.01	0.72	0.01
Jowl saturated, %	39.7	39.3	37.0	36.8	36.0	38.6	34.7	33.7	32.7	32.9	32.1	0.053	0.04	0.01	0.60	0.01	0.01	0.01

[a]Total of 144 pigs were used for carcass data collection and analysis.

EFFECTS OF DRIED DISTILLERS GRAINS WITH SOLUBLES ON GROWTH PERFORMANCE AND FAT QUALITY OF FINISHING PIGS[1]

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Summary

A total of 1,112 pigs were used in a 78-d growth assay evaluating the effects of increasing dried distillers grains with solubles (DDGS, 0, 5, 10, 15, or 20%) on pig growth performance and carcass characteristics. At the end of the trial, jowl fat, belly fat, and backfat samples were collected and analyzed for fatty acid profile and iodine value (IV). From d 0 to 78, ADG and ADFI decreased (linear; $P<0.04$) with increasing DDGS with the greatest reduction occurring between pigs fed 15 and 20% DDGS. Feed efficiency tended to improve ($P<0.06$) for pigs fed 5% DDGS compared with those fed other dietary treatments. Increasing DDGS decreased ($P<0.04$) carcass weight and percent yield. There was no difference ($P>0.22$) in loin depth, but increasing DDGS tended to decrease ($P<0.09$) backfat and fat-free lean index (FFLI). Backfat, jowl fat, and belly fat iodine values and percentage C 18:2 fatty acids increased (linear, $P<0.02$) with increasing DDGS in both the "topped" pigs marketed 21 d before trial conclusion and pigs marketed at trial completion. Increasing DDGS decreased (linear, $P<0.05$) percentage saturated fatty acids in backfat and belly fat in both marketing groups and percentage saturated fatty acids in jowl fat with increasing DDGS in the diet in the pigs marketed at trial completion. Barrows had decreased ($P<0.04$) belly fat iodine values and percentage 18:2 fatty acids when compared to gilts. Barrows also had increased ($P<0.05$) jowl fat and belly fat percentage 18:2 fatty acids when compared to gilts. Based on these results and previous research trials, dried distillers grain with solubles from this source can be fed up to 15% before seeing reductions in ADG; however, the increase in iodine value and decrease in dressing percentage must be considered in determining the economic value of DDGS.

(Key words; DDGS, feed ingredients, pork quality.)

Introduction

Demands in fuel ethanol production have led to an increase in dried distillers grains with solubles (DDGS), which is the major by-product of dry corn milling from fuel ethanol production. The swine industry has the opportunity to incorporate DDGS into diets because of increased availability. Newer ethanol plants, built after 1990, have improved processing techniques that can increase amino acid digestibility and make DDGS more applicable to swine industry use.

[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.

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When fed to livestock, the impact of DDGS on growth performance has been inconsistent due to product variability in drying methods, levels of residual sugars, or grain quality with respect to batch-to-batch variation. Research has shown that DDGS levels anywhere from 0% to 30% of the diet could be fed before growth performance was reduced. It has been theorized that variation in DDGS palatability between sources can influence performance.

Dried distillers grain with solubles also has been shown to impact carcass quality and characteristics when fed to grow-finish 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 research was to test the effect of DDGS on grow-finish pig performance, carcass characteristics and iodine value of belly fat and backfat.

Procedures

A total of 1,112 pigs were used in a 78-d growth assay evaluating the effects of increasing DDGS in the diet on pig growth performance and carcass characteristics. Dietary treatments were fed in meal form and contained 0, 5, 10, 15, or 20% DDGS. All diets contained 6% added fat with choice white grease as the fat source. Treatments were fed in four phases with Phase 1 fed from 110 to 130 lb, Phase 2 from 130 to 181 lb, Phase 3 from 181 to 232 lb, and Phase 4 from 232 to 271 lb (Tables 1 to 4).

Diets were formulated to 0.98, 0.83, 0.73, and 0.66% true ileal digestible (TID) lysine and to maintain minimum available P concentrations of 0.28, 0.25, 0.23, and 0.22% for phases 1 to 4, respectively. The diet containing 20% DDGS in phase 4 did not include supplemental phosphorus and exceeded the minimum requirement. There were 9 replicates per treatment with 25 to 28 pigs per pen. There was an equal distribution of barrows and gilts in each pen. The experiment was conducted in a commercial research finishing barn in southwestern Minnesota. Pens were 18 × 10 feet. The barns were double curtain sided, with completely slatted flooring and a deep pit for manure storage. Each pen contained one self feeder and one cup waterer.

Pigs and feeders were weighed on d 0, 15, 29, 43, 57, and 78 to determine the response criteria of ADG, ADFI, and F/G. On d 57, the barn was "topped" to simulate normal pig marketing under commercial production practices. The three heaviest pigs from all pens were visually selected, removed, and marketed. From the tops, six barrows were randomly chosen from each treatment to collect jowl, backfat, and belly samples and analyze them for fatty acid analysis.

At the end of the experiment, pigs from each pen were individually tattooed with pen number and shipped to Swift processing plant (Worthington, MN) where standard carcass criteria of body weight (BW), loin and backfat (BF) depth, hot carcass weight, lean percentage, and yield were collected. Fat-free lean index (FFLI) was also measured using the equation 50.767 + (0.035 × hot carcass weight) – (8.979 × BF). Jowl, backfat, and belly samples were collected on one barrow and one gilt randomly chosen from each pen to analyze fat for fatty acid analysis. Samples were collected and frozen until further processing and analysis.

Iodine value was calculated from 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).

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

Data were analyzed by Analysis of Variance using the MIXED procedure of SAS

(SAS Inst., Inc., Cary, NC). Pigs from all experiments were blocked based on initial weight. Linear and polynomial contrasts were used to determine the effects of increasing DDGS. Pen was the experimental unit, except for data analyzing "topped" pigs, where pig was the experimental unit. All growth data were analyzed as randomized complete block design. The "topped" pig fat analysis data was evaluated as a completely random design. The fat analysis data from the closeout pigs were analyzed as a split plot with DDGS treatments as a whole plot and gender as the subplot. Carcass weight was used as a covariate for the responses of BF, FFLI, and loin depth.

Results and Discussion

Overall (d 0 to 78), ADG and ADFI decreased (linear; $P<0.04$) with increasing DDGS (Table 5); however, the greatest difference in ADG occurred when DDGS in the diet was increased from 15 to 20%. Pigs fed 5% DDGS tended ($P<0.06$) to have improved F/G compared with pigs fed other dietary treatments. There were no differences ($P>0.17$) in live slaughter weight or loin depth. Carcass weight and percent yield decreased ($P<0.04$) with increasing DDGS in the diet. Increasing DDGS tended to decrease ($P<0.09$) backfat and FFLI.

Backfat, jowl fat, and belly fat iodine values and percentage C 18:2 fatty acids increased (linear, $P<0.02$) with increasing DDGS in both the "topped" pigs (Table 6) and pigs marketed at trial completion (Table 7). Percentage saturated fatty acids in backfat and belly fat decreased (linear, $P<0.05$) with increasing DDGS in the "topped" pigs and pigs marketed at trial completion. Percentage of saturated fatty acids in jowl fat also decreased (linear, $P<0.03$) with increasing DDGS in the pigs marketed at trial completion.

There were no gender by treatment interactions observed. Barrows had decreased ($P<0.04$) belly fat iodine values and percentage 18:2 fatty acids compared to gilts. Barrows also had increased ($P<0.05$) jowl fat and belly fat percentage 18:2 fatty acids compared to gilts.

Increasing DDGS reduced ADG, carcass weights and percent yield. The reduction in ADG was driven by a reduction in ADFI as DDGS level increased in the diet. The reduced carcass weights equated to a reduction of 4 lb per pig fed 20% DDGS. This reduction was caused by the combination of lower ADG and decreased percent yield as DDGS increased. First, the reduction in percent yield may be explained by the fact that visceral organ weights are not included in percent yield. Further, increased dietary protein, which caused increased metabolic activity may have contributed to percent yield reduction. Secondly, the reduction in percent yield could also be contributed to an increase in dietary fiber for pigs fed diets containing DDGS because of its high fiber content. Feeding fiber increases the rate of passage causing increased intestinal growth and gut cell proliferation. The weight of digesta is increased causing reduced percent yield. It has been well documented that feeding pigs diets high in fiber reduces percent yield, as is potentially the case when pigs consume diets containing DDGS.

Iodine values were also increased by feeding increasing DDGS, showing an increase of 3 to 4 g/100g in the various fat stores in pigs fed 20% DDGS. This increase caused jowl fat samples to exceed the maximum level of 73 g/100g for jowl fat set by Triumph Foods, St. Joseph, MO. Based on these results and previously conducted research trials, dried distillers grain with solubles from this source can be fed up to 15% before seeing reductions in growth performance. The linear reduction in yield and increase in iodine value must be considered when determining the economic value of DDGS.

Table 1. Phase 1 Diet Composition (Fed from 108 to 130 lb; as-fed basis)

	DDGS, %				
Item	0	5	10	15	20
Ingredient, %					
Corn	65.00	60.65	56.30	51.95	47.60
Soybean meal (46.5 % CP)	26.85	26.30	25.75	25.15	24.60
DDGS	---	5.00	10.00	15.00	20.00
Choice white grease	6.00	6.00	6.00	6.00	6.00
Monocalcium P (21% P)	0.63	0.50	0.38	0.25	0.13
Limestone	0.85	0.90	0.94	0.99	1.03
Salt	0.35	0.35	0.35	0.35	0.35
L-lysine HCl	0.150	0.150	0.150	0.150	0.150
Vitamin premix with phytase	0.075	0.075	0.075	0.075	0.075
Trace mineral premix	0.075	0.075	0.075	0.075	0.075
Total	100.00	100.00	100.00	100.00	100.00
Calculated analysis					
True ileal digestible amino acids					
Lysine, %	0.98	0.98	0.98	0.98	0.98
Methionine:lysine ratio, %	27	28	29	31	32
Met & cys:lysine ratio, %	55	58	60	63	65
Threonine:lysine ratio, %	60	62	64	66	68
Tryptophan:lysine ratio, %	19	20	20	21	21
Total lysine, %	1.10	1.10	1.10	1.11	1.11
CP, %	18.2	18.9	19.7	20.4	21.2
TID lysine:calorie ratio, g/Mcal	2.71	2.71	2.71	2.70	2.70
ME, kcal/kg	3,616	3,618	3,622	3,624	3,627
Ca, %	0.55	0.55	0.55	0.55	0.55
P, %	0.50	0.49	0.49	0.49	0.48
Available P, %	0.28	0.28	0.28	0.28	0.28
Analyzed values					
Dietary fat IV	80.9	83.9	88.0	87.5	89.1
Dietary IV	78.5	82.2	91.5	95.4	99.8

Table 2. Phase 2 Diet Composition (Fed from 130 to 181 lb; as-fed basis)

	DDGS, %				
Item	0	5	10	15	20
Ingredient, %					
Corn	71.05	66.70	62.35	58.00	53.65
Soybean meal (46.5 % CP)	20.90	20.35	19.75	19.20	18.65
DDGS	---	5.00	10.00	15.00	20.00
Choice white grease	6.00	6.00	6.00	6.00	6.00
Monocalcium P (21% P)	0.58	0.45	0.33	0.20	0.08
Limestone	0.85	0.89	0.92	0.98	1.03
Salt	0.35	0.35	0.35	0.35	0.35
L-lysine HCl	0.150	0.150	0.150	0.150	0.150
Vitamin premix with phytase	0.063	0.063	0.063	0.063	0.063
Trace mineral premix	0.063	0.063	0.063	0.063	0.063
Total	100.00	100.00	100.00	100.00	100.00
Calculated analysis					
True ileal digestible amino acids					
Lysine, %	0.83	0.83	0.83	0.83	0.83
Methionine:lysine ratio, %	28	30	31	33	34
Met & cys:lysine ratio, %	59	62	64	67	70
Threonine:lysine ratio, %	61	63	65	68	70
Tryptophan:lysine ratio, %	19	20	20	21	22
Total lysine, %	0.93	0.94	0.94	0.94	0.94
CP, %	15.9	16.7	17.4	18.2	18.9
TID lysine:calorie ratio, g/Mcal	2.29	2.29	2.29	2.29	2.29
ME, kcal/kg	3,620	3,622	3,627	3,629	3,633
Ca, %	0.52	0.52	0.52	0.52	0.52
P, %	0.46	0.46	0.46	0.45	0.45
Available P, %	0.25	0.25	0.25	0.25	0.25
Analyzed values					
Dietary fat IV	84.2	86.4	86.2	87.3	88.6
Dietary IV	78.3	86.4	87.9	96.9	97.4

Table 3. Phase 3 Diet Composition (Fed from 181 to 231 lb; as-fed basis)

	DDGS, %				
Item	0	5	10	15	20
Ingredient, %					
Corn	75.15	70.80	66.45	62.10	57.75
Soybean meal (46.5 % CP)	16.90	16.35	15.80	15.20	14.65
DDGS	---	5.00	10.00	15.00	20.00
Choice white grease	6.00	6.00	6.00	6.00	6.00
Monocalcium P (21% P)	0.53	0.40	0.27	0.14	0.01
Limestone	0.80	0.84	0.89	0.93	0.97
Salt	0.35	0.35	0.35	0.35	0.35
L-lysine HCl	0.150	0.150	0.150	0.150	0.150
Vitamin premix with phytase	0.063	0.063	0.063	0.063	0.063
Trace mineral premix	0.063	0.063	0.063	0.063	0.063
Total	100.00	100.00	100.00	100.00	100.00
Calculated analysis					
True ileal digestible amino acids					
Lysine, %	0.73	0.73	0.73	0.73	0.73
Methionine:lysine ratio, %	30	32	33	35	37
Met & cys:lysine ratio, %	62	65	68	71	75
Threonine:lysine ratio, %	62	64	67	70	72
Tryptophan:lysine ratio, %	19	19	20	21	22
Total lysine, %	0.82	0.83	0.83	0.83	0.83
CP, %	14.4	15.1	15.9	16.7	17.4
TID lysine:calorie ratio, g/Mcal	2.01	2.01	2.01	2.01	2.01
ME, kcal/kg	3,628	3,629	3,631	3,635	3,638
Ca, %	0.48	0.48	0.48	0.48	0.48
P, %	0.44	0.43	0.43	0.42	0.42
Available P, %[e]	0.23	0.23	0.23	0.23	0.23
Analyzed values					
Dietary fat IV	84.9	86.7	87.0	90.6	89.7
Dietary IV	74.7	83.3	84.4	91.5	97.8

[a]Dietary treatments fed in meal form from 181 to 231 lb.

Table 4. Phase 4 Diet Composition (Fed from 231 to 271 lb; as-fed basis)

	DDGS, %				
Item	0	5	10	15	20
Ingredient, %					
Corn	77.90	73.55	69.20	64.90	60.55
Soybean meal (46.5 % CP)	14.15	13.55	13.00	12.45	11.85
DDGS	-	5.00	10.00	15.00	20.00
Choice white grease	6.00	6.00	6.00	6.00	6.00
Monocalcium P (21% P)	0.53	0.39	0.26	0.13	-
Limestone	0.83	0.87	0.91	0.96	1.00
Salt	0.35	0.35	0.35	0.35	0.35
L-lysine HCl	0.150	0.150	0.150	0.150	0.150
Vitamin premix with phytase	0.050	0.050	0.050	0.050	0.050
Trace mineral premix	0.050	0.050	0.050	0.050	0.050
Total	100.00	100.00	100.00	100.00	100.00
Calculated analysis					
True ileal digestible amino acids					
Lysine, %	0.66	0.66	0.66	0.66	0.66
Methionine:lysine ratio, %	31	33	35	37	39
Met & cys:lysine ratio, %	64	68	71	75	79
Threonine:lysine ratio, %	63	65	68	71	74
Tryptophan:lysine ratio, %	18	19	20	21	22
Total lysine, %	0.75	0.75	0.75	0.76	0.76
CP, %	13.3	14.1	14.8	15.6	16.4
TID lysine:calorie ratio, g/Mcal	1.82	1.82	1.82	1.82	1.81
ME, kcal/kg	3,626	3,629	3,633	3,636	3,639
Ca, %	0.48	0.48	0.48	0.48	0.48
P, %	0.43	0.42	0.42	0.41	0.41
Available P, %[e]	0.22	0.22	0.22	0.22	0.22
Analyzed values					
Dietary fat IV	86.9	90.0	86.9	86.6	87.1
Dietary IV	86.0	91.8	89.5	94.4	95.0

Table 5. Effects of Increasing DDGS on Growing-finishing Pig Performance and Carcass Characteristics (Exp. 3)[a]

	DDGS, %					Probability, *P* <			
Item	0	5	10	15	20	Treatment	Linear	Quadratic	SE
D 0 to 78									
ADG, lb	2.03	2.02	2.02	1.98	1.95	0.0003	0.02	0.43	11.9
ADFI, lb	5.27	5.11	5.22	5.09	5.05	0.0003	0.04	0.98	31.4
F/G	2.60	2.53	2.59	2.58	2.59	0.06	0.46	0.14	0.003
Slaughter wt, lb[b]	259.9	259.7	259.6	256.7	256.7	0.68	0.17	0.85	1.03
Carcass wt, lb	196.7	195.9	195.4	193.1	192.7	0.7	0.04	0.86	0.83
Yield, %	75.67	75.46	75.39	75.22	75.06	0.24	0.02	1.00	0.002
Backfat, in[c]	0.733	0.741	0.717	0.713	0.705	0.016	0.07	0.97	0.35
Loin depth, mm[c]	2.31	2.30	2.29	2.26	2.27	0.03	0.22	0.98	0.81
FFLI, %[cd]	49.34	49.45	49.53	49.70	49.65	0.48	0.09	0.67	0.15

[a]A total of 1,112 pigs (initially 49.67 kg) with 25 to 28 pigs per pen and 9 replications per treatment.
[b]Weight determined at slaughter plant.
[c]Data analyzed using carcass weight as a covariate.
[d]Fat-free lean index.

Table 6. Effects of Increasing DDGS on Fat Quality of Topped Pigs (Exp. 3)[a]

	DDGS, %					Probability, *P* <			
Item	0	5	10	15	20	Treatment	Linear	Quadratic	SE
Iodine value, g/100 g									
Backfat	67.9	69.3	71.8	72.3	72.3	0.01	0.01	0.15	0.94
Jowl fat	69.3	70.3	70.3	71.3	72.9	0.11	0.02	0.53	1.00
Belly fat	67.5	69.6	70.8	72.0	73.8	0.02	0.01	0.92	1.20
C 18:2 fatty acids, %									
Backfat	13.7	15.2	16.5	17.5	17.6	0.01	0.01	0.24	0.69
Jowl fat	13.0	13.9	14.1	15.4	15.8	0.01	0.01	0.99	0.57
Belly fat	13.3	14.8	15.8	17.3	17.9	0.01	0.01	0.60	0.64
Saturated fatty acids, %									
Backfat	36.1	35.1	34.4	34.6	33.7	0.21	0.03	0.62	0.73
Jowl fat	33.8	33.6	33.9	33.9	32.5	0.47	0.27	0.28	0.68
Belly fat	36.2	35.4	35.1	35.1	33.7	0.30	0.05	0.76	0.83

[a]Means represent 6 observations (pigs) per treatment.

Table 7. Effects of Increasing DDGS on Fat Quality[a]

	DDGS, %					Gender		Probability, $P <$				Treatment SE	Gender SE
Item	0	5	10	15	20	Barrows	Gilts	Treatment	Linear	Quadratic	Gender		
Iodine value, g/100 g													
Backfat	68.3	70.0	71.2	72.4	72.8	70.7	71.1	0.01	0.01	0.33	0.52	0.76	0.46
Jowl fat	70.7	70.8	71.9	72.6	73.8	71.6	72.3	0.01	0.01	0.49	0.25	0.74	0.46
Belly fat	70.2	71.5	72.4	73.3	74.5	71.8	72.9	0.01	0.01	0.95	0.03	0.61	0.44
C 18:2 fatty acids, %													
Backfat	14.0	14.9	15.8	17.1	17.6	15.6	16.2	0.01	0.01	0.75	0.17	0.45	0.28
Jowl fat	14.1	14.0	14.9	15.6	16.5	15.0	15.1	0.01	0.01	0.34	0.85	0.55	0.36
Belly fat	14.5	15.3	16.3	16.8	17.9	15.9	16.5	0.01	0.01	0.89	0.04	0.38	0.22
Saturated fatty acids, %													
Backfat	36.0	35.0	34.5	34.4	34.5	34.9	34.9	0.16	0.03	0.19	0.97	0.53	0.34
Jowl fat	33.3	33.1	32.8	32.7	32.3	33.2	32.5	0.25	0.03	0.91	0.02	0.38	0.22
Belly fat	34.4	33.8	33.7	33.2	32.9	33.9	33.3	0.03	0.01	0.81	0.05	0.42	0.33

[a]Means represent 9 observations per treatment.

EFFECTS OF DRIED DISTILLERS GRAINS WITH SOLUBLES AND EXTRUDED EXPELLED SOYBEAN MEAL ON GROWTH PERFORMANCE AND CARCASS CHARACTERISTICS OF GROW-FINISH PIGS[1]

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Summary

A total of 120 barrows (maternal line PIC 1050) with an initial BW of 105.7 lb were used in an 83-d trial to study the effects of dried distillers grains with solubles (DDGS) and extruded expelled soybean meal (EESM) on growth performance and fat quality. Pigs were blocked by weight and randomly allotted to one of six treatments with two pigs per pen and 10 pens per treatment. Diets were: a corn-soybean meal control diet with no added fat, corn-EESM diet with no added fat, corn-EESM diet with 15% DDGS, corn-soybean meal diet with 15% DDGS, and 1.55% choice white grease (CWG), corn-soybean meal diet with 3.25% CWG, and corn-soybean meal diet with 4.7% CWG. Diets were formulated to have three dietary iodine value (IV) levels (42, 55, and 62) to compare the impact of fat source within dietary IV levels. On d 83, jowl and backfat samples were collected. Pigs fed the control diet, EESM, or 4.7% CWG had increased ADG compared with pigs fed the diet containing EESM with 15% DDGS. Pigs fed the control diet had increased ADFI compared with all other treatment. Pigs fed EESM with 15% DDGS and the diets with 4.7% CWG had improved F/G compared with pigs fed the control and pigs fed DDGS with CWG. Pigs fed high CWG had greater (P<0.05) loin depth compared with pigs fed low CWG. Pigs fed either of the diets with 15% DDGS had increased backfat IV compared with pigs fed diets without DDGS. Pigs fed EESM had increased backfat IV when compared with the control diet or diets with 3.25 or 4.7% CWG. Adding DDGS to the diet or using EESM increased IV of jowl fat. Adding CWG to the control diet also increased IV of jowl fat. Feeding ingredients with higher levels of unsaturated fat, such as EESM and DDGS, had a greater impact on fat IV than CWG even when diets were formulated to similar IV levels.

(Key words, added fat, pork quality, iodine value.)

Introduction

Dried distillers grains with solubles (DDGS) and extruded expelled soybean meal (EESM) can be economical to feed to growing and finishing hogs. However, the inclusion of these ingredients increases the dietary fat level when they are substituted for corn or soybean meal. Carcass composition is altered when fat level increases in the diet, causing softer carcass fat. This may have implications from a

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processor acceptance standpoint. Iodine value is a measure of the level of unsaturation of fats, and therefore a measure of fat firmness. Carcass iodine value must be further researched to know the full carcass quality implications from feeding different fat sources for various time periods. Therefore, the purpose of this trial was to evaluate the effects of dried distillers grains (DDGS) and extruded expelled soybean meal (EESM) growth performance and carcass characteristics of grow-finish pigs.

Procedures

One hundred twenty crossbred barrows, (PIC 1050) with an initial weight of 105.7 lb were used in an 83-d experiment. Pigs were blocked by weight and allotted to one of six treatments with 10 replicate pens per treatment. Pigs were housed with two pigs per pen in an environmentally controlled finishing barn with 4 ft × 4 ft pens with totally slatted floors. Each pen was equipped with a one-hole dry self-feeder and nipple waterer to allow *ad libitum* access to feed and water.

Diets were: a corn-soybean meal control diet with no added fat (calculated IV of 42), corn-EESM diet with no added fat (calculated IV of 54), corn-EESM diet with 15% DDGS (calculated IV of 62), corn-soybean meal diet with 15% DDGS, and choice white grease (CWG, calculated IV of 54); corn-soybean meal diet with low CWG (calculated IV of 54), and corn-soybean meal diet with high CWG (calculated IV of 62). Diets were formulated to have three dietary IV levels to compare the impact of fat source within dietary IV levels. The analyzed dietary IV was lower than the calculated values. However, two treatments had very similar weighted IV (DDGS with CWG and high CWG (Table 6). Prior to being placed on test, pigs were fed a corn-soybean meal-based diet.

Diets were formulated to be fed in three phases from d 0 to 26, 26 to 55, and 55 to 83 to correspond with approximate weight ranges of 90 to 150, 150 to 210, and 210 to 270 lb (Tables 1, 2, and 3). A constant TID lysine: ME ratio was maintained by altering the corn and soybean meal level in the basal diet when adding the fat sources.

Pigs and feeders were weighed on d 12, 26, 41, 55, 69, and 83 to calculate ADG, ADFI, and F/G. Pen served as experimental unit for all statistical analysis.

Pigs were slaughtered at Triumph Foods of St. Joseph, MO at the end of the 83 d trial for collection of individual carcass data. The pigs were marked with an individual tattoo prior to marketing. At 24 hours postmortem, jowl samples were collected and frozen until further processing and analysis. Iodine value was calculated from 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).

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

Data were analyzed in a randomized complete-block design with pen as the experimental unit. Analysis of variance was performed by using the MIXED procedure of SAS. Contrasts were used to determine the effects of the dietary treatments. Hot carcass weight was used as a covariate for last rib backfat, 10^{th} rib backfat, loin depth, and percentage lean.

Results and Discussion

From d 0 to 83, pigs fed the control diet, EESM or high CWG had greater (P<0.05) ADG compared with pigs fed EESM with 15% DDGS (Table 4). Pigs fed the control diet had greater (P<0.05) ADFI compared with pigs fed all other treatments. Pigs fed EESM with 15% DDGS and high CWG had improved (P<0.05) F/G compared with pigs

fed the control diet or those fed DDGS and CWG.

Pigs fed high CWG had greater ($P<0.05$) loin depth compared with pigs fed low CWG. Pigs fed EESM tended to have greater ($P<0.08$) loin depth than pigs fed low CWG (Table 5). Percentage lean was unaffected by dietary treatment. Pigs fed the control, 15% DDGS with CWG, low CWG, and high CWG tended to have greater ($P<0.08$) dressing percentages compared with pigs fed EESM.

Pigs fed EESM with 15% DDGS had increased ($P<0.05$) iodine value for jowl fat compared with all other treatments. Pigs fed 15% DDGS with CWG had increased ($P<0.05$) iodine value for jowl fat compared with pigs fed the control, EESM, low CWG, and high CWG. Pigs fed EESM had increased ($P<0.05$) iodine value for jowl fat compared with pigs fed the control and low CWG. Pigs fed low CWG and high CWG had increased iodine value for jowl fat compared with pigs fed the control. Pigs fed EESM with 15% DDGS and 15% DDGS with CWG had increased ($P<0.05$) iodine value and percentage 18:2 fatty acids for backfat compared with all other treatments. Pigs fed EESM and EESM with 15% DDGS had increased ($P<0.05$) iodine value and percentage 18:2 fatty acids for backfat compared with pigs fed the control, low CWG, and high CWG. Pigs fed EESM with 15% DDGS had increased ($P<0.05$) percentage 18:2 fatty acids for jowl fat compared with pigs fed the control, EESM, low CWG, and high CWG. Pigs fed EESM and 15% DDGS with CWG had increased ($P<0.05$) percentage 18:2 fatty acids for jowl fat compared with pigs fed the control, low CWG, and high CWG. Pigs fed the control had increased ($P<0.05$) percentage saturated fatty acids for jowl fat and backfat compared with all other treatments. Pigs fed EESM, low CWG, and high CWG had increased ($P<0.05$) percentage saturated fatty acids for jowl fat compared with pigs fed the EESM with 15% DDGS. Pigs fed the EESM, low CWG, and high CWG had increased ($P < 0.05$) percentage saturated fatty acids for backfat compared with pigs fed EESM with 15% DDGS and 15% DDGS with CWG.

Most treatments had jowl fat iodine values approximately 5 g/100g h greater than backfat iodine values. However, both diets containing DDGS had jowl fat and backfat iodine values that were more similar. This can be explained by evaluating the effect each individual fatty acid had on iodine value (Table 6). Pigs fed the control diet had an increase of 4 g/100g from backfat to jowl fat due to C 18:1 fatty acids (effect of backfat C 18:1 = 36.05, effect of jowl fat C 18:1 = 40.05). This trend is similar for all treatments and explains why jowl fat iodine value is higher than backfat iodine value. The effect C 18:2 fatty acids had on iodine value is similar for jowl fat and backfat in most treatments. However, pigs fed either diet containing DDGS had less C 18:2 fatty acids in jowl fat than backfat. This difference was similar to the effect C 18:1fatty acids had, and essentially cancelled it out.

These results confirm that adding fat to finishing pig diets improves growth performance. Feeding DDGS in this trial resulted in a decrease in ADG and ADFI. Adding DDGS, EESM, or CWG increased IV and C 18:2, and reduced C saturated fatty acids. Finally, feeding ingredients with higher levels of unsaturated fat, such as EESM and DDGS, had a greater impact on fat iodine value than CWG even when dietary iodine values were similar. Also, feeding pigs a diet with more unsaturated fat may lead to jowl fat and backfat to have more similar iodine values.

Table 1. Phase 1 Diet Composition (as-fed basis)[a]

Ingredient, %	Control	EESM	EESM + DDGS	DDGS + CWG	Low CWG	High CWG
Corn	72.06	70.31	57.27	56.41	66.84	64.54
Soybean meal (46.5% CP)	25.09	---	---	24.44	27.06	27.86
Dried distillers grains with solubles	---	---	15.00	15.00	---	---
Extruded expelled soybean meal	---	26.85	25.15	---	---	---
Choice white grease	---	---	---	1.55	3.25	4.70
Monocalcium P (21% P)	1.10	1.15	0.75	0.75	1.15	1.20
Limestone	0.95	0.90	1.05	1.05	0.90	0.90
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.15	0.15	0.15	0.15	0.15	0.15
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15
L-lysine HCl	0.15	0.15	0.15	0.15	0.15	0.15
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis						
Total lysine, %	1.06	1.11	1.12	1.10	1.11	1.13
True ileal digestible amino acids						
Lysine, %	0.95	0.98	0.98	0.97	0.99	1.01
Methionine:lysine ratio, %	28	28	31	31	27	27
Met & cys:lysine ratio, %	57	56	64	64	56	55
Threonine:lysine ratio, %	61	60	66	66	60	60
Tryptophan:lysine ratio, %	19	19	21	21	19	19
ME, kcal/lb	1,505	1,562	1,562	1,541	1,572	1,601
Crude fat, %	3.2	4.5	5.1	5.4	6.3	7.6
Ca, %	0.67	0.67	0.67	0.67	0.67	0.68
P, %	0.61	0.62	0.61	0.60	0.62	0.62
Available P, %	0.30	0.31	0.31	0.31	0.31	0.32
TID Lys:Cal ratio	2.58	2.58	2.58	2.58	2.58	2.58
Calculated IV	40	57	65	57	57	65
Analyzed IV	33.27	50.01	53.83	57.36	46.34	54.70

[a] Diets fed in meal form from d 0 to 26.
[b]DDGS nutrient values for diet formulation were derived from NRC, 1998.

Table 2. Phase 2 Diet Composition (as-fed basis)[a]

Ingredient, %	Control	EESM	EESM + DDGS	DDGS + CWG	Low CWG	High CWG
Corn	80.07	79.08	66.05	66.18	76.82	74.60
Soybean meal (46.5% CP)	17.28	---	---	15.87	18.33	19.05
Dried distillers grains with solubles	---	---	15.00	15.00	---	---
Extruded expelled soybean meal	---	18.20	16.50	---	---	---
Choice white grease	---	---	---	0.50	2.15	3.65
Monocalcium P (21% P)	1.00	1.05	0.65	0.65	1.05	1.05
Limestone	0.90	0.90	1.05	1.05	0.90	0.90
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.13	0.13	0.13	0.13	0.13	0.13
Trace mineral premix	0.13	0.13	0.13	0.13	0.13	0.13
L-lysine HCl	0.15	0.15	0.15	0.15	0.15	0.15
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis						
Total lysine, %	0.85	0.87	0.88	0.86	0.87	0.89
True ileal digestible amino acids						
Lysine, %	0.75	0.77	0.77	0.76	0.77	0.79
Methionine:lysine ratio, %	30	30	35	35	30	29
Met & cys:lysine ratio, %	63	62	71	72	61	60
Threonine:lysine ratio, %	62	62	69	70	62	62
Tryptophan:lysine ratio, %	19	19	21	21	19	19
ME, kcal/lb	1,510	1,547	1,548	1,524	1,553	1,584
Crude fat, %	3.4	4.3	4.9	4.6	5.4	6.8
Ca, %	0.61	0.62	0.63	0.62	0.62	0.62
P, %	0.55	0.57	0.55	0.55	0.56	0.56
Available P, %	0.27	0.28	0.28	0.28	0.28	0.28
TID Lys:Cal ratio	2.14	2.14	2.14	2.14	2.14	2.14
Calculated IV	42	54	62	54	54	62
Analyzed IV	37.68	46.67	58.90	49.79	43.96	54.48

[a]Diets fed in meal form from d 26 to 55.
[b]DDGS nutrient values for diet formulation were derived from NRC, 1998.

Table 3. Phase 3 Diet Composition (as-fed basis)[a]

Ingredient, %	Control	EESM	EESM + DDGS	DDGS + CWG	Low CWG	High CWG
Corn	84.18	83.54	70.50	71.13	81.79	79.66
Soybean meal (46.5% CP)	13.37	---	---	11.67	14.06	14.74
Dried distillers grains with solubles	---	---	15.00	15.00	---	---
Extruded expelled soybean meal	---	14.00	12.30	---	---	---
Choice white grease	---	---	---	---	1.70	3.15
Monocalcium P (21% P)	0.80	0.80	0.45	0.45	0.85	0.85
Limestone	0.90	0.90	1.00	1.00	0.85	0.85
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.13	0.13	0.13	0.13	0.13	0.13
Trace mineral premix	0.13	0.13	0.13	0.13	0.13	0.13
L-lysine HCl	0.15	0.15	0.15	0.15	0.15	0.15
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis						
Total lysine, %	0.74	0.76	0.77	0.75	0.76	0.77
True ileal digestible amino acids						
Lysine, %	0.65	0.66	0.66	0.65	0.67	0.68
Methionine:lysine ratio, %	32	32	38	38	32	31
Met & cys:lysine ratio, %	67	66	77	78	65	64
Threonine:lysine ratio, %	64	63	72	72	63	63
Tryptophan:lysine ratio, %	19	18	21	21	19	19
ME, kcal/lb	1,514	1,543	1,544	1,518	1,549	1,578
Crude fat, %	3.5	4.2	4.8	4.2	5.1	6.5
Ca, %	0.56	0.56	0.56	0.55	0.55	0.55
P, %	0.50	0.50	0.49	0.49	0.50	0.50
Available P, %	0.22	0.22	0.23	0.23	0.23	0.23
TID Lys:Cal ratio	1.85	1.85	1.85	1.85	1.85	1.85
Calculated IV	44	53	61	53	53	61
Analyzed IV	37.11	45.88	55.25	46.52	41.29	46.96

[a]Diets fed in meal form from d 55 to 82.
[b]DDGS nutrient values for diet formulation were derived from NRC, 1998.

Table 4. Effects of DDGS and EESM on Growth Performance[a]

Item	Control	EESM	EESM + DDGS	DDGS + CWG	Low CWG	High CWG	SE
D 0 to 82							
ADG, lb	2.08[b]	2.07[b]	1.83[c]	2.00[bc]	2.04[bc]	2.18[b]	0.08
ADFI, lb	6.37[b]	5.98[c]	5.54[d]	5.92[c]	5.75[cd]	5.86[cd]	0.16
F/G	3.17[c]	2.95[bc]	2.65[b]	3.00[c]	2.88[bc]	2.74[b]	0.13

[a]Total of 120 pigs (initial weight 105.7 lbs) with 10 observations per treatment.
[bcd]Treatments with different superscripts differ $P<0.05$.

Table 5. Effects of DDGS and EESM on Carcass Performance[a]

Item	Control	EESM	EESM + DDGS	DDGS + CWG	Low CWG	High CWG	SE
Loin depth, in	2.04[bc]	2.00[bc]	2.13[bc]	2.08[bc]	1.93[b]	2.19[c]	0.09
Lean, %	50.8	50.9	51.2	51.1	50.6	51.3	0.49
Dress, %	73.0	71.7	72.0	73.0	73.1	73.0	0.54
Last rib fat, in	0.94	0.90	0.88	0.94	0.92	0.97	0.04
10th rib fat, in	0.82	0.78	0.82	0.79	0.78	0.83	0.04
BF IV	59.92[b]	64.99[c]	70.78[d]	69.34[d]	62.11[b]	61.82[b]	0.94
Jowl IV	64.60[b]	68.80[d]	72.30[f]	70.16[e]	66.25[c]	67.09[cd]	0.61
BF 18:2, %	11.20[b]	14.48[c]	18.44[d]	17.32[d]	11.80[b]	11.36[b]	0.58
Jowl 18:2, %	11.02[b]	13.82[c]	16.17[d]	14.90[cd]	11.61[b]	11.86[b]	0.43
BF Sat., %	42.83[b]	41.06[c]	38.43[b]	38.48[b]	41.03[c]	40.78[c]	0.52
Jowl Sat., %	37.43[e]	36.07[c]	34.41[b]	35.18[bc]	36.26[d]	35.48[cd]	0.38

[a]Total of 110 pigs.
[bcdef]Treatments with different superscripts differ, $P<0.05$.

Table 6. Effects of Individual Fatty Acids on Iodine Value

Item	Control	EESM	EESM + DDGS	DDGS + CWG	Low CWG	High CWG
Calculated diet IV	42.1	54.28	62.22	54.35	54.32	62.19
Analyzed diet IV	36.27	47.32	56.1	50.67	43.59	51.59
Analyzed carcass IV						
Backfat	59.92	64.99	70.78	69.34	62.11	61.82
Jowl	64.60	68.80	72.30	70.16	66.25	67.09
Effect of individual fatty acid on IV						
Backfat						
C 16:1	2.23	2.07	1.85	1.98	2.41	2.14
C 18:1	36.05	34.48	33.30	34.30	36.80	37.61
C 18:2	19.40	25.08	31.93	30.01	20.44	19.68
C 18:3	1.51	2.56	2.74	2.09	1.70	1.58
C 20:1	0.72	0.80	0.95	0.95	0.76	0.81
C 22:1	0.01	0.01	0.01	0.01	0.01	0.01
Jowl						
C 16:1	2.91	2.82	2.61	2.76	3.03	2.86
C 18:1	40.05	38.51	37.94	38.46	40.32	40.84
C 18:2	19.09	23.93	28.01	25.80	20.11	20.54
C 18:3	1.75	2.63	2.73	2.17	1.93	1.92
C 20:1	0.79	0.90	1.00	0.96	0.85	0.91
C 22:1	0.01	0.01	0.01	0.01	0.01	0.01

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

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Summary

A total of 112 barrows (average weight of 158 lb) were used in a 65-d growth assay to determine the effects of adding beef tallow (a source of saturated fat) into diets with high inclusion of dried distillers grains with solubles (DDGS). The pigs were sorted by ancestry and blocked by weight with seven pigs/pen and four pens/treatment. Treatments were a corn-soybean, meal-based control and diets having 40% DDGS (US Energy Partners, Russell, KS) with none, 2.5, and 5% added tallow. Feed and water were consumed on an *ad libitum* basis until the pigs were slaughtered (average wt of 287 lb) to allow collection of carcass data and jowl samples. Fatty acid composition of the jowl samples was used to calculate iodine value as an indicator of carcass fat firmness. Overall (d 0 to 65), the corn-soy control supported greater ADG ($P< 0.03$) and ADFI ($P<0.001$) with no difference in F/G ($P>0.35$) compared to the DDGS treatments. Increasing fat additions from none to 5% in diets with DDGS did not affect ADG ($P>0.76$) but improved (linear effect, $P<0.03$) F/G by 9%. As for carcass data, adding DDGS to diets reduced HCW ($P<0.004$) and dressing percentage ($P<0.03$) but increased iodine value of jowls ($P<0.001$) compared to pigs fed the corn-based control diet. Among the DDGS treatments, hot carcass weight (linear increase, $P<0.07$), dressing percentage (linear increase, $P<0.07$), and backfat thickness (quadratic decrease, $P<0.08$) responded positively as fat addition to the diets was increased from none to 5%. However, changes in iodine value indicated a trend for deposition of softer fat in pigs fed DDGS when additions of beef tallow were increased in the diet (linear effect, $P<0.06$). In conclusion, adding beef tallow to diets with DDGS improved efficiency of growth and several carcass measurements but did not improve iodine value of jowl fat.

(Key words: DDGS, feed ingredient, meat quality, sorghum.)

Introduction

In conversion of starch to ethanol during the fermentation process, components (such as the vegetable oil) are concentrated by about three times. It is known that nonruminants tend to deposit fat similar to that which they consume and that vegetable oil in dried distillers grains with solubles (DDGS) will soften the adipose tissue in pig carcasses. So, there is a question of whether feeding a source of saturated fat can counteract the negative effects of DDGS on carcass fat firmness. The objective of the experiment reported herein was to

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determine the effects of adding a source of saturated fat (beef tallow) into diets with sorghum-based DDGS.

Procedures

A total of 112 barrows (average initial wt of 158 lb) were used in a 65-d growth assay. The pigs were sorted by ancestry, blocked by weight, and assigned to pens. There were seven pigs/pen and four pens/treatment. The pigs were housed in a finishing facility having 6-ft x 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 until the pigs were slaughtered at an average wt of 287 lb.

Treatments were a corn-soybean, meal-based control and diets having 40% sorghum-based DDGS (US Energy Partners, Russell, KS) with none, 2.5, and 5% added tallow (Table 1). The control diet was formulated to 0.90% lysine, 0.60% Ca, and 0.50% total P for d 0 to 31 and 0.70% lysine, 0.55% Ca, and 0.45% total P for d 31 to 65. Nutrient:calorie ratios were kept constant for diets with added tallow.

Pigs and feeders were weighed at d 0, 31, and 65 to allow calculation of ADG, ADFI, and F/G. The pigs were killed on d 65 (average wt of 287 lb) and carcass data were collected. Because differences in slaughter weight, and thus hot carcass weight, are known to affect carcass measurements, hot carcass weight was used as a covariate to separate any effect of treatment from the effects of slaughtering our pigs at a constant age rather than constant weight. Samples of jowl fat were collected and a fatty acid profile was determined to allow estimation of iodine value (AOCS Cd 1c-85 Official Method) as an indicator of carcass firmness.

All data were analyzed as a randomized complete block design using the MIXED procedure of SAS. Orthogonal contrasts and polynomial regression were used to separate treatment means with comparisons among the control vs DDGS treatments and linear and quadratic effects of increasing tallow additions in diets with DDGS.

Results and Discussion

The corn-soybean meal control diet supported greater ADG and ADFI for d 0 to 31 ($P<0.04$) and 0 to 65 ($P<0.03$) with no differences in F/G ($P>0.32$) compared to the DDGS treatments. Increasing tallow additions from none to 5% in diets with DDGS did not affect overall ADG ($P>0.76$) but improved (linear effect, $P<0.03$) F/G by 9%. Thus, as would be expected in a simple corn-soy diet, each 1% fat added to a diet with DDGS increased F/G by about 2%

As for carcass data, adding DDGS to diets reduced HCW ($P<0.004$) and dressing percentage ($P<0.03$) but increased iodine value of jowls ($P<0.001$) compared to pigs fed the corn-based control diet. Among the DDGS treatments, hot carcass weight (linear increase, $P<0.07$), dressing percentage (linear increase, $P<0.07$), and backfat thickness (quadratic decrease, $P<0.08$) responded positively as fat addition to the diets was increased from none to 5%. However, changes in iodine value indicated a trend for deposition of softer fat in pigs fed DDGS when additions of beef tallow were increased in the diet (linear effect, $P<0.06$). Thus, even what traditionally has been considered a source of saturated fat (tallow) will not counteract the negative effects of adding DDGS (a source of unsaturated vegetable oil) to diets for finishing pigs. In conclusion, adding beef tallow to diets with DDGS improved efficiency of growth and several carcass measurements but did not improve iodine value of jowl fat.

Table 1. Composition of Diets, %

	d 0 to 31				d 31 to 65			
Ingredient	Control	0% Tallow	2.5% Tallow	5% Tallow	Control	0% Tallow	2.5% Tallow	5% Tallow
Corn	79.90	53.10	49.32	45.50	84.96	58.10	54.56	50.96
DDGS	---	40.00	40.00	40.00	---	40.00	40.00	40.00
Beef tallow	---	---	2.50	5.00	---	---	2.50	5.00
Soybean meal (46.5% CP)	17.70	4.80	6.00	7.20	12.90	---	1.00	2.00
Limestone	1.09	1.35	1.34	1.35	1.07	1.27	1.31	1.32
Monocalcium P (21% P)	0.73	0.04	0.13	0.22	0.59	-	-	0.08
Salt	0.23	0.10	0.10	0.11	0.23	0.10	0.10	0.11
L-lysine HCl	0.20	0.47	0.47	0.48	0.12	0.39	0.39	0.39
L-threonine	0.03	-	-	-	-	-	-	-
Vitamin premix	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Trace mineral premix	0.03	0.05	0.05	0.05	0.04	0.05	0.05	0.05
Antibiotic [a]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Calculated analysis [b]								
Lys, %	0.90	0.90	0.93	0.96	0.70	0.70	0.73	0.75
Ca, %	0.60	0.60	0.62	0.64	0.55	0.55	0.57	0.59
P total, %	0.50	0.50	0.52	0.53	0.45	0.45	0.47	0.48
Iodine value [c]	120	118	99	87	119	116	90	86

[a]To provide 40 g/ton of tylosin.
[b]Nutrient:calorie ratios were kept constant for diets with added tallow.
[c]As calculated from fatty acid profile of the diets.

Table 2. Effects of Adding Beef Tallow to Diets with Sorghum-Based DDGS on Growth Performance and Carcass Characteristics in Finishing Pigs [a]

		40% DDGS				P value		
Item	Control	0% Tal-low	2.5% Tallow	5% Tal-low	SE	Control vs DDGS	Tallow lin	Tallow quad
D 0 to 31								
ADG, lb	2.15	1.95	1.91	1.93	0.08	0.04	--- [b]	---
ADFI, lb	6.62	6.40	6.21	5.75	0.18	0.03	0.02	---
F/G	3.08	3.28	3.25	2.98	0.07	---	0.02	---
D 0 to 65								
ADG, lb	2.12	1.96	1.94	1.95	0.06	0.03	---	---
ADFI, lb	7.34	6.98	6.44	6.33	0.10	0.001	0.003	0.12
F/G	3.46	3.56	3.32	3.25	0.08	---	0.03	---
HCW, lb	210.5	196.3	196.8	203.8	7.0	0.004	0.07	---
Dress, % [c]	71.3	69.3	69.5	70.7	0.5	0.03	0.07	---
Carcass lean, % [c]	53.3	52.4	53.9	53.7	0.3	--	0.03	0.08
Backfat thickness, in [c]	0.76	0.80	0.71	0.72	0.02	---	0.03	0.08
Loin depth, in [c]	2.03	1.95	1.98	1.97	0.04	---	---	---
Iodine value [c]	67.9	72.3	73.3	74.2	0.6	0.001	0.06	---

[a]A total of 112 barrows (initial weight of 158 lb) with seven pigs/pen and four pens/treatment.
[b]Dashes indicate *P*>0.15.
[c]Hot carcass weight used as a covariate.

EFFECTS OF DIETARY ELECTROLYTE BALANCE AND MOLASSES IN DIETS WITH DRIED DISTILLERS GRAINS WITH SOLUBLES ON GROWTH PERFORMANCE IN NURSERY AND FINISHING PIGS

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Summary

Two experiments were conducted to determine the effects of dietary electrolyte balance (dEB) and(or) molasses in diets with dried distillers grains with solubles (DDGS) on growth performance of nursery and finishing pigs. For Exp. 1, 126 nursery pigs (35 d old and average wt of 22.5 lb) were used with six pigs/pen and seven pens/treatment. Treatments were a corn-soybean meal-based control and diets with 30% DDGS without and with 0.93% sodium bicarbonate to adjust the dEB back to that of the control diet. Pigs fed the control diet had greater ADG ($P<0.03$) and ADFI ($P < 0.08$) but did not differ ($P>0.58$) in F/G compared to pigs fed diets with DDGS. Addition of sodium bicarbonate to nursery diets with 30% DDGS did not improve ($P>0.3$) growth performance.

For Exp. 2, a total of 70 gilts (average wt of 196 lb) were assigned with two pigs/pen and five pens/treatment. The pigs were fed experimental diets for 26 d, a common diet for 6 d, and then reassigned to a different treatment for an additional 26-d assay. The end result was 10 pens/treatment. Treatments were a corn-soybean meal-based control and diets with 40% DDGS without and with molasses (5%) and sodium bicarbonate (none, 1, and 2%). Pigs fed the control diet had greater ($P<0.001$) ADG, ADFI, and better ($P<0.03$) F/G compared to those fed diets with DDGS. Adding molasses and(or) sodium bicarbonate did not affect ADG ($P>0.26$), ADFI ($P>0.16$), or F/G ($P>0.24$). In conclusion, adding sodium bicarbonate and(or) molasses to diets with high inclusion of DDGS did not improve growth performance in nursery or finishing pigs.

(Key words: DDGS, dietary electrolyte balance, feed ingredients, molasses.)

Introduction

Previous data from our laboratory suggested poor feed consumption in sows fed corn-soy diets with low dietary electrolyte balance (dEB). Addition of dried distillers grains with solubles (DDGS) into swine diets results in reduced dEB. It seems plausible that balancing diets with DDGS for dEB and(or) adding a flavor enhancer might have a positive effect on feed intake and, thus, growth performance. Therefore, the objectives of the experiments reported herein were to determine the effects of dEB and(or) molasses in diets with high inclusion of DDGS on growth performance of nursery and finishing pigs.

Procedures

For Exp. 1, 126 nursery pigs (35 d old and average initial wt of 22.5 lb) were used in a

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24-d growth assay. The pigs were sorted by sex and ancestry, blocked by weight, and assigned to pens. There were six pigs/pen and seven pens/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, with pigs and feeders weighed on d 0 and 24 to allow calculation of ADG, ADFI, and F/G.

Treatments (Table 1) were a corn-soybean meal-based control and diets with 30% DDGS (Sioux River Ethanol, Hudson, SD) without and with 0.93% sodium bicarbonate to bring dEB to 64 mEq/kg [(Na + K) – (Cl + S)] as calculated for the control diet. All diets were formulated to 1.4% lysine, 0.75% Ca, and 0.35% available P. Data were analyzed as a randomized complete block design using the MIXED procedure of SAS. Orthogonal contrasts were used to separate treatment means with comparison of the control vs DDGS diets and none vs 0.93% sodium bicarbonate.

For Exp. 2, a total of 70 gilts (average initial wt of 157 lb for the first replication and 235 lb for the second replication) were used in a 58-d growth assay to determine the effects of molasses and dEB on palatability of diets with 40% DDGS in finishing pigs. The pigs were sorted by ancestry, blocked by location, and assigned to pens. There were two pigs/pen and five pens/treatment. The pigs were fed experimental diets for 26 d, a common diet for 6 d, and then reassigned to a different treatment for an additional 26 d. The end result was 10 pens/treatment. The pigs were housed in an environmentally-controlled finishing facility having 5-ft × 5-ft pens with slatted concrete flooring. Each pen had a self-feeder and nipple waterer to allow *ad libitum* consumption of feed and water. Pigs and feeders were weighed at d 0 and 26 of each replication to allow calculation of ADG, ADFI, and F/G.

Treatments (Table 2) were a corn-soybean meal-based control, and diets with 40% DDGS without and with 5% molasses and sodium bicarbonate (none, 1, and 2%). Thus, the treatments were arranged as a 2 × 3 factorial plus control. All diets were formulated to 0.90% lysine, 0.60% Ca, and 0.22% available P. Data were analyzed as a randomized complete block design with initial weight as a covariate using the MIXED procedure of SAS. Orthogonal contrasts and polynomial regression were used to separated treatment means with comparisons of control vs DDGS treatments, none vs 5% molasses, linear and quadratic effects of sodium bicarbonate, and interactions among the molasses and sodium bicarbonate main effects.

Results and Discussion

In the nursery experiment, pigs fed the control diet had greater ADG ($P<0.03$) and ADFI ($P<0.08$) but did not differ ($P>0.58$) in F/G compared with pigs fed diets with DDGS. Addition of sodium bicarbonate to diets with 30% DDGS did not improve ($P>0.3$) growth performance. For the finishing experiment, pigs fed the control diet had greater ($P<0.001$) ADG and ADFI, and better ($P<0.03$) F/G compared with those fed diets with 40% DDGS. Adding molasses and(or) sodium bicarbonate did not affect ADG ($P>0.26$), ADFI ($P>0.16$), or F/G ($P>0.24$). In conclusion, adding sodium bicarbonate to adjust dEB and(or) molasses to enhance flavor of diets with high inclusion of DDGS did not improve growth performance in nursery or finishing pigs.

Table 1. Composition of Nursery Diets, % [a]

Ingredient	Corn-Soy	DDGS	DDGS Adjusted
Corn	63.11	43.03	42.00
DDGS	---	30.00	30.00
Soybean meal (47.5% CP)	32.60	22.90	23.00
Limestone	1.11	1.50	1.50
Monocalcium P (21% P)	1.30	0.65	0.65
Salt	0.36	0.35	0.35
L-lysine HCl	0.32	0.53	0.53
DL-methionine	0.12	0.03	0.03
L-threonine	0.09	0.05	0.05
Vitamin premix	0.11	0.11	0.11
Trace mineral premix	0.08	0.05	0.05
Copper sulfate	0.10	0.10	0.10
Antibiotic [b]	0.70	0.70	0.70
Sodium bicarbonate	---	---	0.93
Dietary electrolyte balance, mEq/kg [c]			
Calculated	64	-45	64
Analyzed	103	-33	25

[a]Diets were formulated to 1.40% lys, 0.75% Ca, and 0.35% available P.
[b]To supply 140 g/ton oxytetracycline and 140 g/ton neomycin.
[c]Formula used to calculate dEB was (Na + K) – (Cl + S).

Table 2. Composition of Finishing Diets, % [a]

		No Molasses			5% Molasses		
Ingredient	Control	0% Bicarb	1% Bicarb	2% Bicarb	0% Bicarb	1% Bicarb	2% Bicarb
Corn	77.48	50.36	50.26	50.10	45.20	45.10	44.99
DDGS	-	40.00	40.00	40.00	40.00	40.00	40.00
Soybean meal (47.5% CP)	18.10	5.25	5.35	5.50	5.50	5.60	5.70
Limestone	1.08	1.52	1.51	1.51	1.40	1.39	1.39
Monocalcium P (21% P)	0.76	0.05	0.06	0.07	0.08	0.09	0.10
Salt	0.25	0.25	0.25	0.25	0.25	0.25	0.25
L-lysine HCl	0.20	0.47	0.47	0.47	0.47	0.47	0.47
L-threonine	0.03	---	---	---	---	---	---
Vitamin premix	0.05	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	0.05
Sodium bicarbonate	---	---	1.00	2.00	---	1.00	2.00
Sand [b]	2.00	2.00	1.00	---	2.00	1.00	---
Molasses	---	---	---	---	5.00	5.00	5.00
Dietary electrolyte balance, mEq/kg [c]							
Calculated	33	-112	6	124	-81	37	155
Analyzed	69	-107	9	88	-91	-33	47

[a]Formulated to 0.90% lysine, 0.60% Ca, and 0.22% available P.
[b]Non-nutritive ingredient replaced by sodium bicarbonate.
[c]Formula used to calculate dEB was (Na + K) – (Cl + S).

Table 3. Effect of dEB in Diets with DDGS on Growth Performance in Nursery Pigs [a]

					P value	
Item	Corn-Soy	DDGS	DDGS Adjusted [b]	SE	Corn-soy vs DDGS	Bicarb effect
ADG, lb	1.34	1.26	1.29	0.02	0.03	- [c]
ADFI, lb	2.01	1.91	1.95	0.04	0.08	-
F/G	1.50	1.52	1.51	0.01	-	-

[a]A total of 126 nursery pigs (initial wt of 22.5 lb) with six pigs/pen and seven pens/treatment.
[b]Electrolyte balance was adjusted to that of the control diet through the addition of sodium bicarbonate (Bicarb) to the DDGS diet.
[c]Dashes indicate $P>0.15$.

Table 4. Effects of dEB and Molasses in Diets with DDGS on Growth Performance in Finishing Pigs [a]

		40% DDGS									
		No molasses			5% Molasses						
	Corn-	0%	1%	2%	0%	1%	2%		*P* value[c]		
Item	Soy	Bicarb[b]	Bicarb	Bicarb	Bicarb	Bicarb	Bicarb	SE	DDGS	Molasses	Bicarb
ADG, lb	2.46	2.07	1.95	1.94	2.00	1.97	1.94	0.25	0.001	-	-
ADFI, lb	7.43	6.44	6.26	6.31	6.68	6.57	6.42	0.19	0.001	-	-
F/G	3.11	3.28	3.29	3.33	3.40	3.35	3.41	0.30	0.03	-	-

[a]A total of 70 finishing gilts (average initial wt of 157 lb for the first replication and 235 lb for the second replication), with two pigs/pen and five pens/treatment in each of two replicates for a total of 10 observations/treatment.
[b]Bicarb is used as the abbreviation for sodium bicarbonate.
[c]Dashes indicate $P>0.15$. There were no molasses × Bicarb interactions or linear or quadratic effects of Bicarb.

DIGESTIBLE ENERGY CONTENT OF CORN- VS SORGHUM-BASED DRIED DISTILLERS GRAINS WITH SOLUBLES AND THEIR EFFECTS ON GROWTH PERFORMANCE AND CARCASS CHARACTERISTICS IN FINISHING PIGS

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Summary

Two experiments were conducted to determine the nutritional value of corn- and sorghum-based dried distillers grains with solubles (DDGS). In Exp. 1, 120 finishing pigs (average initial weight of 244 lb) were used in a 19-d DE determination. The reference diet was 97% corn with vitamins, minerals, and amino acids added to meet or exceed all NRC suggested nutrient concentrations. Treatments were corn-based (Sioux River Ethanol, Hudson, SD and MGP Ingredients, Atchison, KS) and sorghum-based (US Energy Partners, Russell, KS and Western Plains Energy, Oakley, KS) DDGS substituted as 50% of the reference diet in place of corn. Comparisons among the treatments indicated that DDGS from corn had 101 kcal/lb greater DE than DDGS from sorghum ($P<0.02$). However, DE was different among the sources of corn-based DDGS ($P<0.001$) and sorghum-based DDGS ($P<0.03$) suggesting that plant of origin affects DE of DDGS.

In Exp. 2, 176 finishing pigs (average initial weight of 141 lb) were used in a 72-d growth assay. There were 11 pigs/pen and four pens/treatment with feed and water consumed on an *ad libitum* basis until the pigs were slaughtered at an average weight of 286 lb. Treatments were a corn-soybean meal-based control diet and diets with 40% corn-based, high-energy DDGS (Sioux River Ethanol), 40% corn-based, moderate-energy DDGS (MGP Ingredients), and 40% sorghum-based, moderate-energy DDGS (US Energy Partners). Pigs fed the control diet had greater overall ADG ($P<0.003$) and digestibility of DM ($P<0.001$), N ($P<0.02$), and GE ($P<0.001$) compared to pigs fed the DDGS treatments. Among the DDGS treatments, pigs fed the high-energy product had lower overall ADG ($P<0.06$), ADFI ($P<0.02$), and digestibility of DM ($P<0.03$) but tended to have better F/G ($P<0.07$) than pigs fed the moderate energy DDGS sources. As for carcass data, hot carcass weight ($P<0.001$) and dressing percentage ($P<0.003$) were greater and iodine value of jowl fat lower ($P<0.001$) for pigs fed the control vs DDGS treatments. Among the DDGS treatments, pigs fed the sorghum-based DDGS had greater dressing percentage ($P<0.04$) and lower iodine value ($P<0.001$) than pigs fed the corn-based DDGS. Backfat thickness ($P>0.58$) and percentage carcass lean ($P>0.25$) were not affected by treatment. In conclusion, plant of origin and substrate used in the fermentation process (corn vs sorghum) affected the nutritional value of DDGS for finishing pigs.

(Key words: DDGS, feed ingredient, meat quality, sorghum.)

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Introduction

Current government policy is to increase ethanol production in an effort to improve air quality, stabilize farm prices, and reduce dependence on foreign oil. According to the Renewable Fuels Association, there are 128 ethanol bio-refineries in the United States as of August 29, 2007 with capacity to produce about 6.8 billion gallons of ethanol each year. However, production from plants that are under construction will more than double those numbers in the near future. Thus, dried distillers grains with solubles (DDGS), as a coproduct of the ethanol industry, will increase in availability for use in livestock diets.

Previous research from our laboratory suggested that as much as 60% DDGS could be used in diets for finishing pigs without negative effects on growth performance and carcass characteristics while other researchers have recommended a maximum of 10 to 20% inclusion to avoid negative effects. Furthermore, most results are from experiments with only corn-based DDGS originating from a single source. Therefore, the objective of the experiments reported herein was to determine the DE content of corn- vs sorghum-based DDGS from different processing plants and to elucidate the effects of those DDGS on growth performance and carcass characteristics in finishing pigs.

Procedures

In Exp. 1, 120 finishing pigs (average initial wt of 244 lb) were used in a 19-d DE determination. The pigs were sorted by sex and ancestry, blocked by weight, and assigned to pens. There were 12 pigs/pen and two pens/treatment in each of two replicates for a total of four observations per treatment. The pigs were housed in a finishing facility with 6-ft × 16-ft pens that had 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.

The reference diet (Table 1) was 97.5% corn with vitamins, minerals, and amino acids added to meet or exceed all nutrient concentrations suggested by the NRC. Treatments were corn-based (Sioux River Ethanol, Hudson, SD and MGP Ingredients, Atchison, KS) and sorghum-based (US Energy Partners, Russell, KS and Western Plains Energy, Oakley, KS) DDGS substituted as 50% of the reference diet in place of corn. Diets were formulated to 0.52% lysine, 0.45% Ca, and 0.40% total P with 0.25% chromic oxide added as an indigestibility marker.

Table 1. Composition of Diets for the DE Determination, % [a]

Ingredient	Corn	DDGS
Corn	97.49	48.63
DDGS [b]	---	50.00
Limestone	0.89	0.94
Monocalcium P (21% P)	0.60	-
Salt	0.20	-
L-lysine HCl	0.34	0.11
L-threonine	0.03	---
L-tryptophan	0.04	---
L-isoleucine	0.02	---
Vitamin premix	0.03	0.03
Sow add pack	0.02	---
Trace mineral premix	0.09	0.04
Chromic oxide [c]	0.25	0.25
Total	100.00	100.00

[a]Formulated to 0.52% lysine, 0.45% Ca, and 0.40% total P.
[b]Substituted for corn on a lb:lb basis.
[c]Used as an indigestible marker.

The pigs were allowed to adjust to the experimental diets for 4 d. Each morning for the next 2 d, grab samples of feces were collected from at least six pigs/pen via rectal massage. Then, the pigs were fed a common diet for 7 d, and the treatments were reassigned for a second replicate with the restriction that a pen could not receive the same treatment twice.

The result was four observations per treatment for determination of DE.

Pigs and feeders were weighed on d 0 and 6 for Replicate 1, and d 13 and 19 for Replicate 2 to verify the pigs were gaining weight and consuming feed. Additionally, feed and fecal samples were dried, ground, and analyzed for concentrations of DM, N, GE, and Cr to allow calculation of apparent digestibilities using the indirect ratio method.

All digestibility data were analyzed as a randomized complete block design using the MIXED procedure of SAS. Orthogonal contrasts were used to separate treatment means with comparisons among the control vs DDGS diets, corn- vs sorghum-based DDGS, the two corn-based DDGS sources, and the two sorghum-based DDGS sources.

In Exp. 2, 176 finishing pigs (average initial wt of 141 lb) were used in a 72-d growth assay. The pigs were sorted by sex and ancestry, blocked by weight, and assigned to pens. There were 11 pigs/pen and four pens/treatment. The experimental diets (Table 2) were fed in two phases and formulated to 1.10% lysine, 0.60% Ca, and 0.50% total P for d 0 to 35, and 0.80% lysine, 0.55% Ca, and 0.45% total P for d 35 to 72. Treatments were a corn-soybean meal-based control diet and diets with 40% high-energy DDGS from Sioux River Ethanol (corn-based, crude fat of 10.4%, mean particle size of 328 μm, and DE of 1,646 kcal/lb as determined in Exp. 1), 40% moderate energy DDGS from MGP Ingredients (corn-based, crude fat of 8.5%, mean particle size of 796 μm, and DE of 1,333 kcal/lb as determined in Exp. 1), and 40% moderate energy DDGS from US Energy Partners (sorghum-based, crude fat of 7.3%, mean particle size of 563 μm, and DE of 1,454 kcal/lb as determined in Exp. 1).

Feed and water were consumed on an *ad libitum* basis with the pigs and feeders weighed on d 0, 35, and 72 to allow calculation of ADG, ADFI, and F/G. Chromic oxide (0.25%) was added to the diets as an indigestible marker and on d 40 and 41, fecal samples were collected via rectal massage. Concentrations of DM, N, GE, and Cr in the diets and feces were determined to allow calculation of apparent digestibility of nutrients. The pigs were killed on d 72 (average wt of 286 lb) and carcass data were collected. Because differences in slaughter weight and, thus, hot carcass weight are known to affect carcass measurements, hot carcass weight was used as a covariate to separate any effect of treatment from the effects of slaughtering our pigs at a constant age rather than constant weight. Samples of jowl fat were collected and fatty acid profile was determined to allow estimation of iodine value (AOCS Cd 1c-85 Official Method) as an indicator of carcass firmness.

All growth, digestibility, and carcass data were analyzed as a randomized complete block design using the MIXED procedure of SAS. Orthogonal contrasts were used to separate treatment means with comparisons of control vs the DDGS treatments, high vs moderate energy DDGS, and corn- vs sorghum-based DDGS.

Results and Discussion

Analyses of the DDGS sources (Table 3) indicated that protein and fiber content were greater in DDGS that originated from sorghum vs corn whereas fat and GE were greater for the corn-based DDGS. Particle size of DDGS varied among sources, primarily when originating from corn. Hunter LAB (color) measurements showed that sorghum-based DDGS were darker (lower L*) and less yellow (lower b*) than corn-based DDGS which is logical considering the differences in color of seed coat for corn vs sorghum.

When the dietary treatments were fed to pigs, they gained weight (an average of 0.70

lb/d) and ate the diets well (greater than 6 lb/d) during this brief (6-d) feeding assay. As for nutrient utilization among pigs fed the treatments (Table 4), corn had greater (P<0.001) digestibility of DM and GE than the DDGS treatments. Corn-based DDGS had greater (P<0.002) digestibility of N than sorghum-based DDGS and this result is in agreement with the greater N digestibility that we have reported previously for corn grain itself when compared to sorghum grain. Within the corn-based DDGS, those originating from Hudson had greater (P<0.002) digestibility of DM, N, and GE compared to DDGS from Atchison. There also was variability among the sorghum-based DDGS, with those from Russell having greater (P<0.03) digestibility of DM and GE compared to DDGS from Oakley. Digestible energy content of the DDGS themselves was calculated by multiplying the digestibility of GE in the DDGS by their total GE. Analyses of those data indicated that DDGS from the Hudson plant were higher (P<0.001) in DE content compared to DDGS from the Atchison plant. The greater DE of the Hudson DDGS corresponded well with its high fat content (10.4%) and small particle size (328 μm) compared to all of the other DDGS sources.

Finally, it has been suggested by some researchers and commodity brokers that lighter and more yellow DDGS are of greater nutritional value. However, in our experiment the darkest and least yellow DDGS had greater DE content than two of the other three DDGS treatments. This suggested that DDGS color was not a good predictor of nutritional value.

In Exp. 2 (Table 5), pigs fed the control diet had greater overall ADG (P<0.003) and digestibility of DM (P<0.001), N (P<0.02), and GE (P<0.001) compared to pigs fed the DDGS treatments. Among the DDGS treatments, pigs fed the high-energy product had lower ADG (P<0.06), ADFI (P<0.02), and digestibility of DM (P<0.03) but tended to have better F/G (P<0.07) and digestibility of N (P<0.05) than pigs fed the moderate energy DDGS sources.

As for carcass data, the effects of DDGS on ADG were reflected on greater (P<0.001) HCW for pigs fed the control diet. Furthermore, even when corrected to a constant HCW (via covariate analysis), dressing percentage (P<0.003) and loin depth (P<0.05) were greater, and iodine value of jowl fat was lower (P<0.001) for pigs fed the control vs DDGS treatments. Among the DDGS sources, iodine value was greater (P<0.001) for pigs fed the high vs moderate energy and corn- vs sorghum-based DDGS treatments. These results confirm that increased oil content in corn-based, high energy DDGS causes increased unsaturation of carcass fat. Backfat thickness (P>0.58) and percentage carcass lean were not affected (P>0.25) by treatment.

In conclusion, these experiments indicate that both plant of origin and substrate used in the fermentation process (corn vs sorghum) affect the nutritional value of DDGS when fed to finishing pigs. Yet, our data do not support the idea that color of DDGS is an acceptable indicator of nutritional value.

Table 2. Composition of Diets for the Growth Assay, % [a]

	d 0 to 35		d 35 to 72	
Ingredient	Control	DDGS	Control	DDGS
Corn	69.69	46.91	81.42	54.62
DDGS [b]	---	40.00	---	40.00
Soybean meal (46.5% CP)	28.00	11.00	16.15	3.25
Limestone	1.04	1.31	1.06	1.24
Monocalcium phosphate (21% P)	0.66	---	0.53	---
Salt	0.43	0.20	0.38	0.15
L-lysine HCl	0.10	0.50	0.13	0.40
DL-methionine	0.01	---	---	---
Vitamin premix	0.04	0.04	0.04	0.04
Trace mineral premix	0.03	0.04	0.04	0.05
Chromic oxide [c]	---	-	0.25	0.25
Total	100.00	100.00	100.00	100.00

[a]Formulated to 1.10% lysine, 0.60% Ca, and 0.50% total P for d 0 to 35, and 0.80% lysine, 0.55% Ca, and 0.45% total P for d 35 to 72.
[b]Substituted for corn on a lb:lb basis.
[c]Used as an indigestible marker.

Table 3. Analyses of DDGS Sources

		Corn-based DDGS		Sorghum-based DDGS	
Item	Corn	Hudson	Atchison	Oakley	Russell
Chemical analysis [a]					
DM, %	87.0	90.1	88.2	88.5	88.1
CP, %	8.7	26.4	25.6	29.8	30.5
EE, % [c]	3.4	10.4	8.5	7.9	7.3
CF, %	1.8	6.0	6.0	7.9	6.4
Ash, %	1.1	5.1	4.7	3.5	3.7
NFE, %	72.0	42.2	43.4	39.4	40.2
P, %	0.25	0.77	0.77	0.62	0.66
GE, mcal/lb	1.77	2.15	2.05	1.85	2.09
Physical characteristics					
d_{gw}, μm [b]	666	328	796	606	563
s_{gw} [b]	2.5	1.7	1.9	1.8	1.9
L* [c]	86	61	65	60	57
a* [c]	4	12	8	9	9
b* [c]	27	32	25	20	16

[a]DM (AOAC 930.15), CP (AOAC 990.03), EE (AOAC 920.39), CF, ash, P, and GE were determined using AOAC procedures.
[b]ANSI/ASAE S319.3.
[c]Hunter LAB MiniScan. Illuminant D65.

Table 4. Digestible Energy Content of Corn and Corn- or Sorghum-based DDGS for Finishing Pigs[a]

				Sorghum			*P* value			
		Corn DDGS		DDGS			Cont vs	Corn vs	Hud vs	Oak vs
Item	Corn	Hudson	Atchison	Oakley	Russell	SE	DDGS	Sorg	Atch	Rus
Digestibility, %										
Dry matter	87.4	81.6	76.1	76.6	80.6	1.1	0.001	---[b]	0.002	0.02
N (protein)	74.4	82.9	74.3	73.9	72.4	1.5	-	0.002	0.001	---
GE	85.4	81.1	74.6	74.0	77.9	1.1	0.001	0.10	0.001	0.03
DE, kcal/lb	1,507	1,646	1,333	1,323	1,454	40	0.13	0.02	0.001	0.03

[a]A total of 120 finishing pigs (12 pigs/pen and two pens/treatment with two replicates) with an average initial weight of 244 lb.
[b]Dashes indicate *P*>0.15.

Table 5. Effects of Corn- and Sorghum-based DDGS in Diets for Finishing Pigs[a]

		Corn-based			Sorg-based		*P* value		
		High energy	Moderate energy				Control vs	High vs Mod	Corn vs
Item	Control	Hudson	Atchison	Russell	SE	DDGS	energy	Sorg
D 0 to 35									
ADG, lb	2.08	1.92	2.05	2.01	0.06	0.10	0.06	---[b]
ADFI, lb	6.35	5.79	6.24	6.28	0.42	0.14	0.02	---
F/G	3.05	3.02	3.04	3.12	0.15	---	---	---
D 0 to 72									
ADG, lb	2.08	1.96	2.02	2.00	0.05	0.003	0.06	---
ADFI, lb	6.93	6.44	6.89	7.15	0.30	---	0.02	---
F/G	3.33	3.29	3.41	3.58	0.09	---	0.07	---
Digestibility, %[c]									
Dry matter	82.5	76.0	78.4	78.4	1.3	0.001	0.03	---
N (Protein)	75.4	73.8	74.9	66.3	1.7	0.02	0.05	0.001
Gross energy	80.0	74.7	76.2	75.2	1.3	0.001	---	---
HCW, lb	217.5	208.0	208.4	209.8	3.7	0.001	---	---
Dress, %[d]	74.8	73.7	72.7	73.6	0.8	0.003	0.12	0.04
Carcass lean, %[d]	54.1	53.4	53.6	53.7	0.6	---	---	---
Backfat, in[d]	0.64	0.64	0.62	0.64	0.05	---	---	---
Loin depth, in[d]	2.46	2.31	2.32	2.37	0.05	0.05	---	---
Iodine value[d]	69.3	80.2	78.4	74.2	0.8	0.001	0.001	0.001

[a]A total of 176 finishing pigs (11 pigs/pen and four pens/treatment) with an average initial weight of 141 lb.
[b]Dashes indicate *P*>0.15.
[c]Fecal samples for digestibility determinations were taken on d 40 and 41.
[d]Hot carcass weight used as a covariate.

AMINO ACID DIGESTIBILITY AND ENERGY CONTENT OF CORN DISTILLERS MEAL FOR SWINE[1]

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

Summary

An experiment was conducted to determine the apparent ileal digestibility and standardized ileal digestibility of amino acids and energy of corn distillers meal in pigs. Five growing barrows (initially 150 lb) were allotted to one of two diets in a crossover design. One diet contained corn distillers meal (66.7%) as the sole protein source. The second diet was nitrogen-free to determine basal endogenous AA losses. Ileal digesta and fecal samples were collected during each period and analyzed for amino acid and energy contents. Based on these analyses, apparent ileal digestibility (AID), standardized ileal digestibility (SID), gross energy (GE), digestible energy (DE), metabolizable energy (ME), and net energy (NE) were calculated. Apparent ileal digestibility values of lysine, methionine, and threonine in corn distillers meal were 47.2, 79.4, and 64.1%, respectively while SID values of the same amino acids were 50.4, 80.4, and 66.3%, respectively. The ME, DE, and estimated NE values of the corn distillers meal were 1,137; 1,233; and 813 kcal/lb, respectively.

(Key words: corn distillers meal, feed ingredients, digestibility.)

Introduction

With the increase in bio-fuel production, the availability of feed co-products like dried distillers grains with solubles (DDGS), especially 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 when compared to corn. While traditional DDGS have been evaluated for feeding value in swine, many other new products are being developed. One such product is corn distillers meal, in which the oil is removed and used in other industries. The remaining co-product has increased protein, fiber, and mineral concentrations. However, no data is available as to the actual digestibility of amino acids and energy of this coproduct. Thus, determination of nutrient digestibility is needed for accurately formulating and valuing corn distillers meal in diets for swine. The objective of this study was to determine the apparent ileal digestibility (AID) and standardized ileal digestibility (SID) of AA, DE, and ME, to estimate NE for corn distillers meal.

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Procedures

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

This experiment was done concurrently in a digestibility study with 2 different feed ingredients utilizing the same animals. Five growing barrows (initially 65 lb) were fitted with a T-cannula on their right flank approximately 15 cm anterior to the ileocecal valve. The pigs were housed individually in stainless steel metabolism crates in an environmentally controlled building after surgery and fed a standard corn-soybean meal-based diet for 10 d during the recovery period. After the recovery period, the pigs were utilized in a separate digestibility study for 5 weeks and then fed a common corn-soybean meal diet for 7 d. Pigs were then randomly allotted in a balanced crossover design with an initial starting weight of 150 lb. Two diets were utilized for this experiment with one diet formulated to contain the corn distillers meal while the second diet was formulated to be nitrogen-free to determine the basal AA endogenous losses (Table 1). Both diets contained 0.25% chromic oxide as an indigestible marker. Each feeding period consisted of 7 d with the first 4 d as adaptation period to the diet. On d 5 and 6, feces were collected in the morning and ileal digesta was collected on d 6 and 7 throughout a 10 h period (between 0600 and 1800 each day). Pigs were weighed at the beginning of each period to determine the amount of feed to be given each day. Feed was given at a daily level of 3 times the estimated maintenance requirement for energy. Feeding was done twice a day at 0600 and 1800 with the allocated daily amount divided into two equal meals. At the end of each period, all the pigs were taken off feed overnight before the next experimental diet was fed the following morning. The pigs were given free access to water through a nipple waterer throughout the duration of the experiment.

Table 1. Diet Composition (as-fed basis)

Ingredient, %	Corn Distillers meal	N-Free
Corn starch	27.05	81.15
Corn distillers meal	66.70	---
Soybean oil	1.00	3.00
Monocalcium P (21% P)	---	1.75
Limestone	1.25	0.40
Salt	0.35	0.45
Vitamin premix	0.25	0.25
Trace mineral premix	0.15	0.15
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	0.58	0.00
CP	20.80	0.00
Ca	0.51	0.38
P	0.51	0.30
Available P	0.39	0.30

Ileal digesta were collected by attaching a latex balloon to the cannula. Balloons were removed periodically or as soon as they were filled with digesta and emptied in a collection container which was stored in a freezer. After the collection phase of the experiment, ileal samples from each period from each animal were thawed and homogenized. A subsample was taken from each homogenized sample, freeze-dried and ground for amino acid (AA) analysis. Grab-samples of feces collected on d 5 and d 6 were stored and frozen. Fecal samples were then thawed at the conclusion of the collection phase, homogenized within each pig and diet. A subsample was taken and dried in a forced air oven, and ground for analysis. Energy concentration in diets, corn distillers

meal, and fecal samples were determined using bomb calorimetry. Chromic oxide served as the indigestible marker for calculation of AA and energy digestibility values. Corn Distillers meal, diets, and digesta samples were also analyzed for DM and CP.

The AID for AA in the corn distillers meal diet was calculated as:

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

where AID is the apparent ileal digestibility of an AA (%), AAd is the concentration of that AA in the ileal digesta (g/kg of DM), AAf is the concentration of that 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 amino acid at the ileum was determined based on the digesta samples obtained after feeding the N-free diet using the equation:

$$IAAend = [AAd \times (Crf/Crd)],$$

where IAAend is the basal ileal endogenous loss of an AA (g/kg of DMI).

SID value for each AA was calculated using the equation:

$$SID = [AID + (IAAend/AAf)],$$

where SID is the standardized ileal digestibility of an AA (%).

Digestible Energy value (DE) of corn distillers meal diet was calculated using the same equation for AID to determine the apparent total tract digestibility (ATTD) of energy. This value was then multiplied by the analyzed concentration of GE in the diets to get the DE of the diet. DE of the corn distillers meal was calculated by subtracting 33% of the N-free DE from the DE of the corn distillers meal diet. Metabolizable Energy (ME) and Net Energy (NE) were calculated using the following equations:

$$ME = 1 * DE – 0.68 * CP$$
$$NE = (0.87 * ME) – 442$$

Results and Discussion

The nutrient composition of the corn distillers meal used in the experiment is reported in Table 2. The CP of the corn distillers meal was 31.2%, which, as expected was higher than the CP content in traditional DDGS. Also, as expected, fat level was lower than traditional DDGS as a result of oil separation to produce the corn distillers meal. In addition, analyzed values of most amino acids and ADF and NDF were higher than in typical DDGS.

Lysine, methionine, and threonine in corn distillers meal had AID values of 47.2, 79.4, and 64.1%, respectively (Table 3). The AID value of lysine was lower than published values but most of the other AA AID values were higher than published values for DDGS. Standardized ileal digestibility values were 50.4% for lysine, 80.4% for methionine, and 66.3% for threonine. Just like AID, SID value of lysine was lower than most published values. It has been proposed that a lysine to CP ratio of greater then 2.8 indicates a DDGS co-product with higher amino acid digestibility. The ratio for the corn distillers meal tested in this study was 2.8.

The DE, ME, and estimated NE values of the corn distillers meal were 1,233; 1,137; and 813 kcal/lb, respectively. These values were lower than traditional DDGS energy values, which was expected, because the removal of the majority of the oil.

The AA and energy digestibility values have been established for corn distillers meal in this trial and can now be used as basis when formulating diets. This coproduct of ethanol and fat extraction industries has increased CP

and AA levels compared with traditional DDGS. However, it does contain lower energy and slightly lower lysine digestibility. Experiments to determine the effects of corn distillers meal on pig growth performance are necessary to further evaluate this ingredient and determine optimum use in the swine industry.

Table 2. Analyzed Nutrient Composition of Corn Distillers Meal

Nutrient, %	DM basis	As-is basis
DM	100.00	87.69
Crude protein	35.58	31.20
Crude fat	4.56	4.00
ADF	18.36	16.1
NDF	39.46	34.60
Ca	0.06	0.05
P	0.87	0.76
Ash	5.29	4.64
Amino acids, %		
Arginine	1.50	1.31
Histidine	0.93	0.82
Isoleucine	1.38	1.21
Leucine	4.15	3.64
Lysine	0.99	0.87
Methionine	0.67	0.58
Phenylalanine	1.92	1.69
Threonine	1.26	1.10
Tryptophan	0.22	0.19
Valine	1.75	1.54
Alanine	2.43	2.13
Aspartic acid	2.10	1.84
Cysteine	0.62	0.54
Glutamic acid	4.85	4.26
Glycine	1.35	1.18
Proline	2.41	2.11
Serine	1.48	1.30
Tyrosine	1.29	1.13

Table 3. Standardized and Apparent Ileal Digestibility of Amino Acids in Corn Distillers Meal [a]

Amino acid	SID, % [b]	AID, %[c]
Indispensable amino acids		
Arginine	82.70	79.65
Histidine	74.63	72.79
Isoleucine	74.52	72.46
Leucine	83.79	82.68
Lysine	50.38	47.20
Methionine	80.41	79.42
Phenylalanine	80.77	79.35
Threonine	66.31	64.09
Tryptophan	77.96	73.72
Valine	73.75	71.75
Dispensable amino acids		
Alanine	74.04	77.22
Aspartic acid	62.79	61.31
Cysteine	57.90	64.14
Glutamic acid	76.62	77.45
Glycine	57.26	52.69
Proline	83.45	73.44
Serine	71.08	73.20
Tyrosine	77.77	80.60

[a]Values are means of 5 pigs (initially 150 lb) used in a crossover design.
[b]Standardized ileal digestibility.
[c]Apparent ileal digestibility.

Table 4. Energy Analysis of Corn Distillers Meal [a]

Energy, kcal/lb	DM Basis	As-is Basis
Gross energy	2,116	1,855
Digestible energy	1,406	1,233
Metabolizable energy[b]	1,296	1,137
Net energy[c]	927	813

[a]Values are means of 5 observations per treatment.
[b]The ME value of corn distillers meal was calculated using the equation: ME = 1 * DE – 0.68 * CP (Noblet and Perez, 1993).
[c]The NE value of corn distillers meal was calculated by using the equation: NE = (0.87 * ME) – 442 (Noblet et al., 1994).

AMINO ACID DIGESTIBILITY AND ENERGY CONTENT OF TWO DIFFERENT SOY HULL SOURCES FOR SWINE

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Summary

This trial was conducted to determine and compare the digestibility of amino acids and energy of soy hulls from two different sources. Five growing barrows (initially 150 lb) fitted with T-cannulas were each fed three different diets in a crossover design. Each of the first two diets contained 66.7% soy hulls from two different sources (Soy hulls A and Soy Hulls B). The third experimental diet was N-free and based on corn starch and sucrose for determining basal endogenous amino acid (AA) losses. Ileal digesta and fecal samples were collected during each period and analyzed for amino acid and energy contents. Due to poor flowability of digesta through the T-cannula of one pig when fed diets containing soy hulls, it was removed from the experiment and thus, only four pigs were used in all data analyses. Apparent (AID) and standardized (SID) ileal digestibilites, and gross (GE), digestible (DE), metabolizable (ME), and estimated net (NE) energy values were then calculated from these analyses. Both samples were analyzed for particle size using Ro-Tap shaker with a stack of Tyler screens. Particle size of soy hulls A and soy hulls B were 619 and 691µ, respectively. The results of the trial showed differences in nutrient composition and in amino acid and energy digestibilities between the two soy hulls. Apparent ileal digestibility values of lysine, methionine, and threonine in soy hulls A were 58.38, 65.93, and 50.68%, respectively and 51.10, 57.51, and 37.54%, respectively in soy hulls B. Standardized ileal digestibility values of the same amino acids were 61.13, 69.53, and 62.25%, respectively for soy hulls A and 54.60, 62.32, and 51.96%, respectively for soy Hulls B. As a percentage of CP, standardized ileal digestible lysine, methionine, and threonine values were 4.09, 0.83, and 2.16% for soy hulls A; and 4.01, 0.85, and 2.01% for soy hulls B, respectively. The ME, DE, and estimated NE values were 1,037; 1,097; and 722 kcal/lb for soy hulls A and 989, 1,030, and 680 kcal/lb for soy hulls B, respectively.

(Key words: feed ingredients, soy hulls, digestibility.)

Introduction

Soybean hulls, or soy hulls, is an inexpensive co-product of soybean processing for oil and meal production. This product is very high in fiber containing mainly insoluble non-starch oligosaccharides, which is mostly cellulosic in nature. Although they are well digested and a rich source of energy in ruminants, high fiber feed products like soy hulls are poorly digested by non-ruminants such as pigs. The high fiber content of soy hulls has also been shown to have some drastic effects on nutrient digestibility like that of protein and

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energy. Thus, its recognized potential use in pigs has been mainly in sow diets to increase gut-fill in sows during gestation. With the increased availability of soy hulls for livestock, several studies have examined the effects of the soy hulls in the performance of growing pigs and odor production. However, limited data exists on the nutrient digestibility of soy hull products available in the market today. In addition, variability in nutritive and energy values may exist between soy hulls from different sources. Thus, the objective of this experiment was to determine and compare the digestibility of amino acids and energy in two sources of soy hulls.

Procedures

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

This experiment was done concurrently with a digestibility study with another feed ingredient utilizing the same animals. Five growing barrows (initially 65 lb) were fitted with a T-cannula on their right flank about 15-cm anterior to the ileocecal valve. After surgery, the pigs were housed individually in stainless steel metabolism crates in an environmentally controlled building and allowed to recover. After recovery, the pigs were utilized in a separate digestibility study for 5 weeks and then fed a common corn-soybean meal diet for 7 d. The pigs were then randomly allotted to 1 of 3 dietary treatments in a crossover design with an initial starting weight of 150 lb. Diets A and B contained 66.7% each of soy hulls A and soy hulls B, respectively, while the third diet was a N-free diet based on corn starch and sucrose for determining the basal AA endogenous losses. Due to poor flowability of digesta through the T-cannula of one pig when fed diets containing soy hulls, it was removed from the experiment and thus, only four pigs were used in all data analyses. All diets contained 0.25% chromic oxide as an indigestible marker. There were 7 d in each period where the first 4 d served as an adaptation period to the diet. Grab-samples of feces were collected on d 5 and 6, while ileal digesta collection was completed throughout a 10 h period (between 0600 and 1800) on d 6 and 7. Each pig's weight was determined at the beginning of each period and used to calculate the daily feed amount to be allocated for each period. Feed was provided at a daily level of 3 times the estimated maintenance requirement for energy. The pigs were fed half of the daily feed allocation twice a day at 0600 and 1800. At the end of each period feed was withheld from all pigs overnight and pigs were given the next experimental diet the following morning to avoid carry-over effect. Water was provided *ad libitum* through a nipple waterer throughout the duration of the trial.

Table 1. Diet Composition (as-fed basis)

Ingredient, %	Soy hulls A & B	N-Free
Corn starch	27.05	81.15
Soy hulls A or B	66.70	---
Soybean oil	1.00	3.00
Monocalcium P (21% P)	1.25	1.75
Limestone	---	0.40
Salt	0.35	0.45
Vitamin premix	0.25	0.25
Trace mineral premix	0.15	0.15
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

Ileal digesta collection was done using latex balloons attached to the cannula. Balloons were removed periodically or as soon as they were filled with digesta, transferred in a collection container, and stored in a freezer. At the end of the collection phase of the experiment, each pig's ileal samples from each period was thawed and homogenized. A subsample was taken from each homogenized

sample, freeze-dried and ground for AA analysis. Fecal samples from each period were also frozen after every collection. These samples were then thawed after the collection phase of the trial and homogenized within each pig and diet. Subsamples were taken and dried in a forced air oven, and ground for analysis. Energy concentration in diets, the two soy hulls, and fecal samples were determined using bomb calorimetry. Chromic oxide served as the indigestible marker to calculate AA and energy digestibility values. The two soy hulls, diets, and digesta samples were also analyzed for DM and CP. Particle size analysis of the two soy hulls was done using a Ro-Tap shaker with a stack of Tyler screens.

The AID for AA in the two soy hull diets was calculated as:

AID = [1 - (AAd/AAf) × (Crf/Crd)] × 100%,

where AID is the apparent ileal digestibility of an AA (%), AAd is the concentration of that AA in the ileal digesta (g/kg of DM), AAf is the concentration of that 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 at the ileum was determined based on the digesta samples obtained after feeding the N-free diet using the equation:

IAAend = [AAd × (Crf/Crd)],

where IAAend is the basal ileal endogenous loss of an AA (g/kg of DMI).

Standardized ileal digestible value for each AA was calculated using the equation:

SID = [AID + (IAAend/AAf)],

where SID is the standardized ileal digestibility of an AA (%).

Digestible Energy value (DE) of the soy hull diets were calculated using the same equation for AID to determine the apparent total tract digestibility (ATTD) of energy. This value was then multiplied by the analyzed concentration of GE in the diets to get the DE of the diet. DE of the two soy hulls were calculated by subtracting 33% of the N-free DE from the DE of the soy hull diets and dividing by 0.67 to correct back to 100% of the ingredient value. Metabolizable Energy (ME) and Net Energy (NE) were calculated using the following equations:

ME = 1 * DE – 0.68 * CP

NE = (0.87 * ME) – 442

Data was analyzed using PROC MIXED procedure of SAS with the pig as the experimental unit and with soy hulls source and pig as main effects. Least squares means was used to determine differences between treatments.

Results and Discussion

The results of the analysis for the two soy hulls' nutrient composition are shown in Tables 2 and 3. Amino acid composition as a percentage of CP is also presented in Table 3. Both soy hulls had higher CP and amino acid values than published book values. Comparing the two samples in this study, the AA in soy hulls A were higher than those in soy hulls B on an as-fed basis. However, most of the AA from soy hulls B were higher on a CP basis except for tryptophan and glutamic acid. Crude fat (2.3%), ADF (40.3%), NDF (53.6%), and calcium (0.72%) levels were higher in soy hulls B than in soy hulls A (1.60, 37.50, 50.80, and 0.59%, respectively). Calcium and phosphorous levels of the two soy hulls were higher than published book values.

Apparent ileal digestibility values and most AA in of soy hulls A were higher (P<0.05) than those of soy hulls B except for histidine, lysine, phenylalanine, threonine, as-

partic acid, cysteine, glycine, and proline, which were not significantly different (Table 4). Methionine AID value was 8 percentage points higher ($P<0.05$) in soy hulls A than in soy hulls B. Lysine, methionine, and threonine had AID values of 58.38, 65.93, and 50.68%, respectively in soy hulls A and 51.10, 57.51, and 37.54%, respectively, in soy hulls B.

Soy hulls A SID AA values for arginine, isoleucine, methionine, valine, alanine, glutamic acid, serine, and tyrosine were higher ($P<0.05$) than those in soy hulls B (Table 5). Standardized ileal digestible lysine, methionine, and threonine were 61.13, 69.53, and 62.25% for soy hulls A; and 54.60, 62.32, and 51.96% for soy hulls B, respectively. As a percentage of CP (Table 5), SID lysine, methionine, and threonine were 4.09, 0.83, and 2.16% for soy hulls A and 4.01, 0.85, and 2.01% for soy hulls B, respectively. For many of the major amino acids, it appears that expressing SID amino acids as a percentage of analyzed crude protein for the soy hulls may provide a relatively accurate estimate of the SID amino acid content.

Particle size has been shown to influence nutrient digestibility of soybean meal and, in this case, may partially explain the lower nutrient digestibility in soy hulls B, which had a greater particle size of 691µ compared to soy hulls A which was 619µ (Table 6).

Although soy hulls A had higher GE ($P<0.05$), DE, ME, and estimated NE values of the two soy hulls were not significantly different with 1,097; 1,037; and 722 kcal/lb in soy hulls A and 1,030; 989; and 680 kcal/lb in soy hulls B, respectively (Table 7).

This study shows that AID and SID of soy hulls may differ from one source to another. High fiber feed ingredients are poorly digested in pigs and this may explain the low nutrient digestibilities of soy hulls, regardless of source in this study. Particle size may also partially explain the difference in digestibility between the two soy hulls but other factors such as plant source (processing efficiency), and quality of the soy hulls may also account for the variability in nutrient and digestibility values. It may be necessary to source soy hulls from one supplier to aid in consistency for diet formulation. In addition, routine nutrient analyses should be completed to ensure consistency in nutrient content. Further research is necessary to test a wider range of soy hull sources to develop a database of digestibility by source.

Table 2. Proximate Analysis of Two Soy Hull Sources

	DM Basis		As-fed Basis	
Nutrient, %	Soy Hulls A	Soy Hulls B	Soy Hulls A	Soy Hulls B
DM	100.00	100.00	90.99	90.68
Crude protein	17.50	13.30	15.90	12.10
Crude fat	1.70	2.60	1.60	2.30
ADF	41.20	44.50	37.50	40.30
NDF	55.90	59.10	50.80	53.60
Ca	0.65	0.79	0.59	0.72
P	0.23	0.22	0.21	0.20
Ash	5.62	6.20	5.11	5.62

Table 3. Analyzed Amino Acid Composition of Two Soy Hull Sources

Nutrient, %	As-fed Basis			CP Basis		
	Soy hulls A	Soy Hulls B	Average	Soy Hulls A	Soy Hulls B	Average
Crude protein	15.90	12.10	14.00	100.00	100	100.00
Indispensable amino acids						
Arginine	0.87	0.69	0.78	5.44	5.67	5.55
Histidine	0.41	0.33	0.37	2.55	2.76	2.66
Isoleucine	0.65	0.52	0.58	4.09	4.27	4.18
Leucine	1.08	0.87	0.98	6.79	7.21	7.00
Lysine	1.06	0.89	0.98	6.69	7.35	7.02
Methionine	0.19	0.17	0.18	1.20	1.37	1.28
Phenylalanine	0.66	0.50	0.58	4.13	4.15	4.14
Threonine	0.55	0.47	0.51	3.47	3.86	3.66
Tryptophan	0.08	0.06	0.07	0.50	0.50	0.50
Valine	0.72	0.59	0.65	4.55	4.83	4.69
Dispensable amino acids						
Alanine	0.67	0.56	0.62	4.21	4.65	4.43
Aspartic acid	1.52	1.23	1.37	9.53	10.13	9.83
Cysteine	0.25	0.23	0.24	1.58	1.93	1.75
Glutamic acid	2.08	1.54	1.81	13.11	12.71	12.91
Glycine	1.09	0.94	1.02	6.87	7.76	7.32
Proline	0.72	0.61	0.67	4.53	5.04	4.78
Serine	0.72	0.61	0.66	4.52	5.00	4.76
Tyrosine	0.54	0.46	0.50	3.38	3.82	3.60

Table 4. Apparent Ileal Digestibility of Two Soy Hull Sources[a]

Amino acid, %	Soy hulls A	Soy hulls B	SE	*P* value
Indispensable amino acids				
Arginine	71.44	62.82	2.25	0.03
Histidine	57.92	49.63	2.88	0.06
Isoleucine	58.39	43.34	3.79	0.03
Leucine	58.93	45.43	4.12	0.05
Lysine	58.38	51.10	2.42	0.06
Methionine	65.93	57.51	1.90	0.02
Phenylalanine	66.33	57.61	3.06	0.07
Threonine	50.68	37.54	4.58	0.06
Tryptophan	N/A	N/A		
Valine	57.53	43.79	3.76	0.04
Dispensable amino acids				
Alanine	53.23	40.72	3.36	0.03
Aspartic acid	56.59	45.40	3.56	0.05
Cysteine	31.53	19.73	9.45	0.34
Glutamic acid	67.15	56.18	2.70	0.03
Glycine	25.99	24.82	3.80	0.79
Proline	28.19	28.93	9.99	0.95
Serine	46.18	31.10	3.19	0.02
Tyrosine	60.90	48.23	2.46	0.01

[a]Values are means of 4 pigs (initially 150 lb) used in a crossover design.
[b]Values were not determined due to some exceptionally low values in some samples.

Table 5. Standardized Ileal Digestibility of Two Soy Hull Sources[a]

	SID, %				SID AA / CP, %	
Amino acid	Soy hulls A	Soy Hulls B	SE	*P* value	Soy Hulls A	Soy Hulls B
Indispensable amino acids						
Arginine	76.51	69.58	2.10	0.05	4.16	3.94
Histidine	61.93	54.68	2.84	0.08	1.58	1.51
Isoleucine	62.52	48.92	3.80	0.04	2.56	2.09
Leucine	63.07	50.96	4.14	0.06	4.28	3.67
Lysine	61.13	54.60	2.40	0.07	4.09	4.01
Methionine	69.53	62.32	1.91	0.03	0.83	0.85
Phenylalanine	70.35	62.88	3.08	0.09	2.90	2.61
Threonine	62.25	51.96	4.68	0.12	2.16	2.01
Tryptophan[b]	N/A	N/A	7.58			
Valine	62.24	50.12	3.75	0.05	2.83	2.42
Dispensable amino acids						
Alanine	59.76	49.16	3.24	0.05	2.52	2.29
Aspartic acid	61.37	51.57	3.56	0.07	5.85	5.23
Cysteine	38.21	22.04	7.26	0.11	0.60	0.43
Glutamic acid	71.21	61.81	2.66	0.04	9.33	7.86
Glycine	40.08	32.59	8.83	0.46	2.76	2.53
Proline	70.84	73.68	22.02	0.91	3.21	3.71
Serine	53.57	40.88	3.12	0.03	2.42	2.04
Tyrosine	64.42	53.11	2.45	0.02	2.18	2.03

[a]Values are means of 4 pigs (initially 150 lb) used in a crossover design.
[b]Values were not determined due to some exceptionally low values in some samples.

Table 6. Particle Size Analysis of Two Soy Hull Sources

Item	Soy hulls A	Soy hulls B
Particle size, µ	619	691
Standard deviation	2.07	1.84
Surface area (cm^2/g)	95.7	79.1

Table 7. Energy Analysis of Two Soy Hull Sources[a]

	DM basis		As-fed basis		*P* values	
Energy, kcal/lb	Soy hull A	Soy hull B	Soy hull A	Soy hull B	DM basis	As-fed basis
Gross energy	1,901	1,848	1,755	1,676	<.0001	0.02
Digestible energy	1,211	1,088	1,097	1,030	0.13	0.27
Metabolizable energy	1,157	1,047	1,037	989	0.16	0.45
Net energy	806	710	722	680	0.16	0.44

[a]Values are means of 4 pigs (initially 150 lb) used in a crossover design.
[b]The ME value of soy hulls were calculated using the equation: **ME** = 1 * DE – 0.68 * CP (Noblet and Perez, 1993).
[c]The NE value of soy hulls were calculated by using the equation: **NE** = (0.87 * ME) – 442 (Noblet et al., 1994).

EFFECTS OF INCREASING ADDED CHOICE WHITE GREASE IN CORN AND SORGHUM-BASED DIETS ON GROWTH PERFORMANCE AND FAT QUALITY CHARACTERISTICS OF FINISHING PIGS[1]

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Summary

One hundred twenty crossbred barrows and gilts (TR4 × 1050) with an initial weight of 119.9 lb were used in an 83-d experiment to evaluate the effects of increasing added fat to corn or sorghum-based diets on growth performance and fat quality characteristics of finishing pigs. Treatments were arranged in a 2 × 2 × 3 factorial based on grain source (corn or sorghum), gender, and added fat (0, 2.5, or 5% choice white grease, CWG). At the end of the trial, jowl fat and backfat samples were collected. Pigs fed sorghum-based diets had increased (P<0.01) ADG compared with pigs fed corn-based diets. Pigs fed increasing CWG had increased (P<0.01) ADG. Pigs fed corn-based diets tended to have improved (P<0.06) dressing percentage, 10th rib BF, and percentage lean when compared with pigs fed sorghum-based diets. Barrows tended to have greater (P<0.06) dressing percentage and decreased (P<0.07) percentage lean when compared to gilts. Pigs fed increasing CWG had increased (P<0.02) 10th rib backfat, tended to have increased (P<0.08) hot carcass weight, and tended to have decreased (P<0.07) percentage lean. There was a fat level by grain source interaction (P<0.03) for percent C 18:2 fatty acids and iodine value in jowl fat. The interaction was due to the greatest increase in IV and percentage C 18:2 fatty acids occurring when CWG was increased from 2.5 to 5% for corn-based diets, while the greatest increase was from 0 to 2.5% CWG for sorghum-based diets. Despite this interaction, adding CWG increased (linear, P<0.02) percentage C 18:2 fatty acids and iodine value in jowl fat. Pigs fed corn-based diets had increased (P<0.01) iodine values and percentage C 18:2 fatty acids in jowl fat and backfat compared with pigs fed sorghum-based diets. Increasing dietary CWG increased (P<0.01) iodine value in jowl fat and backfat, increased (P<0.01) percentage C 18:2 fatty acids in backfat, tended to increase (P<0.06) percentage 18:2 fatty acids in jowl fat, and decreased (P<0.01) percentage saturated fatty acids in jowl fat and backfat. In summary, substituting sorghum for corn in diets for finishing pigs can be an effective way to reduce iodine value without affecting growth.

(Key words: corn, fat, feed ingredients, pork quality, sorghum.)

Introduction

Considerable research has shown improvements in feed efficiency and average

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daily gain from feeding added fat to finishing pigs. Composition of carcass fat, however, is altered when fat is included in diets, which may have implications from a processor acceptance standpoint. Iodine Value is a measure of the degree of unsaturation of a fat. Carcass iodine value, an indicator of carcass firmness, must be further researched to know the full carcass quality implications from feeding different fat sources for various time periods. Currently, Triumph Foods, St. Joseph, MO has set a maximum jowl iodine value of 73. Our previous research has demonstrated that including an unsaturated fat source in the diet during any portion of the finishing phase can result in iodine values above 73. Sorghum is often an economical replacement for corn in swine diets in Kansas. Additionally, sorghum has lower oil content than corn, which may lead to a lower carcass iodine value. With this in mind, the objective of this trial was to evaluate the effects adding fat to corn and sorghum diets would have on growth performance and fat quality characteristics of finishing pigs.

Procedures

One hundred twenty crossbred barrows and gilts, (TR4 × 1050) with an initial weight of 119.9 lb were used in an 83-d experiment. Pigs were blocked by weight and allotted to one of six treatments. Treatments were arranged in a 2 × 3 factorial based on grain source (corn or sorghum) and added fat (0, 2.5, or 5% choice white grease). Prior to being placed on test, all pigs were fed a corn-soybean meal-based diet. Diets were formulated to be fed in three phases from d 0 to 22, 22 to 53, and 53 to 83 to correspond with approximate weight ranges of 90 to 150, 150 to 210, and 210 to 270 lb. A constant TID lysine:ME ratio was maintained by altering the corn and soybean meal level in the basal diet when adding the fat to the diets.

There were two pigs per pen with ten replicate pens per treatment. Pigs were housed in an environmentally-controlled finishing barn with 4 ft × 4 ft pens with totally slatted flooring. Each pen was equipped with a one-hole dry self-feeder and nipple waterer to allow *ad libitum* access to feed and water. Pigs and feeders were weighed on d 14, 22, 39, 53, 67, and 83 to calculate ADG, ADFI, and F/G. Pen served as experimental unit for all statistical analysis.

Pigs were slaughtered at Triumph Foods of St. Joseph, MO at the end of the 83-d trial for collection of individual carcass data. The pigs were marked with an individual tattoo prior to marketing. At 24 hours postmortem, jowl and backfat samples were collected and frozen until further processing and analysis. Iodine value was calculated from 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).

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

Data were analyzed as a randomized complete-block design with pen as the experimental unit. Analysis of variance was performed by using the MIXED procedure of SAS. Linear and quadratic contrasts were used to evaluate the effects of increasing of choice white grease on growth and carcass performance. Hot carcass weight was used as a covariate for 10th rib backfat, last rib backfat, loin depth, and percentage lean.

Results and Discussion

Pigs fed sorghum-based diets had increased (P<0.01) ADG compared with pigs fed corn-based diets. The increase in ADG was due to a numerical (P = 0.15) increase in ADFI for pigs fed sorghum-based diets. Also,

pigs fed increasing CWG had improved (P<0.01) ADG.

Pigs fed corn-based diets tended to have improved (P<0.09) dressing percentage, 10th rib backfat (BF), and percentage lean when compared to pigs fed sorghum-based diets. Barrows tended to have greater (P<0.06) dressing percentage and decreased (P<0.07) percentage lean when compared to gilts. Increasing CWG increased (P<0.02) 10th rib backfat, tended to increase (P<0.08) hot carcass weight, and tended to decrease (P<0.07) percentage lean.

There was a fat level by grain source interaction (P<0.03) for percent C 18:2 fatty acids and iodine value in jowl fat. Adding CWG increased iodine value and percentage C 18:2 fatty acids in jowl fat for pigs fed sorghum and corn-based diets; however, the greatest increase was between 0 and 2.5% CWG for sorghum-based diets and between 2.5 and 5% CWG for corn-based diets.

Despite this interaction, pigs fed corn-based diets had increased (P<0.01) iodine values and percentage C 18:2 fatty acids in jowl fat and backfat compared with pigs fed sorghum-based diets. Increasing dietary CWG increased (P<0.01) iodine value in jowl fat and backfat, increased (P<0.01) percentage C 18:2 fatty acids in backfat, tended to increase (P<0.06) percentage 18:2 fatty acids in jowl fat, and decreased (P<0.01) percentage saturated fatty acids in jowl fat and backfat.

These results confirm that added dietary fat improves pig growth performance. Unexpectedly, pigs fed sorghum-based diets had improved ADG compared to pigs fed corn-based diets with the response due to increased feed consumption for pigs fed sorghum-based diets. Typically, we would expect similar ADG and slightly poorer F/G for pigs fed sorghum based diets compared with corn-based diets. Pigs fed corn-based diets had improved dressing percentage, reduced 10th rib fat and improved percentage lean compared with pigs fed sorghum-based diets. The results also demonstrate the expected lower percentage lean for barrows compared with gilts.

Our findings confirm that adding fat to finishing pig diets increases iodine value and percentage C 18:2 fatty acids, and reduce percentage saturated fatty acids in jowl fat and backfat. However, the CWG used in this trial from our Midwestern source resulted in jowl iodine values below the maximum level of 73 g/100g established by the Triumph Foods. This experiment demonstrated that compared to corn, feeding sorghum decreases iodine value. Therefore, sorghum could potentially be used to replace corn when iodine values approach the maximum level.

Table 1. Phase 1 Diet Composition (as-fed basis)[a]

	Corn			Sorghum		
Ingredients Added fat:	0%	2.5%	5%	0%	2.5%	5%
Corn	72.18	68.18	64.19	- - -	- - -	- - -
Sorghum	- - -	- - -	- - -	72.25	68.25	64.20
Soybean meal (46.5% CP)	25.23	26.70	28.14	25.25	26.73	28.25
Choice white grease	- - -	2.50	5.00	- - -	2.50	5.00
Monocalcium P (21% P)	1.03	1.05	1.10	0.93	0.98	1.00
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	0.10	0.10	0.10	0.10	0.10	0.10
Trace mineral premix	0.10	0.10	0.10	0.10	0.10	0.10
L-lysine HCl	0.15	0.15	0.15	0.15	0.15	0.15
DL-methionine	0.02	0.02	0.02	0.02	0.02	0.02
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis						
Total lysine, %	1.07	1.10	1.13	1.04	1.08	1.11
True ileal digestible amino acids						
Lysine, %	0.95	0.98	1.01	0.93	0.97	1.00
Methionine:lysine ratio, %	29	29	28	30	29	28
Met & cys:lysine ratio, %	59	58	56	58	57	56
Threonine:lysine ratio, %	61	60	60	64	63	62
Tryptophan:lysine ratio, %	19	19	19	22	22	22
ME, kcal/lb	1,510	1,561	1,611	1,485	1,537	1,589
Crude fat, %	3.2	5.6	7.9	2.5	4.9	7.3
Ca, %	0.62	0.63	0.64	0.60	0.61	0.62
P, %	0.59	0.60	0.60	0.58	0.59	0.59
Available P, %	0.28	0.29	0.30	0.28	0.29	0.29
TID Lys:Cal ratio, g/Mcal ME	2.58	2.58	2.58	2.58	2.58	2.58
Analyzed values						
Dietary fat IV	111.14	92.39	85.71	108.65	87.88	71.32
Dietary IV	35.56	51.37	72.62	26.88	42.88	51.96

[a]Diets fed in meal form from d 0 to 22.

Table 2. Phase 2 Diet Composition (as-fed basis)[a]

		Corn			Sorghum		
Ingredients	Added fat:	0%	2.5%	5%	0%	2.5%	5%
Corn		80.26	76.53	72.81	- - -	- - -	- - -
Sorghum		- - -	- - -	- - -	80.10	76.35	72.60
Soybean meal (46.5% CP)		17.27	18.47	19.66	17.53	18.73	19.97
Choice white grease		- - -	2.50	5.00	- - -	2.50	5.00
Monocalcium P (21% P)		0.93	0.95	0.98	0.83	0.85	0.90
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		0.10	0.10	0.10	0.10	0.10	0.10
Trace mineral premix		0.10	0.10	0.10	0.10	0.10	0.10
L-lysine HCl		0.15	0.15	0.15	0.15	0.15	0.15
Total		100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis							
Total lysine, %		0.85	0.87	0.90	0.82	0.85	0.88
True ileal digestible amino acids							
Lysine, %		0.75	0.78	0.80	0.74	0.76	0.79
Methionine:lysine ratio, %		30	30	29	31	30	29
Met & cys:lysine ratio, %		63	61	60	62	60	59
Threonine:lysine ratio, %		63	62	61	67	66	65
Tryptophan:lysine ratio, %		19	19	19	23	23	22
ME, kcal/lb		1,513	1,564	1,614	1,485	1,537	1,589
Crude fat, %		3.4	5.8	8.1	2.6	5.0	7.4
Ca, %		0.58	0.58	0.59	0.56	0.57	0.58
P, %		0.54	0.54	0.54	0.53	0.53	0.54
Available P, %		0.25	0.26	0.26	0.25	0.25	0.26
TID Lys:Cal ratio, g/Mcal ME		2.14	2.14	2.14	2.14	2.14	2.14
Analyzed values							
Dietary fat IV		113.97	94.99	84.76	106.83	90.83	83.71
Dietary IV		38.75	54.73	68.95	21.76	45.38	61.98

[a]Diets fed in meal form from d 22 to 53.

Table 3. Phase 3 Diet Composition (as-fed basis)[a]

Ingredients	Added fat:	Corn			Sorghum		
		0%	2.5%	5%	0%	2.5%	5%
Corn		84.18	80.54	76.98	- - -	- - -	- - -
Sorghum		- - -	- - -	- - -	83.90	80.35	76.75
Soybean meal (46.5% CP)		13.44	14.56	15.60	13.82	14.82	15.91
Choice white grease		- - -	2.50	5.00	- - -	2.50	5.00
Monocalcium P (21% P)		0.88	0.90	0.93	0.78	0.83	0.85
Limestone		0.80	0.80	0.80	0.80	0.80	0.80
Salt		0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix		0.10	0.10	0.10	0.10	0.10	0.10
Trace mineral premix		0.10	0.10	0.10	0.10	0.10	0.10
L-lysine HCl		0.15	0.15	0.15	0.15	0.15	0.15
Total		100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis							
Total lysine, %		0.74	0.77	0.79	0.72	0.74	0.77
True ileal digestible amino acids							
Lysine, %		0.65	0.68	0.70	0.64	0.66	0.69
Methionine:lysine ratio, %		32	31	30	33	32	31
Met & cys:lysine ratio, %		66	65	63	65	63	62
Threonine:lysine ratio, %		64	63	62	69	67	66
Tryptophan:lysine ratio, %		19	19	19	23	23	23
ME, kcal/lb		1,515	1,566	1,617	1,486	1,538	1,590
Crude fat, %		3.5	5.9	8.2	2.6	5.1	7.5
Ca, %		0.54	0.54	0.55	0.52	0.53	0.54
P, %		0.51	0.51	0.52	0.50	0.51	0.51
Available P, %		0.24	0.24	0.25	0.23	0.24	0.25
TID Lys:Cal ratio, g/Mcal ME		1.85	1.85	1.85	1.85	1.85	1.85
Analyzed values							
Dietary fat IV		120.3	99.03	84.03	94.62	85.38	83.21
Dietary IV		42.11	58.03	69.21	24.99	43.14	62.11

[a]Diets fed in meal form from d 53 to 83.

Table 4. Effects of Adding Fat to Corn and Sorghum-based Diets on Growth Performance[a]

										Probability, *P*<				
	Corn			Sorghum			Fat Level SE	Source SE	Gender SE			Fat level		Source × Fat Level
Added CWG	0%	2.5%	5%	0%	2.5%	5%				Source	Gender	Linear	Quad	
D 0 to 83														
ADG, lb	1.97	2.04	2.13	2.10	2.18	2.23	0.17	0.14	0.14	0.01	0.89	0.01	0.98	0.89
ADFI, lb	5.62	5.75	5.57	5.88	5.82	6.02	0.04	0.04	0.04	0.15	0.49	0.51	0.23	0.61
F/G	2.85	2.82	2.62	2.81	2.67	2.70	0.07	0.05	0.06	0.90	0.49	0.18	0.16	0.68

[a]A total of 120 pigs (initial weight 119.9 lbs) with 2 pigs per pen and 10 replicates per treatment.

Table 5. Main Effects of Adding Fat to Corn and Sorghum-based Diets on Growth Performance[a]

											Probability, *P*<				
	Fat Level			Source		Gender		Fat Level SE	Source SE	Gender SE			Fat level		Source × Fat Level
Added CWG	0%	2.5%	5%	Corn	Sorghum	Barrows	Gilts				Source	Gender	Linear	Quad	
D 0 to 83															
ADG, lb	2.03	2.11	2.19	2.05	2.17	2.12	2.09	0.17	0.14	0.14	0.01	0.89	0.01	0.98	0.89
ADFI, lb	5.72	5.79	5.84	5.65	5.91	5.94	5.62	0.04	0.04	0.04	0.15	0.49	0.51	0.23	0.61
F/G	2.81	2.75	2.67	2.76	2.73	2.81	2.69	0.07	0.05	0.06	0.90	0.49	0.18	0.16	0.68

[a]A total of 120 pigs (initial weight 119.9 lbs) with 2 pigs per pen and 20 replicates per fat level treatment, and 30 per gender treatment.

Table 6. Effects of Adding Fat to Corn and Sorghum-based Diets on Carcass Performance[a]

										Probability, P<				
	Corn			Sorghum								Fat level		
Item Added fat, %	0%	2.5%	5%	0%	2.5%	5%	Fat Level SE	Source SE	Gender SE	Source	Gender	Linear	Quad	Source × Fat Level
Hot carcass wt, lb	206.9	213.9	217.3	212.5	220.6	221.2	2.68	2.14	2.14	0.46	0.64	0.08	0.92	0.34
Dress, %	73.0	73.6	73.3	72.2	72.8	72.4	0.37	0.30	0.32	0.06	0.06	0.28	0.36	0.91
10th rib fat, in [b]	0.65	0.72	0.71	0.72	0.72	0.81	0.06	0.05	0.06	0.06	0.15	0.02	0.77	0.06
Loin depth, in [b]	2.40	2.50	2.48	2.41	2.55	2.45	0.93	0.74	0.74	0.98	0.53	0.52	0.03	0.80
Last rib fat, in [b]	0.88	0.99	0.98	0.95	0.96	1.00	0.06	0.03	0.03	0.83	0.69	0.18	0.61	0.44
Lean, % [b]	53.9	53.6	53.4	53.2	53.5	52.3	0.28	0.26	0.22	0.09	0.07	0.07	0.13	0.13
Backfat iodine value	63.77	66.55	67.21	60.96	65.95	64.68	0.55	0.45	0.45	0.01	0.50	0.01	0.01	0.27
Jowl fat iodine value	69.24	69.30	72.24	66.22	69.64	68.87	0.57	0.46	0.46	0.01	0.83	0.01	0.66	0.03
Backfat C 18:2, %	13.81	14.83	14.52	11.06	13.29	12.50	0.31	0.25	0.25	0.01	0.88	0.02	0.01	0.37
Jowl fat C 18:2, %	14.57	14.13	15.35	11.97	13.85	13.04	0.32	0.26	0.26	0.01	0.83	0.06	0.47	0.02
Backfat saturated fatty acids, %	41.27	39.15	38.00	41.77	38.34	38.92	0.41	0.34	0.34	0.54	0.36	0.01	0.03	0.26
Jowl fat saturated fatty acids., %	36.21	35.56	33.49	36.98	35.02	34.87	0.37	0.29	0.30	0.14	0.97	0.01	0.89	0.14

[a]Total of 120 pigs (initial weight 119.9 lbs) with 2 pigs per pen and 10 replicates per treatment.
[b]Hot carcass weight used as a covariate.

Table 7. Main Effects of Adding Fat to Corn and Sorghum-based Diets on Carcass Performance[a]

	Fat Level			Source		Gender					Probability, P<				
								Fat Level	Source	Gender			Fat level		Source ×
Added CWG	0%	2.5%	5%	Corn	Sorghum	Barrows	Gilts	SE	SE	SE	Source	Gender	Linear	Quad	Fat Level
Hot carcass wt, lb	210.7	214.3	217.2	212.7	215.2	214.8	213.2	2.68	2.14	2.14	0.46	0.64	0.08	0.92	0.34
Dress, %	72.5	73.2	73.1	73.3	72.5	73.4	72.4	0.37	0.30	0.32	0.06	0.06	0.28	0.36	0.91
10th rib fat, in [b]	0.68	0.72	0.78	0.70	0.76	0.75	0.70	0.06	0.05	0.06	0.06	0.15	0.02	0.77	0.06
Loin depth, in [b]	2.41	2.54	2.45	2.47	2.47	2.45	2.479	0.93	0.74	0.74	0.98	0.53	0.52	0.03	0.80
Last rib fat, in [b]	0.91	0.98	1.00	0.96	0.97	0.97	0.95	0.06	0.03	0.03	0.83	0.69	0.18	0.61	0.44
Lean, % [b]	53.6	53.6	52.6	53.6	52.9	52.9	53.6	0.28	0.26	0.22	0.09	0.07	0.07	0.13	0.13
Backfat iodine value	62.54	66.24	65.94	65.82	63.86	64.70	64.96	0.55	0.45	0.45	0.01	0.50	0.01	0.01	0.27
Jowl fat iodine value	68.03	69.47	70.48	70.29	68.29	69.51	69.13	0.57	0.46	0.46	0.01	0.83	0.01	0.66	0.03
Backfat C 18:2, %	12.50	14.02	13.49	14.37	12.29	13.32	13.30	0.31	0.25	0.25	0.01	0.88	0.02	0.01	0.37
Jowl fat C 18:2, %	13.39	13.99	14.19	14.69	12.99	13.95	13.76	0.32	0.26	0.26	0.01	0.83	0.06	0.47	0.02
Backfat saturated fatty acids, %	41.38	38.72	38.46	39.49	39.67	39.74	39.41	0.41	0.34	0.34	0.54	0.36	0.01	0.03	0.26
Jowl fat saturated fatty acids., %	36.36	35.29	34.26	35.05	35.60	35.24	35.38	0.37	0.29	0.30	0.14	0.97	0.01	0.89	0.14

[a]A total of 120 pigs (initial weight 119.9 lbs) with 2 pigs per pen and 20 replicates per fat level treatment, and 30 per gender treatment.
[b] Hot carcass weight used as a covariate.

DETERMINATION OF THE FOURTH-LIMITING AMINO ACID IN SWINE DIETS CONTAINING NUTRIDENSE® CORN[1]

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Summary

Two studies were conducted to determine the fourth-limiting amino acid in swine diets containing NutriDense® corn. Both experiments were conducted at a commercial swine research facility in southwest Minnesota. In Exp. 1, 1,259 pigs (initially 82.1 lb, PIC) were used in a 28-d study. Pigs were blocked by weight, and were randomly allotted to one of six dietary treatments. Pigs were fed NutriDense® corn-soybean meal-based diets. The treatments were 1) a positive control diet containing 0.15% L-lysine HCl and 0.015% added L-threonine; 2) a negative control diet with 0.45% L-lysine HCl, 0.085% added DL-methionine, and 0.15% added L-threonine; 3) treatment 2 with 0.05% L-isoleucine; 4) treatment 2 with 0.05% L-valine; 5) treatment 2 with 0.05% L-tryptophan; and 6) treatment 2 with a combination of 0.05% L-isoleucine, 0.05% L-tryptophan, and 0.05% L-valine. Pigs fed the positive control and the diet with the combination of added isoleucine, tryptophan, and valine had greater ADG ($P<0.05$) than all other treatments. Also, pigs fed added isoleucine or tryptophan had greater ADG ($P<0.05$) than pigs fed the negative control with those fed added valine being intermediate. Pigs fed the diet with the combination of added isoleucine, tryptophan, and valine had greater ADFI ($P<0.05$) then pigs fed the negative control. There were no significant differences in F/G.

In Exp. 2, 1,038 pigs (initially 170.4 lb, PIC) were used in the 28-d study with six dietary treatments similar to Exp. 1 to determine the fourth-limiting amino acid in late finishing pigs. Overall, pigs fed the positive control diet had greater ($P<0.05$) ADG and lower ($P<0.05$) F/G then pigs fed the negative control diet and those fed either L-isoleucine, L-tryptophan, or L-valine. Pigs fed the diet containing added tryptophan or the combination of isoleucine, tryptophan, and valine had improved ($P<0.05$) ADG and F/G compared with those fed the negative control, or added isoleucine or valine. Pigs fed added isoleucine and valine had greater ($P<0.05$) ADG than pigs fed the negative control diet. There was no difference amongst the treatments for ADFI. These results suggest that in the 80 to 130 lb growing pig, tryptophan and isoleucine are the co-limiting fourth amino acid in diets containing NutriDense® corn. In 170 to 220 lb

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pigs, tryptophan appears to be fourth-limiting followed by isoleucine and valine.

(Key words: amino acids, feed ingredients, NutriDense® corn.)

Introduction

NutriDense® (ND) corn is a nutritionally enhanced product containing a stacked set of traits to provide greater nutrient density than conventional yellow dent (YD) corn. Specifically, it contains approximately 23% more lysine, 19% more sulfur amino acids, 18% more threonine, almost 34% more tryptophan, and 5% more energy than normal corn. Because ND corn contains greater levels of amino acids, inclusion of ND corn in the diet lowers soybean meal use and alters the amino acid balance, which should decrease the need for secondary amino acids when high levels of synthetic L-lysine are used. NutriDense® corn also contains higher levels of other amino acids relative to lysine, which may allow for higher levels of synthetic amino acids to be used in diets containing ND corn.

Recent reductions in the price of L-threonine have made it feasible to add L-threonine and DL-methionine with L-lysine to further reduce the soybean meal level in corn-soybean meal based diets. In order to formulate ND corn-based diets with the maximum amount of added L-lysine, DL-methionine and L-threonine the fourth-limiting amino acid must be determined. Therefore, the objective of these studies was to determine the fourth-limiting amino acid in diets containing ND corn and to evaluate whether pig performance could be maintained with the inclusion of high levels of synthetic amino acids in diets containing ND corn.

Procedures

Procedures used in these experiments were approved by the Kansas State University Animal Care and Use Committee. The two experiments were conducted at a commercial research facility in southwest Minnesota. The facility had a totally slatted floor, with approximately 7.2 ft^2 provided per pig. Each pen was equipped with a four-hole dry self feeder and one 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. Experiments 1 and 2 were conducted in summer and spring, respectively. Pigs were randomly allotted and blocked to one of six dietary treatments with seven pens per treatment. Pigs and feeders were weighed on d 0, 14, and 28 to determine the response criteria of ADG, ADFI, and F/G. All pigs were fed diets containing ND corn. A single lot of ND corn was stored and used in both trials. The ND corn was sampled for amino acid analysis (Table 1) and the values used in diet formulation.

Table 1. Composition of NutriDense® Corn[a]

Item	NutriDense® Corn
Dry matter, %	86.36
Crude Fat, %	6.16
CP, %	7.98
ME, kcal/lb	1,628
Fiber, %	3.06
Calcium, %	0.01
Total P, %	0.32
Available P, %	0.33
Amino acids,%	
Lysine	0.30
Cystine	0.20
Isoleucine	0.29
Leucine	0.97
Methionine	0.20
Tryptophan	0.07
Threonine	0.30
Valine	0.42

[a]Values represent the mean of 2 samples analyzed in duplicate.

Experiment 1. A total of 1,259 pigs (initially 82.1 lb, PIC L 337 × 1050) were used in the 28-d study. Each pen contained 26 to 28 pigs with an equal distribution of barrows and gilts in each pen with 7 replicate pens per experimental diet. Experimental diets (Table 2) were fed in meal form. Pigs were fed ND corn-soybean meal-based diets. The treatments were: 1) a positive control diet containing 0.15% added L-lysine and 0.015% added L-threonine; 2) a negative control diet with 0.45% added L-lysine, 0.085% added DL-methionine, and 0.15% added L-threonine; 3) treatment 2 with 0.05% added L-isoleucine; 4) treatment 2 with 0.05% added L-valine; 5) treatment 2 with 0.05% added L-tryptophan; and 6) treatment 2 with a combination of 0.05% added L-isoleucine, 0.05% L-tryptophan, and L-valine, 0.05%. All experimental diets were balanced to maintain a constant true ileal digestible (TID) lysine:ME ratio and available P level.

Experiment 2. A total of 1,038 pigs (initially 170.4 lb, L 327 × C22) were used in the 28-d study. Each pen contained 23 to 25 pigs with an equal distribution of barrows and gilts in each pen with 7 replicate pens per experimental diet. Experimental diets (Table 3) were fed in meal form and based on the same formulation concept as Exp. 1. The treatments were: 1) a positive control diet containing 0.15% added L-lysine and 0.02% added L-threonine; 2) a negative control diet containing 0.40% added L-lysine, 0.03% added DL-methionine, and 0.13% added L-threonine; 3) treatment 2 with 0.05% added L-isoleucine; 4) treatment 2 with 0.05% added L-valine; 5) treatment 2 with 0.05% added L-tryptophan; 6) treatment 2 with a combination of 0.05% added L-isoleucine, 0.05% L-tryptophan and 0.05% L-valine. All other procedures were identical to Exp. 1.

Statistical Analysis. In both experiments, 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. Overall (d 0 to 28), pigs fed the positive control and the diet with the combination of added isoleucine, tryptophan, and valine had greater ADG ($P<0.05$) than pigs fed all other treatments (Table 4). Pigs fed added isoleucine or tryptophan had greater ADG ($P<0.05$) than pigs fed the negative control with those fed valine being intermediate. Average daily feed intake was greatest for pigs fed the combination of isoleucine, tryptophan, and valine compared with pigs fed the negative control diet, with those fed the other dietary treatments intermediate. There were no significant differences in F/G with numerical differences following the ADG response. Final weight reflects the differences in ADG with pigs fed the positive control diet or the diet with the combination of added isoleucine, tryptophan, and valine being heavier ($P<0.05$) than those fed the negative control diet, with those fed the other treatments being intermediate.

Experiment 2. Overall (d 0 to 28), pigs fed the positive control diet had greater ($P<0.05$) ADG than pigs fed the negative control diet and those fed added isoleucine, tryptophan, or valine. Pigs fed the combination of isoleucine, tryptophan, and valine had greater ADG than those fed the negative control, or added isoleucine or valine. Also, pigs fed added tryptophan had greater ($P<0.05$) ADG than pigs fed the negative control diet and those fed additional isoleucine or valine. Furthermore, pigs fed added isoleucine or valine had greater ($P<0.05$) ADG than pigs fed the negative control diet. There was no difference amongst the treatments for ADFI. Pigs fed the positive control diet had better ($P<0.05$) F/G than pigs fed all other treatments, with those fed the combination of added isoleucine, tryptophan and valine, or tryptophan being intermediate followed by those fed the negative

control, added isoleucine or valine. Pigs fed the positive control diet had greater ($P<0.05$) final BW than pigs fed the negative control diet and pigs fed diets with added isoleucine or valine.

Discussion

The true ileal digestible (TID) amino acid ratios for isoleucine, valine, and tryptophan recommended for grow-finish pigs by Kansas State University are 55, 16.5 and 65% relative to lysine, respectively. During the grower trial, the negative control diet was calculated to be deficient in isoleucine (51% of lysine) and tryptophan (14% of lysine), and marginally deficient in valine (63% of lysine). The growth data indicates that these amino acid ratios and recommendations appear to be accurate. Adding tryptophan or isoleucine to the diet increased ADG to a similar extent with only a minor numerical increase in ADG with the addition of valine. Adding all three amino acids together allowed performance to return to the level achieved by the positive control diet. Thus, very high levels of synthetic amino acids can be added to diets formulated with ND corn for grower pigs without sacrificing performance.

As TID lysine levels were lowered in the finishing phase to match the amino acid requirements, more ND corn and less soybean meal was used in the diets. Thus, the ratios of amino acids also changed. The negative control diet for the finishing experiment were calculated to be most deficient in tryptophan (12.5% of lysine), deficient in isoleucine (51% of lysine), and adequate in valine (66% of lysine). Performance data again indicates that the amino acid ratios and recommendations appear to be accurate. Adding tryptophan to the negative control diet resulted in the greatest improvement in ADG and F/G with the addition of isoleucine providing a small benefit over the negative control. Adding valine to the diet did not influence performance. Adding all three amino acids provided only a small benefit over the addition of tryptophan alone and was not successful in returning F/G back to the level achieved by the positive control diet. The lack of completely returning performance of the tryptophan supplemented treatments diets does not appear to be because of a tryptophan, isoleucine or valine deficiency. These results are similar to other trials with late finishing pigs where additions of high levels (0.45% in this experiment) of L-lysine HCl with other amino acids were not able to equal the performance of finishing pigs fed diets with lower levels of synthetic amino acids. However, the results in this trial indicate that the use of ND corn allows performance to be returned closer to the performance of the control pigs than in much of the previous research with normal yellow dent corn.

Interestingly, a response was obtained in both the grower and finisher experiments with the addition of either tryptophan or isoleucine alone to the negative control diet. In the classical interpretation of an amino acid deficiency, a response to a secondary limiting amino acid should not be present until the most limiting amino acid is added to the diet. In both of these trials, a response was found to either amino acid added alone. This suggests that the amino acids may be acting through different mechanisms. For example, tryptophan appears to have a bigger impact on ADFI. Thus, the classical interpretation of an amino acid deficiency may be wrong.

In conclusion, these results suggest that in the 80 to 130 lb growing pig, tryptophan and isoleucine are the co-limiting fourth amino acid in diets containing ND corn. In 170 to 220 lb pigs, tryptophan appears to be the fourth-limiting amino acid followed by isoleucine.

Table 2. Composition of Diets (Exp. 1; as-fed basis)

Item	Positive Control	Negative Control	Added Isoleucine	Added Valine	Added Trypto-phan	Added Ile, Try and Val
NutriDense® corn	75.12	83.88	83.88	83.88	83.88	83.8
Soybean meal (46.5% CP)	22.70	13.25	13.25	13.25	13.25	13.25
Monocalcium P (21% P)	0.65	0.70	0.70	0.70	0.70	0.70
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
Vitamin premix with phytase	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
L-lysine HCl	0.15	0.45	0.45	0.45	0.45	0.45
DL-methionine	---	0.09	0.09	0.09	0.09	0.09
L-threonine	0.015	0.15	0.15	0.15	0.15	0.15
L-tryptophan	---	---	---	---	0.05	0.05
L-isoleucine	---	---	0.05	---	---	0.05
L-valine	---	---	---	0.05	---	0.05
Total	100	100	100	100	100	100
Calculated analysis						
Total lysine, %	1.03	1.01	1.01	1.01	1.01	1.01
Lysine:ME ratio, g/Mcal	2.62	2.61	2.61	2.61	2.61	2.61
True ileal amino acids, %						
Lysine	0.91	0.91	0.91	0.91	0.91	0.91
Isoleucine:lysine ratio	69	51	57	51	51	57
Leucine:lysine ratio	154	129	129	129	129	129
Methionine:lysine ratio	30	34	34	34	34	34
Met & Cys:lysine ratio	60	60	60	60	60	59
Threonine:lysine ratio	62	62	62	62	62	62
Tryptophan:lysine ratio	19	14	14	14	19	19
Valine:lysine ratio	80	63	63	68	63	68
ME, kcal/lb	1,574	1,584	1,583	1,583	1,584	1,583
CP, %	16.8	13.5	13.5	13.5	13.6	13.6
Ca, %	0.55	0.52	0.52	0.52	0.52	0.52
P, %	0.53	0.51	0.51	0.51	0.51	0.51
Available P, %	0.25	0.26	0.26	0.26	0.26	0.26
Available P equivalent, %	0.31	0.32	0.32	0.32	0.32	0.32
Avail P:calorie ratio g/mcal	0.9	0.91	0.91	0.91	0.91	0.91

Table 3. Compostition of Diets (Exp 2; as-fed basis)

Ingredient	Positive Control	Negative Control	Added Isoleucine	Added Valine	Added Trypto-phan	Added Ile, Try and Val
NutriDense® corn	82.98	90.34	90.34	90.34	90.34	90.2
Soybean meal (46.5% CP)	15.00	7.15	7.15	7.15	7.15	7.15
Monocalcium P (21% P)	0.45	0.50	0.50	0.50	0.50	0.50
Limestone	0.95	1.00	1.00	1.00	1.00	1.00
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix with phytase	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
L-lysine HCl	0.15	0.40	0.40	0.40	0.40	0.40
DL-methionine	---	0.03	0.03	0.03	0.03	0.03
L-threonine	0.02	0.13	0.13	0.13	0.13	0.13
L-tryptophan	---	---	---	---	0.05	0.05
L-isoleucine	---	---	0.05	---	---	0.05
Valine	---	---	---	0.05	---	0.05
Total	100	100	100	100	100	100
Calculated analysis						
Total lysine, %	0.82	0.80	0.80	0.80	0.80	0.80
TID Lysine:ME ratio, g/Mcal	2.06	2.05	2.05	2.05	2.05	2.05
True Ileal amino acids, %						
Lysine	0.72	0.72	0.72	0.72	0.72	0.72
Isoleucine:lysine ratio	69	51	58	51	51	58
Leucine:lysine ratio	170	144	144	144	144	144
Methionine:lysine ratio	33	32	32	32	32	32
Met & Cys:lysine ratio	66	60	60	60	60	60
Threonine:lysine ratio	65	65	65	65	65	65
Tryptophan:lysine ratio	18	12.7	12.7	12.7	19	19
Valine:lysine ratio	84	66	66	73	66	72
ME, kcal/lb	1,585	1,592	1,591	1,591	1,593	1,591
CP, %	13.8	11.1	11.1	11.1	11.2	11.2
Ca, %	0.5	0.51	0.51	0.51	0.51	0.51
P, %	0.46	0.44	0.44	0.44	0.44	0.44
Available P, %	0.21	0.21	0.21	0.21	0.21	0.21
Available P equivalent, %	0.24	0.25	0.25	0.25	0.25	0.25
Avail P:calorie ratio g/mcal	0.7	0.71	0.71	0.71	0.71	0.71

Table 4. Determination of the Fourth-limiting Amino Acid in Swine Diets Containing NutriDense® Corn (Exp.1)[a]

Item	Positive Control	Negative Control	Added Isoleucine	Added Valine	Added Tryptophan	Added Ile, Val and Try	SE
D 0 to 28							
ADG, lb	1.93[b]	1.69[d]	1.81[c]	1.76[cd]	1.80[c]	1.92[b]	0.04
ADFI, lb	4.99[bc]	4.62[c]	4.87[bc]	4.68[bc]	4.81[bc]	5.05[b]	0.13
F/G	2.59	2.73	2.69	2.66	2.68	2.63	0.07
Final wt, lb	136.5[b]	130.4[c]	133.1[bc]	131.4[bc]	132.4[bc]	136.0[b]	1.83

[a]A total of 1,259 pigs, initially 82.1 lb, were used in a 28 d experiment to evaluate growth performance and determine the 4th limiting amino acid for pigs fed diets containing NutriDense® corn. Experimental diets were formulated to contain 0.91% TID Lysine using either 0.15% added L-lysine HCl (Control), 0.45% added L-lysine HCl (Negative Control), 0.45% added L-lysine HCl + 0.05% added L-isoleucine (NC + Ile), 0.45% added L-lysine HCl + 0.05% added L-valine (NC + Val), 0.45% added L-lysine HCl + 0.05% L-tryptophan (NC + Try), or 0.45% added L-lysine HCl + 0.05% added L-isoleucine + 0.05% added L-valine + 0.05% added L-tryptophan (NC + Ile + Val + Try).

[bcd]Means within a row containing different superscripts are different $P<0.05$.

Table 5. Determination of the Fourth-limiting Amino Acid in Swine Diets Containing NutriDense® Corn (Exp. 2)[a]

Item	Positive Control	Negative Control	Added Isoleucine	Added Valine	Added Tryptophan	Added Ile, Val and Try	SE Mean
D 0 to 28							
ADG, lb	1.94[b]	1.62[e]	1.72[d]	1.65[de]	1.85[c]	1.88[bc]	0.04
ADFI, lb	5.83	5.81	5.89	5.76	6.00	6.05	0.11
F/G	3.01[b]	3.60[d]	3.44[d]	3.48[d]	3.25[c]	3.23[c]	0.07
Final wt, lb	226.0[b]	218.8[cd]	218.7[cd]	216.6[d]	222.0[bcd]	224.2[bc]	2.74

[a]A total of 1,038 pigs, initially 170.4 lb, were used in a 28 d experiment to evaluate growth performance and determine the 4th limiting amino acid for pigs fed diets containing NutriDense® corn. Experimental diets were formulated to contain 0.72% TID Lysine using either 0.15% added L-lysine HCl (Control), 0.40% added L-lysine HCl (Negative Control), 0.40% added L-lysine HCl + 0.05% added L-isoleucine (NC + Ile), 0.40% added L-lysine HCl + 0.05% added L-valine (NC + Val), 0.40% added L-lysine HCl + 0.05% L-tryptophan (NC + Try), or 0.40% added L-lysine HCl + 0.05% added L-isoleucine + 0.05% added L-valine + 0.05% added L-tryptophan (NC + Ile + Val + Try).

[bcde]Means within a row containing different superscripts are different $P<0.05$.

DIGESTIBLE ENERGY CONTENT OF CORN AND TRITICALE WHEN FED TO FINISHING PIGS[1]

C. Feoli, J. D. Hancock, C. R. Monge, and T. L. Gugle

Summary

A total of 96 pigs (average initial wt of 201 lb) was used to determine the DE content of corn and triticale. The pigs were sorted by sex and ancestry, blocked by weight, and assigned with 12 pigs/pen and four pens/treatment. The diets were corn (97.5% of the formulation) and triticale (97.8% of the formulation) with added vitamins, minerals, and amino acids. Feed (meal form) and water were consumed on an *ad libitum* basis. The pigs were allowed to adjust to the experimental diets for 4 d. On the afternoon of d 4 and morning of d 5, feces were collected from no less than six pigs/pen (via rectal massage). The feed and fecal samples were dried, ground, and analyzed for concentrations of DM, N, and GE with chromic oxide used as an indigestible marker. Digestibility of DM was greater ($P<0.03$) for pigs fed corn vs triticale (82.8 vs 81.2%, respectively). However, the opposite was true for digestibility of N ($P<0.002$) with values of 67.8% for corn and 74.7% for triticale. Digestibility of GE was not different ($P>0.26$) among the cereal grains. However, when the gross energy for the cereals was multiplied by their respective digestibility coefficients, triticale grain had greater ($P<0.02$) DE with a value of 1,531 kcal/lb vs 1,479 kcal/lb for corn. The DE of the corn used in this experiment was low compared to NRC values, but nonetheless our results indicated that this particular triticale was utilized well by finishing pigs supporting greater digestibility of N and having greater DE than corn.

(Key words: feed ingredients, triticale.)

Introduction

Triticale is a hybrid resulted from a cross between wheat and rye. This "small grain" crop was developed as a forage source for cattle and for its improved protein quality (e.g., greater lysine content) for nonruminants. Development of new varieties has renewed interest in this cereal as a feedstuff in Kansas but also has led to questions about its feeding value for pigs. Therefore, the objective of the experiment reported herein was to determine the nutrient digestibility of corn and triticale when fed to finishing pigs.

Procedures

A total of 96 pigs (average initial weight of 201 lb) was used. The pigs were sorted by sex and ancestry, blocked by weight, and assigned to pens. There were 12 pigs/pen and four pens/treatment. Diets (Table 1) were yellow corn (97.5% of the formulation) and triticale (ThunderCale as 97.8% of the formulation) with added vitamins, minerals, and amino acids. The diets had 0.52% lysine,

[1]Appreciation is given to Ehmke Seed for supplying the triticale (ThunderCale) used in this experiment.

0.45% Ca, and 0.40% total P with 0.25% chromic oxide added as an indigestible marker.

Table 1. Composition of Diets, %[a]

Ingredient	Corn	Triticale
Cereal grain	97.53	97.83
Limestone	0.89	0.95
Monocalcium phosphate (21% P)	0.60	0.37
Salt	0.20	0.18
L-lysine HCl	0.34	0.18
L-threonine	0.03	-
L-isoleucine	0.02	-
Vitamin premix	0.03	0.05
Sow add pack	0.02	0.06
Trace mineral premix	0.09	0.13
Chromic oxide [b]	0.25	0.25
Total	100.00	100.00

[a]Diets were formulated to 0.52% lysine, 0.45% Ca, and 0.40% total P.
[b]Used as an indigestible marker.

Feed (meal form) and water were consumed on an *ad libitum* basis with pigs and feeders weighed on d 0 and 5. The pigs were allowed to adjust to the experimental diets for 4 d. Feces were collected from no less than six pigs/pen (via rectal massage) on the afternoon of d 4 and morning of d 5. The feed and fecal samples were dried, ground, and analyzed for concentrations of DM, N, GE, and Cr to allow calculation of apparent digestibility of nutrients using the indirect ratio method. All data were analyzed as a randomized complete block design using the MIXED procedure of SAS with a significant F-test indicating treatment differences.

Results and Discussion

The pigs gained weight (an average of 1.75 lb/d) and ate the diets well (greater than 7 lb/d) during this brief (5-d) experiment. Comparison of nutrient utilization among the cereals showed digestibility of DM was greater ($P<0.03$) for pigs fed corn vs triticale (82.8 vs 81.2%, respectively). However, the opposite was true for digestibility of N ($P<0.002$) with values of 67.8% for corn and 74.7% for triticale. Digestibility of GE was not different ($P>0.26$) among the cereal grains. However, when the gross energy for the cereals was multiplied by their respective digestibility coefficients, triticale grain had greater ($P<0.02$) DE with a value of 1,531 kcal/lb vs 1,479 kcal/lb for corn. The DE of the corn used in this experiment was low compared to NRC values, but nonetheless our results indicated that this particular triticale was utilized well by finishing pigs supporting greater digestibility of N and having greater DE than corn.

Table 2. Digestibility of Nutrients in Corn and Triticale for Finishing Pigs [a]

Item	Corn	Triticale	SE	P value
Digestibility, %				
Dry matter	82.8	81.2	0.8	0.03
Nitrogen (protein)	67.8	74.7	1.6	0.002
Gross energy	81.1	80.5	0.9	- [b]
DE content of the grain, kcal/lb	1,479	1,531	16	0.02

[a]A total of 96 pigs (12 pigs/pen and four pens/treatment) with an average initial weight of 201 lb.
[b]Dash indicates $P>0.15$.

THE EFFECT OF LYSINE LEVEL OR METHIONINE/COPPER/MANGANESE ON OSTEOCHONDROSIS LESIONS AND CARTILAGE PROPERTIES IN PIGS

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Summary

A total of 120 gilts (PIC 327 × 1050; 89.2 lb initial BW) were used in a 3 × 2 factorial, 84-d study to determine the effect of lysine (Lys) fed either below the calculated requirement (0.8% true ileal digestible (TID) Lys Phase I and 0.6% TID Lys Phase II), at requirement (1.0% TID Lys Phase I and 0.8% TID Lys Phase II), or above the requirement (1.3% TID Lys Phase I and 1.1% TID Lys Phase II) with standard concentrations or with high added methionine (Met, 1 %), copper sulfate (Cu, 250 ppm), and manganese sulfate (Mn, 220 ppm) on the occurrence and severity of osteochondrosis (OC) lesions, growth performance, soundness, carcass traits, and several cartilage criteria. Upon completion of the feeding period, pigs were harvested and the distal aspect of the left humerus and femur were evaluated by gross examination for OC lesions. The external surface was evaluated for abnormalities and received a severity score. For the external femur evaluation, increasing dietary Lys concentration tended (linear, $P<0.08$) to increase the number of abnormalities and there was a numerical trend for an increased severity score ($P<0.13$) with increasing dietary Lys. The addition of high Met/Cu/Mn to the diet reduced the number of abnormalities ($P<0.02$) and severity score ($P<0.01$) at the external femur compared to pigs fed diets with standard concentrations of Met/Cu/Mn. At the external humerus, increasing dietary Lys increased both the number of abnormalities (linear, $P<0.01$) and severity score (linear, $P<0.01$). The addition of high Met/Cu/Mn to the diet reduced the number of abnormalities ($P<0.03$) and severity score ($P<0.03$) for the external humerus. Increasing dietary Lys concentration or high-added Met/Cu/Mn had no effect ($P>0.14$) on the number of faces with lesions at the femoral growth plate or the severity score ($P>0.19$). The number of faces with lesions and severity score at the humerus articular cartilage was unaffected by increasing dietary Lys concentration ($P>0.16$) or the addition of high Met/Cu/Mn to the diet ($P>0.37$). The total faces with lesions were not impacted by increasing dietary Lys concentration ($P>0.78$) or additional high Met/Cu/Mn ($P>0.86$). The total abnormalities (external and number of faces) tended to increase with increasing dietary Lys (linear, $P<0.12$). The addition of high Met/Cu/Mn did not affect the total number of abnormalities ($P>0.16$). The total severity score for both external and OC evaluation increased with increasing dietary Lys concentration (linear, $P<0.01$). The addition of high Met/Cu/Mn decreased the total severity score ($P<0.02$) compared to pigs fed diets with standard concentrations of Met/Cu/Mn. Finally, increasing dietary Lys concentration

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increased the sum (linear, $P<0.05$) of abnormalities and total severity score. The addition of high Met/Cu/Mn tended ($P<0.09$) to reduce the overall severity score compared to pigs fed diets with standard concentrations of Met/Cu/Mn. In conclusion, feeding growing gilts dietary Lys to maximize growth performance may increase the severity of OC lesions, while a diet with additional Met/Cu/Mn may aid in the reduction of OC severity scores.

(Key words: amino acids, cartilage, health, osteochondrosis.)

Introduction

Previously, we have attempted to determine the role of nutritional ingredients related to cartilage and bone metabolism on the occurrence of osteochondrosis (OC). Osteochondrosis is the focalized disruption in the endochondral ossification of cartilage at the end of growing long bones leaving areas of retained cartilage in the subchondral bone. Our first experiment revealed several minerals and amino acids that showed positive results on reducing the severity of OC. In our second experiment, we attempted to further investigate the effect of minerals and amino acids but were unable to replicate the results of the first experiment. In our second experiment, pigs were fed in one phase, whereas the first experiment was conducted with a three-phase feeding program to allow optimum performance and to closely match amino acid requirements. In addition, the occurrence of OC was lower in the second experiment, and our ability to influence OC may have been compromised due to pigs starting at a heavier weight, being slaughtered at a lighter weight, the shorter duration of the trial, and the fact that pigs were fed slightly under their requirement for Lys early in the study and slightly more than their requirement for Lys late in the study. The occurrence of OC is thought to be bilateral or occur in multiple joints, thus we also collected the left humerus as well as the femur to improve our detection of OC. Previously, it has been thought that pigs with the fastest growth rate may have an increased occurrence of OC; however, the available data suggests conflicting results.

The objective of this experiment was to determine the effect of lysine level and the combination of additional methionine, copper sulfate, and manganese sulfate on growth performance, OC lesions, and several cartilage criteria in grow-finish pigs.

Materials and Methods

General. Procedures used in these experiments were approved by the Kansas State University Animal Care and Use Committee. The experiment was conducted at the Kansas State University Swine Research and Teaching Center. Each pen contained two pigs per pen and there were 10 replicates (pens) per treatment. The barn contains 80 pens with totally slatted concrete flooring (5 × 5 ft), providing approximately 12.5 sq ft/pig. Each pen was equipped with a one-hole dry self-feeder (Farmweld, Tuetopolis, IL) and nipple waterer to allow *ad libitum* access to feed and water.

A total of 120 gilts (PIC line 327 × 1050; 89.2 lb initial BW) were blocked by weight in an 84-d growth assay. Dietary treatments were arranged in a 3 × 2 factorial consisting of three TID Lys levels fed below (0.8% Phase I, 0.6% Phase II), at the requirement (1.0% Phase I, 0.8% Phase II), or above their requirement (1.3% Phase I, 1.1% Phase II). The Met/Cu/Mn treatments were either at standard inclusions typical of swine diets (no added methionine, 9 ppm of Cu and 20 ppm of Mn) or high-added methionine (1% added DL-methionine), 250 ppm Cu (Copper sulfate), and 220 ppm Mn (Manganese sulfate). The addition of Met/Cu/Mn replaced sand to form the other dietary treatments. The dietary Lys requirement was determined from previous experiments conducted in this facility. Experimental diets were fed in meal form for 84 d in two 42 d phases. The values used in diet

formulation and TID digestibilities were based on those published in the NRC (1998). Diet samples were analyzed for amino acid content and contained levels similar to calculated concentrations.

Growth Performance and Carcass Composition. Pigs and feeders were weighed every 14 d to determine ADG, ADFI, and F/G. At the end of the trial, pigs were weighed before transport to the Kansas State University Meats Laboratory, where the left front (elbow joint) and hind leg (knee joint) were collected for determination of OC lesions for one pig in each pen. Before transport, the heaviest pig from each pen was marked with a distinctive tattoo to allow data to be recorded for each pig. Pigs were loaded onto a trailer in small groups (15 pigs) and transported approximately 2 miles to the processing facility. For carcass data, 10^{th} rib backfat depth, longissimus muscle area (LMA), percentage lean, and hot carcass weight were evaluated. Fat depth was measured with a ruler at the 10^{th} rib, 2.4 inches off of the midline, while LMA was traced on translucent paper and calculated using a grid. Percentage lean was calculated using an equation from the National Pork Producers Council (NPPC).

Visual Soundness Scores. Prior to slaughter, the heaviest pig from each pen was scored by two evaluators for the front leg and rear leg (1-5 where 1=poor and 5=excellent) based on angle and conformation, and for locomotion (1-5 where 1=poor and 5=excellent) as an indication of mobility. The front and rear legs scores were added together to form the total score according to the National Swine Improvement Federation (NSIF) system (where 1-3=poor or unsuitable for breeding purposes, 4-7=average, and 8-10=excellent or desirable for breeding purposes).

Collection of Cartilage Data and OC Lesions Scores. The left front leg (elbow joint) and hind leg (knee joint) were collected and removed to visually determine the number of cartilage abnormalities and the occurrence of OC lesions by gross examination of the humerus and femoral condyles for one pig from each pen. The joints were cleaned of excess tissue and then stored in 10% formalin until evaluation. After external evaluation, the distal end of the humerus and femur were sliced into 3 mm thick sections by cutting perpendicular to the long axis of the bone using a bandsaw. Each joint was evaluated for the number of external abnormalities at femoral and humerus condyles, OC lesions at the articular cartilage and growth plate cartilage of the distal femur, humerus articular cartilage, and given a severity score (0-4) for all locations, where 0=normal, 1=mild, 2=moderate, 3=severe, and 4= OC dissecans based on the extent of tissue involvement. All pigs had OC lesions at one of the locations evaluated, so we were unable to analyze for differences in OC occurrence (number of animals with OC).

In addition, a cartilage sample was cut from the patella for cartilage property analysis. Cartilage samples were weighed, measured for thickness and length using a caliper, and then tested for the ability to absorb compression or to resist shearing using an Instron testing machine. Cartilage samples were placed between two flat surfaces of the Instron to perform texture profile analysis and compressed half of the thickness to measure the ability of the cartilage to resist compression force. A second measure was conducted in which the cartilage was cut using a Warner-Bratzler shear blade to determine the ability of the cartilage to withstand shearing force. Compression values and shear values were adjusted to a per gram of cartilage weight to equalize for differences in the actual cartilage sample weight.

Relationship between Growth Rate, Weight, Visual Soundness, and Overall Severity Score. Because there were differences in growth rate among our dietary treatments, a correlation between growth rate or weight and the overall severity score was conducted.

Visual evaluation of soundness or leg conformation was also evaluated for correlation with the overall severity score. Each prediction variable was plotted by the overall severity score and a linear regression line fitted to determine how much of the variation in overall severity score could be explained by the variables (r^2 value).

Statistical Analysis. Data were analyzed as a randomized complete block design using the PROC MIXED procedure of SAS with pig as the experimental unit to determine the main effect of treatment. The response criteria of growth performance, carcass composition, cartilage compression and shear energy, and number of abnormalities were tested. Although scored categorically, soundness and OC severity scores were analyzed via PROC MIXED because low numbers of observations at some of the severity scores prevented categorical analysis. Linear and quadratic effects of increasing dietary Lys were determined using single degree of freedom contrasts.

Results and Discussion

Growth. Overall (d 0 to 84), a Lys × Met/Cu/Mn interaction was detected for ADG ($P<0.02$, Table 2), thus the interactive means are presented. Increasing dietary Lys concentration improved ADG up to the requirement (quadratic, $P<0.01$). Addition of high Met/Cu/Mn to the diet reduced ADG ($P<0.01$) compared to diets with standard concentrations of Met/Cu/Mn, particularly in the diets with Lys fed below or at the requirement. Increasing dietary Lys tended (linear, $P<0.09$) to increase ADFI, while high-added Met/Cu/Mn reduced ADFI ($P<0.01$) compared to pigs fed diets with standard concentrations of Met/Cu/Mn. Increasing dietary Lys up to the requirement improved F/G (quadratic, $P<0.01$), but feeding diets containing high added Met/Cu/Mn had similar F/G ($P>0.57$) compared to pigs fed diets with standard concentrations of Met/Cu/Mn.

Carcass Data. No interaction between Lys × Met/Cu/Mn was detected for carcass traits ($P>0.49$, Table 3). There was a trend (linear, $P<0.15$) for increasing dietary Lys concentration to reduce backfat thickness, while high added Met/Cu/Mn tended ($P<0.07$) to reduce backfat thickness. Increasing dietary Lys up to the requirement increased loin eye area (quadratic, $P<0.04$), but the addition of high Met/Cu/Mn did not affect loin eye size ($P>0.61$). Increasing dietary Lys improved percentage lean (linear, $P<0.01$), while high-added Met/Cu/Mn had no affect on percentage lean ($P> 0.14$).

Leg Scoring. A Lys × Met/Cu/Mn interaction was not detected for leg scores ($P>0.21$, Table 4). Visual soundness scores were unaffected by dietary Lys level ($P>0.26$); however, the addition of high Met/Cu/Mn to the diet tended ($P<0.07$) to reduce front leg scores and locomotion ($P<0.06$). Previous research suggests that high levels of manganese may cause bones to become stiff and may decrease mobility.

Cartilage Properties. There tended to be an interaction for both cartilage weight and thickness between Lys × Met/Cu/Mn ($P<0.06$, Table 5); however, an interaction for instron measurements was not detected ($P>0.17$) and thus the main effects are presented. Both cartilage sample weight (quadratic, $P<0.08$) and length (quadratic, $P<0.06$) tended to increase with increasing dietary Lys level, while cartilage thickness was unaffected by dietary Lys level ($P>0.27$). Cartilage sample weight, thickness, and length were unaffected ($P>0.11$) by addition of high Met/Cu/Mn to the diet. Increasing dietary Lys decreased cartilage shear energy (quadratic, $P<0.01$); however, no other instron measurement was affected by Lys level ($P>0.24$). High-added Met/Cu/Mn had no effect on any cartilage instron measurement ($P>0.23$). We do not have a reason why pigs fed Lys at their requirement had decreased shear energy values compared with pigs fed below or above their require-

ment. This may be due to alterations in cartilage metabolism when amino acids are limiting or provided in excess.

Osteochondrosis Evaluation. No Lys × Met/Cu/Mn interactions were detected for OC measures (P>0.12, Table 6). All animals had gross OC at either the humerus or femur. For the external femur evaluation, increasing dietary Lys concentration tended (linear, P<0.08) to increase the number of abnormalities. There was a trend (P<0.13) for increasing dietary Lys to increase the severity score for the external femur. The addition of high Met/Cu/Mn to the diet reduced the number of abnormalities (P<0.02) and severity score (P<0.01) at the external femur compared to pigs fed diets with standard concentrations of Met/Cu/Mn. At the external humerus, increasing dietary Lys increased both the number of abnormalities (linear, P<0.01) and severity score (linear, P<0.01). The addition of high Met/Cu/Mn to the diet reduced the number of abnormalities (P<0.03) and severity score (P<0.03) for the external humerus. The increase in external abnormalities seen at both the femur and humerus with increasing dietary Lys concentration may be due to greater muscle mass providing additional stress on the joint. Faster growing pigs have been theorized to be more susceptible to mechanical stressors due to their increased weight relative to the maturity of the joint. Furthermore, the reduction in external abnormalities that were seen with the addition of high Met/Cu/Mn is similar to results with previous experiments and may be due to the positive influence of Met on cartilage metabolism and Cu/Mn in stabilizing the extracellular matrix through preventing excessive degradation. This combination of ingredients may allow articular cartilage a greater ability to repair damage caused by mechanical stressors.

At the femoral articular cartilage, increasing dietary Lys did not impact either the number of faces with lesions (P>0.35) or the severity score (P>0.36). The addition of high Met/Cu/Mn to the diet did not influence the number of faces with lesions (P>0.57) or the severity score (P>0.89) at the femoral articular cartilage compared to pigs fed diets without high Met/Cu/Mn. Increasing dietary Lys concentration had no affect (P>0.55) on the number of faces with lesions at the femoral growth plate or the severity score (P>0.52). The addition of high Met/Cu/Mn to the diet did not affect either the number of faces with lesions (P>0.14) at the femoral growth plate or the severity score (P > 0.19) compared to pigs fed diets without additional Met/Cu/Mn.

The number of faces with lesions and severity score at the humerus articular cartilage was unaffected by increasing dietary Lys concentration (P>0.16) or the addition of high Met/Cu/Mn to the diet (P>0.37).

Overall, the total faces with lesions were not impacted by increasing dietary Lys concentration (P>0.78) or additional high Met/Cu/Mn (P>0.86). The total abnormalities (external abnormalities and the number of faces with lesions) tended (linear, P<0.12) to increase with increasing dietary Lys. The addition of high Met/Cu/Mn did not affect the total number of abnormalities (P>0.16). The total severity score (external and OC evaluation) increased with increasing dietary Lys concentration (linear, P<0.01). The addition of high Met/Cu/Mn decreased the total severity score (P<0.02) compared to pigs fed diets without Met/Cu/Mn. Finally, increasing dietary Lys concentration did not affect the overall severity score (P>0.64). The addition of high Met/Cu/Mn tended (P<0.09) to reduce the overall severity score compared with pigs fed diets without high Met/Cu/Mn.

Correlation of Growth Rate and Visual Evaluation with Overall Severity Score. Because of the difference in growth rates between dietary treatments and increasing severity found in pigs fed increasing dietary Lys concentrations, we plotted ADG, weight, total leg score, or locomotion score versus the

overall severity score for each pig. Fitting a linear regression line to the data resulted in almost no correlation with ADG (R^2 0.0316, Chart 1), weight (R^2 0.0262, Chart 2), Total leg score (R^2 0.0153, Chart 3), or Locomotion score (R^2 0.0197, Chart 4). This suggests that even though increasing dietary Lys increased severity scores, this increase can not only be attributed to increasing growth rate. As well, visually evaluating structural correctness as a function of front and rear leg scores or locomotion scores also did not correlate with the overall severity score.

In summary, increasing dietary Lys concentration up to the requirement improved ADG and F/G, confirming our estimation of the requirement. Increasing dietary Lys resulted in a decrease in backfat, an increase in loin eye area, and thus pigs with greater percentage lean. The addition of high Met/Cu/Mn to the diet reduced ADG, ADFI, and backfat depth. These results were expected as high dietary Met is know to dramatically reduce feed intake and limit growth performance. The addition of high Met/Cu/Mn also tended to have adverse affects on visual front leg and mobility scores. This may have been mainly due to the high level of Mn fed in these diets as excessive Mn is known to result in stiffer bones and reductions in mobility. Increasing dietary Lys had negative effects on external abnormalities and the total severity score; however, the additional growth achieved in pigs fed increasing dietary lysine did not correlate with the overall severity score. In a previous study, we reported negative effects of high dietary arginine and glycine on OC. Arginine is the precursor of nitric oxide, one of the mediators of the inflammatory response and may have negative implications on joint health. This suggests that it is not simply growth rate that influences OC severity but rather may be the result of increased dietary protein supplying additional non-essential amino acids that may have negative effects on cartilage metabolism. The addition of Met/Cu/Mn at high levels resulted in a reduction in the number of external abnormalities and overall severity score. This is similar to our first study and is probably a result of the positive influence Met has on increased cartilage metabolism, the role of Cu in crosslinking collagen molecules, and Mn in proteoglycans within the extracellular matrix. These dietary ingredients potentially could enhance the ability of the cartilage to repair damaged tissue or prevent excessive degradation of the extracellular matrix as the loss of proteoglycan content and decreased collagen type II content is seen in cartilage with OC.

In conclusion, increasing dietary Lys concentration resulted in an increase in both external abnormalities and total severity score but could not be attributed to ADG, while the addition of high Met/Cu/Mn reduced external abnormalities at the femur and humerus and overall severity score. This study suggests that the addition of high Met/Cu/Mn to the diets of growing gilts may aid in the reduction of defects in the cartilage surface and thus provide a mechanism to limit reductions in sow herd longevity due to OC.

Table 1. Diet Composition (as-fed)

	Phase I[a]			Phase II[b]		
Item	Below	Requirement	Above	Below	Requirement	Above
Ingredient						
Corn	76.20	69.05	58.25	83.90	76.75	65.95
Soybean meal (46.5% CP)	16.05	23.25	34.15	8.75	16.00	26.85
Soy oil	3.00	3.00	3.00	3.00	3.00	3.00
Monocalcium P (21% P)	1.85	1.8	1.75	1.50	1.45	1.40
Limestone	1.03	0.98	0.9	1.03	0.98	0.90
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.15	0.15	0.15	0.13	0.13	0.13
Trace mineral premix	0.08	0.08	0.08	0.08	0.08	0.08
L-Lysine HCl	0.15	0.15	0.15	0.15	0.15	0.15
DL-Methionine	-	0.02	0.09	-	-	0.04
L-Threonine	0.02	0.04	0.07	-	0.03	0.05
Manganese sulfate	-	-	-	-	-	-
Copper sulfate	-	-	-	-	-	-
Sand[c]	1.15	1.15	1.15	1.15	1.15	1.15
Calculated analysis						
Total lysine, %	0.80	1.00	1.30	0.60	0.80	1.10
True ileal digestible amino acids						
Lysine, %	0.71	0.89	1.16	0.53	0.71	0.98
Isoleucine:lysine ratio, %	70	70	69	71	70	69
Leucine:lysine ratio, %	168	153	140	192	168	149
Methionine:lysine ratio, %	30	30	32	34	30	30
Met & Cys:lysine ratio, %	63	60	60	71	63	60
Threonine:lysine ratio, %	67	67	67	68	68	67
Tryptophan:lysine ratio, %	19	19	20	18	19	19
Valine:lysine ratio, %	68	66	64	88	83	79
ME, kcal/lb	1546	1546	1546	1553	1553	1553
CP, %	13.9	16.7	20.8	11.2	14.0	18.1
Ca, %	0.81	0.80	0.80	0.71	0.71	0.70
P, %	0.71	0.73	0.77	0.61	0.63	0.66
Available P equiv.	0.52	0.52	0.52	0.43	0.43	0.43
Lysine:calorie ratio, g/mcal	2.3	2.9	3.8	1.7	2.3	3.2

[a]Phase I fed in meal form from d 0 to 42.

[b]Phase II fed in meal form from d 42 to 84.

[c]Methionine added at 1%, manganese sulfate at 0.05%, and copper sulfate at 0.1% replaced sand to form the other dietary treatments.

Table 2. Effect of Dietary Lysine and Methionine/Copper/Manganese on Growth Performance[abc]

	TID Lysine[c]			Met/Cu/Mn[d] TID Lysine[c]				Probability, $P <$				
									Lysine			
Item	Below	Requirement	Above	Below	Requirement	Above	SED	Trt	Linear	Quadratic	Met/ Cu/Mn	Lys × Met/Cu/Mn
D 0 to 84												
Initial weight, lb	89.0	89.3	89.5	88.8	89.2	89.3	1.10	0.80	0.18	0.76	0.55	0.99
ADG, lb	1.97[f]	2.22[g]	2.19[g]	1.68[e]	2.04[f]	2.17[g]	0.060	0.01	0.01	0.01	0.01	0.02
ADFI, lb	5.67[g]	5.65[g]	5.65[g]	5.06[e]	5.19[ef]	5.50[fg]	0.169	0.01	0.09	0.64	0.01	0.12
F/G	2.89[e]	2.55[f]	2.58[f]	3.02[e]	2.54[f]	2.54[f]	0.077	0.01	0.01	0.01	0.57	0.68
Final weight, lb	263.1[f]	285.8[g]	283.0[g]	237.4[e]	269.9[f]	283.8[g]	5.57	0.01	0.01	0.01	0.01	0.06

[a]Each value is the mean of 10 replications with two pigs per pen initially 89.2 lb and an average final weight of 280 lb.
[b]Pigs were fed meal diets in two 42 d phases.
[c]Diets contained 0.71, 0.89, and 1.16 % TID lysine during Phase I and 0.53, 0.71, and 0.98 TID lysine during Phase II, respectively.
[d]Diet contained additional methionine (1%), copper (250 ppm), and manganese (220 ppm).
[e,f,g]Means with different superscripts differ by $P < 0.05$.

Table 3. Main Effect of Lysine Level and Additional Methionine/Copper/Manganese on Carcass Characteristics[a]

	TID Lysine[b]			Met/Cu/Mn[c]			Probability, $P<$				
								Lysine			
Item	Low	Requirement	High	Standard	Added	SED	Lys	Linear	Quadratic	Met/ Cu/Mn	Lys × Met/Cu/Mn
Final wt, lb[d]	261.6	286.9	291.9	286.4	273.9	4.64	0.03	0.01	0.02	0.10	0.81
HCW, lb[e]	178.4	199.6	201.3	197.8	188.4	---	---	---	---	---	---
Backfat, in	0.61	0.57	0.54	0.61	0.54	0.053	0.33	0.15	0.99	0.07	0.80
Loin eye area, in^2	7.48	9.59	10.13	8.98	9.16	0.494	0.01	0.01	0.04	0.61	0.49
% lean	56	59	61	58	59	0.11	0.01	0.01	0.14	0.14	0.92

[a]Each mean represents 10 replications with one pig from each pen initially 89.2 lb and an average final wt of 280 lb.
[b]Diets contained 0.71, 0.89, and 1.16 % TID lysine during Phase I and 0.53, 0.71, and 0.98 TID lysine during Phase II, respectively.
[c]Diet contained 1% added methionine, copper (250 ppm), and manganese (220 ppm).
[d]Average final weight of the heaviest pig from each pen used to determine lesions and carcass data.
[e]Hot carcass weight used as the covariate in analysis.

Table 4. Main Effect of Lysine Level and Additional Methionine/Copper/Manganese on Visual Soundness Scores[ab]

	TID Lysine[c]			Met/Cu/Mn[d]			Probability, *P* <				
							Lysine				
Item	Below	Requirement	Above	Standard	Added	SED	Lys	Linear	Quadratic	Met/ Cu/Mn	Lys × Met/Cu/Mn
Front leg	2.7	2.4	2.5	2.7	2.4	0.13	0.49	0.45	0.36	0.07	0.37
Rear leg	2.8	2.4	2.6	2.6	2.6	0.12	0.28	0.39	0.18	0.69	0.28
Total[e]	5.4	4.8	5.1	5.3	4.9	0.21	0.26	0.34	0.18	0.17	0.21
Locomotion[f]	2.9	2.6	2.8	3.0	2.6	0.14	0.51	0.68	0.28	0.06	0.34

[a]Each mean represents 20 replications for Lysine treatments and 30 for Met/Cu/Mn with one pig per pen initially 89.2 lb and an average final wt of 280 lb.
[b]Front, Rear, and Locomotion scores are the mean of two evaluators for each animal.
[c]Diets contained 0.71, 0.89, and 1.16 % TID lysine during Phase I and 0.53, 0.71, and 0.98 TID lysine during Phase II, respectively.
[d]Diet contained 1% added methionine, copper (250 ppm), and manganese (220 ppm).
[e]Sum of front and rear scores according to NSIF system (7-10, excellent, 4-6, average, 1-3, poor)
[f]An independent measure of mobility scored from 1-5 (1=poor and 5=excellent) according to NSIF system.

Table 5. Main Effects of Lysine Level and Additional Methionine/Copper/Manganese on Cartilage Characteristics[a]

	TID Lysine[b]			Met/Cu/Mn[c]			Probability, $P <$				
							Lysine				
	Below	Requirement	Above	Standard	Added	SED	Lys	Linear	Quadratic	Met/ Cu/Mn	Lys × Met/Cu/Mn
Cartilage measurements											
weight, g	1.13	1.21	1.04	1.07	1.18	0.078	0.11	0.26	0.08	0.11	0.05
thickness, mm	3.47	3.28	3.18	3.34	3.28	0.252	0.52	0.27	0.83	0.74	0.06
length, mm	32.68	33.75	32.35	32.83	33.03	0.718	0.14	0.65	0.06	0.75	0.46
Instron measurements[d]											
Compression energy, newtons/g[e]	13.2	9.5	19.0	12.7	15.1	6.74	0.37	0.40	0.27	0.67	0.35
Shear energy, newtons/g[f]	558.1	432.2	591.1	538.1	516.2	59.06	0.03	0.58	0.01	0.66	0.34
Total Energy, newtons/g[g]	572.9	611.4	716.2	696.2	570.6	297.11	0.50	0.30	0.75	0.23	0.61
Ratio CF/SF[h]	0.122	0.178	0.183	0.151	0.172	0.076	0.68	0.43	0.71	0.74	0.66
RatioCE/SE[h]	0.025	0.025	0.033	0.024	0.031	0.012	0.73	0.49	0.72	0.52	0.51

[a]Each mean represents 20 replications for Lysine treatments and 30 for Met/Cu/Mn with one pig per pen initially 89.2 lb and an average final wt of 280 lb.
[b]Diets contained 0.71, 0.89, and 1.16 % TID lysine during Phase I and 0.53, 0.71, and 0.98 TID lysine during Phase II, respectively.
[c]Diet contained methionine (1%), copper (250 ppm), and manganese (220 ppm).
[d]Instron measurements were conducted on model 4201 Instron.
[e]Amount of force required in newtons per gram of cartilage to compress the cartilage half its thickness.
[f]Amount of force required to shear the cartilage into two pieces in newtons per gram of cartilage.
[g]Total amount of energy required to shear cartilage into two pieces in newtons per gram of cartilage.
[h]Ratio of compression force or compression energy to shear force or shear energy, respectively.

Table 6. Main Effect of Lysine Level and Additional Methionine/Copper/Manganese on Osteochondrosis Evaluation[ab]

	TID Lysine[c]			Met/Cu/Mn[d]			Probability, $P <$				
							Lysine				
	Below	Requirement	Above	Standard	Added	SED	Lys	Linear	Quadratic	Met/ Cu/Mn	Lys × Met/Cu/Mn
External femur											
No. abnormalities	0.7	1.4	1.3	1.5	0.8	0.33	0.11	0.08	0.23	0.02	0.73
Severity score	0.8	1.4	1.3	1.5	0.8	0.32	0.14	0.13	0.21	0.01	0.26
External humerus											
No. abnormalities	0.8	1.4	1.9	1.6	1.1	0.30	0.01	0.01	0.99	0.03	0.52
Severity score	0.7	1.3	1.7	1.4	1.0	0.26	0.01	0.01	0.74	0.03	0.62
Femur articular cartilage											
No. of faces	4.4	4.4	3.6	4.3	3.9	0.84	0.56	0.35	0.59	0.57	0.78
Severity score	1.4	1.4	1.2	1.3	1.3	0.28	0.57	0.36	0.60	0.89	0.86
Femur growth plate											
No. of faces	0.5	0.4	0.6	0.3	0.7	0.32	0.83	0.88	0.55	0.14	0.13
Severity score	0.2	0.3	0.3	0.2	0.3	0.16	0.81	0.52	0.96	0.19	0.12
Humerus articular cartilage											
No. of faces	0.9	1.6	1.9	1.5	1.4	0.70	0.36	0.16	0.81	0.86	0.61
Severity score	0.5	0.6	0.8	0.7	0.5	0.28	0.55	0.28	0.99	0.37	0.82
Overall											
Total faces	5.8	6.2	6.1	6.1	5.9	1.13	0.94	0.83	0.78	0.86	0.45
Total abnormalities[g]	7.3	8.9	9.3	9.2	7.8	1.23	0.25	0.12	0.56	0.16	0.66
Total severity[h]	3.6	4.8	5.2	5.2	3.9	0.59	0.03	0.01	0.44	0.01	0.32
Overall severity[i]	15.2	16.5	16.9	18.7	13.7	3.56	0.89	0.64	0.88	0.09	0.43

[a]Each mean represents 20 replications for Lys treatments and 30 replications for the Met/Cu/Mn treatment with pigs initially 89.2 lb and an average final wt of 280 lb.

[b]Joints were scored on a scale of 0-4 (0=normal,1=mild, 2=moderate, 3= severe, and 4=OC dissecans) for each location.

[c]Diets contained 0.71, 0.89, and 1.16 % TID lysine during Phase I and 0.53, 0.71, and 0.98 TID lysine during Phase II, respectively.

[d]Diet contained additional methionine (1%), copper (250 ppm), and manganese (220 ppm).

[e]Analysis of the number of animals with osteochondrosis determined by Cochran-Mantzel-Haenzel statistic of Proc Freq.

[f]Combined severity of osteochondrosis at the femoral articular cartilage, femoral growth plate, and humerus articular cartilage.

[g]Total number of external abnormalities and faces with lesions.

[h]Total severity of external severity scores and OC severity scores at all locations.

[i]Calculated as abnormalities multiplied by severity for each location and then summed for all locations.

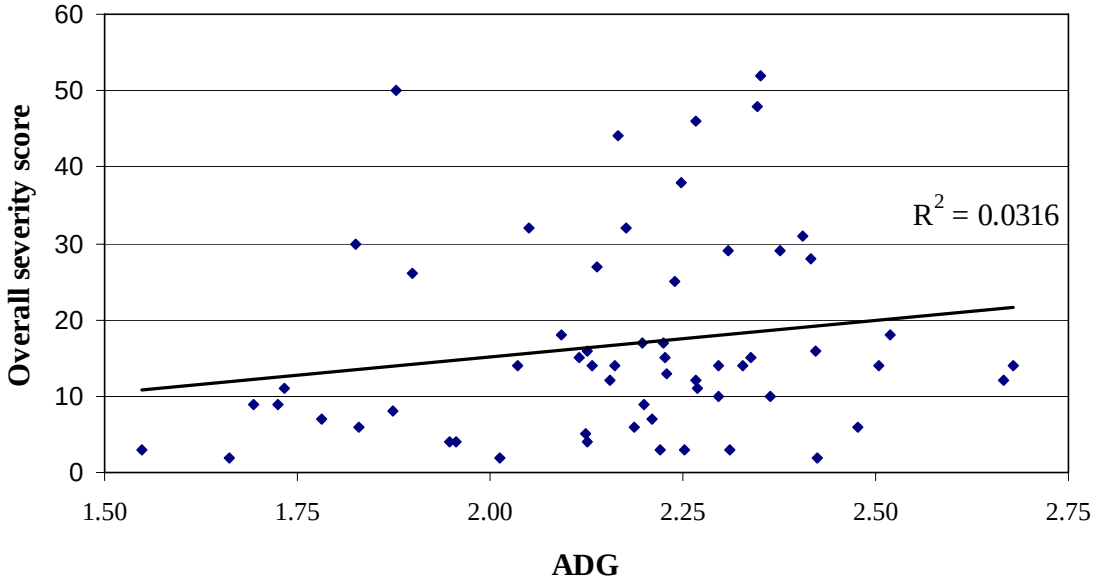

Chart 1. Average Daily Gain (ADG) versus Overall Severity Score of Osteochondrosis Using 60 Gilts.

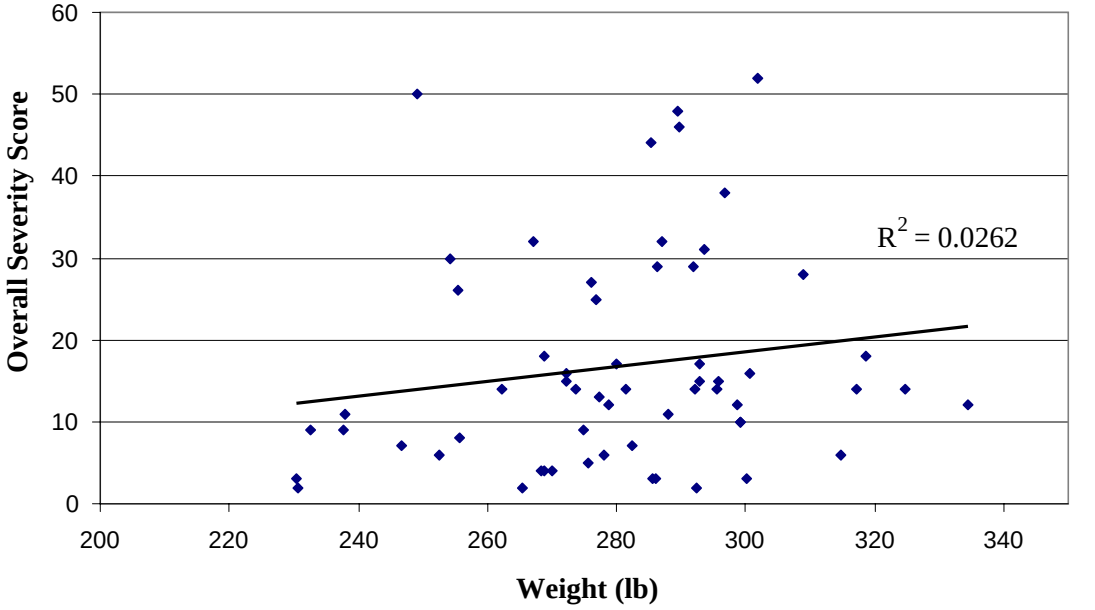

Chart 2. Weight versus Overall Severity Score of Osteochondrosis Using 60 Gilts.

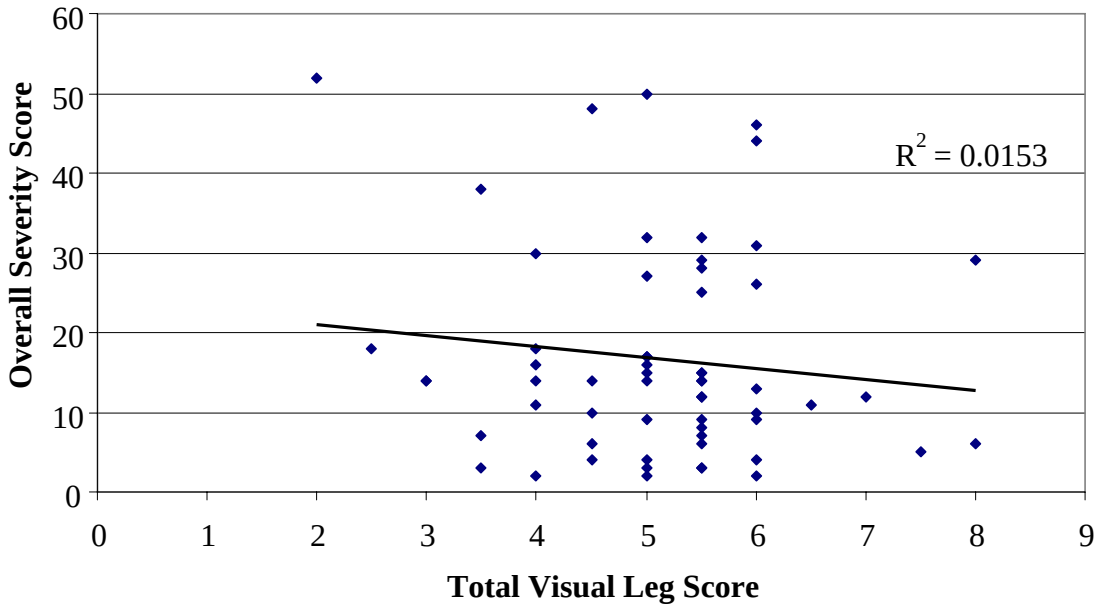

Chart 3. Total Visual Leg Score versus Overall Severity Score of Osteochondrosis. Total leg score is the sum of the front and rear leg scores, which were scored from 1-5 where 1=poor and 5=excellent from two evaluators and then summed to form the total score (2-10) according to the NSIF system on 60 gilts.

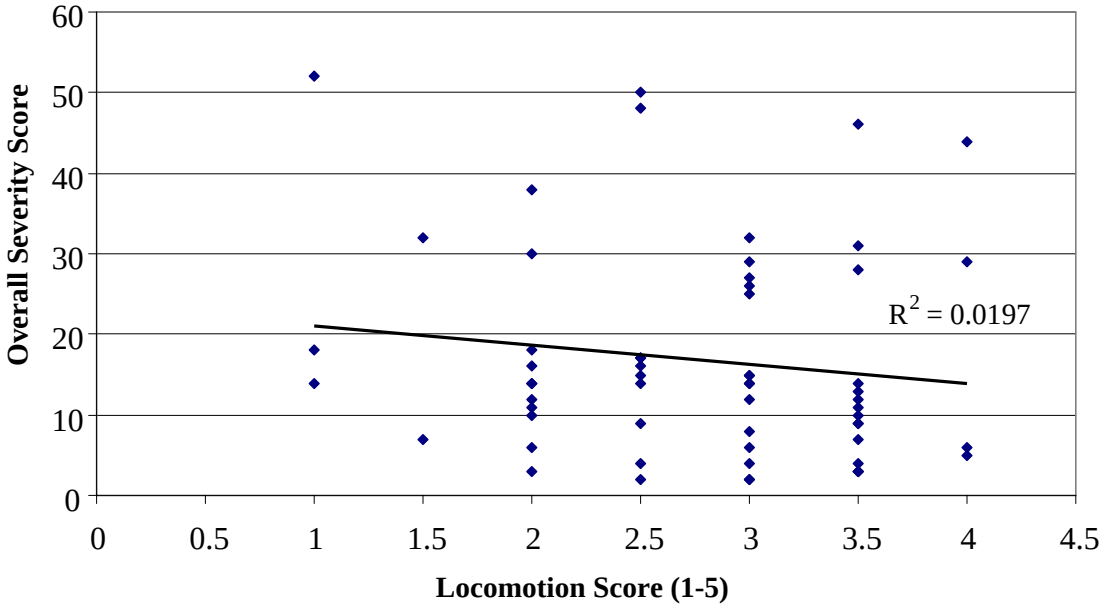

Chart 4. Locomotion Score versus Overall Severity Score of Osteochondrosis. Locomotion (measure of mobility) was scored from 1-5 where 1=poor and 5=excellent according to the NSIF system and is the average of two evaluators using 60 gilts.

THE EFFECTS OF TWO TRUE-ILEAL-DIGESTIBLE LYSINE CONCENTRATIONS, OPTIPAK®, RACTOPAMINE HCL (PAYLEAN®), AND THEIR COMBINATIONS, ON THE GROWTH PERFORMANCE AND CARCASS CHARACTERISTICS OF FINISHING PIGS REARED IN COMMERCIAL FACILITY[1]

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Summary

A total of 1,207 pigs (PIC, 337 × 1050) were used in a 28-d experiment in a commercial research barn to evaluate the effects of two true ileal digestible (TID) lysine concentrations, Optipak®, ractopamine HCl, and their combinations, on the growth performance and carcass characteristics of finishing pigs. There were 6 replicates per treatment (with the exception of one treatment that had 5), and 19 to 26 pigs per pen. Pigs were weighed at approximately 220 lb and allotted to six, corn-soybean meal-based dietary treatments. Four diets were formulated to 0.80% TID lysine: a control diet, the control diet with 5 lb/ton of Optipak®, the control diet with 4.5 g/ton of ractopamine HCl, or the control diet with both Optipak® and ractopamine HCl. The two remaining diets were formulated to 0.94% TID lysine and contained 4.5 g/ton of ractopamine HCl, with or without 5 lb/ton of Optipak®. The treatment structure provided for two 2 × 2 factorial arrangements of treatments. The first factorial utilized the four 0.80% TID lysine diets to evaluate the effects of Optipak® and ractopamine HCl. The second factorial utilized the four diets containing ractopamine HCl to evaluate the effects of TID lysine and Optipak®. Pigs fed diets containing ractopamine HCl had improved ($P<0.04$) ADG, F/G, and final weight. In the diets containing ractopamine HCl, ADFI tended ($P<0.07$) to be lower for pigs fed 0.94% TID lysine. There were no other differences in growth performance among the treatments. For carcass characteristics, plant live weight, hot carcass weight, and dressing percentage were improved ($P<0.04$) for pigs fed ractopamine HCl. Additionally, loin depth increased ($P<0.03$) when Optipak® was included in the diet. This experiment provides further evidence that ractopamine HCl improves late-finishing growth performance, hot carcass weight, and dressing percentage. Although Optipak® did not improve growth performance, it increased loin depth. The different responses to ractopamine HCl and Optipak® suggest that the incentives for justifying their use need to be evaluated independently.

(Key words: amino acids, feed ingredient, lysine, ractopamine HCl.)

Introduction

In modern swine production, the "quest" for technologies to maximize growth rate and

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efficiency of the terminal market hog is constant. Ractopamine HCl (marketed as Paylean®, Elanco Animal Health, Indianapolis, IN) is commonly fed to late-finishing pigs to improve growth rate and feed efficiency. A vast amount of research and field data support that appropriate use of this compound in feeding programs is economically justified. The value of the improvements in growth rates and feed conversion associated with its use usually outweigh the costs.

Recently, Hubbard Feeds has been marketing a nutritional supplement (Optipak®) to improve the growth rate and carcass characteristics of finishing pigs. Reports on the responses of finishing pigs in the field have stimulated interest in feeding Optipak® among producers. The suggested benefits are achieved at a considerably lower cost than ractopamine HCl partly because Optipak® is usually included in a diet containing a lower lysine concentration than that considered necessary in a diet containing Paylean®. Because a diet containing Optipak® is less expensive than a Paylean® diet, some producers have elected to use Optipak® in their feeding program instead of Paylean®. However, there is little scientific data to qualify the magnitude or value of the responses to the proprietary blend of nutrients in Optipak®. Therefore, the objective of this experiment was to evaluate Optipak®, Paylean® and their combination at two concentrations of TID lysine.

Procedures

Procedures used in the experiment were approved by the Kansas State University Animal Care and Use Committee. The experiment was conducted in a commercial research finishing facility in southwestern Minnesota. The facility was double curtain sided with pit fans to enable minimum ventilation, and completely slatted flooring over a deep pit for manure storage. Individual pens were 18 × 10 feet. Each pen contained one self-feeder and one cup waterer.

A total of 1,207 pigs were weighed and allotted to one of six dietary treatments. There were 6 replicate pens (with the exception of one treatment that had 5) per treatment. Each pen contained 19 to 26 pigs, depending on the block. Four diets were formulated to 0.80% TID lysine: a control diet, the control diet with 5 lb/ton of Optipak®, the control diet with 4.5 g/ton of ractopamine HCl, or the control diet with both Optipak® and ractopamine HCl. The two remaining diets were formulated to 0.94% TID lysine and contained 4.5 g/ton of ractopamine HCl, with or without 5 lb/ton of Optipak®. Pigs were weighed and feeder measurements taken on d 0, 14, and 28 to determine ADG, ADFI, and F/G. On d 28, pigs were individually tattooed by pen number, and transported to Swift and Co. (Worthington, MN) for carcass data on the following day.

Data were analyzed as a randomized complete block design using the PROC MIXED procedure of SAS with pen as the experimental unit. Least squares means were used to determine differences among treatments. The treatment structure provided for two, 2 × 2 factorial arrangements of treatments. The first factorial utilized the four 0.80% TID lysine diets to evaluate the effects of Optipak® and ractopamine HCl. The second factorial utilized the four diets containing ractopamine HCl to evaluate the effects of TID lysine and Optipak®. Additionally, the effect of Optipak was evaluated using a contrast between those treatments that contained Optipak in the feed and those that did not.

Results

Overall (d 0 to 28), pigs fed diets containing ractopamine HCl had improved ($P<0.04$) ADG, F/G, and final weight. In the diets containing ractopamine HCl, ADFI tended ($P<0.07$) to be lower for pigs fed 0.94% TID lysine than pigs fed the diets containing 0.8% TID lysine. There were no other differences in growth performance among the treatments.

For carcass characteristics, plant live weight, hot carcass weight, and dressing percentage were improved ($P<0.04$) for pigs fed ractopamine HCl. Additionally, loin depth increased ($P<0.03$) when Optipak® was included in the diet.

In conclusion, other than the trend for lower feed usage, there were no advantages to increasing the TID lysine concentration from 0.80% to 0.94% in diets containing ractopamine HCl. Previous research in this facility has demonstrated a response to higher lysine levels when ractopamine HCl was fed for 21 d prior to market. The lack of response to lysine level in this experiment may have been due to the longer feeding duration or higher feed intake than achieved in the previous experiments. In agreement with earlier research, this experiment provides further evidence that ractopamine HCl improves late-finishing growth performance and carcass characteristics. Growth performance was not improved by adding Optipak® to the diet; however, Optipak® increased loin depth.

Therefore, Optipak® should not be utilized as a substitute for Paylean® in late-finishing diets. The use of Optipak® must be justified independently, and may vary depending upon the incentives offered by the packer.

Table 1. Composition of Experimental Diets[a]

TID lysine, %:	0.80				0.94	
Optipak®:	-	+	-	+	-	+
Ingredient, % Paylean®:	-	-	+	+	+	+
Corn	75.50	75.25	75.47	75.22	69.80	69.55
Soybean meal (46.5% CP)	19.50	19.50	19.50	19.50	25.20	25.20
Choice white grease	3.00	3.00	3.00	3.00	3.00	3.00
Monocalcium P (21% P)	0.54	0.54	0.54	0.54	0.53	0.53
Limestone	0.89	0.89	0.89	0.89	0.85	0.85
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
L-threonine	---	---	---	---	0.02	0.02
Vitamin premix	0.03	0.03	0.03	0.03	0.03	0.03
Trace mineral premix	0.04	0.04	0.04	0.04	0.04	0.04
Paylean®, 9 g/lb[b]	---	---	0.025	0.025	0.025	0.025
Optipak®[c]	---	0.25	---	0.25	---	0.25
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis						
Total lysine, %	0.90	0.90	0.90	0.90	1.06	1.06
True digestible amino acids						
Lysine, %	0.80	0.80	0.80	0.80	0.94	0.94
Isoleucine:lysine ratio, %	70	70	70	70	69	69
Leucine:lysine ratio, %	165	165	165	165	154	154
Methionine:lysine ratio, %	29	29	29	29	28	28
Met & Cys:lysine ratio, %	60	60	60	60	57	57
Threonine:lysine ratio, %	62	62	62	62	62	62
Tryptophan:lysine ratio, %	19	19	19	19	19	19
Valine:lysine ratio, %	81	81	81	81	78	78
Protein, %	15.60	15.60	15.60	15.60	17.70	17.70
ME, kcal/lb	1,581	1,577	1,581	1,577	1,581	1,577
TID lysine:ME ratio, g/Mcal	2.30	2.30	2.30	2.30	2.71	2.72
Ca, %	0.53	0.53	0.53	0.53	0.53	0.53
P, %	0.46	0.46	0.46	0.46	0.48	0.48
Available P, %	0.18	0.18	0.18	0.18	0.18	0.18

[a]Experimental diets fed for 28 d before slaughter.
[b]Paylean® fed at a rate of 4.5 g/ton of complete feed.
[c]Optipak® fed at recommended rate of 5 lb/ton of complete feed.

Table 2. An Evaluation of the Growth Performance and Carcass Characteristics of Finishing Pigs fed Two TID Lysine Levels, Optipak®, 4.5 g/Ton of Paylean®, or the Combination for 28 Days Prior to Slaughter – Interactive Means[a,b]

								P <						
	TID Lysine, %:	0.80	0.80	0.80	0.80	0.94	0.94			0.80% TID lys diets			Paylean diets	
	Optipak:	-	+	-	+	-	+	SE	Overall			Optipak ×			Lysine ×
Item	Paylean:	-	-	+	+	+	+	Mean	Optipak	Optipak	Paylean	Paylean	Lysine	Optipak	Optipak
D 0 to 28															
D 0 wt, lb		220	222	222	219	221	218	2.31	-	-	-	-	-	-	-
ADG, lb		1.93	2.00	2.13	2.17	2.12	2.10	0.09	-	-	0.03	-	-	-	-
ADFI, lb		5.72	5.99	6.02	6.00	5.76	5.78	0.14	-	-	-	-	0.07	-	-
F/G		3.00	3.02	2.84	2.78	2.72	2.78	0.10	-	-	0.04	-	-	-	-
Final wt, lb		275	276	280	282	280	280	2.60	-	-	0.03	-	-	-	-
Carcass characteristics															
Plant live wt, lb		273	274	277	278	278	276	2.35	-	-	0.04	-	-	-	-
Hot carcass wt, lb		205	206	211	211	211	210	2.05	-	-	0.01	-	-	-	-
Dressing percentage, %		75.3	75.1	76.1	76.0	76.1	75.8	0.003	-	-	0.01	-	-	-	-
Backfat – 10th rib, in		0.67	0.70	0.71	0.69	0.68	0.70	0.01	-	-	-	0.09	-	-	-
Loin depth, in		2.45	2.46	2.42	2.53	2.48	2.54	0.04	0.03	0.07	-	-	-	0.02	-
Percent lean		55.93	55.54	54.87	55.85	55.56	55.72	0.37	-	-	-	0.05	-	-	-
FFLI		50.48	50.14	50.22	50.46	50.60	50.29	0.16	-	-	-	0.05	-	-	0.07

[a]A total of 1,207 pigs were used in a 28 d experiment to compare the growth performance and carcass characteristics of pigs fed two levels of TID Lys, Optipak®, 4.5 g/ton Paylean, or the combination prior to slaughter. Six pens of 19 to 26 pigs (5 pens for the 0.94% TID Lys + Optipak® + Paylean treatment) were assigned to the treatments in a completely randomized design. This provided 148, 140, 144, 146, 149 and 118 pigs per treatment for the 0.80% TID Lys, 0.80% TID Lys + Optipak®, 0.80% TID Lys + Paylean, 0.80% TID Lys + Paylean + Optipak®, 0.94% TID Lys + Paylean, and 0.94% TID Lys + Paylean + Optipak®; respectively.
[b]Data were analyzed using the initial average weight as a covariate.

Table 3. An Evaluation of the Growth Performance and Carcass Characteristics of Finishing Pigs fed Two TID Lysine Levels, Optipak®, 4.5 g/Ton of Paylean®, or the Combination for 28 Days Prior to Slaughter – Main Effects[a,b]

	0.80% TID Lysine Treatments				Paylean Treatments				Optipak Treatments			P <						
													0.80% TID Lysine Diets			Paylean Diets		
	Optipak		Paylean, g/ton		TID Lysine, %		Optipak											
Item	-	+	0	4.5	0.80	0.94	-	+	-	+	SE Mean	All Optipak	Optipak	Pay-lean	Optipak × Pay-lean	Lys	Opti-pak	Lys × Optipak
D 0 to 28																		
D 0 wt, lb	221	221	221	221	221	220	222	219	221	220	2.31	-	-	-	-	-	-	-
ADG, lb	2.03	2.09	1.97	2.15	2.15	2.11	2.13	2.14	2.06	2.09	0.09	-	-	0.03	-	-	-	-
ADFI, lb	5.87	6.00	5.86	6.01	6.01	5.77	5.89	5.89	5.83	5.92	0.14	-	-	-	-	0.07	-	-
F/G	2.92	2.90	3.01	2.81	2.81	2.75	2.78	2.78	2.85	2.86	0.10	-	-	0.04	-	-	-	-
Final wt lb	278	279	276	281	281	280	280	281	278	279	2.60	-	-	0.03	-	-	-	-
Carcass characteristics																		
Plant live wt, lb	275	276	274	278	278	277	278	277	276	276	2.35	-	-	0.04	-	-	-	-
Hot carcass wt, lb	208	209	206	211	211	211	211	211	209	209	2.05	-	-	0.01	-	-	-	-
Dressing percent, %	75.7	75.6	75.2	76.1	76.1	76.0	76.1	75.9	75.8	75.6	0.003	-	-	0.01	-	-	-	-
Backfat – 10th rib, in	0.69	0.70	0.69	0.70	0.70	0.69	0.70	0.70	0.69	0.70	0.01	-	-	-	0.09	-	-	-
Loin depth, in	2.44	2.50	2.46	2.48	2.48	2.51	2.45	2.54	2.45	2.51	0.04	0.03	0.07	-	-	-	0.02	-
Percent lean	55.4	55.7	55.7	55.4	55.4	55.6	55.2	55.8	55.5	55.7	0.37	-	-	-	0.05	-	-	-
FFLI	50.4	50.3	50.3	50.3	50.3	50.4	50.4	50.4	50.4	50.3	0.16	-	-	-	0.05	-	-	0.07

[a]A total of 1,207 pigs were used in a 28 d experiment to compare the growth performance and carcass characteristics of pigs fed two levels of TID Lys, Optipak®, 4.5 g/ton Paylean, or the combination prior to slaughter. Six pens of 19 to 26 pigs (5 pens for the 0.94% TID Lys + Optipak® + Paylean treatment) were assigned to the treatments in a completely randomized design. This provided 148, 140, 144, 146, 149 and 118 pigs per treatment for the 0.80% TID Lys, 0.80% TID Lys + Optipak®, 0.80% TID Lys + Paylean, 0.80% TID Lys + Paylean + Optipak®, 0.94% TID Lys + Paylean, and 0.94% TID Lys + Paylean + Optipak®; respectively.
[b]Data were analyzed using the initial average weight as a covariate.

EFFECTS OF γ-BUTYROBETAINE AND L-CARNITINE ON CARNITINE CONCENTRATIONS IN VARIOUS MUSCLE TISSUES OF FINISHING PIGS

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

Summary

The primary method of L-carnitine production, similar to the biological process that occurs in the liver and kidneys, is from microbial fermentation of γ-Butyrobetaine. Therefore, the objective of this study was to see if supplementing the diet with γ-Butyrobetaine would increase organ and muscle tissue carnitine concentrations. One-hundred-twenty-five barrows were fed diets containing either L-carnitine (100 ppm), γ-Butyrobetaine (100 ppm) or a combination of L-carnitine (50 ppm) and γ-Butyrobetaine (50 ppm). The addition of L-carnitine, γ-Butyrobetaine and the combination of L-carnitine and γ-Butyrobetaine increased (P<0.01) free carnitine concentration in the longissimus, diaphragm, and heart. L-carnitine and the combination of L-carnitine and γ-Butyrobetaine increased (P<0.01) free carnitine concentration in the kidney. Therefore, these results suggest that γ-Butyrobetaine and/or L-carnitine can be used to increase carnitine concentrations of organ and muscle tissues.

(Key words: vitamins, L-carnitine, γ-Butyrobetaine.)

Introduction

It is well known that Carnitine's role in intermediary metabolism is to transport fatty acyl groups across the mitochondrial membrane. More recent studies have indicated L-carnitine improves sow production, increases body leanness in market hogs, and improves feed efficiency in nursery pigs. The primary method of L-carnitine production, similar to the biological process that occurs in the liver and kidneys, is from microbial fermentation of γ-Butyrobetaine. This process leaves a small amount of residual γ-Butyrobetaine with the L-carnitine. The remaining γ-Butyrobetaine must be removed and discarded. Because γ-Butyrobetaine is a precursor for L-carnitine production in the body, we hypothesized the remaining γ-Butyrobetaine from the production of synthetic L-carnitine may be fed to pigs to increase the L-carnitine levels in muscle tissues. Therefore, the objective of this study was to evaluate the effects of γ-Butyrobetaine and L-carnitine on free carnitine concentration in various muscle tissues.

Procedures

A total of 125 barrows (PIC 1050) with an initial body weight of 165 lb were used. Pigs were blocked by weight and allotted to one of four dietary (Table 1) treatments 34 d before slaughter. Diets were corn-soybean meal-based and were formulated to contain 0.76% total lysine. Vitamin and trace mineral levels were identical to KSU recommendations, and all other nutrients met or exceeded the re-

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quirements estimates provided by NRC (1998). The treatments consisted of a control diet, or the control diet plus 100 ppm of added L-carnitine, 100 ppm of added γ-Butyrobetaine, or control plus 50 ppm of added L-carnitine and 50 ppm of added γ-Butyrobetaine. There were eight pigs per pen and four pens per treatment. Pigs were housed in a modified-open front building with 50% solid concrete and 50% concrete slat flooring. Each 6 × 16-ft pen had a one-hole self-feeder and a nipple waterer to allow *ad libitum* access to feed and water.

Table 1. Basal Diet Composition [a]

Item	%
Corn	83.63
Soybean meal (46.5% CP)	14.00
Monocalcium P (21% P)	0.80
Limestone	0.85
Salt	0.35
Vitamin premix	0.10
Trace mineral premix	0.10
L-lysine HCl	0.15
Corn starch[b]	0.02
Total	100.00

[a] Diets were formulated to 0.76% lysine.
[b] L-carnitine (100 ppm), γ-Butyrobetaine (100 ppm), or L-carnitine (50 ppm) and γ-Butyrobetaine (50 ppm) replaced corn starch in experimental diets.

At the end of the trial, ten pigs per treatment were selected, individually tattooed and slaughtered at the Kansas State University Meats Laboratory. Pigs for slaughter were selected to have similar growth and market weights across blocks. At this time, heart and kidney samples were collected and placed in liquid nitrogen and stored at -80° C until analysis. At 24 hours postmortem, diaphragm and longissimus tissues were collected and placed in liquid nitrogen and stored at -80° C until analysis. Samples were taken from the interior portion of each muscle to ensure uniform samples from the same anatomical region of the tissue. Samples were then packed in dry ice and sent to Metabolic Labs, Madison, WI for analysis of carnitine concentration.

Data were analyzed in a randomized complete-block design using the MIXED procedure of SAS with pig as the experimental unit. Mean separation was used to test for differences between treatments.

Results and Discussion

The addition of L-carnitine, γ-Butyrobetaine, and the combination of L-carnitine and γ-Butyrobetaine to the control diet increased ($P<0.01$) the concentration of free carnitine in the longissimus, diaphragm, and heart (Table 2) of test pigs when compared with control pigs. The addition of L-carnitine and the combination of L-carnitine and γ-Butyrobetaine increased ($P<0.01$) the concentration of free carnitine in the kidney. Although not significant, the addition of γ-Butyrobetaine numerically increased ($P<0.07$) free carnitine in the kidney.

The results of this experiment indicate that L-carnitine and γ-Butyrobetaine may be used to increase free carnitine in muscle tissue. Also, there was no difference in the free carnitine concentration if pigs were fed L-carnitine, γ-Butyrobetaine, or the combination of L-carnitine and γ-Butyrobetaine. Therefore γ-Butyrobetaine could be used with or in place of L-carnitine to increase free carnitine concentrations in muscle. However, the benefits of additional free carnitine concentrations in muscle must be determined in subsequent experiments.

Table 2. Effects of γ-Butyrobetaine and L-carnitine on Free Carnitine Concentration in Organ and Muscle Tissues [a]

	Treatment				
Item (ppm)	Control	L-carnitine [b]	γ-Butyrobetaine [b]	Combination [b]	SED
Longissimus	111.7[c]	162.8[d]	158.7[d]	156.7[d]	6.13
Diaphragm	150.5[c]	200.2[d]	212.2[d]	210.7[d]	7.51
Heart	66.1[c]	101.5[d]	89.2[d]	102.7[d]	5.24
Kidney	12.3[c]	17.0[d]	16.0[cd]	16.3[d]	1.42

[a]Total of 40 pigs, initial weight 165 lb, 10 pigs/treatment.
[b]Diet contained 100 ppm of L-carnitine or γ-Butyrobetaine, or 50 ppm of L-carnitine and γ-Butyrobetaine.
[c, d]Means within rows different superscripts differ ($P<0.05$).

EFFECT OF RESTRICTED FEED INTAKE ON FINISHING PIGS WEIGHING BETWEEN 150 AND 250 lb FED TWICE OR SIX TIMES DAILY

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Summary

Two 42-d trials and two 28-d trials were conducted to evaluate the effects of restricted feed intake and feeding frequency (2 or 6 times daily) on the performance of pigs weighing between 150 to 250 lb (initially 148 lb in Exp. 1; 155 lb in Exp. 2; 156 lb in Exp. 3; and 156 lb in Exp. 4). In all experiments, pigs were housed in 6 × 10 ft pens with half-solid concrete and half-slatted flooring and with one nipple waterer. Pigs were fed a corn-soybean meal-based diet formulated to 1.15% TID lysine and 1,491 kcal of ME/lb.

In Exp. 1 to 3, energy and lysine were supplied to pigs to target an average growth rate of 1.75 lb/d based on NRC (1998) values. In Exp. 4, the diet was supplied to pigs to target growth rates of 1.75 lb/d (low feed intake) or 2.1 lb/d (high feed intake) based on NRC (1998) values to determine if the amount of energy above maintenance and feeding frequency has an effect on performance. Pigs were fed by dropping similar daily amounts of feed, either 2 (0700 and 1400) or 6 times (3 meals within 2 h at AM and PM feedings) per day, by an Accu-Drop Feed Dispenser® on the solid concrete flooring.

In Exp. 1 and 2, increasing the feeding frequency of pigs fed a restricted diet from 2 to 6 times per day improved ($P<0.02$) ADG and F/G. Increasing the feeding frequency increased ($P<0.05$) the duration of time spent feeding and standing, and reduced lying time. In Exp. 3, a third treatment was included in addition to those used in Exp. 1 and 2 to determine whether the improvements in performance were due to decreased feed wastage. This treatment was designed to minimize feed wastage by dropping feed closer to the floor in pigs fed 2 times per day. Like Exp. 1 and 2, pigs fed 6 times per day had improved ($P<0.05$) ADG and F/G compared to either treatment fed 2 times per day. There was no difference ($P>0.05$) in performance between pigs fed 2 times per day when feed was dropped from the feed drop or by the modified method. In Exp. 4, increasing the feeding frequency from 2 to 6 feeding periods improved ($P<0.01$) ADG and F/G for pigs fed a low level of feed intake and tended to increase ($P<0.06$) ADG and improve ($P<0.05$) F/G for pigs fed a high level of feed intake. In conclusion, these studies indicate that increasing the frequency of feeding from 2 to 6 times a day improves pig performance compared with feeding 2 times per day.

(Key words: feed management, restricted intake.)

Introduction

In last year's Swine Industry Day Report of Progress, we tested whether increasing the feeding frequency would improve the welfare

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and/or reduce the variation of weight gain in group-housed sows. Results from this trial showed an increase in ADG for gilts fed six times versus two times a day during the first 42 d of gestation; however, this response was not found in sows. Because of the difference seen in performance between feeding frequencies we wanted to further evaluate the response. Therefore, the objective of this study was to determine the effects of restricting feed intake of pigs fed either 2 or 6 times per day in a group housed environment.

Experimental Procedures

All experiments were conducted at the Kansas State University Swine Research and Teaching Center. Each pen was 6 × 10 ft and contained half solid and half slatted flooring with a deep pit and one curtain side (Figure 1). Each pen was equipped with solid side partitioning gates over the solid flooring between pens to prevent feed transfer. In each pen there was one nipple waterer to allow *ad libitum* access to water. The experimental diet was a corn-soybean meal diet formulated to 1.15% true ileal digestible lysine and 1,490 ME kcal/lb (Table 1). If a pig was removed from the study for any reason, the pig weight and pen feed consumption to date was recorded and feed drops were adjusted to accommodate changes in the feeding calculation. Feed was measured and delivered using an Accu-Drop Feed Dispenser® (Automated Production Systems, Assumption, IL) which was located approximately 6 ft from the solid concrete floor where the feed was consumed.

Experiments 1 and 2. A total of 320 pigs (Exp. 1, initial wt = 148 lb, n = 160; Exp. 2 initial wt = 155 lb, n = 160) were used in a 42-d growth assay to determine the effects of feeding a restricted feed level either two or six times per day on growth performance. Pigs were separated by sex and blocked by body weight to 16 pens of 10 pigs each. There were 4 pens of barrows and 4 pens of gilts per treatment for a total of 8 replications. Pigs were provided their daily feed allotment in two or six meals. In Exp. 1, Pigs receiving two meals were fed at 0700 and 1530 hr. Pigs fed six times per day were fed at 0700, 0730, 0800, 1530, 1600, and 1630 hr. In Exp. 2, Pigs receiving two meals were fed at 0700 and 1500 hr. Pigs fed six times per day were fed

Table 1. Composition of Experimental Diet[a]

Item	Diet, %
Corn	63.14
Soybean meal (46.5% CP)	33.26
Monocalcium P (21% P, 18% Ca)	1.40
Limestone	1.25
Salt	0.35
Trace mineral premix	0.20
Vitamin premix	0.15
L-lysine HCL	0.15
L-threonine	0.05
DL-methionine	0.05
Total	100.00
Calculated analysis	
ME, kcal/lb	1,491
CP, %	21.0
Total lysine, %	1.29
TID amino acids, %	
Lysine	1.15
Threonine	0.74
Isoleucine	0.79
Leucine	1.66
Ca	0.87
Available P	0.37
Analyzed composition, %	
CP	21.05
Total lysine	1.19
Total threonine	0.82
Total isoleucine	1.33
Total leucine	0.84

[a]This diet, fed in meal form, was used in all experiments.

at 0700, 0800, 0900, 1500, 1600, and 1700 hr. All pigs were fed a restricted feed level that was calculated to allow a gain of 0.80 kg/day based on NRC (1998) values. In these experiments the amount of feed given to a pen was determined every 14 d based on combined pen weight. Pigs were weighed individually on d 0, 14, 28, and 42 to determine ADG, F/G, and CV for individual pig weight gain within the pen.

Experiment 3. A total of 150 pigs (initial wt = 156) were used in a 28-d growth assay to determine the effects of feeding a restricted feed level either two or six times per day on growth performance and to determine whether feed wastage was the reason for the difference in performance found in Exp. 1 and 2. Pigs were assigned to one of three treatments with 15 pens of 10 pigs each. The treatments consisted of feeding times with pigs fed six times daily, pigs fed twice daily, and pigs fed twice daily with an modified feeding system to attempt to limit feed wastage (2 Modified; Figure 2). The modified treatment consisted of using PVC piping and flex-tubing to place the daily feeding allotment on the concrete flooring, also boards were attached in front of the partial slats to prevent feed from entering the partial slats. Pigs were provided their daily feed allotment in two or six meals. Pigs receiving two meals were fed at 0700 and 1500 h. Pigs fed six times per day were fed at 0700, 0800, 0900, 1500, 1600, and 1700 h. All pigs were fed a restricted feed level that was calculated to allow a gain of 1.75 lb/day based on NRC (1998) values. In these experiments the amount of feed given to a pen was determined every 14 d based on combined pen weight. Pigs were weighed individually on d 0, 14, and 28 to determine ADG, F/G, and CV for individual pig weight gain within the pen.

Experiment 4. A total of 160 pigs (initial BW = 156 lb) were used in a 28-d growth assay to determine the effects of feeding different levels of feed intake either two or six times per day on pig growth performance. The pigs were separated by sex and randomly allotted by weight to 16 pens of 10 pigs each. Energy and lysine were supplied to pigs to target an average growth rate of 1.75 lb/day (low feed intake level) or 2.1 lb/day (high feed intake level) based on NRC (1998) values to determine if the amount of energy above maintenance and feeding frequency has an effect on performance. Pigs receiving two meals were fed at 0700 and 1500 h. Pigs fed six times per day had a greater interval between meals within the morning and afternoon with feedings at 0700, 0800, 0900, 1500, 1600, and 1700 h. Pigs were weighed individually every 14 d to determine ADG, F/G, and CV for individual pig weight gain within the pen.

Behavioral Measures. Behaviors were recorded continuously for 24 h using a digital video recorder on d 3 to 4, 15 to 16, 29 to 30, and 40 to 41 of Exp. 1 and 2. Behaviors were observed using the Observer 5.1 behavior program which allowed the frequency and duration of behaviors to be averaged for the 24 h periods. Behavior videos were blocked by time, and pens were randomly selected for observations. The behaviors were adapted from work at Texas Tech University and were recorded as time spent drinking, eating, oral-nasal-facial (ONF), sitting, standing, lying, or antagonistic (behavior indicative of social conflict). The total active behaviors were calculated by subtracting lying behavior from the sum of all behaviors.

Standing behavior was defined as having taken place when the animal adopted an upright position with all legs supporting the body. Lying was defined to involve contact of the body with the ground and the legs not supporting the body. Sitting behavior was defined as when the hindquarter portion of the body was in contact with the ground and support of body weight by front legs. Feeding behavior was when the pig was standing and with its head down on the solid concrete floor.

Drinking behavior was defined as when pigs pressed their nose against the nipple waterer. Antagonistic was defined as physical encounters between at least two pigs. Oral-nasal-facial behavior was defined as belly-nosing, rubbing, sniffing, or licking of their pen mates.

Statistical Analysis. The data from all experiments were analyzed as a randomized complete block design with pen as the experimental unit. There was no significant effect of sex in any of the experiments; therefore, all performance data within a treatment will be pooled. The behavioral data was averaged over the 24 h period and represented as a percent of behavioral actions throughout the recorded period. The model for the behavioral observations included the fixed effect of treatment and the random effect of pen and block. Analysis of variance was performed by using the MIXED procedure of SAS.

Results

Experiment 1. Overall (d 0 to 42), pigs fed 6 times versus 2 times a day had increased ($P<0.01$; Table 2) ADG and improved ($P<0.01$) F/G. As expected, ADFI was not different ($P=0.77$) due to the fact that similar amounts of feed were provided to both treatments. The CV for individual pig weight gain within the pen was not ($P=0.83$) influenced by feeding frequency. Increasing the feeding frequency increased the duration of time spent feeding ($P<0.03$; Table 3), standing ($P<0.01$), ONF ($P<0.03$), and reduced the time spent lying ($P<0.01$). This resulted in an overall increase in activity level ($P<0.01$).

Experiment 2. Overall (d 0 to 42), pigs fed 6 times versus 2 times a day had improved ($P<0.02$; Table 4) ADG and ($P<0.02$) F/G. Average daily feed intake was not influenced ($P=0.91$) as expected because similar amounts of feed were given to both treatments. The CV for individual pig weight gain within the pen was not influenced ($P=0.45$) by treatments. Increasing the feeding frequency increased the duration of time spent feeding ($P<0.01$; Table 5), standing ($P<0.01$), and reduced the time spent lying ($P<0.01$). This resulted in an overall increase in activity level ($P<0.01$).

Experiment 3. Overall (d 0 to 28), pigs fed 6 times a day had improved ($P<0.05$; Table 6) ADG and F/G over pigs fed twice a day from either the modified feeders and directly from the feed drops. Average daily feed intake was not influenced ($P = 0.57$) as expected because similar amounts of feed were given to all treatments. The CV for individual pig weight gain within the pen was not influenced ($P = 0.36$) by treatments.

Experiment 4. There were no interactions between feed intake level and feeding frequency for any response criteria. Overall (d 0 to 28), pigs fed the low feed intake level had increased ($P<0.01$; Table 7) ADG while those fed the high feed intake level had a tendency for increased ($P<0.06$) ADG when fed 6 times per day versus being fed 2 times per day. Pigs fed both high and low feed intake levels had improved ($P<0.05$) F/G when fed 6 times per day versus being fed 2 times per day. Average daily feed intake was not influenced by feeding frequency for pigs fed the high feed intake level ($P = 0.26$) or low feed intake level ($P = 0.63$). This was expected because similar amounts of feed were given to both treatments. The CV for individual pig weight gain within the pen was not influenced by feeding frequency for the pigs fed the high feed intake level ($P=0.15$) or low feed intake level ($P=0.35$) treatments.

Discussion

In these experiments, feeding six times increased ADG and improved feed efficiency versus pigs fed twice a day, even though the pigs were fed an equal amount of feed based

on average weight to attain a specific growth pattern. Other researchers have shown that feeding multiple times per day can improve nutrient digestibility. Increasing feeding frequency has been shown to increase the flow of digestive enzyme production in the small intestine.

Another possible explanation to the improved performance is a response called the second-meal phenomenon. This phenomenon is thought to improve carbohydrate tolerance and reduce the insulin response by spreading the nutrient load over a longer period of time. Furthermore, the closeness of one meal to the next determined the glycemic response and potentially eliminates the extreme high and low glycemic peaks. The result is a smoother more controlled response, thus creating more efficient tissue utilization. This hypothesis is used in human health studies that attempt to decrease the occurrence of diabetes by manipulating the frequency of meals. Diabetic patients improved their glucose tolerance when consuming an isocaloric diet over 10 meals versus three meals.

Regardless of the response method, in all studies increasing the feeding frequency from twice to six times a day increased ADG and improved F/G. Feed wastage was hypothesized to be responsible for the ADG response in Exp. 1 and 2. This was due to the potential wastage of feed that falls directly onto the pigs during feeding. Therefore, the modified treatment in Exp. 3 delivered feed directly to the floor, thus prevent feed from dropping directly onto the pig. However, the growth performance of pigs fed six or two times per day mimicked the response found in Exp. 1 and 2. Thus, it was concluded that the ADG response was not due to differences in feed wastage between treatments. This is further confirmed with the consistent improvement in F/G, indicating improved nutrient utilization.

Previous data on feeding frequency for finishing pigs is limited. One study found that pigs fed multiple times had higher maintenance requirements, but were also more efficient converters of the available ME taken above maintenance for tissue deposition. On the other hand, other researchers did not demonstrate differences in digestibility or performance between pigs fed the same total amount of feed in large meals or several small meals. Previously, we tested the same feeding regimen in gestating gilts and sows. There was no difference in growth performance for gestating sows, but there was an increase in ADG for gestating gilts in the first period measured (d 0 to 42). The reason for the treatment effect in the present experiments and in the first period of gestating gilts may be related to the amount of energy available above maintenance requirements. After examining these results a question arose concerning the amount of energy above maintenance and its effects on performance.

In Exp. 4, energy and lysine were supplied to pigs to target an average growth rate of 1.75 lb/day (low feed intake) or 2.1 lb/day (high feed intake) based on NRC (1998) values. The purpose of these dietary energy levels was to determine if similar growth response would be seen in pigs fed six times a day on a diet that was closer to *ad libitum* intake (low feed intake level = 2.1 times above maintenance; high feed intake level = 2.7 times above maintenance). We found improvements in ADG and F/G for both feed intake levels as feeding frequency increased from 2 to 6 times daily. However, those fed the lower feed intake level had larger improvements than those fed the higher feed intake level.

An area of concern with the present studies may be related to the discrepancies in the predicted growth rate versus the actual growth response. In Exp. 1, 2, and 3, all pigs were fed to gain 1.75 lb/d using the NRC (1998) calculations. However, the ADG responses in

our growth assays were under those predicted by the NRC (1998) calculations and may be due to environment, genetics, or inaccuracies in the NRC (1998) equations.

Results of the observation of behavior revealed that increasing the feeding frequency from 2 to 6 times per day increased active behavior (12.2 to 12.5% vs. 14.3 to 14.9%, respectively) and decreased the amount of time spent lying. Similar results were found by others when comparing an increase in feeding frequency of growing-finishing pigs fed a liquid diet when pigs were fed 2 vs. 3 times per day and when pigs were fed 3 vs. 9 times per day. The amount of time spent feeding was increased for pigs fed 6 times a day versus pigs fed 2 times a day. This also was similar to the results of others where pigs fed 9 times per day spent more time feeding than pigs fed 3 times per day. Almost 90% of all aggressive interactions between pigs occur during feeding as a direct result of competition. Time budgets of agonistic behavior were not influenced by feeding frequency in our study.

Figure 1. Pen Design for Pigs fed 2 or 6 Times per Day in All Experiments.

Figure 2. Picture Represents the Modified Treatment that Delivered Feed Directly onto the Concrete Flooring (Exp. 3).

Table 2. Effect of Feeding Frequency on Energy Restricted Diet on Performance of Finishing Pigs (Exp. 1)[a]

	Frequency of Feeding per Day			
Item	2	6	SE	*P*-value (*P* <)
ADG, lb	1.34	1.51	0.035	0.01
ADFI, lb	3.70	3.70	0.001	0.77
F/G	2.78	2.44	0.061	0.01
CV of gain, %	4.62	4.52	0.23	0.83

[a]Each value is the mean of eight replications with 10 pigs (initially 148 lb) per pen. Pens that were fed twice daily received feed at 0700 and 1530 h; Pens that were fed six times a day received feed at 0700, 0730, 0800, 1530, 1600, and 1630 h, respectively. Feed drops were adjusted every 14 d based on the average weight of pigs.

Table 3. The Duration of Behaviors Expressed as a Percentage of Time over 24 h (Exp. 1)[a]

	Frequency of Feeding per Day			
Behavior	2	6	SE	*P*-value (*P* <)
Agonistic	0.26	0.28	0.06	0.51
Active	12.20	14.35	0.19	0.01
Oral-nasal-facial	1.30	1.65	0.09	0.03
Lie	87.80	85.65	0.19	0.01
Stand	4.70	5.70	0.12	0.01
Sit	0.62	0.67	0.06	0.44
Drink	0.31	0.33	0.03	0.40
Feed	5.03	5.73	0.16	0.03

[a]Values for the behavior observations were averaged over a 24 h period for a combination of 4 total days per treatment. Active behavior was determined by subtracting lying behavior from the sum of all behavior

Table 4. Effect of Feeding Frequency on Energy Restricted Diet on Performance of Finishing Pigs (Exp. 2)[a]

	Frequency of Feeding per Day			
Item	2	6	SE	*P*-value (*P* <)
ADG, lb	1.11	1.37	0.06	0.02
ADFI, lb	3.81	3.81	0.01	0.91
F/G	3.45	2.78	0.16	0.02
CV of gain, %	5.18	4.77	0.37	0.45

[a]Each value is the mean of eight replications with 10 pigs (initially 155 lb) per pen. Pens that were fed twice daily received feed at 0700 and 1500 h. Pens that were fed six times a day received feed at 0700, 0800, 0900, 1500, 1600, and 1700 h, respectively. Feed drops were adjusted every 14 d based on the average weight of pigs.

Table 5. The Duration of Behaviors Expressed as a Percentage of Time over 24 h (Exp. 2)[a]

	Frequency of Feeding per Day			
Behavior	2	6	SE	*P*-value (*P* <)
Agonistic	0.29	0.31	0.03	0.60
Active	12.46	14.88	0.08	0.01
Oral-nasal-facial	1.38	1.50	0.06	0.15
Lie	87.55	85.12	0.08	0.01
Stand	5.15	6.08	0.13	0.01
Sit	0.61	0.63	0.03	0.55
Drink	0.31	0.32	0.01	0.45
Feed	4.73	6.05	0.15	0.01

[a]Values for the behavior observations were averaged over a 24 h period for a combination of 4 total days per treatment. Active behavior was determined by subtracting lying behavior from the sum of all behavior.

Table 6. Effect of Feeding Frequency on Energy Restricted Diet on Performance of Finishing Pigs (Exp. 3)[a]

	Frequency of feeding per day			
Item	2 Modified	2	6	SE
ADG, lb	1.12 [b]	1.14 [b]	1.34 [c]	0.06
ADFI, lb	3.65	3.66	3.65	0.00
F/G	3.23 [b]	3.23 [b]	2.70 [c]	0.15
CV of gain, %	4.01	4.46	4.75	0.55

[a]Each value is the mean of eight replications with 10 pigs (initially 156 lb) per pen. Pens that were fed twice daily received feed at 0700 and 1500 h. Pens that were fed six times a day received feed at 0700, 0800, 0900, 1500, 1600, and 1700 h, respectively. Feed drops were adjusted every 14 d based on the average weight of pigs. Pens fed the 2 modified treatment were fed twice daily with feed delivered directly onto the concrete floor.
[bc]Values within a row lacking a common superscript letter are different (*P*<0.05).

Table 7. Effect of Feeding Frequency on Energy Restricted Diet on Performance of Finishing Pigs (Exp. 4)[a]

	Frequency of Feeding per Day			
Item	2	6	SE	*P*-value (*P* <)
Low feed intake[b]				
ADG, lb	1.03	1.396	0.10	0.01
ADFI, lb	3.55	3.549	0.00	0.26
F/G	3.45	2.56	0.14	0.01
CV of gain, %	4.62	4.24	0.27	0.35
High feed intake[c]				
ADG, lb	1.40	1.563	0.10	0.06
ADFI, lb	4.52	4.513	0.00	0.63
F/G	3.23	2.86	0.17	0.05
CV of gain, %	4.12	3.53	0.27	0.15

[a]Each value is the mean of eight replications with 10 pigs (initially 156 lb) per pen. Pens that were fed twice daily received feed at 0700 and 1500 h. Pens that were fed six times a day received feed at 0700, 0800, 0900, 1500, 1600, and 1700 h, respectively. Feed drops were adjusted every 14 d based on the average weight of pigs.
[b]Pigs were fed to gain 1.75 lb/d based on NRC (1998) values.
[c]Pigs were fed to gain 2.1 lb/d based on NRC (1998) values.

EFFECT OF GLYCEROL ON PELLET MILL PRODUCTION EFFICIENCY

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Summary

Crude glycerol is a by-product of the biofuels industry, which has the potential to be used as a feed ingredient in animal diets. However, little is known about glycerol's nutritional value or how it impacts feed quality and feed processing efficiency. Three experiments were conducted to evaluate the effects of glycerol on production efficiency of a pellet mill. In all three experiments, diets were manufactured, pelleted, and data collected at the KSU Grain Science Feed Mill. All diets were steam conditioned to 85°F and pelleted at 150°F using a CPM pellet mill equipped with a 4 mm × 32 mm pellet die. In Exp. 1, the six treatments were a corn-soybean meal-based swine grower diet formulated to contain 0, 3, 6, 9, 12, and 15% crude glycerol. Experiment 2 included seven treatments: the control with no added soy oil or glycerol, the control diet with 3 or 6% added soy oil, the control diet with 3 or 6% added glycerol, and the control with 6 or 12% of a 50:50 soy oil to glycerol blend. Experiment 3 included five treatments: a control with no added lactose or glycerol, the control diet with 3.6 or 7.2% lactose, or the control with 3.6 or 7.2% glycerol. Each experimental diet was replicated by manufacturing a new batch of feed three times. Glycerol lowered delta temperature, amperage, and motor load in Exp. 1, 2, and 3. The addition of glycerol consistently improved pellet quality. Production rate was not affected by the addition of glycerol; however, glycerol decreased total energy usage (KWh/t). Furthermore, glycerol can be added to a diet in combination with soy oil in a blend to improve production efficiency and pellet quality compared to a diet containing only soy oil. The addition of glycerol will improve the production efficiency of pelleting, pellet quality, and decrease energy cost when included in diets prior to pelleting.

(Key words: feed manufacturing, glycerol, pelleting.)

Introduction

The Renewable Fuel Standards Program, which is part of the Energy Policy Act of 2005, mandates that a minimum level of renewable fuels be consumed in the United States each year. In 2006, the minimum biofuels consumption level was set at four billion gallons with expectations of doubling by 2012. Consequently, there has and will continue to be an unprecedented level of growth in the biofuels industries. Biodiesel is the renewable alternative to petroleum-based diesel fuel. It consists of monoalkyl esters formed through an alcohol-based catalyzed reaction of triglycerides in oils and fats. According to the National Biodiesel Board, there are currently 105 biodiesel production facilities operating in

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the United States and 77 facilities are in the planning or construction stage. If all of these facilities are realized, the estimated U.S. biodiesel production capacity will exceed 2.5 billon gallons. This level of production will yield nearly 1.3 million tons of glycerol, the primary co-product of the biodiesel production process. Glycerol constitutes approximately 10 to 11% of a typical triglyceride. Purification of crude glycerol to a chemically pure substance results in a valuable industrial chemical. However, it is costly and the glycerol market is already saturated, thus the price of glycerol continues to decline. This trend will continue as more and more biodiesel production facilities come online. Consequently, 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 or how it impacts feed quality and feed processing efficiency. Therefore, the objective of these trials was to evaluate the effects of glycerol on pelleting production efficiency.

Materials and Methods

In all three experiments, diets were manufactured, pelleted, and data collected at the KSU Grain Science Feed Mill. All diets were steam conditioned to 85°F and pelleted at 150°F using a CPM pellet mill (Master Model HD, Series 2000) equipped with a 4 mm × 32 mm pellet die. In all three experiments, each diet was replicated by manufacturing a new batch of feed three times. Pellet mill electrical consumption, production rate, hot-pellet temperature, motor load, feeder rate, conditioning rate, and pellet durability were measured.

Experiment 1 included six treatments that were corn-soybean meal-based swine grower diets formulated to contain 0, 3, 6, 9, 12, and 15% crude glycerol (Table 1).

Experiment 2 included seven treatments: the control with no added soy oil or glycerol, the control diet with 3 or 6% added soy oil, the control diet with 3 or 6% added glycerol, and the control with 6 or 12% of a 50:50 soy oil to glycerol blend (Table 2). All diets were formulated to the same lysine to metabolizable energy ratio. The metabolizable energy value used for glycerol was 1,555 kcal/lb.

Experiment 3 included five treatments: a control with no added lactose or glycerol, the control diet with 3.6 or 7.2% lactose, or the control with 3.6 or 7.2% glycerol (Table 3).

Results and Discussion

Experiment 1. There was no difference ($P>0.11$) in conditioning temperature, indicating that all diets were indeed pelleted at 150°F (Table 4). Hot pellet temperature initially decreased (quadratic; $P<0.05$) through 6% added glycerol, increased at 9% added glycerol, and again decreased through 15% added glycerol. Delta temperature also decreased (quadratic; $P<0.01$) though 6% added glycerol, increased at 9% added glycerol, and again decreased through 15% added glycerol. Delta temperature should follow a similar pattern to hot pellet temperature as delta temperature is calculated using both hot pellet temperature and conditioning temperature. There was no difference ($P>0.46$) in voltage (volts) with increasing added glycerol. Amperage (Amps) decreased (quadratic; $P<0.01$) with the addition of glycerol. The greatest decreases occurred with the addition of 3% glycerol and again at the 12% glycerol additions; however, all diets with glycerol had lower amps than the control. Motor load was also decreased (quadratic; $P<0.01$) with the addition of glycerol. Similar to amps, motor load decreased the greatest with the initial addition of 3% glycerol and again from 9 to 12% glycerol addition. Voltage, amps, and motor load are measures of energy. Amperage and motor load values follow similar trends. Amperage measures the electrical current pulled from the pellet mill, and motor load energy needed to rotate the pellet die. Motor load will increase

with increased friction in the die and decrease as friction is decreased. The decrease in motor load when glycerol is added to the diet indicates a decrease in pellet die friction. Pellet quality was also improved ($P<0.01$) with the addition of glycerol. Pellet durability index (PDI) increased (linear; $P<0.01$) through 15% added glycerol for both the standard and modified PDI. The addition of glycerol had no effect ($P>0.14$) on production rate (t/h). The kWh/t production rate decreased (quadratic; $P<0.01$) with the addition of glycerol; it increased at 9%, and decreased again through 15% glycerol addition. The response exhibited at the 9% added glycerol treatment doesn't follow the trend for all other glycerol levels. This spike at the 9% added glycerol treatment is not completely understood. The 9% diet caused problems when attempting to pellet the diet at higher conditioning temperatures. It continually overloaded the pellet mill at approximately 168°F. This phenomenon warrants further investigation of a potential interaction with added glycerol and conditioning temperature.

Experiment 2. Similar to Exp. 1, a conditioning temperature of 150°F was targeted. There was a tendency ($P<0.08$) for the 3% soy oil, 3% glycerol, and the 6% blend treatments to have a higher conditioning temperature of 151°F compared to all other treatments at 150°F (Table 5). Although statistically significant, this small difference is of little practical importance. Hot pellet temperature and delta temperature were decreased (linear; $P<0.01$) with the addition of soy oil, glycerol, and their blend. Hot pellet temperature and delta temperature decreased ($P<0.01$) when soy oil, glycerol, or the blend was added to the diet when compared to the control. Hot pellet temperature and delta temperature was also decreased ($P<0.01$) for the soy oil/glycerol blend when compared to soy oil and glycerol additions. There was no difference ($P>0.10$) between hot pellet temperature and delta temperature between soy oil and glycerol additions. There was no difference ($P>0.11$) in voltage between any of the treatments.

Amperage and motor load decreased (linear; $P<0.01$) with the addition of soy oil, glycerol, and their blend. The addition of 3 and 6% glycerol decreased (quadratic, $P<0.05$) amps and motor load; the greatest decrease occurred with the initial addition of glycerol to the diet.

The addition of the soy oil/glycerol blend had the greatest decrease in motor load, and amps (quadratic; $P<0.03$), with the12% blend addition decreasing amps and motor load the greatest. The addition of soy oil, glycerol, and soy oil/glycerol blend all decreased ($P<0.01$) amps and motor load compared to the control. The addition of soy oil and glycerol resulted in increased ($P<0.01$) amps and motor load compared to the blend. The soy oil/glycerol blend had the lowest amps and motor load compared to all other treatments, indicating the largest reduction in pellet die friction.

Pellet quality was not affected ($P>0.26$) with the addition of glycerol; however, the 6% added glycerol had the greatest standard and modified PDI compared to all other treatments. The addition of soy oil decreased (quadratic; $P<0.01$) PDI. The blend of soy oil and glycerol decreased (linear; $P<0.01$) PDI but the overall PDI of the blend was greater ($P<0.01$) than the PDI of soybean oil alone. The overall PDI was greater ($P<0.01$) for glycerol when compared to the soy oil/glycerol blend and soy oil treatments. Soy oil had a slightly increased ($P>0.01$) production rate compared to glycerol. Production rate (t/h) was not different ($P>0.10$) between glycerol and the soy oil/glycerol blend or the control. The soy oil/glycerol blend was not different ($P>0.10$) from any of the other treatments. The kWh/t production rate decreased (quadratic; $P<0.01$) with the addition of soy oil, glycerol, and the soy oil/glycerol blend. The greatest benefit occurred with the initial addition of any of the liquid sources.

All treatment means were different (P<0.01), with the control having the highest kWh/h and the soy oil/glycerol blend having the lowest. Glycerol had a slightly higher mean than the soy oil, but it was intermediate to the control and soy oil/glycerol blend.

Experiment 3. There was no difference (P>0.12) in conditioning temperature among treatments: all treatments were pelleted at 150 °F (Table 6). Hot pellet temperature and delta temperature decreased (linear; P<0.01) through 7.2% added glycerol. Hot pellet temperature and delta temperature increased (linear; P<0.01) through 7.2% added lactose. Hot pellet temperature and delta temperature were different (P<0.01) among all treatments. The diet containing lactose had the highest hot pellet temperature and delta temperature, and the diet containing glycerol had the lowest. The control diet hot pellet and delta temperatures were intermediate to the lactose and control treatment temperatures. The addition of lactose also resulted in an increase (linear; P<0.01) in amps and motor load. The increase in amps and motor load indicates an increase in pellet die friction with added lactose. The addition of glycerol decreased (linear; P<0.01) amps and motor load, similar to Exp. 1 and 2, indicating a decrease in pellet die friction. The added lactose resulted in an increased (P<0.01) hot pellet temperature and delta temperature compared with the control and glycerol. The added glycerol resulted in decreased (P<0.01) hot pellet temperature and delta temperature compared with the control and lactose diets. Pellet quality was improved (linear; P<0.01) with either added lactose or glycerol. Standard and modified PDI were not different (P>0.10) between lactose and glycerol. Lactose and glycerol resulted in an increased (P<0.01) standard and modified PDI compared with the control. Standard and modified PDI were greatest for the 7.2% added lactose and 7.2% added glycerol. Production rate (t/h) increased (quadratic; P<0.04) with the addition of lactose. The increase in production rate was greatest at the 3.6% added lactose, with no additional production rate benefit at the 7.2% added lactose. Adding glycerol had no effect (P>0.10) on production rate. Adding lactose increased (P<0.01) production rate when compared with the control and glycerol. The kWh/t decreased (linear; P<0.01) through 7.2% added glycerol, indicating a decrease in energy consumption without decreasing pellet mill output compared with the control. The diet containing lactose had an increased (P<0.01) kWh/t compared with the diet containing glycerol and the control diet.

In conclusion, glycerol consistently lowered delta temperature (less die friction), amperage, and motor load. The addition of glycerol also improved pellet quality in Exp. 1, 3, and tended to improve pellet quality in Exp. 2. Production rate was not affected by the addition of glycerol in Exp 1 and 3; however, glycerol decreased kWh/t in Exp 1, 2 and 3. This indicates that a pellet mill could decrease energy cost without decreasing tons of feed produced. These data also indicate that glycerol can be added to a diet in combination with soy oil to improve production efficiency and pellet quality compared to a diet containing only soy oil. The addition of glycerol improved production efficiency of pelleting, pellet quality, and decreased energy cost for the pellet mill.

Table 1. Composition of Diets, Exp. 1 (as-fed basis)

	Added Glycerol, %					
Item	0	3	6	9	12	15
Corn	63.54	60.30	57.06	53.82	50.57	47.33
Soybean meal (46.5% CP)	32.57	32.81	33.06	33.30	33.54	33.78
Crude glycerol[a]	---	3.00	6.00	9.00	12.00	15.00
Monocalcium phosphate (21% P)	1.65	1.65	1.65	1.65	1.65	1.65
Limestone	0.95	0.95	0.95	0.95	0.95	0.95
Salt	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
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15
L-lysine HCl	0.30	0.30	0.30	0.30	0.30	0.30
DL-methionine	0.12	0.12	0.12	0.12	0.12	0.12
L-threonine	0.12	0.12	0.12	0.12	0.12	0.12
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis						
Total lysine, %	1.38	1.38	1.38	1.38	1.38	1.38
ME, kcal/lb	1,496	1,496	1,496	1,496	1,496	1,496
Protein, %	21.0	20.8	20.7	20.5	20.3	20.2
Ca, %	0.80	0.80	0.80	0.80	0.80	0.80
P, %	0.75	0.74	0.73	0.73	0.72	0.71
Available P, %	0.42	0.42	0.42	0.42	0.42	0.42
Lysine:calorie ratio, g/Mcal	3.79	3.79	3.79	3.79	3.79	3.79

[a]Contained 90.7% glycerin and 136 ppm methanol.

Table 2. Composition Diets, Exp. 2 (as-fed basis)

		Soy Oil, %		Glycerol, %		Blend[a], %	
Item	Control	3	6	3	6	6	12
Corn	53.71	47.92	42.55	50.44	47.18	44.67	35.91
Soybean meal (46.5% CP)	41.98	44.62	46.86	42.23	42.47	44.86	47.54
Crude glycerol[b]	---	---	---	3.00	6.00	3.00	6.00
Soybean oil	---	3.00	6.00	---	---	3.00	6.00
Monocalcium phosphate (21% P)	1.60	1.71	1.81	1.61	1.61	1.71	1.77
Limestone	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Salt	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
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-lysine HCl	0.30	0.30	0.30	0.30	0.30	0.30	0.30
DL-methionine	0.11	0.13	0.15	0.12	0.13	0.14	0.16
L-threonine	0.10	0.12	0.13	0.11	0.11	0.12	0.13
Antibiotic[c]	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis							
Total lysine, %	1.38	1.45	1.50	1.38	1.38	1.45	1.51
ME, kcal/lb	1,489	1,555	1,621	1,489	1,489	1,555	1,621
Protein, %	20.9	21.7	22.3	20.8	20.6	21.6	22.1
Ca, %	0.79	0.81	0.84	0.79	0.79	0.81	0.83
P, %	0.74	0.76	0.78	0.73	0.72	0.76	0.76
Available P, %	0.41	0.44	0.46	0.41	0.41	0.44	0.45
Lysine:calorie ratio, g/Mcal	3.81	3.82	3.81	3.81	3.81	3.82	3.82

[a]Contained a 50:50 blend of soy oil to crude glycerol.
[b]Contained 90.7 % glycerin and 136 ppm methanol.
[c]Provided 140 g of Neomycin sulfate and 140 g Oxytetracycline HCl per ton of complete feed.

Table 3. Composition Diets, Exp. 3 (as-fed basis)

		Lactose, %		Glycerol, %	
Item	Control	3.6	7.2	3.6	7.2
Corn	63.25	59.36	55.47	59.36	55.47
Soybean meal (46.5% CP)	26.87	27.16	27.45	27.16	27.45
Crude glycerol[a]	---	---	---	3.60	7.20
Fish meal	4.50	4.50	4.50	4.50	4.50
Lactose	---	3.60	7.20	---	---
Soybean oil	1.00	1.00	1.00	1.00	1.00
Monocalcium phosphate (21% P)	1.40	1.40	1.40	1.40	1.40
Limestone	0.70	0.70	0.70	0.70	0.70
Salt	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.25	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15	0.15
L-lysine HCl	0.30	0.30	0.30	0.30	0.30
DL-methionine	0.14	0.14	0.14	0.14	0.14
L-threonine	0.14	0.14	0.14	0.14	0.14
Antibiotic[b]	0.70	0.70	0.70	0.70	0.70
Total	100.00	100.00	100.00	100.00	100.00
Calculated analysis					
Total lysine, %	1.43	1.43	1.43	1.43	1.43
ME, kcal/lb	1,512	1,512	1,512	1,511	1,511
Protein, %	21.2	21.0	20.8	21.0	20.8
Ca, %	0.87	0.87	0.87	0.87	0.87
P, %	0.79	0.78	0.78	0.78	0.78
Available P, %	0.49	0.49	0.49	0.49	0.49
Lysine:calorie ratio, g/Mcal	3.90	3.90	3.90	3.90	3.90

[a]Provided 90.7% glycerin and 136 ppm methanol.
[b]Provided 140 g of Neomycin sulfate and 140 g Oxytetracycline HCl per ton of complete feed.

Table 4. Effects of Added Glycerol on Production Efficiency, Exp 1[ab]

	Added Glycerol, %							Contrast, *P* <	
Item	0	3	6	9	12	15	SE	Linear	Quadratic
Conditioning temp, °F	149.7	150.0	150.2	150.2	149.8	149.8	0.37	0.11	0.98
Hot pellet temp, °F	169.1	167.8	166.1	169.9	161.9	163.0	2.16	0.26	0.05
Delta temp, °F	18.9	17.3	15.5	19.2	11.7	12.6	2.04	0.33	0.01
Voltage, volts	250.4	250.0	248.9	252.3	250.1	250.3	1.94	0.74	0.46
Amperage, amps	29.3	25.2	23.6	22.9	19.5	18.1	0.85	0.11	0.01
Motor load, %	54.7	45.7	41.7	41.0	33.3	30.3	2.00	0.12	0.01
Pellet durability									
Standard, %	90.1	92.1	93.5	95.7	94.9	94.7	0.73	0.01	0.33
Modified, %	87.5	89.4	91.2	93.9	92.3	91.6	1.14	0.01	0.97
Production rate, t/hr	1.32	1.27	1.24	1.11	1.09	1.10	0.04	0.14	0.35
Total energy, kWh/t	7.62	6.81	6.51	7.09	6.10	5.60	0.26	0.91	0.01

[a]All diets were corn-soybean meal-based swine grower diets.
[b]Each experimental diet was replicated by manufacturing a new batch of feed three times.

Table 5. Effects of Added Glycerol on Production Efficiency, Exp 2[ab]

									Contrasts, $P <$[d]					
		Soy Oil,%		Glycerol, %		Blend[c], %			Soy		Glycerol		Blend	
Item	Control	3	6	3	6	6	12	SE	L	Q	L	Q	L	Q
Conditioning temp, °F	150.4	151.3	150.6	151.3	150.5	151.1	150.4	0.36	0.70	0.07	0.82	0.06	0.94	0.07
Hot pellet temp, °F[fg]	171.1	165.5	161.0	165.4	164.1	159.9	156.7	1.30	0.01	0.71	0.01	0.11	0.01	0.01
Delta temp, °F[fg]	20.2	13.9	10.0	13.7	13.2	8.4	5.9	1.28	0.01	0.33	0.01	0.03	0.01	0.01
Voltage, volts	247.7	249.9	245.8	248.4	250.1	249.4	249.3	1.53	0.40	0.11	0.28	0.82	0.45	0.62
Amperage, amps[fg]	28.3	23.0	19.6	23.7	22.8	20.9	16.0	0.52	0.01	0.10	0.01	0.01	0.01	0.03
Motor load, %[fg]	53.6	45.9	34.6	42.9	41.6	36.3	26.9	2.22	0.01	0.41	0.01	0.05	0.01	0.09
Pellet durability														
Standard, %[efg]	92.6	81.6	58.3	94.7	95.5	85.4	80.3	1.84	0.01	0.01	0.26	0.79	0.01	0.52
Modified, %[efg]	89.9	74.7	40.0	91.9	92.2	78.3	65.8	1.80	0.01	0.01	0.39	0.69	0.01	0.82
Production rate, t/hr[e]	1.38	1.42	1.40	1.35	1.38	1.40	1.36	0.02	0.29	0.19	0.95	0.16	0.44	0.16
Total energy, kWh/t[efg]	7.58	6.09	5.16	6.50	6.18	5.45	4.44	0.14	0.01	0.01	0.01	0.01	0.01	0.01

[a]All diets were formulated to the same lysine to metabolizable energy ratio.
[b]Each experimental diet was replicated by manufacturing a new batch of feed three times; each run consisted of 750 lb batches.
[c]Addition of 50% soy oil and 50% glycerol.
[d]Linear (L) and quadratic contrasts (Q).
[e]Contrast soy oil vs. glycerol, $P<0.01$.
[f]Contrast soy oil vs. blend, $P<0.01$.
[g]Contrast glycerol vs. blend, $P<0.01$.

Table 6. Effects of Added Glycerol on Production Efficiency, Exp 3[a]

							Contrasts, $P <$[b]			
		Lactose, %		Glycerol, %			Lactose		Glycerol	
Item	Control	3.6	7.2	3.6	7.2	SE	Linear	Quadratic	Linear	Quadratic
Conditioning temp, °F	150.3	150.2	150.3	149.7	150.3	0.28	1.00	0.64	0.93	0.12
Hot pellet temp, °F[bcd]	166.9	168.3	171.3	164.5	158.3	1.01	0.01	0.56	0.01	0.17
Delta temp, °F[bcd]	16.5	18.2	20.9	14.7	8.0	0.95	0.01	0.63	0.01	0.06
Voltage, volts	252.2	251.9	248.0	251.7	252.3	2.10	0.19	0.51	0.97	0.82
Amperage, amps[bcd]	21.6	22.2	23.0	19.3	17.2	0.34	0.01	0.79	0.01	0.64
Motor Load, %[bcd]	33.8	37.1	38.4	30.1	27.1	1.32	0.01	0.40	0.01	0.78
Pellet durability										
Standard, %[bc]	86.1	88.5	90.1	89.9	91.8	1.15	0.01	0.75	0.01	0.39
Modified, %[bc]	87.0	89.2	90.8	89.8	92.0	1.17	0.01	0.81	0.01	0.80
Production rate, t/hr[bd]	0.98	1.03	1.02	0.99	0.97	0.01	0.01	0.04	0.19	0.10
Total energy, kWh/t[cd]	8.10	8.00	8.20	7.20	6.60	0.65	0.65	0.42	0.01	0.28

[a]Each experimental diet was replicated by manufacturing a new batch of feed three times; each run consisted of 750 lb batches.
[b]Contrast control vs. lactose, $P<0.01$.
[c]Contrast control vs. glycerol, $P<0.01$.
[d]Contrast lactose vs. glycerol, $P<0.01$.

EFFECT OF GLYCEROL ON FLOW ABILITY OF SWINE DIETS

C. N. Groesbeck, L. J. McKinney[1], J. M. DeRouchey, M. D. Tokach, R. D. Goodband, J. M. Nelssen, and S. S. Dritz[2]

Summary

We conducted two experiments to determine the effect of added glycerol or a 50:50 soy oil/glycerol blend on the flow ability characteristics of ground corn or ground corn and 15 or 30% spray-dried whey. Experiments were conducted using corn ground by either a full circle, tear drop hammer mill or a three-high roller mill at the Kansas State University Grain Science Feed Mill. Flow ability was determined by measuring angle of repose. In Exp. 1 we evaluated the effects of added soy oil, glycerol, or a 50:50 soy oil/glycerol blend on the flow ability of ground corn. Samples were ground through a roller mill (RM) or hammermill (HM). Particle size mean and standard deviations of the ground corn were 645 microns and 1.97 for the roller mill and 674 microns and 2.31 for the hammer mill. Soy oil, glycerol, or a 50:50 blend of soy oil/glycerol was added to the ground corn at 0, 2, 4, 6, or 8% for a total of 30 samples (1 RM sample, 1 HM sample, 3 liquid sources, and 5 levels of added liquid). In Exp. 2, we evaluated the effects of added soy oil, glycerol, or a 50:50 soy oil/glycerol blend on the flow ability of 85:15 or 70:30 blend of HM ground corn and spray-dried whey. Soy oil, glycerol, or a 50:50 blend of soy oil/glycerol was added to the ground corn and spray-dried whey-based diets at 0, 4, or 8% for a total of 18 samples (1 HM sample, 2 levels of added whey, 3 liquid sources, and 3 levels of added liquid). Angle of repose was then measured, and replicated 4 times on each sample. In Exp. 1 there was a three way interaction ($P<0.05$) between mill type, liquid source, and percent liquid added. Roller mill ground grain had decreased angle of repose (better flow ability) compared to HM ground grain. The addition of soy oil increased angle of repose, decreasing flow ability. The addition of glycerol or a 50:50 soy oil/glycerol blend decreased angle of repose, improving flow ability with HM ground corn. Addition of glycerol did not influence flow ability when added to RM corn ground. In Exp. 2 there was a three way interaction ($P<0.05$) between spray-dried whey level, added liquid source, and percent of liquid added. The addition of glycerol or the 50:50 soy oil/glycerol blend decreased angle of repose, improving flow ability. The addition of glycerol decreased angle of repose greater in the 15% spray-dried whey sample compared to the 30% spray-dried whey sample. The addition of soy oil increased angle of repose regardless of spray-dried whey concentration. These data suggest that the addition of glycerol to a meal diet containing HM ground corn will improve flow ability.

(Key words: feed manufacturing, glycerol, flow ability.)

[1]Department of Grain Science and Industry.
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Introduction

Decreasing particle size and adding fat sources, such as soy oil or choice white grease to a swine diet, can improve pig performance and profitability. Limits to reducing particle size and the amount of added fat are based on the ability of the feed to flow through feed handling systems and feeders. Previous research has demonstrated that grain ground with a roller mill (RM) had improved flow ability compared to grain ground with a hammermill (HM). These data also demonstrate that decreasing particle size and adding increasing levels of fat to a diet will decrease flow ability and increase feed handling problems. Glycerol is currently being evaluated for use as a feed ingredient in swine diets. The influence of glycerol on feed flow ability is not known. Therefore, the objective of our study was to evaluate the effects of added glycerol or a 50:50 soy oil/glycerol blend to the flow ability of ground corn or a ground corn diet with either 15 or 30% spray-dried whey.

Procedures

Experiments were conducted using corn ground by either a full circle, tear drop hammer mill or a three-high roller mill at the Kansas State University Grain Science Feed Mill. The corn contained 10.1% CP and 3.1% fat on an as-fed basis. Particle size and standard deviation were determined with a Ro-Tap tester with a stack of 13 screens, as outlined in the American Society of Agricultural Engineers (publication S319). Angle of repose was defined as the maximum angle measured in degrees at which a pile of grain retains its slope. An angle of repose tester was constructed from 4 pieces of poly vinyl chloride (PVC). The tester is 3" in diameter and 36" tall and attached to a 3" PVC floor mounting. A 3" diameter plate was mounted to the top of the machine, which allowed two 3" PVC couplers to slide up and down the long axis of the tester. To conduct the angle of repose test, a 500 g sample was placed inside the couplers at a specified height at the top of the tester. The base of the angle of repose tester was held stationary and the PVC couplers were lifted vertically, allowing the test ingredient to flow downward resulting in a pile on top of the plate. The height of the pile was measured, and angle of repose was calculated by the following equation, Angle of repose = $\tan^{-1}$ (the height of the pile divided by one half the diameter of the plate). A larger angle of repose represents a steeper slope and poorly flowing product; a low angle of repose would represent a freer flowing product. All data was analyzed using PROC MIXED in SAS 8.1.

Experiment 1. The objective was to evaluate the effects of added soy oil, glycerol, or a 50:50 soy oil/glycerol blend on the flow ability of ground corn. Samples were ground through a roller mill or hammermill. Particle size mean and standard deviations were 645 microns and 1.97 for corn ground through the roller mill and 674 microns and 2.31 for corn ground through the hammer mill. Soy oil, glycerol, or a 50:50 blend of soy oil/glycerol was added to the ground corn at 0, 2, 4, 6, or 8% for a total of 30 samples (1 RM sample, 1 HM sample, 3 liquid sources, and 5 levels of added liquid). Angle of repose was then measured, and replicated 4 times on each sample.

Experiment 2. The objective was to evaluate the effects of added soy oil, glycerol, or a 50:50 soy oil/glycerol blend on the flow ability of a HM ground corn diet with either 15 or 30% spray-dried whey. The HM sample used in Exp.1 was the same corn sample used in Exp. 2. Soy oil, glycerol, or a 50:50 blend of soy oil/glycerol was added to the ground corn and spray-dried whey-based diet at 0, 4, or 8% for a total of 18 samples (1 HM sample, 2 levels of added whey, 3 liquid sources, and 3 levels of added liquid). Angle of repose was then measured and replicated 4 times on each sample.

Results and Discussion

Experiment 1. There was a three way interaction ($P<0.05$) between mill type, fat source, and percent fat source added (Figure 1). Roller mill ground grain had decreased angle of repose (better flow ability) compared to HM ground grain. The addition of soy oil increased angle of repose, decreasing flow ability.

The addition of glycerol or a 50:50 soy oil/glycerol blend decreased angle of repose, improving flow ability when added to the diet containing HM ground corn. Adding glycerol or the 50:50 soy oil/glycerol blend to the diet containing RM ground corn did not influence angle of repose.

Experiment 2. There was a three way interaction ($P<0.05$) between spray-dried whey level, added liquid source, and percent of liquid added (Figure 2). The addition of glycerol or the 50:50 soy oil/glycerol blend decreased angle of repose, improving flow ability. The addition of glycerol decreased angle of repose greater in the 15% spray-dried whey sample compared with the 30% spray-dried whey sample. The addition of soy oil increased angle of repose regardless of spray-dried whey concentration.

These data suggest that the addition of glycerol to a meal diet will improve flow ability. The addition of glycerol to a HM ground diet will improve flow ability more than when added to RM ground corn. This could be the result of glycerol interacting with the smaller particles due to the increased standard deviation of the HM ground grain. The addition of a 50:50 soy oil/glycerol blend will also improve flow ability of a corn-based diet compared to the addition of soy oil. These data also suggest that glycerol will improve the flow ability of diets with added spray-dried whey. Our experiments suggest that flow ability of feed will be improved by the addition of glycerol, especially when added to diets containing corn ground through a hammer mill.

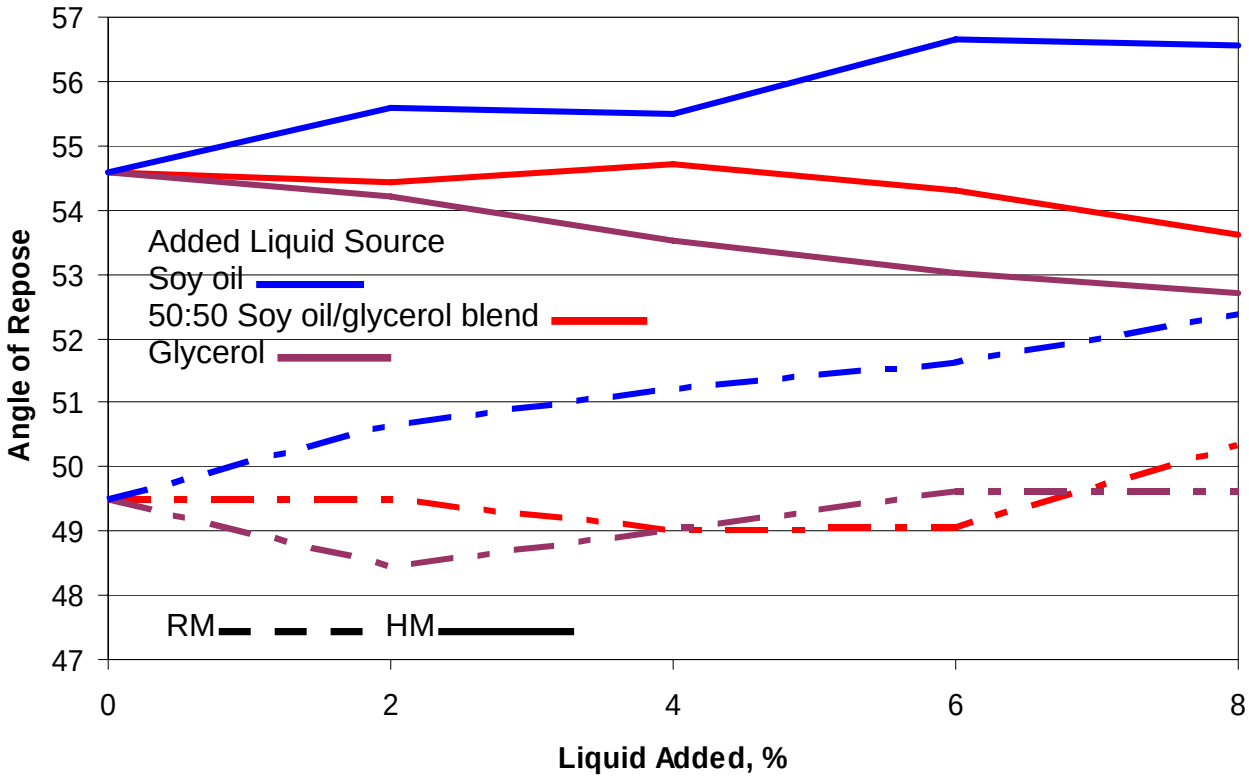

Figure 1. Influence of Corn Ground Through a Hammer (HM) or Roller (RM) Mill, Liquid Source, and Liquid Level on Angle of Repose (Mill type × liquid source × percent liquid interaction (*P*<0.05).

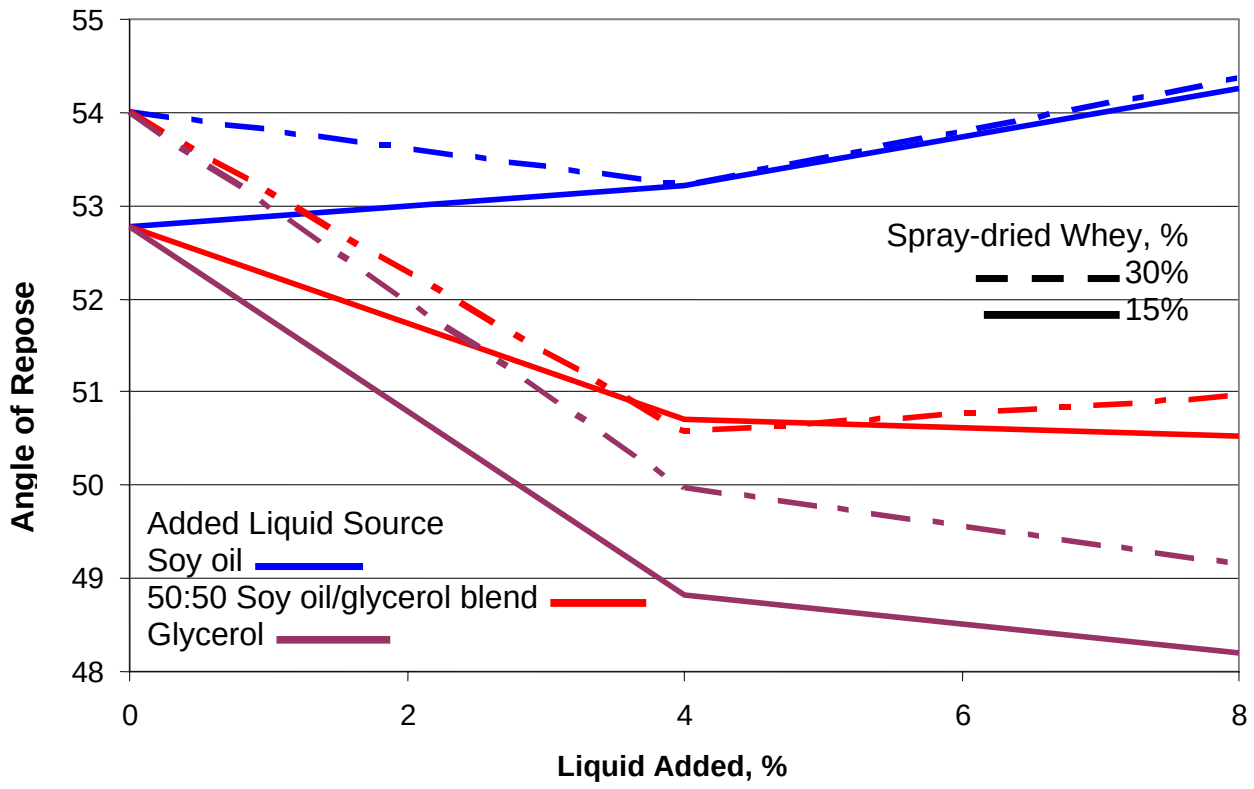

Figure 2. Influence of Spray-dried Whey Level, Liquid Source, and Percent Liquid Added on Angle of Repose (Spray-dried whey level × liquid source, × percent liquid interaction, *P*<0.05).

EFFECT OF HUMIDITY ON FLOW ABILITY OF SPECIALTY PROTEIN SOURCES IN NURSERY DIETS

E. E. Carney, C. N. Groesbeck, R. D. Goodband, S. S. Dritz[1], M. D. Tokach, J. L. Nelssen, and J. M. DeRouchey

Summary

We conducted an experiment to determine the effects of humidity on angle of repose (flowabilty) of different specialty protein sources. Five specialty proteins sources were used: fish meal, powdered blood meal (AP301), granulated blood meal (AP301G), powdered spray-dried animal plasma (AP920), and granulated spray-dried animal plasma (Appetein). The specialty protein sources were added at 0, 2.5, 5, 7.5, and 10% to a 70:30 corn-soybean meal blend. The experiment was conducted in an environmentally controlled nursery to minimize temperature and humidity fluctuations. There were two relative humidity levels, 34 and 64%. All samples were placed in the barn 24 h before the experiment was conducted to allow acclimation to the conditions. Flow ability was then determined by measuring angle of repose. Angle of repose is the maximum angle in which a pile of ingredient retains its slope. A large angle of repose represents a steeper slope and poorer flow ability. There was a protein source × inclusion level × humidity interaction observed ($P<0.01$). Humidity increased angle of repose, decreasing flow ability. Angle of repose increased with increasing inclusions of powdered animal plasma and fish meal, resulting in poorer flow ability. Powdered blood cells did not affect angle of repose with increasing inclusion levels. Angle of repose decreased as granular animal plasma and blood cell inclusions increased, improving flow ability. In conclusion, specialty protein ingredients in powder form reduce flow ability, while granulated specialty protein sources improve flow ability.

(Key words: feed manufacturing, angle of repose, humidity.)

Introduction

Specialty protein sources are often included in nursery pig diets to stimulate feed intake and improve growth performance. High concentrations of these ingredients, unless pelleted, frequently increase the incidence of bridging in bins and feeders. If these ingredients would flow easier in a meal diet, it would give producers and nutritionists more options in diet formulation. It would also mean fewer "out of feed" occurrences. Quantifying the differences in flow ability among different ingredients could also justify the selection of one ingredient over another. Previous research confirms that specialty ingredients influence the flow ability of nursery diets. Previous data also demonstrated that granular specialty protein sources improve flow ability

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compared with powdered products. Specialty protein sources in powder form decrease flow ability. However, these prior research trials were conducted in a laboratory environment and not under typical nursery barn conditions. Humidity is one factor that could contribute to feed handling issues. The increase in humidity in a barn could result in an increase in water absorbed by specialty ingredients included in the diet and cause an increase in feed bridging and handling issues. Therefore, the objective of the study was to evaluate the effects of humidity on angle of repose (a measure of flow ability) of different specialty protein sources.

Procedures

Five specialty proteins sources were used: fish meal, powdered blood meal (AP301), granulated blood meal (AP301G), powdered spray-dried animal plasma (AP920), and granulated spray-dried animal plasma (Appetein). The specialty protein sources were added at 0, 2.5, 5, 7.5, and 10% to a 70:30 corn-soybean meal blend.

This experiment was conducted in an environmentally controlled nursery to minimize temperature and humidity fluctuations. The experiment was conducted at two relative humidity levels of 34 and 64%. All samples were placed into the environmentally controlled nursery 24 h before the experiment was conducted to allow acclimation of the ingredients to the environmental conditions. Temperature was held constant at 90°F. Temperature and humidity were monitored throughout the acclimation period. Six digital humidity and temperature recorders were placed in the nursery to measure minimum and maximum temperature and humidity. Flow ability was determined by measuring angle of repose. Angle of repose was replicated three times with each sample.

Angle of repose is defined as the maximum angle measured in degrees at which a pile of grain retains its slope. An angle of repose tester was constructed from four pieces of poly vinyl chloride (PVC). The tester was 3" in diameter and 36" tall and attached to a 3" PVC floor mounting. A 3" diameter plate was mounted to the top of the machine, which allowed two 3" PVC couplers to slide up and down the long axis of the tester. To conduct the angle of repose test, a 500 g sample was placed inside the couplers at a specified height at the top of the tester. The base of the angle of repose tester was held stationary and the PVC couplers were lifted vertically, allowing the test ingredient to flow downward resulting in a pile on top of the plate. The height of the pile was measured and angle of repose was calculated by the following equation: angle of repose = $\tan^{-1}$ (the height of the pile divided by one half the diameter of the plate). A larger angle of repose represents a steeper slope and poorly flowing product; a low angle of repose represents a freer flowing product.

All data was analyzed using PROC MIXED in SAS 8.1. Ingredient source and inclusion level were modeled and parameter estimates were then obtained to develop regression equations. A graph showing the modeled data was generated.

Results and Discussion

There was a protein source × inclusion level × humidity interaction observed (Figure 1, $P<0.01$). Spray-dried animal plasma in powder form increased angle of repose as inclusion level increased, decreasing flow ability. There was little to no increase in angle of repose with increasing powdered spray-dried blood cells. The granulated spray-dried blood cells and animal plasma decreased angle of repose, improving flow ability compared with the powdered ingredients. Increasing the inclusion level of fish meal resulted in an increase in angle of repose, decreasing flow ability. This response was not expected since previous research demonstrated no change in angle of repose with increasing inclusions of

fish meal. Although the source was the same as our previous research, the fish meal used in this experiment may have had smaller particle size or been more hydroscopic than fish meal used previously. As relative humidity was increased from 34 to 64%, angle of repose increased (poorer flow ability) for all ingredients. All ingredients followed the same trends at both humidity levels.

These data confirm that humidity, ingredient inclusion percentage, and ingredient form (powder or granulated) will affect flow ability of diets fed in meal form. Humidity increased angle of repose, which decreased flow ability of meal diets. Specialty protein ingredients in powder form reduce flow ability, although granulated specialty protein sources improve flow ability.

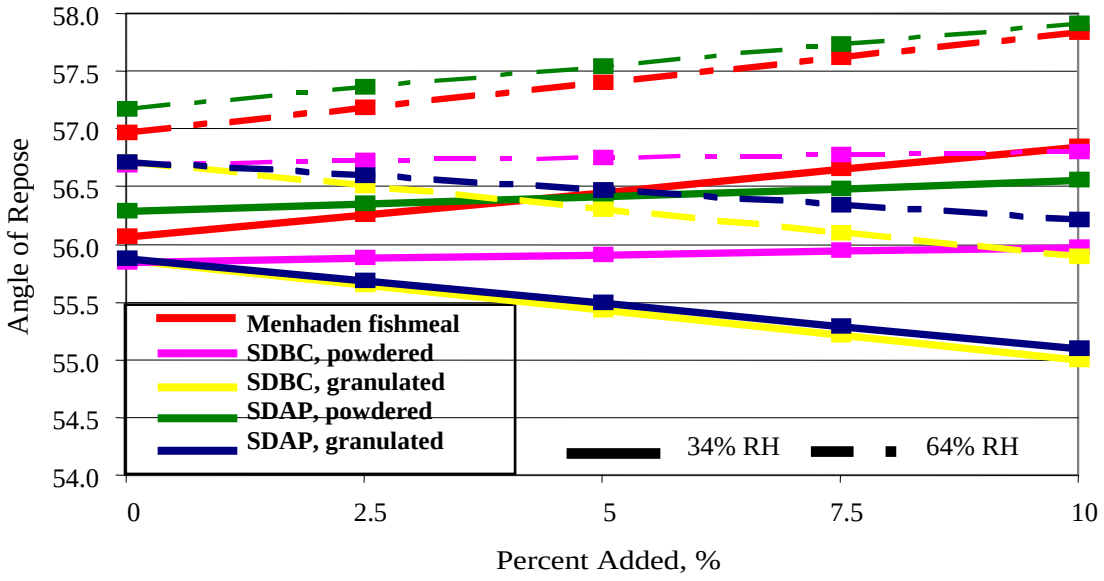

Figure 1. There was a specialty protein source × inclusion level × humidity interaction ($P<0.01$). Angle of repose increased with increasing inclusions of powdered animal plasma and fish meal, resulting in poorer flow ability. Powdered blood cells did not affect angle of repose with increasing inclusion levels. Angle of repose decreased as granular animal plasma and blood cell inclusions increased, improving flow ability. Humidity increased angle of repose, decreasing flow ability.

INDEX OF KEY WORDS

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