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SWINE DAY 2010

Report of Progress 1038

K-STATE Kansas State University Research and Extension

Kansas State University Agricultural Experiment Station and Cooperative Extension Service

KANSAS STATE UNIVERSITY SWINE INDUSTRY DAY 2010

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SWINE DAY 2010

Foreword

It is with great pleasure that we present the 2010 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.

2010 Swine Day Report of Progress Editors

Bob Goodband Mike Tokach Steve Dritz Joel DeRouchey

Standard Abbreviations

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

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K-State Vitamin and Trace Mineral Premixes

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

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

Note

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

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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.

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Effect of Standardized Ileal Digestible Lysine Level on Growth Performance of Nursery Pigs from 15 to 25 lb[1]

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

Summary

A total of 294 nursery pigs (PIC TR4 × 1050, initially 14.9 lb and 3 d postweaning) were used in a 28-d growth trial to evaluate the effects of standardized ileal digestible (SID) lysine level on pig growth performance. Pigs were allotted to 1 of 6 dietary treatments. There were 7 pigs per pen and 7 pens per treatment. Pigs and feeders were weighed on d 0, 7, 14, 21, and 28 to calculate ADG, ADFI, and F/G. A 2-phase diet series was used, with treatment diets fed from d 0 to 14 and a common diet fed from d 14 to 28. All diets were in meal form. The 6 SID lysine levels were 1.15, 1.23, 1.30, 1.38, 1.45, and 1.53%. From d 0 to 14, ADG and ADFI increased (quadratic; $P < 0.002$) as SID lysine level increased from 1.15 to 1.30% where it began to plateau with no additional benefit observed from the three highest dietary lysine levels. Feed efficiency also improved (linear; $P < 0.0001$) with increasing dietary lysine. From d 14 to 28, when the common diet was fed, there were no differences ($P > 0.36$) in ADG, ADFI, or F/G. For the overall trial (d 0 to 28), the greatest improvement (quadratic; $P < 0.05$) in ADG and ADFI was observed in pigs fed 1.30% SID lysine from d 0 to14; however, there was no difference ($P > 0.11$) in overall F/G. In conclusion, the SID lysine requirement of 15- to 25-lb pigs was 1.30% or 3.86 g lysine/Mcal ME.

Key words: lysine, amino acid requirements, nursery pig

Introduction

Lysine is the first limiting amino acid in many corn-soybean meal swine-diet formulations and is used as a reference point to formulate the required levels of other essential amino acids. These amino acid levels are typically expressed as a ratio relative to lysine. In addition, several experiments have been conducted to replace expensive specialty protein sources (fish meal, blood products, poultry meal, etc.) in the diet with crystalline amino acids for 15- to 25-lb pigs. Use of the amino acids has resulted in similar performance to that of the specialty protein sources in some trials, but not in others. To allow diet formulations with higher levels of synthetic amino acids while removing specialty protein sources, we conducted a series of experiments to determine the reason for response inconsistency between experiments and to help determine the minimum ratio for the key amino acids relative to lysine.

1 The authors wish to thank Ajinomoto Heartland LLC, Chicago, IL, for providing the synthetic amino acids used in diet formulation and partial financial support.

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

[3] Ajinomoto Heartland LLC, Chicago, IL.

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To establish essential amino acid requirements of nursery pigs relative to lysine, the first step is to confirm an appropriate lysine level. Therefore, the objective of this study was to establish the standardized ileal digestible (SID) lysine level required for optimal growth performance of 15- to 25-lb pigs fed a Phase-2 nursery diet. This information can then be used to conduct further trials to determine the requirements of other essential amino acids.

Procedure

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

A total of 294 nursery pigs (PIC TR4 × 1050, initially 14.9 lb) were used in a 28-d growth trial to evaluate the effects of SID lysine level on growth performance. Pigs were weaned at approximately 21 d of age and fed a common diet for 3 d. At weaning, pigs were allotted to pens by initial BW to achieve the same average weight for all pens. On d 3 after weaning, pens were allotted to 1 of 6 dietary treatments. Thus, d 3 after weaning was d 0 of the experiment. There were 7 pigs per pen and 7 pens per treatment. Each pen contained a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water. Pigs and feeders were weighed on d 0, 7, 14, 21, and 28 to calculate ADG, ADFI, and F/G.

A 2-phase diet series was used, with treatment diets fed from d 0 to 14 and a common diet fed from d 14 to 28 (Table 1). The 6 SID lysine levels were 1.15, 1.23, 1.30, 1.38, 1.45, and 1.53% (Table 2). Large batches of the 1.15 and 1.53% lysine diets were made and then blended to achieve the intermediate lysine levels. Treatment diets were corn-soybean meal based and contained 10% dried whey and 4.5% fish meal. The common diet fed in Phase 3 was a corn-soybean meal-based diet formulated to 1.26% SID lysine. All experimental diets were in meal form and were prepared at the K-State Animal Science Feed Mill.

Experimental data were analyzed for linear and quadratic effects of increasing SID lysine using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). Pen was the experimental unit for all data analysis.

Results and Discussion

From d 0 to 14, ADG and ADFI increased (quadratic; $P < 0.002$, Table 3) as SID lysine increased from 1.15 to 1.30%. There was no further increase in growth rate with the three highest dietary lysine levels. Feed efficiency improved linearly ($P < 0.0001$) with increasing SID lysine.

From d 14 to 28, when the common diet was fed, there was no difference ($P > 0.36$) in ADG, ADFI, or F/G. This suggests that the lysine level fed from d 0 to 14 had no effect on subsequent pig performance.

Because of the improvement in ADG and ADFI from d 0 to 14, ADG and ADFI increased (quadratic; $P < 0.05$) for the overall trial (d 0 to 28) as SID lysine increased. Again, the greatest ADG and ADFI was observed in pigs fed the 1.30% SID lysine

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during Phase 1. There was no difference (P > 0.11) in F/G for the overall period. In conclusion, 1.30% SID lysine was required for optimal growth of 15- to 25-lb pigs.

Table 1. Diet composition (as-fed basis)

	Phase 1 standardized ileal digestible lysine, %[1]						Common
Item	1.15	1.23	1.30	1.38	1.45	1.53	Phase 2[2]
Ingredient, %							
Corn	61.12	58.85	56.58	54.31	52.04	49.77	65.05
Soybean meal (46.5% CP)	20.80	23.00	25.21	27.41	29.62	31.83	30.73
Spray-dried whey	10.00	10.00	10.00	10.00	10.00	10.00	-
Select menhaden fish meal	4.50	4.50	4.50	4.50	4.50	4.50	-
Soybean oil	1.00	1.00	1.00	1.00	1.00	1.00	-
Monocalcium phosphate (21% P)	0.55	0.53	0.51	0.49	0.47	0.45	1.08
Limestone	0.55	0.55	0.55	0.55	0.55	0.55	0.95
Salt	0.30	0.30	0.30	0.30	0.30	0.30	0.35
Zinc oxide	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
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25	0.25
L-Lysine HCl	0.225	0.250	0.275	0.300	0.325	0.350	0.360
DL-Methionine	0.080	0.102	0.124	0.146	0.168	0.190	0.130
L-Threonine	0.100	0.118	0.136	0.154	0.172	0.190	0.130
L-Tryptophan	0.040	0.043	0.046	0.049	0.052	0.055	-
L-Valine	0.005	0.021	0.037	0.053	0.069	0.085	-
Phytase[3]	0.085	0.085	0.085	0.085	0.085	0.085	0.165
TOTAL	100	100	100	100	100	100	100
Calculated analysis							
Standardized ileal digestible (SID) amino acids, %							
Lysine	1.15	1.23	1.30	1.38	1.45	1.53	1.26
Isoleucine:lysine	62	61	60	60	59	59	61
Leucine:lysine	132	128	125	122	119	116	129
Methionine:lysine	34	34	35	35	36	36	33
Met & Cys:lysine	58	58	58	58	58	58	58
Threonine:lysine	64	64	64	64	64	64	63
Tryptophan:lysine	20	20	20	20	20	20	17.4
Valine:lysine	70	70	70	70	70	70	68
Total lysine, %	1.27	1.35	1.43	1.51	1.59	1.67	1.39
ME, kcal/lb	1,528	1,528	1,528	1,529	1,529	1,530	1,503
SID lysine:ME, g/Mcal	3.41	3.64	3.86	4.08	4.30	4.52	3.80
CP, %	19.3	20.2	21.1	22.0	22.9	23.8	20.8
Ca, %	0.71	0.71	0.72	0.72	0.72	0.72	0.69
P, %	0.64	0.64	0.65	0.65	0.66	0.66	0.62
Available P, %	0.47	0.47	0.47	0.47	0.47	0.47	0.42

[1] Treatment diets were fed from d 0 to 14.
[2] Common diet was fed from d 14 to 28.
[3] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO.) provided 231 FTU/lb, with a release of 0.10% available P.

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Table 2. Analyzed nutrient composition of experimental diets (as-fed basis)[1]

	Phase 1 standardized ileal digestible lysine, %					
Nutrient, %	1.15	1.23	1.30	1.38	1.45	1.53
DM	88.58	88.30	88.66	88.52	88.69	88.72
CP	18.52	19.42	20.21	20.44	22.70	23.09
Indispensable AA						
Arg	1.10	1.17	1.21	1.25	1.35	1.40
His	0.50	0.49	0.51	0.52	0.53	0.57
Ile	0.78	0.79	0.84	0.89	0.92	0.95
Leu	1.63	1.68	1.73	1.76	1.84	1.89
Lys	1.20	1.24	1.34	1.39	1.46	1.50
Met	0.41	0.42	0.46	0.48	0.47	0.51
Phe	0.91	0.94	0.98	1.00	1.06	1.10
Thr	0.83	0.85	0.90	0.95	0.97	1.01
Trp	0.26	0.26	0.28	0.30	0.32	0.32
Val	0.86	0.90	0.96	1.00	1.07	1.09
Total indispensable AA	8.48	8.74	9.21	9.54	9.99	10.34
Dispensable AA						
Ala	0.99	0.96	0.99	1.03	1.10	1.12
Asp	1.79	1.88	1.99	2.06	2.20	2.28
Cys	0.27	0.28	0.29	0.30	0.31	0.32
Glu	3.12	3.26	3.40	3.51	3.70	3.84
Gly	0.80	0.82	0.86	0.90	0.94	0.96
Pro	1.00	1.02	1.07	1.11	1.07	1.19
Ser	0.88	0.92	0.97	1.00	1.04	1.09
Tyr	0.54	0.56	0.58	0.59	0.64	0.63
Total dispensable AA	9.39	9.70	10.15	10.50	11.00	11.43

[1] A representative sample of each diet was collected and analyzed for amino acid composition.

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Table 3. Evaluation of standardized ileal digestible (SID) lysine on growth performance of nursery pig diets[1, 2]

	SID lysine, %[3]							Probability, $P <$	
	1.15	1.23	1.30	1.38	1.45	1.53	SEM	Linear	Quadratic
d 0 to 14									
ADG, lb	0.64	0.67	0.75	0.72	0.73	0.63	0.03	0.80	0.001
ADFI, lb	0.86	0.87	0.96	0.87	0.88	0.74	0.04	0.04	0.002
F/G	1.35	1.29	1.27	1.21	1.21	1.18	0.02	0.0001	0.30
d 14 to 28									
ADG, lb	1.04	1.06	1.04	1.05	1.00	1.04	0.04	0.54	0.96
ADFI, lb	1.76	1.79	1.82	1.76	1.77	1.75	0.04	0.61	0.36
F/G	1.70	1.69	1.76	1.68	1.77	1.68	0.05	0.79	0.44
d 0 to 28									
ADG, lb	0.84	0.87	0.90	0.89	0.87	0.83	0.03	0.81	0.05
ADFI, lb	1.31	1.33	1.39	1.32	1.33	1.24	0.03	0.17	0.03
F/G	1.56	1.53	1.55	1.49	1.53	1.50	0.03	0.11	0.86
wt, lb									
d 0	14.9	14.9	14.9	14.9	14.9	14.9	1.28	0.95	0.90
d 14	23.8	24.3	25.4	25.0	25.1	23.7	3.40	0.75	0.001
d 28	38.4	39.1	40.2	39.8	39.1	38.3	6.65	0.82	0.11

[1] A total of 294 nursery pigs (initially 14.9 lb) were used in a 28-d growth trial to evaluate the effects of SID lysine level on growth performance. There were 7 pigs per pen and 7 pens per treatment. Pigs were weaned at approximately 21 d of age, fed a common diet for 3 d, and then started on test.

[2] Treatment diets were fed from d 0 to 14 and a common diet fed from d 14 to 28.

[3] Corresponding SID Lysine:ME, g/Mcal ratios were 3.41, 3.64, 3.86, 4.08, 4.30 and 4.52, respectively.

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Effect of Replacing Fish Meal with Crystalline Amino Acids on Growth Performance of Nursery Pigs from 15 to 25 lb[1]

J. E. Nemechek, M. D. Tokach, S. S. Dritz[1], R. D. Goodband, J. M. DeRouchey, J. L. Nelssen, and J. Usry[2]

Summary

A total of 282 nursery pigs (PIC TR4 × 1050, initially 16.1 lb, 3 d postweaning) were used in a 28-d growth trial to evaluate the effects of replacing fish meal with crystalline amino acids on growth performance. Pigs were allotted to 1 of 6 dietary treatments with 7 replications per treatment. There were 5 replications with 7 pigs per pen and 2 replications with 6 pigs per pen. Pigs and feeders were weighed on d 0, 7, 14, 21, and 28 to calculate ADG, ADFI, and F/G. A 2-phase diet series was used, with treatment diets fed from d 0 to 14 and a common diet fed from d 14 to 28. All diets were in meal form. For the 6 dietary treatments, the fish meal was included at: 4.50, 3.60, 2.70, 1.80, 0.90, and 0.00% respectively. Crystalline lysine, methionine, threonine, tryptophan, isoleucine, and valine all increased as fish meal decreased to maintain minimum amino acid ratios. Also, increasing amounts of glutamine and glycine were used in diets containing 3.60% to 0.00% fish meal to maintain a lysine-to-CP ratio. From d 0 to 14, there was no difference ($P > 0.29$) in ADG, ADFI, or F/G as the level of fish meal decreased and crystalline amino acids increased. From d 14 to 28 (common diet period), no clear effects ($P > 0.09$) on growth performance were detected. Overall (d 0 to 28), there was no difference ($P > 0.16$) in ADG or ADFI. For F/G, a quadratic effect ($P < 0.04$) was detected, which was the result of small improvements in F/G at the intermediate fish meal levels (2.70 and 1.80). In conclusion, these data suggest that crystalline amino acids, when balanced for minimum amino acid ratios, can be used to replace fish meal in diets for 15- to 25-lb pigs.

Key words: fish meal, crystalline amino acids, amino acid requirements

Introduction

Several experiments have been conducted in which expensive specialty protein sources (fish meal, blood products, poultry meal, etc.) were replaced with crystalline amino acids in the diet for 15- to 25-lb pigs. These experiments have yielded mixed results. Recently at Kansas State University (K-State), a series of experiments has been conducted to determine the reason for inconsistency. The experiments also will help determine the minimum ratio for other amino acids relative to lysine in order to allow formulation with higher levels of crystalline amino acids and removal of dietary specialty protein sources. The objective of this study was to determine the effects of replacing fish meal with crystalline amino acids on growth performance of nursery pigs from 15 to 25 lb.

[1] The authors wish to thank Ajinomoto Heartland LLC, Chicago, IL, for providing the synthetic amino acids used in diet formulation and partial financial support.

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

[3] Ajinomoto Heartland LLC, Chicago, IL.

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Procedure

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

A total of 282 nursery pigs (PIC TR4 × 1050, initially 16.1 lb) were used in a 28-d trial to evaluate the effect on growth performance of replacing dietary fish meal with crystalline amino acids. Pigs were weaned at approximately 21 d of age and allotted to pens by initial BW to achieve the same average pen weight. Pigs were fed a common pelleted SEW diet for 3 d. On d 3 postweaning, pens were allotted to 1 of 6 dietary treatments with 7 replications per treatment. Thus, d 3 postweaning was d 0 of the experiment. . Each treatment had 5 replications with 7 pigs per pen and 2 replications with 6 pigs per pen.

A 2-phase diet series was used, with treatment diets fed from d 0 to 14 and a common diet fed from d 14 to 28 (Table 1). For the 6 dietary treatments, 4.50, 3.60, 2.70, 1.80, 0.90, and 0.00% fish meal was added, respectively. Crystalline lysine, methionine, threonine, tryptophan, isoleucine, and valine all increased as fish meal decreased to maintain minimum amino acid ratios. Also, increasing amounts of glutamine and glycine were used in diets containing 3.60% to 0.00% fish meal to maintain a lysine-to-CP ratio of no more than 7:1. Large batches of the 4.50 and 0.00% fish meal diets were first manufactured then blended to achieve the intermediate diets. Treatment diets were corn-soybean meal-based and contained 10% dried whey. The common diet was corn-soybean meal-based diet formulated to contain 1.26% standardized ileal digestible lysine. All experimental diets were in meal form and were prepared at the K-State Animal Science Feed Mill. Each pen contained a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water. Pigs and feeders were weighed on d 0, 7, 14, 21, and 28 to calculate ADG, ADFI, and F/G.

Data were analyzed using orthogonal polynomial contrasts to determine the effect of decreasing dietary fish meal. The PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) was used for statistical analysis. Pen was the experimental unit for all data analysis.

Results and Discussion

From d 0 to 14 (treatment diet period), there was no difference ($P > 0.29$, Table 2) in ADG, ADFI, or F/G as dietary fish meal decreased and crystalline amino acids increased. From d 14 to 28 (common diet period), no clear effects ($P > 0.09$) on growth performance were detected.

Overall (d 0 to 28), there were no differences ($P > 0.16$) in ADG or ADFI. For F/G, a quadratic effect ($P < 0.04$) was detected, which was the result of small improvements in F/G at the intermediate fish meal levels (2.70 and 1.80% fish meal).

The diet formulation used in this experiment suggests that crystalline amino acids can be used to replace fish meal in diets for 15- to 25-lb pigs.

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Table 1. Diet composition (as fed)

Item	Phase 1[1]						Common phase 2[2]
Fish meal, %:	4.50	3.60	2.70	1.80	0.90	0.00	
Ingredient, %							
Corn	56.58	56.83	57.07	57.53	57.57	57.81	65.05
Soybean meal (46.5% CP)	25.21	25.21	25.20	25.20	25.20	25.19	30.73
Spray-dried whey	10.00	10.00	10.00	10.00	10.00	10.00	-
Select menhaden fish meal	4.50	3.60	2.70	1.80	0.90	-	-
Soybean oil	1.00	1.00	1.00	1.00	1.00	1.00	-
Monocalcium P (21% P)	0.51	0.63	0.75	0.86	0.98	1.10	1.08
Limestone	0.55	0.62	0.69	0.76	0.83	0.90	0.95
Salt	0.30	0.31	0.32	0.33	0.34	0.35	0.35
Zinc oxide	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
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25	0.25
L-lysine HCl	0.275	0.327	0.379	0.430	0.482	0.534	0.360
DL-methionine	0.124	0.143	0.162	0.182	0.201	0.220	0.130
L-threonine	0.136	0.155	0.174	0.192	0.211	0.230	0.130
L-tryptophan	0.046	0.051	0.056	0.060	0.065	0.070	-
L-isoleucine	-	0.02	0.04	0.06	0.08	0.10	-
L-valine	0.037	0.062	0.086	0.111	0.135	0.160	-
Glutamine	-	0.16	0.32	0.48	0.64	0.80	-
Glycine	-	0.16	0.32	0.48	0.64	0.80	-
Phytase[3]	0.085	0.085	0.085	0.085	0.085	0.085	0.165
TOTAL	100	100	100	100	100	100	100
Calculated analysis							
Standardized ileal digestible amino acids, %							
Lysine	1.30	1.30	1.30	1.30	1.30	1.30	1.26
Isoleucine:lysine	60	60	60	60	60	60	61
Leucine:lysine	125	122	119	116	114	111	129
Methionine:lysine	35	35	35	36	36	36	33
Met & Cys:lysine	58	58	58	58	58	58	58
Threonine:lysine	64	64	64	64	64	64	63
Tryptophan:lysine	20	20	20	20	20	20	17.4
Valine:lysine	70	70	70	70	70	70	68
Total lysine, %	1.43	1.43	1.43	1.42	1.42	1.42	1.39
ME, kcal/lb	1,528	1,527	1,525	1,523	1,522	1,520	1,503
SID lysine:ME, g/Mcal	3.86	3.86	3.87	3.87	3.87	3.88	3.80
CP, %	21.1	20.9	20.8	20.6	20.5	20.3	20.8
Ca, %	0.72	0.72	0.72	0.72	0.72	0.72	0.69
P, %	0.65	0.65	0.64	0.64	0.64	0.64	0.62
Available P, %	0.47	0.47	0.47	0.47	0.47	0.47	0.42

[1] Treatment diets were fed from d 0 to 14.
[2] Common diet was fed from d 14 to 28.
[3] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 231 FTU/lb, with a release of 0.10% available P.

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Table 2. Evaluation of replacing fish meal with crystalline amino acids on growth performance in nursery pig diets[1, 2]

	Fish meal, %							Probability, $P <$		
Item	4.50	3.60	2.70	1.80	0.90	0.00	SEM	Treatment	Linear	Quadratic
d 0 to 14										
ADG, lb	0.83	0.82	0.86	0.83	0.84	0.84	0.024	0.92	0.71	0.73
ADFI, lb	1.17	1.14	1.18	1.16	1.17	1.20	0.035	0.86	0.38	0.62
F/G	1.41	1.39	1.38	1.40	1.40	1.44	0.034	0.88	0.49	0.29
d 14 to 28										
ADG, lb	1.28	1.22	1.28	1.16	1.24	1.21	0.029	0.07	0.11	0.45
ADFI, lb	2.10	2.00	2.08	1.90	2.06	2.03	0.042	0.02	0.31	0.09
F/G	1.65	1.64	1.63	1.64	1.67	1.68	0.024	0.65	0.21	0.23
d 0 to 28										
ADG, lb	1.05	1.02	1.07	1.00	1.04	1.02	0.020	0.19	0.34	0.71
ADFI, lb	1.63	1.57	1.63	1.53	1.62	1.62	0.032	0.16	0.86	0.16
F/G	1.55	1.54	1.53	1.53	1.56	1.58	0.016	0.22	0.12	0.04
wt, lb										
d 0	16.0	16.1	16.0	16.2	16.2	16.1	0.17	0.96	0.68	0.70
d 14	27.6	27.6	28.0	27.8	27.9	27.8	0.40	0.98	0.64	0.66
d 28	45.5	44.7	45.7	44.1	45.2	44.7	0.66	0.56	0.50	0.74

[1] A total of 282 nursery pigs (initially 16.1 lb) were used in a 28-d trial to evaluate the effects of replacing fish meal with crystalline amino acids on growth performance.

[2] Treatment diets were fed from d 0 to 14 and a common diet fed from d 14 to 28.

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Evaluation of Deleting Crystalline Amino Acids from Low-CP, Amino Acid-Fortified Diets on Growth Performance of Nursery Pigs from 15 to 25 lb[1]

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

Summary

A total of 294 nursery pigs (PIC TR4 × 1050, initially 15.2 lb, 3 d postweaning) were used in a 28-d trial to evaluate the effects on growth performance of eliminating specific crystalline amino acids from a low-CP, amino acid-fortified diet. On d 3 after weaning, pigs were allotted to 1 of 6 dietary treatments. A 2-phase diet series was used, with treatment diets fed from d 0 to 14 and a common diet fed from d 14 to 28. All diets were in meal form. The formulation was based on data from previous trials in which fish meal was replaced with crystalline amino acids in the diet for 15- to 25-lb pigs. The objective of this trial was to determine which amino acids are required in this low-CP, amino acid-fortified diet. The positive control diet contained L-lysine HCl, DL-methionine, L-threonine, L-isoleucine, L-tryptophan, L-valine, L-glutamine, and L-glycine. The 6 treatments were (1) positive control, (2) positive control with L-isoleucine deleted from the diet, (3) positive control with L-tryptophan deleted, (4) positive control L-valine deleted, (5) positive control with L-glutamine and L-glycine deleted, and (6) positive control with L-isoleucine, L-tryptophan, L-valine, L-glutamine, and L-glycine deleted from diet (negative control). There were 7 pigs per pen and 7 pens per treatment. Pigs and feeders were weighed on d 0, 7, 14, 21, and 28 to calculate ADG, ADFI, and F/G. From d 0 to 14, pigs fed the positive control diet had improved ($P < 0.03$) ADG and ADFI compared with pigs fed the negative control or diets with L-tryptophan or L-valine deleted, with pigs fed the diet without crystalline glutamine and glycine being intermediate. The pigs fed the diet containing no crystalline isoleucine had similar ($P > 0.40$) ADG, ADFI, and F/G to pigs fed the positive control, but had improved ($P < 0.03$) ADG compared to the pigs fed the other 4 diets. For unknown reasons, when the common diet was fed from d 14 to 28, the deletion of crystalline isoleucine in the previous period caused a decrease ($P < 0.01$) in ADG compared to the positive control. Pigs from the other treatment groups had similar ($P > 0.12$) ADG to the positive control. There were no differences ($P > 0.10$) in ADFI from d 14 to 28. Because of the decrease in ADG from d 0 to 14, pigs fed the negative control or diets without L-tryptophan or L-valine had decreased ($P < 0.04$) ADG for the overall trial (d 0 to 28) compared to pigs fed the positive control. ADFI from all treatment diets decreased compared to the positive control, although only the negative control group tested significantly ($P < 0.04$). There was no difference ($P > 0.24$) in F/G for the overall data. In conclusion, L-tryptophan and L-valine were needed in the low-CP, high amino acid-fortified

[1] Appreciation is expressed to Ajinomoto Heartland LLC, Chicago, IL, for providing the crystalline amino acids used in diet formulation and partial financial support.

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

[3] Ajinomoto Heartland LLC, Chicago, IL.

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nursery diet to achieve maximum growth performance from 15 to 25 lb. This suggests that the tryptophan:lysine and valine:lysine requirements are greater than 15 and 57% of lysine, respectively. The numerical decrease in performance when L-glutamine and L-glycine were removed from the diet during the first period suggests a need for nonessential nitrogen in the low-CP, amino acid-fortified diet or a benefit to one of these amino acids separate from its role as a nitrogen source.

Key words: amino acid requirement, glutamine, glycine, isoleucine, tryptophan, valine

Introduction

Several experiments have been conducted to replace expensive specialty protein sources (fish meal, blood products, poultry meal, etc.) with crystalline amino acids in the diet for 15- to 25-lb pigs. The experiments have yielded mixed results. A series of experiments have been conducted to determine the reason for inconsistency. Defining the minimum ratio for the key amino acids relative to lysine is essential to allow diet formulations with higher levels of crystalline amino acids and removal of the specialty protein sources. This will ensure that amino acid requirements relative to lysine are not responsible for the inconsistent responses.

Results from other experiments included in this publication have led to several conclusions about amino acid requirements of nursery pigs from 15 to 25 lb. A lysine titration test was first conducted to determine the standardized ileal digestible (SID) lysine level for optimal growth, which resulted in a value of 1.30% SID lysine. This lysine level was then used to perform an experiment that suggests fish meal can be replaced by crystalline amino acids when balanced for minimum amino acid requirements. Subsequently, the diet without fish meal and including crystalline amino acids was used in this study for further investigation. The object of this study was to determine if L-isoleucine, L-tryptophan, L-valine, and a combination of L-glutamine and L-glycine are required in the low-CP, amino acid-fortified diets for optimal growth performance of nursery pigs from 15 to 25 lb. Once the requirement of individual amino acids is determined, the base diet can be used to determine the ratio of those amino acids relative to lysine.

Procedure

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

A total of 294 weanling pigs (PIC TR4 × 1050, initially 15.2 lb, 3 d postweaning) were used in a 28-d trial to evaluate the effects of eliminating specific crystalline amino acids from a low-CP, amino acid-fortified diet on growth performance. Pigs were weaned at approximately 21 d of age and allotted to pens by initial BW to achieve the same average pen weight for all pens. Pigs were fed a common pelleted, segregated early weaning diet for 3 d. On d 3 postweaning, pens were allotted to 1 of 6 dietary treatments. Thus, d 3 after weaning was d 0 of the experiment. There were 7 pigs per pen and 7 pens per treatment. Each pen contained a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water. Pigs and feeders were weighed on d 0, 7, 14, 21, and 28 to calculate ADG, ADFI, and F/G.

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A 2-phase diet series was used, with treatment diets fed from d 0 to 14 and a common diet fed from d 14 to 28 (Table 1). The positive control diet contained L-lysine, DL-methionine, L-threonine, L-isoleucine, L-tryptophan, L-valine, L-glutamine, and L-glycine. The 6 treatments were (1) positive control, (2) positive control with L-isoleucine deleted from the diet, (3) positive control with L-tryptophan deleted, (4) positive control with L-valine deleted, (5) positive control with L-glutamine and L-glycine deleted, and (6) positive control with L-isoleucine, L-tryptophan, L-valine, L-glutamine, and L-glycine removed from diet. Treatment 6 served as the negative control diet. Treatment diets were corn-soybean meal-based and contained 10% dried whey. The common Phase-2 diet was a corn-soybean meal-based diet formulated to 1.26% SID lysine. All experimental diets were in meal form and were prepared at the K-State Animal Science Feed Mill.

Although analyzed lysine levels were lower than expected, amino acid analysis verified the removal of each individual crystalline amino acid in the experimental diets (Table 2).

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

Results and Discussion

From d 0 to 14 (treatment diet period), the pigs fed the positive control diet had increased ($P < 0.03$) ADG and ADFI compared with pigs fed the negative control diet or diets with L-tryptophan or L-valine deleted (Table 3). The pigs fed the diet containing no crystalline isoleucine had similar ($P > 0.40$) ADG, ADFI, and F/G as pigs fed the positive control, but had increased ($P < 0.03$) ADG compared to the pigs fed the other 4 diets. Pigs fed the diet without L-glutamine and L-glycine had intermediate performance. There were no differences ($P > 0.10$) in F/G between any of the treatments during the first period.

From d 14 to 28, when the common diet was fed, pigs fed the diet with L-isoleucine deleted during the previous period had decreased ($P < 0.01$) ADG and poorer ($P < 0.02$) F/G compared with the positive control. The reason for this response is unclear. Pigs in the other treatment groups had similar ($P > 0.12$) ADG and F/G to the positive control. There were no differences ($P > 0.10$) in ADFI.

Because of the decrease in ADG from d 0 to 14, pigs fed the negative control diet or diets without L-tryptophan or L-valine had decreased ($P < 0.04$) ADG for the overall trial (d 0 to 28) compared to the pigs fed the positive control. A numerical decrease in ADFI was shown from all treatment diets relative to the positive control, although the only significant ($P < 0.04$) comparison was the negative control group. There was no difference ($P > 0.24$) in F/G for the overall data.

In conclusion, L-tryptophan and L-valine were needed in low-CP, amino acid-fortified nursery diets to achieve maximum growth performance from 15 to 25 lb. This suggests that the tryptophan:lysine ratio of 15% in the diet without L-tryptophan was deficient,

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which agrees with other data that suggest a tryptophan:lysine ratio requirement of 16.5%. Also, the valine:lysine ratio of 57% in the diet without L-valine was deficient, which is consistent with data from a subsequent experiment included in this publication, and suggests a valine:lysine ratio of approximately 65% is required for maximum growth. There also was a numerical decrease in performance in the pigs fed the diet without L-glutmaine and L-glycine compared to the positive control. This intermediate performance seems to indicate a benefit to glutamine or glycine either as a source of nonessential nitrogen or as an individual amino acid. Based on the results of this trial, further research should be conducted to determine the requirements for L-tryptophan, L-valine, and glutamine/glycine in a low-CP, amino acid-fortified diet for 15- to 25-lb pigs.

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

Item	Positive Control	Crystalline AA removed from the diet				Negative Control	Common Phase 2
		-Ile	-Trp	-Val	-Gly/Gln		
Ingredient, %							
Corn	58.15	58.15	58.15	58.15	58.15	58.15	65.05
Soybean meal (46.5% CP)	25.20	25.20	25.20	25.20	25.20	25.20	30.73
Spray-dried whey	10.00	10.00	10.00	10.00	10.00	10.00	---
Corn starch	---	0.10	0.07	0.16	1.26	1.59	---
Soybean oil	1.00	1.00	1.00	1.00	1.00	1.00	---
Monocalcium phosphate (21% P)	1.10	1.10	1.10	1.10	1.10	1.10	1.08
Limestone	0.90	0.90	0.90	0.90	0.90	0.90	0.95
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Zinc oxide	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
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25	0.25
L-lysine HCl	0.533	0.533	0.533	0.533	0.533	0.533	0.360
DL-methionine	0.220	0.220	0.220	0.220	0.220	0.220	0.130
L-threonine	0.230	0.230	0.230	0.230	0.230	0.230	0.130
L-tryptophan	0.070	0.070	---	0.070	0.070	---	---
L-isoleucine	0.100	---	0.100	0.100	0.100	---	---
L-valine	0.160	0.160	0.160	---	0.160	---	---
Glutamine	0.630	0.630	0.630	0.630	---	---	---
Glycine	0.630	0.630	0.630	0.630	---	---	---
Phytase 600[2]	0.085	0.085	0.085	0.085	0.085	0.085	0.165
TOTAL	100	100	100	100	100	100	100
Calculated analysis							
Standardized ileal digestible amino acids (SID), %							
Lysine	1.30	1.30	1.30	1.30	1.30	1.30	1.26
Isoleucine:lysine	60	52	60	60	60	52	61
Leucine:lysine	111	111	111	111	111	111	129
Methionine:lysine	36	36	36	36	36	36	33
Met & Cys:lysine	58	58	58	58	58	58	58
Threonine:lysine	64	64	64	64	64	64	63
Tryptophan:lysine	20	20	15	20	20	15	17.4
Valine:lysine	70	70	70	57	70	57	68
Total lysine, %	1.42	1.42	1.42	1.42	1.42	1.42	1.39
ME, kcal/lb	1,516	1,516	1,516	1,516	1,516	1,516	1,503
SID lysine:ME, g/Mcal	5.27	5.28	5.27	5.28	5.23	5.24	3.80
CP, %	20.4	20.4	20.4	20.3	18.9	18.7	20.8
Ca, %	0.72	0.72	0.72	0.72	0.72	0.72	0.69
P, %	0.64	0.64	0.64	0.64	0.64	0.64	0.62
Available P, %	0.47	0.47	0.47	0.47	0.47	0.47	0.42

[1] Treatment diets were fed from d 0 to 14, and a common diet was fed from d 14 to 28.

[2] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 231 FTU/lb, with a release of 0.10% available P.

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Table 2. Analyzed nutrient composition of experimental diets (as-fed basis)[1]

Nutrient, %	Positive control	Crystalline AA removed from the diet				Negative control
		-Ile	-Trp	-Val	-Gly/Gln	
DM	88.71	88.27	88.85	89.37	88.70	89.31
CP	19.26	20.08	19.51	20.59	18.89	18.33
Indispensable AA						
Arg	1.23	1.32	1.24	1.32	1.34	1.29
His	0.40	0.40	0.40	0.42	0.40	0.39
Ile	0.72	0.68	0.73	0.81	0.76	0.72
Leu	1.39	1.41	1.37	1.45	1.42	1.41
Lys	1.16	1.26	1.20	1.28	1.23	1.30
Met	0.37	0.39	0.38	0.39	0.39	0.38
Phe	0.77	0.79	0.79	0.81	0.79	0.75
Thr	0.77	0.80	0.78	0.84	0.79	0.77
Trp	0.27	0.26	0.23	0.27	0.20	0.24
Val	0.84	0.89	0.88	0.80	0.87	0.78
Total indispensable AA	7.92	8.20	8.00	8.39	8.19	8.03
Dispensable AA						
Ala	0.81	0.82	0.79	0.84	0.82	0.79
Asp	1.54	1.60	1.52	1.68	1.60	1.54
Cys	0.24	0.25	0.24	0.26	0.25	0.25
Glu	3.21	3.42	3.37	3.46	3.08	2.82
Gly	1.09	1.18	1.14	1.17	0.72	0.60
Pro	0.96	1.24	1.26	0.93	0.92	1.25
Ser	0.78	0.80	0.76	0.82	0.79	0.77
Tyr	0.30	0.32	0.32	0.33	0.33	0.33
Total dispensable AA	8.93	9.63	9.40	9.49	8.51	8.35

[1] A representative sample of each diet was collected and analyzed for amino acid composition.

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Table 3. Evaluation of deleting crystalline amino acids from low-CP, amino acid-fortified diets on growth performance in nursery pigs[1, 2]

	Positive control[3]	Crystalline AA removed from the diet				Negative control[4]	SEM
		-Ile	-Trp	-Val	-Gly/Gln		
d 0 to 14							
ADG, lb	0.67^{bc}	0.70^{c}	0.56^{a}	0.54^{a}	0.61^{ab}	0.54^{a}	0.030
ADFI, lb	0.93^{b}	0.95^{b}	0.81^{a}	0.76^{a}	0.86^{ab}	0.76^{a}	0.036
F/G	1.39	1.36	1.44	1.42	1.41	1.43	0.035
d 14 to 28							
ADG, lb	1.18^{b}	1.05^{a}	1.11^{ab}	1.15^{b}	1.17^{b}	1.15^{b}	0.031
ADFI, lb	1.88	1.77	1.78	1.83	1.90	1.80	0.056
F/G	1.59^{b}	1.69^{a}	1.60^{b}	1.59^{b}	1.62^{ab}	1.56^{b}	0.030
d 0 to 28							
ADG, lb	0.93^{b}	0.88^{ab}	0.84^{a}	0.85^{a}	0.89^{ab}	0.85^{a}	0.027
ADFI, lb	1.40^{b}	1.36^{ab}	1.29^{ab}	1.30^{ab}	1.38^{ab}	1.28^{a}	0.042
F/G	1.52	1.56	1.54	1.53	1.55	1.52	0.023
wt, lb							
d 0	15.2	15.2	15.1	15.2	15.2	15.1	1.011
d 14	24.6^{bc}	25.0^{c}	23.0^{a}	22.8^{a}	23.7^{ab}	22.7^{a}	3.273
d 28	41.1^{b}	39.7^{ab}	38.6^{a}	38.9^{a}	40.1^{ab}	38.8^{a}	5.472

[1] A total of 294 nursery pigs (initially 15.2 lb and 3 d postweaning) were used in a 28-d growth trial to evaluate the effects on growth performance of deleting crystalline amino acids from the diet.

[2] Treatment diets were fed from d 0 to 14 and a common diet fed from d 14 to 28.

[3] Contained crystalline lysine, methionine, threonine, isoleucine, tryptophan, valine, glutamine, and glycine.

[4] Positive control diet with removal of crystalline isoleucine, tryptophan, valine, glutamine, and glycine

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

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Effect of Increasing Standardized Ileal Digestible Valine to Lysine Ratio on Growth Performance of 15- to 25-lb Nursery Pigs[1]

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

Summary

A total of 294 nursery pigs (PIC TR4 × 1050, initially 15.1 lb, 3 d postweaning) were used in a 28-d growth trial to evaluate the effects of increasing standardized ileal digestible valine:lysine ratio on growth performance. Pigs were allotted to 1 of 6 dietary treatments. A 2-phase diet series was used, with treatment diets fed from d 0 to 14 and a common diet fed from d 14 to 28. All diets were in meal form. The 6 standardized ileal digestible (SID) valine:lysine ratios were 57.4, 59.9, 62.3, 64.7, 67.2, and 69.6%. The SID lysine level of the diet was 1.30%. There were 7 pigs per pen and 7 pens per treatment. Pigs and feeders were weighed on d 0, 7, 14, 21, and 28 to calculate ADG, ADFI, and F/G. From d 0 to 14, ADG and ADFI increased (quadratic, $P < 0.01$) as the valine:lysine ratio increased from 57.4 to 64.7%, with little improvement observed thereafter. Feed efficiency improved (linear, $P < 0.02$) with increasing valine:lysine ratio, but like ADG and ADFI, there was little improvement observed beyond the 64.7% valine:lysine ratio. From d 14 to 28, when the common diet was fed, there were no differences ($P > 0.27$) in ADG and ADFI; however, F/G became poorer (quadratic; $P < 0.02$) in pigs previously fed increasing valine:lysine ratio. The linear response in ADG and ADFI from Phase 1 carried over to the overall data (d 0 to 28), resulting in increased (linear; $P < 0.003$) ADG and ADFI with increasing valine:lysine ratio; however, no improvement was observed beyond the 64.7% valine:lysine ratio. There were no differences ($P > 0.20$) in overall F/G. Therefore, a minimum valine:lysine ratio of 64.7% was required for optimal growth of 15- to 25-lb pigs.

Key words: amino acid ratio, amino acid requirement, lysine, valine

Introduction

Several experiments have been conducted to evaluate replacing expensive specialty protein sources (fish meal, blood products, poultry meal, etc.) with crystalline amino acids in the diet for 15- to 25-lb pigs. The amino acids have resulted in performance similar to that of the specialty protein sources in several trials, but not in others. We conducted a series of experiments to determine the reason for the inconsistent response. One step in this process is to further define the minimum ratio for the key amino acids relative to lysine. Doing so will allow diet formulations with higher levels of crystalline amino acids and removal of specialty protein sources.

[1] The authors wish to thank Ajinomoto Heartland LLC, Chicago, IL, for providing the crystalline amino acids used in diet formulation and for partial financial support.

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[3] Ajinomoto Heartland LLC, Chicago, IL.

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Results from other experiments included in this publication have allowed several conclusions to be drawn about amino acid requirements of nursery pigs from 15 to 25 lb. A lysine titration was first conducted to determine the standardized ileal digestible (SID) lysine level for optimal growth, which resulted in a value of 1.30%. This lysine level was then used to perform an experiment that suggests crystalline amino acids can replace fish meal when balanced for minimum amino acid requirements. Using this low crude protein and high amino acid-fortified diet, follow-up research indicated that a valine:lysine ratio greater than 57% was required for maximum growth performance. Based on these observations, the object of this study is to determine the valine:lysine ratio required for optimal growth performance of nursery pigs from 15 to 25 lb.

Procedures

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

A total of 294 nursery pigs (PIC TR4 × 1050, initially 15.1 lb, 3 d postweaning) were used in a 28-d growth trial to evaluate the effects of increasing (SID) valine:lysine ratio on growth performance. Pigs were weaned at approximately 21 d of age and allotted to pens by initial BW. Pigs were fed a common diet for 3 d. On d 3 postweaning, pens were allotted to 1 of 6 dietary treatments. Thus, d 3 after weaning was d 0 of the experiment. There were 7 pigs per pen and 7 pens per treatment. Each pen contained a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water. Pigs and feeders were weighed on d 0, 7, 14, 21, and 28 to calculate ADG, ADFI, and F/G.

A 2-phase diet series was used, with treatment diets fed from d 0 to 14 and a common diet fed from d 14 to 28 (Table 1). The SID lysine level of the diet was 1.30%. The 6 valine:lysine ratios were 57.4, 59.9, 62.3, 64.7, 67.2, and 69.6%. Large batches of the 57.4% and 69.6% valine diets were manufactured and then blended to achieve the intermediate diets. Treatment diets were corn-soybean meal-based and contained 10% dried whey. The common Phase-2 diet was a corn-soybean meal-based diet formulated to 1.26% SID lysine. All experimental diets were in meal form and were prepared at the K-State Animal Science Feed Mill.

At the conclusion of the experiment, data were analyzed for linear and quadratic effects of increasing SID valine:lysine ratio using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). Pen was the experimental unit for all data analysis.

Results and Discussion

From d 0 to 14, ADG and ADFI increased (quadratic, $P < 0.01$; Table 2) as the valine:lysine ratio increased from 57.4 to 64.7%, with little improvement observed thereafter. Feed efficiency improved (linear; $P < 0.02$) with increasing valine:lysine ratio, but as with ADG and ADFI, there was little improvement observed beyond the 64.7% ratio.

From d 14 to 28, when the common diet was fed, there was no difference ($P > 0.27$) in ADG and ADFI; however, F/G became poorer (quadratic; $P < 0.02$) in pigs previously fed increasing valine:lysine ratio. This suggests that the valine level fed from d 0 to 14

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had no impact on subsequent ADG and ADFI, but did influence F/G. Thus, there was a slight compensatory response for F/G, but not for ADG or ADFI.

Because of the improvement in ADG and ADFI from d 0 to 14, ADG and ADFI increased (linear; $P < 0.003$) for the overall trial (d 0 to 28) as valine:lysine increased. Again, the greatest improvement in ADG and ADFI was observed in pigs fed the diet containing 64.7% valine:lysine ratio during Phase 1. There were no differences ($P > 0.20$) in F/G for the overall trial.

In conclusion, a valine:lysine ratio of 64.7% was required for optimal growth of 15- to 25-lb pigs.

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Table 1. Diet composition (as-fed basis)

	Valine:lysine ratio, %[1]						Common
Item	57.4	59.9	62.3	64.7	67.2	69.6	phase 2[2]
Ingredient, %							
Corn	58.26	58.26	58.26	58.26	58.26	58.26	65.05
Soybean meal (46.5% CP)	25.19	25.19	25.19	25.19	25.19	25.19	30.73
Spray-dried whey	10.00	10.00	10.00	10.00	10.00	10.00	---
Corn starch	0.160	0.128	0.096	0.064	0.032	---	---
Soybean oil	1.00	1.00	1.00	1.00	1.00	1.00	---
Monocalcium phosphate (21% P)	1.10	1.10	1.10	1.10	1.10	1.10	1.08
Limestone	0.90	0.90	0.90	0.90	0.90	0.90	0.95
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Zinc oxide	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
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25	0.25
L-lysine HCl	0.533	0.533	0.533	0.533	0.533	0.533	0.360
DL-methionine	0.220	0.220	0.220	0.220	0.220	0.220	0.130
L-threonine	0.230	0.230	0.230	0.230	0.230	0.230	0.130
L-tryptophan	0.070	0.070	0.070	0.070	0.070	0.070	---
L-valine	---	0.032	0.064	0.096	0.128	0.160	---
Glutamine	0.630	0.630	0.630	0.630	0.630	0.630	---
Glycine	0.630	0.630	0.630	0.630	0.630	0.630	---
Phytase[3]	0.085	0.085	0.085	0.085	0.085	0.085	0.165
TOTAL	100	100	100	100	100	100	100
Calculated analysis							
Standardized ileal digestible (SID) amino acids, %							
Lysine	1.30	1.30	1.30	1.30	1.30	1.30	1.26
Isoleucine:lysine	52	52	52	52	52	52	61
Leucine:lysine	111	111	111	111	111	111	129
Methionine:lysine	36	36	36	36	36	36	33
Met & Cys:lysine	58	58	58	58	58	58	58
Threonine:lysine	64	64	64	64	64	64	63
Tryptophan:lysine	20	20	20	20	20	20	17.4
Valine:lysine	57.4	59.9	62.3	64.7	67.2	69.6	68
Total lysine, %	1.42	1.42	1.42	1.42	1.42	1.42	1.39
ME, kcal/lb	1,516	1,516	1,516	1,516	1,516	1,516	1,503
SID lysine:ME, g/Mcal	3.89	3.89	3.89	3.89	3.89	3.89	3.80
CP, %	20.2	20.3	20.3	20.3	20.3	20.4	20.8
Ca, %	0.72	0.72	0.72	0.72	0.72	0.72	0.69
P, %	0.64	0.64	0.64	0.64	0.64	0.64	0.62
Available P, %	0.47	0.47	0.47	0.47	0.47	0.47	0.42

[1] Treatment diets were fed from d 0 to 14.
[2] Common diet was fed from d 14 to 28.
[3] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 231 FTU/lb, with a release of 0.10% available P.

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Table 2. Evaluation of valine:lysine ratio on growth performance of nursery pigs[1]

	Valine:lysine ratio,%							Probability, *P* <	
	57.4	59.9	62.3	64.7	67.2	69.9	SEM	Linear	Quadratic
d 0 to 14									
ADG, lb	0.44	0.53	0.59	0.64	0.65	0.66	0.023	<0.0001	0.005
ADFI, lb	0.70	0.79	0.92	0.94	0.97	0.94	0.035	<0.0001	0.01
F/G	1.60	1.51	1.58	1.46	1.49	1.46	0.042	0.02	0.84
d 14 to 28									
ADG, lb	1.06	1.06	1.08	1.07	1.02	1.07	0.038	0.82	0.86
ADFI, lb	1.68	1.73	1.78	1.82	1.73	1.77	0.057	0.33	0.27
F/G	1.59	1.63	1.65	1.70	1.69	1.65	0.023	0.01	0.02
d 0 to 28									
ADG, lb	0.75	0.79	0.83	0.86	0.84	0.86	0.027	0.003	0.18
ADFI, lb	1.19	1.26	1.35	1.38	1.35	1.36	0.042	0.002	0.06
F/G	1.59	1.59	1.62	1.61	1.61	1.58	0.024	0.98	0.20
wt, lb									
d 0	15.1	15.1	15.1	15.1	15.1	15.1	0.76	0.97	0.93
d 14	21.2	22.4	23.3	24.1	24.2	24.3	2.61	<0.0001	0.014
d 28	36.0	37.3	38.4	39.1	38.5	39.2	5.58	0.004	0.19

[1] A total of 294 nursery pigs (initially 15.1 lb, 3 d postweaning) were used in a 28-d growth trial to evaluate the effects of valine:lysine ratio on growth performance. There were 7 pigs per pen and 7 pens per treatment. Treatment diets were fed from d 0 to 14, and a common diet was fed from d 14 to 28.

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Does Lysine Level Fed in One Phase Influence Performance During Another Phase in Nursery Pigs?[1]

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Summary

A total of 320 weanling pigs (PIC 1050 barrows, initially 12.6 lb and 21 d of age) were used in a 35-d trial to determine whether the lysine level fed during 1 phase in the nursery influences the response to dietary lysine during another phase. Eight dietary treatments were allotted and arranged as a 2 × 2 × 2 factorial, with 5 pigs per pen and 8 pens per treatment. Diets were fed in 3 phases, with each treatment assigned as low or normal lysine level. Standardized ileal digestible lysine levels were 1.35 vs 1.55% during Phase 1 (d 0 to 7), 1.15 vs 1.35% in Phase 2 (d 7 to 21), and 1.05 vs 1.25% during Phase 3 (d 21 to 35). Pigs and feeders were weighed on d 0, 7, 14, 21, 28, and 35 after weaning to calculate ADG, ADFI, and F/G. There were no dietary interactions between phases ($P > 0.10$). From d 0 to 7, increasing dietary lysine did not influence ($P > 0.10$) ADG (0.35 vs 0.35 lb/d) or ADFI (0.36 vs 0.33 lb/d), but improved ($P < 0.005$) F/G (1.06 vs 0.97). With results similar to those of Phase 1, increasing dietary lysine from d 7 to 21 did not influence ($P > 0.10$) ADG (0.78 vs 0.82 lb/d) or ADFI (1.15 vs 1.13 lb/d), but improved ($P < 0.03$) F/G (1.48 vs 1.39). From d 21 to 35, increasing dietary lysine improved ($P < 0.001$) ADG (1.23 vs 1.32 lb/d) and F/G (1.64 vs 1.54). These results indicate that lysine level fed in each phase did not influence the response to lysine in the subsequent phase. The lysine level fed during the late nursery phase had a greater effect on overall performance than the level fed in earlier phases.

Key words: lysine, phase feeding, requirement

Introduction

In previous trials, increasing standardized ileal digestible (SID) lysine in Phase 1 and 2 nursery diets has improved daily gains and feed efficiency of nursery pigs. However, these gains have not always been maintained throughout subsequent common diets, resulting in a compensatory gain effect. To determine optimal SID lysine levels for nursery pigs, it must first be established whether the response to increasing dietary lysine is maintained through subsequent nursery phases.

In addition to growth performance, diet costs are important considerations for nursery pig diets. To achieve high levels of SID lysine while minimizing soybean meal, it is common to use specialty protein sources, especially in early nursery phases. Because specialty protein sources are typically expensive, diet costs could be reduced if high levels of lysine were not necessary in all nursery dietary phases to achieve maximum

[1] The authors wish to thank Ajinomoto Heartland LLC, Chicago, IL, for providing the crystalline amino acids used in diet formulation.

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performance. Thus, the objective of this experiment was to determine whether the lysine level fed during one phase influenced the response to lysine during subsequent phases.

Procedure

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

A total of 320 weanling pigs (PIC 1050 barrows, initially 12.6 lb and 21 d of age) were used with a 3-phase diet series. Phase 1 diets were fed from d 0 to 7, Phase 2 diets from d 7 to 21, and Phase 3 diets from d 21 to 35 after weaning. Phase 1 diets were prepared and pelleted at the K-State Grain Science Feed Mill. Phase 2 and Phase 3 experimental diets were in meal form and were prepared at the K-State Animal Science Feed Mill. At weaning, pigs were weighed and allotted to the dietary treatments. There were 8 treatments arranged as a 2 × 2 × 2 factorial, with 5 pigs per pen and 8 pens per treatment. Pigs were provided ad libitum access to feed and water via a 4-hole dry self-feeder and a cup waterer in each pen (5 × 5 ft).

For each phase, pigs were fed either a low or normal lysine level. Standardized ileal digestible lysine levels were 1.35 vs 1.55% during Phase 1 (d 0 to 7), 1.15 vs 1.35% in Phase 2 (d 7 to 21), and 1.05 vs 1.25% during Phase 3 (d 21 to 35; Table 1). The lower dietary lysine concentrations were achieved by reducing both crystalline lysine and intact protein sources (Table 2). Pigs and feeders were weighed on d 0, 7, 14, 21, 28, and 35 after weaning to calculate ADG, ADFI, and F/G.

Pen was used as the experimental unit for analysis, and data were analyzed using the MIXED procedure in SAS (SAS Institute, Inc., Cary, NC). A 2 × 2 × 2 factorial arrangement was used in a split-split plot design. The model included dietary treatments and their interactions as fixed effects. Least square means were evaluated using the PDIFF option of SAS.

Results and Discussion

Over the first phase (d 0 to 7), there were no differences ($P > 0.32$) in ADG (0.35 vs 0.35 lb/d) or ADFI (0.36 vs 0.33 lb/d) between pigs fed the 2 dietary lysine levels (1.35 or 1.55%; Table 3). However, increasing lysine during Phase 1 did improve ($P < 0.005$) F/G (1.06 vs 0.97). Because the low lysine level was adequate for ADG and ADFI but not F/G, this suggests that a lysine level of 1.35% was marginally deficient during Phase 1.

When dietary lysine levels were increased (1.15 or 1.35%) during Phase 2, no differences ($P > 0.16$) were detected in ADG (0.78 vs 0.82 lb/d) or ADFI (1.15 vs 1.13 lb/d). Also consistent with Phase 1, pigs fed the high lysine diet during the second period had improved ($P < 0.03$) F/G (1.39 vs 1.48) when compared to the pigs fed the low lysine diet. The lysine levels fed during the previous phase did not influence ($P > 0.27$) the results of the second period. Similar to the response in the first phase, the lower lysine level fed during the second phase appears to be marginally deficient, based on the differences in F/G.

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During Phase 3, the high lysine diet improved ($P < 0.001$) ADG (1.23 vs 1.32 lb/d) and F/G (1.64 vs 1.54). However, the increase in lysine did not affect ADFI (2.02 vs 2.03) from d 21 to 35. Phase 3 lysine response showed no effect ($P > 0.12$) of lysine level fed during any of the previous phases.

For the overall trial (d 0 to 35), pigs fed the high lysine level during Phase 3 had the greatest improvement ($P < 0.03$) in ADG and F/G compared to those fed the low level. Increasing dietary lysine during Phase 2 also tended ($P < 0.08$) to improve overall F/G. Consistent with the data from the previous phases, increasing the lysine level during any phase did not influence ($P > 0.14$) overall ADFI. There were no interactions ($P > 0.38$) between dietary lysine levels for overall ADG or final BW.

In summary, increasing dietary lysine improved feed efficiency in all phases but did not improve ADG until the final period. There were no dietary interactions between phases ($P > 0.10$), meaning that the lysine level fed in each phase did not influence the response to lysine in subsequent phases. Also, the data indicate that the lysine level fed during the late nursery phase had a greater effect on overall performance than the level fed in earlier phases. This suggests that lower levels of lysine can be fed during the early phases with no long-term negative effects, as long as the lysine level fed is high enough during the late nursery period.

Table 1. Dietary treatments[1]

	Standardized ileal digestible lysine, %							
d 0 to 7	1.35	1.35	1.35	1.35	1.55	1.55	1.55	1.55
d 7 to 21	1.15	1.15	1.35	1.35	1.15	1.15	1.35	1.35
d 21 to 35	1.05	1.25	1.05	1.25	1.05	1.25	1.05	1.25

[1]A total of 320 weanling pigs (PIC 1050 barrows, initially 12.6 lb and 21 d of age) were used in a 35-d trial with 8 pens per treatment. Phase 1, 2, and 3 diets were fed from d 0 to 7, 7 to 21, and 21 to 35 after weaning, respectively.

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

	Phase 1		Phase 2		Phase 3	
Item	Low	Normal	Low	Normal	Low	Normal
Ingredient, %						
Corn	45.73	41.26	54.83	48.56	61.36	54.92
Soybean meal (46.5% CP)	9.50	11.61	18.27	23.69	19.80	26.20
Spray-dried animal plasma	5.50	6.70	-	-	-	-
Spray-dried whey	25.00	25.00	10.00	10.00	-	-
DDGS	-	-	10.00	10.00	15.00	15.00
Select menhaden fish meal	4.90	6.00	3.50	4.50	-	-
Spray-dried blood cells	1.35	1.65	-	-	-	-
Soybean oil	5.00	5.00	-	-	-	-
Monocalcium phosphate (21% P)	0.45	0.20	0.43	0.28	0.80	0.75
Limestone	0.50	0.45	0.75	0.65	1.15	1.10
Salt	0.25	0.25	0.30	0.30	0.35	0.35
Zinc oxide	0.38	0.38	0.25	0.25	-	-
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	0.15	0.15	0.33	0.35	0.40	0.45
DL-Methionine	0.12	0.15	0.05	0.10	0.04	0.09
L-Threonine	0.04	0.05	0.08	0.10	0.08	0.11
Medication[2]	0.70	0.70	0.70	0.70	0.50	0.50
Phytase[3]	-	-	0.13	0.13	0.13	0.13
Vitamin E, 20,000 IU	0.05	0.05	-	-	-	-
Total	100.00	100.00	100.00	100.00	100.0	100.00
Calculated analysis						
SID amino acid, %						
Lysine	1.35	1.55	1.15	1.35	1.05	1.25
Isoleucine:lysine	50	49	61	60	60	60
Leucine:lysine	127	123	139	131	152	140
Methionine:lysine	30	31	31	33	31	32
Met & Cys:lysine	56	5	57	57	59	58
Threonine:lysine	62	62	62	62	62	62
Tryptophan:lysine	17	17	16	16	16	16
Valine:lysine	70	70	69	67	72	69
Total lysine, %	1.48	1.69	1.29	1.50	1.19	1.40
CP, %	20.2	22.7	19.7	22.4	19.0	21.5
ME, kcal/lb	1,586	1,592	1,488	1,491	1,498	1,499
Ca, %	0.77	0.77	0.70	0.71	0.68	0.67
P, %	0.71	0.72	0.62	0.64	0.58	0.60
Available P, %	0.53	0.53	0.36	0.37	0.31	0.30

[1] A total of 320 weanling pigs (PIC 1050 barrows, initially 12.6 lb and 21 d of age) were used in a 35-d trial with 8 pens per treatment. Phase 1, 2, and 3 diets were fed from d 0 to 7, 7 to 21, and 21 to 35 after weaning, respectively.
[2] Neo/Oxy 10/10 (Penfield Animal Health, Omaha, NE).
[3] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 231 FTU/lb, with a release of 0.10% available P.

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Table 3. Effects of lysine level fed during each phase (P) on nursery pig performance[1]

	SID Lysine, %															
d 0 to 7	1.35	1.35	1.35	1.35	1.55	1.55	1.55	1.55								
d 7 to 21	1.15	1.15	1.35	1.35	1.15	1.15	1.35	1.35		Probability, *P* <						
d 21 to 35	1.05	1.25	1.05	1.25	1.05	1.25	1.05	1.25	SEM	P1×P2×P3	P1×P2	P2×P3	P1×P3	P1	P2	P3
d 0 to 7																
ADG, lb	0.36	0.33	0.34	0.36	0.34	0.36	0.35	0.36	0.04	0.38	0.98	0.68	0.74	0.69	0.89	0.72
ADFI, lb	0.38	0.36	0.35	0.36	0.32	0.33	0.33	0.36	0.03	0.83	0.32	0.47	0.53	0.37	0.94	0.55
F/G	1.06	1.09	1.05	1.03	0.98	0.92	0.94	1.02	0.06	0.12	0.33	0.56	0.88	0.005	0.97	0.73
d 7 to 14																
ADG, lb	0.80	0.80	0.81	0.82	0.76	0.73	0.82	0.83	0.04	0.73	0.27	0.59	0.74	0.41	0.18	0.98
ADFI, lb	1.19	1.17	1.13	1.15	1.12	1.12	1.10	1.14	0.04	0.95	0.46	0.43	0.72	0.16	0.49	0.78
F/G	1.49	1.46	1.40	1.41	1.47	1.52	1.35	1.39	0.02	0.62	0.32	0.68	0.21	0.83	0.03	0.38
d 21 to 35																
ADG, lb	1.24	1.36	1.28	1.35	1.22	1.26	1.19	1.31	0.06	0.23	0.89	0.75	0.65	0.20	0.78	0.001
ADFI, lb	2.06	2.02	2.08	2.11	2.00	1.95	1.95	2.04	0.09	0.59	0.76	0.12	0.70	0.37	0.53	0.85
F/G	1.67	1.49	1.63	1.57	1.64	1.55	1.64	1.57	0.01	0.28	0.82	0.12	0.31	0.68	0.45	<.0001
d 0 to 35																
ADG, lb	0.89	0.93	0.90	0.94	0.86	0.87	0.87	0.93	0.03	0.55	0.57	0.55	0.77	0.15	0.30	0.03
ADFI, lb	1.64	1.60	1.61	1.65	1.57	1.55	1.53	1.61	0.05	0.86	0.88	0.14	0.60	0.38	0.74	0.65
F/G	1.55	1.45	1.50	1.47	1.52	1.48	1.47	1.46	0.01	0.44	0.43	0.10	0.14	0.47	0.08	0.002
Wt, lb																
d 0	12.60	12.56	12.62	12.51	12.60	12.67	12.59	12.58	0.12	0.92	0.46	0.11	0.05	0.59	0.24	0.43
d 7	15.08	14.90	14.97	15.01	14.98	15.19	15.05	15.06	0.41	0.38	0.89	0.96	0.45	0.67	0.91	0.85
d 21	26.30	26.15	26.34	26.46	25.72	25.47	26.48	26.64	0.78	0.92	0.31	0.66	0.97	0.54	0.14	0.94
d 35	43.60	45.50	44.20	45.40	42.86	43.15	43.15	44.94	0.88	0.38	0.57	0.75	0.68	0.14	0.37	0.04

[1]A total of 320 weanling pigs (PIC 1050 barrows, initially 12.6 lb and 21 d of age) were used in a 35-d trial with 8 pens per treatment. Phase 1, 2, and 3 diets were fed from d 0 to 7, 7 to 21, and 21 to 35 after weaning, respectively.

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Evaluation of Increasing Select Menhaden Fish Meal or Peptone Protein Sources in Nursery Pig Diets[1]

A. J. Myers, M. D. Tokach, R. D. Goodband, S. S. Dritz[2], J. M. DeRouchey, J. L. Nelssen, B. W. Ratliff[3], D. McKilligan[3], G. Xu[4], and J. Moline[4]

Summary

A total of 350 nursery pigs (PIC 1050 × C327, initially 14.3 lb and 28 d of age) were used in a 24-d study to evaluate the effects of select menhaden fish meal (SMFM), PEP2 (also known as Ferm-O-Tide), and Peptone 50, on nursery pig performance. PEP2 and Peptone 50 are a combination of refined porcine intestinal mucosa that is co-dried with vegetable proteins. PEP2 contains an enzymatically processed vegetable protein, while Peptone 50 contains a complementary vegetable protein. There were 10 dietary treatments: a negative control containing no specialty protein, the negative control diet with 2, 4, or 6% SMFM, the negative control diet with 2, 4, or 6% PEP2, or the negative control diet with 2, 4, or 6% Peptone 50. A common pretest diet was fed in pellet form for the first 6 d postweaning. Experimental diets were fed in meal form from d 0 to 14 and a common diet was fed from d 14 to 24. From d 0 to 7, there were no differences among treatments for ADG. Pigs fed diets containing PEP2 had greater (P < 0.03) ADFI compared with pigs fed diets containing SMFM and Peptone 50. From d 7 to 14, increasing PEP2 or SMFM increased (quadratic; P < 0.04) ADG, but there were no differences between pigs fed the two protein sources. Also during this period, pigs fed increasing PEP2 had increased (P < 0.02) ADFI compared to pigs fed SMFM or Peptone 50. In addition, as PEP2 increased from 2 to 4% ADFI increased (quadratic; P < 0.01). In Phase 2, pigs previously fed Peptone 50 had decreased (P < 0.05) ADG compared to pigs previously fed diets containing SMFM. Overall, pigs fed PEP2 had greater (P < 0.02) ADFI compared to pigs fed Peptone 50. In addition, pigs fed PEP2 had improved (P < 0.03) F/G compared to pigs fed SMFM. Finally, increasing PEP2 improved (quadratic; P < 0.04) F/G, with the most improvement seen in pigs fed the 6% PEP2 diets. These results suggest that PEP2 or Peptone 50 are suitable replacements for SMFM

Key words: fish meal, PEP2, PEP50

Introduction

Previous research at Kansas State University (K-State; Myers et al., 2009[5]) found that diets containing at least 4% or greater PEP2 can replace fish meal in Phase 2 diets. PEP2

[1] Appreciation is expressed to Tech Mix, Stewart, MN, and Midwest Ag Exports, Marshal, MN, for providing the PEP products and partial financial support.

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

[3] Tech Mix Inc., Stewart, MN

[4] Midwest Ag Enterprises, Marshall, MN

[5] Myers et al., Swine Day 2009, Report of Progress 1020, pp. 90-95.

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is a porcine intestinal mucosa derived from small intestines collected at pork packing plants and cleaned of any digestive contents. The mucosa linings from the intestines are removed and then hydrolyzed. Following hydrolysis, resin beads are used to extract heparin for use in the human health industry. The remaining material consists of small chain peptides and has an excellent amino acid profile. In addition to the mucosa, unique co-products are added and co-dried to create a final product. PEP2 (proteins enzymatically processed; Protein Resources, West Bend, IA) is a blend of porcine intestinal mucosa and enzymatically processed vegetable protein. In addition to PEP2, we tested a new intestinal protein source, Peptone 50. In Peptone 50, instead of being co-dried, the intestinal mucosa is spray dried onto a complementary vegetable protein. The objective of this study was to evaluate the influence of PEP2, Peptone 50, and select menhaden fish meal on nursery pig growth performance.

Procedures

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

Samples of fish meal, PEP2, and Peptone 50 were collected and analyzed for CP, crude fat, mineral, and amino acid content (Table 1). The nutrient profiles for PEP2 and Peptone 50, along with their digestible amino acid values, were provided by the manufacturer and used in diet formulation.

A total of 350 nursery pigs (PIC 1050 × C327, initially 14.3 lb and 28 d of age) were used in a 24-d study to evaluate the effects on nursery pig performance of select menhaden fish meal (SMFM), PEP2, and Peptone 50. At the nursery facility, pigs were fed a common pretest diet (Table 2) for the first 6 days after weaning. Pigs were then allotted to 1 of 10 dietary treatments. There were 5 pigs per pen and 7 pens per treatment. Pigs were provided unlimited access to feed and water via a 4-hole dry self feeder and a cup waterer in each pen (4 x 4 ft).

The 10 dietary treatments included: negative control containing no specialty protein products, the negative control diet with 2, 4, or 6% SMFM; the negative control with 2, 4, or 6% PEP2; or the negative control with 2, 4, or 6% Peptone 50 (Table 2). A common pretest SEW diet was fed in pellet form for the first 6 d postweaning. Treatment diets were fed in meal form from d 0 to 14. From d 14 to 24, all pigs were fed a common diet. Average daily gain, ADFI, and F/G were determined by weighing pigs and measuring feed disappearance on d 0, 7, 14, and 24.

Data were analyzed as a completely randomized design with pen as the experimental unit. Analysis of variance was performed using the MIXED procedure in SAS (SAS Institute, Inc., Cary, NC). Contrast statements used were: (1) linear and quadratic effects of increasing fish meal, PEP2, and Peptone 50; (2) fish meal vs PEP2; (3) fish meal vs Peptone 50; and (4) PEP2 vs Peptone 50.

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Results and Discussion

From d 0 to 7 there were no differences among treatments for ADG or F/G. However, pigs fed diets containing PEP2 had greater ($P < 0.01$) ADFI compared to pigs fed diets containing SMFM and Peptone 50 (Tables 3 and 4).

From d 7 to 14, pigs fed increasing PEP2 or SMFM had increased (quadratic; $P < 0.04$) ADG, while pigs fed diets containing PEP2 had improved ($P < 0.02$) ADFI compared with pigs fed SMFM or Peptone 50. Pigs fed increasing PEP2 had improved (quadratic; $P < 0.01$) ADFI, with the greatest increase observed when PEP2 increased from 2 to 4%. Pigs fed increasing SMFM had improved ($P < 0.01$) F/G, with the greatest improvement seen as fish meal increased from 2 to 4% of the diet.

From d 0 to 14, pigs fed PEP2 tended to have improved ($P < 0.08$) ADG compared to those fed Peptone 50. Pigs fed PEP2 had increased ($P < 0.01$) ADFI compared to those fed SMFM and Peptone 50. As PEP2 increased from 2 to 4%, ADFI improved (quadratic; $P < 0.01$).

From d 14 to 24, pigs previously fed SMFM had improved ($P < 0.05$) ADG compared to pigs previously fed Peptone 50. In addition, pigs previously fed SMFM had a tendency for increased ($P < 0.06$) ADFI compared to those previously fed Peptone 50.

Overall, there were no differences among treatments for ADG. However, pigs fed PEP2 had greater ($P < 0.02$) ADFI compared to those fed diets containing Peptone 50. Pigs fed PEP2 had poorer ($P <0.03$) F/G compared to those fed SMFM. Feed efficiency became slightly poorer (quadratic; $P < 0.04$) as PEP2 level increased in the diet.

In conclusion, PEP2 increased ADFI from d 0 to 14 when compared to SMFM and Peptone 50. The greatest improvement in d 0 to14 feed intake was seen as PEP2 increased from 2 to 4%. Additionally, pigs fed PEP2 had overall increased ADFI when compared to those fed diets containing Peptone 50. Taking into consideration improvements in ADG and feed intake in pigs fed PEP2 compared to those fed Peptone 50, enzymatically processed vegetable protein maybe a more desirable carrier. These results suggest that 4% PEP2 can be a suitable replacement for SMFM in Phase 2 nursery diets.

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Table 1. Analyzed composition of specialty protein sources[1]

Nutrient,%	Select menhaden fish meal	Spray-dried animal plasma	PEP2	Peptone 50
Dry matter	91.48	91.52	93.97	95.95
CP	62.60	75.9	52.80	52.5
Crude fat	8.80	0.10	12.10	7.0
Crude fiber	0.50	0.10	3.70	2.8
Ash	19.44	9.01	8.76	10.43
Ca	5.20	0.15	0.31	0.32
P	2.97	1.94	0.76	0.72
S	0.89	0.89	1.05	1.43
Amino acids, %				
Arginine	3.53	4.57	3.28	4.42
Histidine	1.46	2.47	1.29	1.29
Isoleucine	2.54	2.99	2.36	2.27
Leucine	4.25	7.68	4.01	4.04
Lysine	4.68	6.54	3.42	3.43
Methionine	1.62	0.67	0.81	0.76
Phenylalnine	2.33	4.39	2.40	2.27
Theronine	2.31	4.28	1.98	2.25
Tryptophan	0.70	1.39	0.65	0.50
Valine	2.95	5.19	2.69	2.87

[1] Values represent the mean of two samples.

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

Item	Pretest diet	SBM control	PEP2[3] 2%	PEP2[3] 4%	PEP2[3] 6%	Fish meal 2%	Fish meal 4%	Fish meal 6%	Peptone 50[3] 2%	Peptone 50[3] 4%	Peptone 50[3] 6%	Common diet
Corn	39.70	55.10	61.50	62.10	62.70	61.90	62.95	63.95	61.50	62.10	62.65	62.79
Soybean meal, (46.5% CP)	22.90	40.10	31.30	28.70	26.10	31.30	28.7	26.10	31.30	28.70	26.10	32.27
Spray dried animal plasma	6.00	---	---	---	---	---	---	---	---	---	---	---
PEP2	---	---	2.00	4.00	6.00	---	---	---	---	---	---	---
Select menhaden fish meal	---	---	---	---	---	2.00	4.00	6.00	---	---	---	---
Peptone 50	---	---	---	---	---	---	---	---	2.00	4.00	6.00	---
Spray-dried whey	25.00	---	---	---	---	---	---	---	---	---	---	---
Soybean oil	3.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Monocalcium P, (21% P)	0.90	1.60	1.60	1.55	1.55	1.38	1.10	0.85	1.60	1.55	1.55	1.25
Limestone	0.93	0.93	0.98	1.03	1.03	0.83	0.72	0.60	0.98	1.03	1.03	1.05
Salt	0.30	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Zinc oxide	0.38	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Lysine HCl	0.28	0.15	0.35	0.35	0.35	0.32	0.30	0.28	0.36	0.36	0.37	0.33
DL-Methionine	0.19	0.09	0.15	0.15	0.15	0.14	0.12	0.12	0.15	0.16	0.16	0.14
L-Threonine	0.08	0.04	0.13	0.13	0.13	0.12	0.11	0.11	0.13	0.13	0.14	0.13
Total	100	100	100	100	100	100	100	100	100	100	100	100

continued

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

Item	Pretest diet	SBM control	PEP2[3] 2%	PEP2[3] 4%	PEP2[3] 6%	Fish meal 2%	Fish meal 4%	Fish meal 6%	Peptone 50[3] 2%	Peptone 50[3] 4%	Peptone 50[3] 6%	Common diet
Calculated analysis												
Standardized ileal digestible (SID) amino acids, %[4]												
Lysine	1.50	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.26
Isoleucine:lysine	54	69	60	60	59	61	61	61	60	60	59	61
Methionine:lysine	31	32	34	34	34	34	35	36	34	34	34	34
Met & Cys:lysine	58	58	58	58	58	58	58	59	58	58	57	59
Threonine:lysine	63	62	62	62	62	62	62	62	62	62	62	63
Tryptophan:lysine	17.7	19.9	17.1	16.9	16.7	17.1	16.9	16.7	16.9	16.7	16.7	17.5
Valine:lysine	65	75	67	67	67	68	68	69	67	67	68	68
Total lysine, %	1.65	1.47	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.44	1.39
CP, %	22.1	23.6	21.4	21.3	21.3	21.5	21.6	21.8	21.4	21.4	21.3	20.8
ME kcal/lb	1,560	1,513	1,513	1,511	1,509	1,521	1,526	1,532	1,513	1,511	1,509	1,519
Ca, %	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.76
P, %	0.74	0.77	0.74	0.73	0.73	0.74	0.73	0.72	0.74	0.73	0.73	0.66
Available P, %	0.51	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42

[1] A total of 350 nursery pigs (initial BW 12.0) were used in a 24-d trial to determine the effects of protein sources on nursery pig growth performance.
[2] The pretest diet was a common diet fed the first 6 days postweaning.
[3] Tech Mix Inc., Stewart, MN, and Midwest Ag Enterprises, Marshall, MN.
[4] Amino acid digestibility values for spray-dried plasma were used as the estimate of standardized amino acid digestibility of amino acids in PEP2.

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

Item	Negative Control	PEP2			Fish meal			Peptone 50			SEM
		2%	4%	6%	2%	4%	6%	2%	4%	6%	
d 0 to 7											
ADG, lb	0.64	0.61	0.70	0.67	0.56	0.62	0.65	0.62	0.57	0.68	0.04
ADFI, lb	0.77	0.81	0.89	0.83	0.74	0.74	0.81	0.79	0.72	0.83	0.05
F/G	1.22	1.33	1.28	1.24	1.39	1.19	1.27	1.28	1.31	1.25	0.09
d 7 to 14											
ADG, lb	0.81	0.93	0.92	0.87	0.87	0.94	0.83	0.84	0.83	0.88	0.04
ADFI, lb	1.17	1.30	1.34	1.20	1.17	1.23	1.17	1.19	1.12	1.23	0.05
F/G	1.45	1.39	1.46	1.39	1.35	1.32	1.41	1.41	1.37	1.41	0.05
d 0 to 14											
ADG, lb	0.72	0.77	0.80	0.77	0.72	0.78	0.74	0.73	0.70	0.78	0.03
ADFI, lb	0.97	1.05	1.12	1.02	0.96	0.98	0.99	0.99	0.92	1.03	0.05
F/G	1.34	1.36	1.38	1.32	1.35	1.27	1.35	1.35	1.34	1.33	0.05
d 14 to 24											
ADG, lb	1.22	1.17	1.17	1.18	1.21	1.19	1.25	1.10	1.20	1.16	0.05
ADFI, lb	1.81	1.77	1.84	1.78	1.79	1.82	1.83	1.69	1.74	1.78	0.05
F/G	1.48	1.53	1.57	1.51	1.48	1.53	1.47	1.54	1.45	1.54	0.03
d 0 to 24											
ADG, lb	0.93	0.94	0.96	0.94	0.92	0.95	0.95	0.88	0.91	0.94	0.03
ADFI, lb	1.32	1.35	1.42	1.33	1.31	1.33	1.34	1.27	1.26	1.34	0.05
F/G	1.42	1.45	1.48	1.42	1.42	1.40	1.41	1.45	1.40	1.44	0.03

[1]A total of 350 nursery pigs (initial BW 14.3) were used in a 24-d to determine the effects of protein sources on nursery pig growth performance. There were 5 pigs per pen with 6 pens per treatment.

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Table 4. Statistics of the effects of specialty protein sources[1]

Item	Treatment	PEP2 vs. Fish meal	PEP50 vs. Fish meal	PEP2 vs. PEP50	PEP2		Fish meal		PEP50	
					Linear	Quadratic	Linear	Quadratic	Linear	Quadratic
d 0 to 7										
ADG, lb	0.20	0.10	0.64	0.25	0.29	0.92	0.59	0.17	0.64	0.10
ADFI, lb	0.02	<0.01	0.47	0.03	0.08	0.11	0.43	0.15	0.40	0.20
F/G	0.49	0.99	0.92	0.92	0.93	0.22	0.84	0.42	0.65	0.31
d 7 to 14										
ADG, lb	0.25	0.44	0.33	0.08	0.36	0.04	0.48	0.03	0.31	0.85
ADFI, lb	0.06	0.02	0.75	<0.01	0.49	<0.01	0.78	0.42	0.59	0.37
F/G	0.16	0.07	0.21	0.54	0.46	0.85	0.37	<0.01	0.27	0.30
d 0 to 14										
ADG, lb	0.37	0.16	0.73	0.08	0.25	0.18	0.46	0.59	0.37	0.28
ADFI, lb	0.20	<0.01	0.92	<0.01	0.19	<0.01	0.57	0.87	0.43	0.21
F/G	0.34	0.14	0.43	0.49	0.84	0.15	0.60	0.27	0.76	0.67
d 14 to 24										
ADG, lb	0.42	0.17	0.05	0.53	0.45	0.42	0.74	0.38	0.55	0.30
ADFI, lb	0.57	0.64	0.06	0.15	0.84	0.84	0.67	0.68	0.86	0.09
F/G	0.27	0.14	0.57	0.36	0.38	0.13	0.89	0.40	0.56	0.62
d 0 to 24										
ADG, lb	0.78	0.89	0.17	0.13	0.73	0.68	0.52	0.90	0.77	0.19
ADFI, lb	0.27	0.20	0.29	0.02	0.55	0.14	0.60	0.76	0.71	0.10
F/G	0.19	0.03	0.35	0.22	0.63	0.04	0.75	0.84	0.88	0.74

[1]A total of 350 nursery pigs (initial BW 14.3) were used in a 24-d trial to determine the effects of protein sources on nursery pig growth performance. There were 5 pigs per pen and 6 pens per treatment.

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An Evaluation of Peptone Products and Fish Meal on Nursery Pig Performance[1]

A. J. Myers, M. D. Tokach, R. D. Goodband, S. S. Dritz[2], J. M. DeRouchey, J. L. Nelssen, J. Moline[3], G. Xu[3], B. W. Ratliff,[4] and D. M. McKilligan[4]

Summary

A total of 360 nursery pigs (PIC C327 × 1050, initially 11.8 lb and 21 d of age) were used in a 35-d study to evaluate the effects of select menhaden fish meal (SMFM), PEP2+ (also known as Ferm O Tide), Peptone 50, and PEP-NS on nursery pig performance. PEP2+, Peptone 50, and PEP-NS are all porcine intestinal mucosa products, but differ based on the carriers with which they are co-dried. PEP2+ is co-dried with enzymatically processed vegetable proteins. Peptone 50 is co-dried with a vegetable protein, while PEP-NS uses by-products from corn wet-milling. Phase 1 diets were fed in pellet form from d 0 to 8. Phase 2 diets were fed in meal form from d 8 to 21. A common corn-soybean meal diet was fed from d 21 to 35. There were 6 dietary treatments: (1) a negative control diet containing 2.5% spray-dried animal plasma (SDAP) in Phase 1 followed by no specialty protein sources in Phase 2; (2) a diet containing 5% SDAP in Phase 1 and 3% SMFM in Phase 2; (3) a blend of 5% SDAP and 3% SMFM during Phase 1 and 6% SMFM during Phase 2; (4) a blend of 5% SDAP and 3% PEP2+ during Phase 1 and 6% PEP2 during Phase 2; (5) a blend of 5% SDAP and 3% PEP 50 during Phase 1 and 6% PEP50 during Phase 2, and (6) a blend of 5% SDAP and 3% PEP-NS during Phase 1 and 6% PEP-NS during Phase 2. During Phase 1, there were no differences in F/G among pigs fed any of the dietary treatments. During Phase 2 (d 8 to 21), pigs fed 6% PEP2+ had greater ($P < 0.05$) ADG compared to those fed the negative control diet, 3% or 6% fish meal, with pigs fed PEP50 and PEP NS intermediate. Furthermore, pigs fed 6% PEP2+ had the greatest improvement ($P < 0.02$) in F/G compared to pigs fed all other experimental diets. Overall, pigs fed diets containing PEP2+ had increased ($P < 0.03$) ADG and ADFI compared to pigs fed the negative control diet. Pigs fed 3% PEP2+ during Phase 1 and 6% PEP2+ during Phase 2 had greater ($P < 0.05$) ADFI compared to those fed 3% SMFM during Phase 1 and 6% SMFM during Phase 2. In conclusion, PEP2+, Peptone 50, and PEP-NS can be used as specialty protein sources to replace select menhaden fish meal in Phase 2 nursery pig diets. In addition pigs fed PEP2+ had greater ADG than those fed fish meal.

Key words: fish meal, PEP2+, Peptone 50, PEP-NS, spray-dried animal plasma

Introduction

Recently, porcine intestinal mucosa products have been gaining attention for use in nursery pig diets, specifically as replacements for fish meal. Porcine intestinal mucosa

[1] Appreciation is expressed to Tech Mix Inc., Stewart, MN, and Midwest Ag Enterprises, Marshal, MN, for providing the PEP products and partial financial support.

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

[3] Midwest Ag Enterprises, Inc., Marshall, MN

[4] TechMix, Inc., Stewart, MN

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products are derived from small intestines collected at pork processing plants. The intestines are first cleaned of any digestive contents and then pressed to remove the mucosa lining. The mucosa is subsequently hydrolyzed, and resin beads are used to extract heparin for use in the human health industry. The remaining material consists of small chain peptides and has an excellent amino acid profile. In addition to the mucosa, unique coproducts are added and co-dried to create a final product. Previous research (Myers et al., 2010[5]) found that 4% PEP2 could be fed in Phase 2 nursery pig diets, replacing select menhaden fish meal, and actually improving ADG and F/G. This study looked at three different porcine intestinal products: PEP2+, Peptone 50, and PEP-NS. PEP2+ is a combination of porcine intestinal mucosa and enzymatically processed vegetable proteins. Peptone 50 is another porcine intestinal mucosa product co-dried onto vegetable protein. Finally, PEP-NS is unique from the other two PEP products in that it does not contain soy products as a carrier. Instead PEP-NS uses by-products from corn wet-milling as its carrier. The objective of this study was to evaluate the influence of PEP2+, Peptone 50, PEP-NS, and fish meal on nursery pig growth performance.

Procedures

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

Samples of PEP2+, Peptone 50, and PEP-NS were collected and analyzed for CP, crude fat, mineral, and amino acid content (Table 1). The nutrient profiles for PEP2+, Peptone 50, PEP-NS and their digestible amino acid values were provided by the manufacturer and used in diet formulation.

A total of 360 nursery pigs (PIC C327 ×1050, initially 11.8 lb and 21 d of age) were used in a 35-d study to evaluate the effects on nursery pig performance of select menhaden fishmeal (SMFM), PEP2+, Peptone 50, and PEP-NS. After arrival at the segregated early weaning facility, pigs were allotted to 1 of 6 dietary treatments. There were 5 pigs per pen and 12 pens per treatment. Pigs were provided ad libitum access to feed and water via a 4-hole dry self-feeder and a cup waterer in each pen (4 x 4 ft).

The 6 dietary treatments were: (1) negative control containing 2.5% spray-dried animal plasma (SDAP) in Phase 1 followed by no specialty protein sources in Phase 2, (2) positive control containing 5% SDAP in Phase 1 and 3% select menhaden fish meal in Phase 2; and the diets containing specialty protein sources (3 through 6) contained 5% SDAP and either 3% fish meal, PEP2+, Peptone 50, and PEP-NS in Phase 1, and 6% fish meal, PEP2+, Peptone 50, PEP-NS in Phase 2, respectively. Phase 1 diets were fed in pellet form from d 0 to 8 after weaning (Table 2). Phase 2 diets were fed in meal form from d 7 to 21 (Table 3). A common Phase 3 diet was fed from d 21-35. Average daily gain, ADFI, and F/G were determined by weighing pigs and measuring feed disappearance on d 0, 8, 16, 21 and 35 (Table 4).

Data were analyzed as a completely randomized design with pen as the experimental unit. Analysis of variance was performed using the MIXED procedure in SAS (SAS Institute, Inc., Cary, NC). Means were separated using the LSD procedure.

[5] Myers et al., Swine Day 2010, Report of Progress 1038, pp. 27-34.

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Results and Discussion

During Phase 1 (d 0 to 8), there were no differences among pigs fed any of the dietary treatments for ADG, ADFI, or F/G.

From d 8 to 21, pigs fed diets containing 6% PEP2+, Peptone 50, or PEP-NS had improved ($P < 0.02$) ADG compared to those fed the negative control. Pigs fed 6% PEP2+ had ($P < 0.05$) increased ADG compared to those fed 3% fish meal, 6% fish meal, or 6% Peptone 50. Furthermore, pigs fed 6% PEP2+, Peptone 50, or PEP-NS had improved ($P < 0.03$) feed intake compared to pigs fed the negative control diet. Pigs fed diets containing 6% PEP2+ had improved ($P < 0.02$) F/G compared to all other treatments.

From d 0 to 21, pigs fed 3% PEP2+, Peptone 50, or PEP-NS in Phase 1 and 6% PEP2+, Peptone50, or PEP-NS in Phase 2 had improved ($P < 0.05$) ADG compared to those fed the negative control diet. While, pigs fed 3% PEP2+ in Phase 1 and 6% PEP2+ in Phase 2 had improved ($P < 0.02$) ADG compared to pigs fed 5% SDAP in Phase 1 and 3% SMFM in Phase 2 or 3% SMFM in Phase 1 and 6% SMFM in Phase 2. In addition, pigs fed 3 % PEP2+ or Peptone50 in Phase 1 and 6% PEP2+ or Peptone 50 during Phase 2 had improved ($P < 0.03$) feed intake compared to those fed the negative control. Pigs fed 3% PEP2+ during Phase 1 and 6% PEP2+ had improved ($P < 0.05$) F/G compared to all other dietary treatments.

During Phase 3, d 21-35, when all pigs were fed a common diet, there were no significant differences found among treatments for ADG and ADFI. However, pigs previously fed 5% SDAP in Phase 1 and 3% SMFM in Phase 2 had improved ($P < 0.04$) F/G compared to pigs previously fed 3% PEP2+ during Phase 1 and 6% PEP2+ during Phase 2.

Overall, pigs fed diets containing PEP2+ had improved ($P < 0.03$) ADG compared to pigs fed the negative control diet. Additionally, pigs fed diets containing PEP2+, Peptone50, and PEP-NS had improved ($P < 0.03$) feed intake compared to pigs fed the negative control. While pigs fed 3% PEP2+ during Phase 1 and 6% PEP2+ during Phase 2 had increased ($P < 0.05$) feed intake compared to pigs fed 3% SMFM during Phase 1 and 6% SMFM during Phase 2.

In conclusion, adding 3% PEP products to Phase 1 nursery-pig diets had no adverse effects on growth performance. However, the greatest benefits were seen when 6% PEP2+ was added to Phase 2 diets. During this period, pigs fed diets containing 6% PEP2+ had increased feed intake compared to those fed the 6% fish meal diet. The added benefits of increased feed intake were carried over to feed efficiency: Pigs fed 6% PEP2+ had the greatest improvement in F/G compared to all other treatments.

In conclusion, PEP2+, Peptone 50, and PEP-NS can be used as specialty protein sources to replace select menhaden fish meal in Phase 2 nursery pig diets, with those fed PEP2+ having greater ADG than those fed fish meal.

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Table 1. Analyzed nutrient composition of ingredients

	Fish meal		PEP2+[1]		Peptone 50[2]		PEP-NS[3]	
Item	Formulated[4,5,7]	Analyzed	Formulated[6]	Analyzed	Formulated[6]	Analyzed	Formulated[6]	Analyzed
CP, %								
Amino Acids, %								
Isoleucine	2.42 (94)	2.42	2.63 (88)	2.67	2.23 (91)	2.38	2.06 (83)	1.99
Leucine	4.27 (94)	4.28	4.23 (89)	4.55	3.78 (91)	4.03	3.44 (72)	3.55
Lysine	4.57 (95)	4.67	4.29 (88)	4.51	3.12 (91)	3.57	3.50 (83)	3.44
Methionine	1.66 (94)	1.55	1.09 (88)	0.97	0.81 (93)	0.75	0.97 (86)	0.80
Threonine	2.32 (88)	2.56	2.47 (83)	2.47	2.00 (88)	2.15	2.06 (77)	1.94
Tryptophan	0.59 (88)	0.56	0.77 (87)	0.68	0.67 (90)	0.68	0.59 (83)	0.55
Valine	2.82 (93)	2.78	3.03 (86)	3.03	2.44 (89)	2.59	2.56 (81)	2.43
Cystine	0.50 (88)	0.49	0.79 (77)	0.68	0.80 (88)	0.62	0.62 (68)	0.47

[1] PEP2+ (Tech Mix, Stewart, MN, and Midwest Ag Enterprises, Marshall, MN).
[2] Peptone 50 (Tech Mix, Stewart, MN, and Midwest Ag Enterprises, Marshall, MN).
[3] PEP-NS (Tech Mix, Stewart, MN, and Midwest Ag Enterprises, Marshall, MN).
[4] Diets were prepared using the formulated values.
[5] Nutrient values from NRC (1998).
[6] Nutrient values provided by the manufacturer.
[7] ( ) indicate standardized ileal digestible amino acid coefficients (%) used in diet formulation.

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

Ingredient, %	Negative control	5% Spay dried animal plasma	3% Select menhaden fish meal	3% PEP2+[3]	3% Peptone 50[3]	3% PEP-NS[3]
Corn	36.19	38.50	38.99	38.36	38.35	38.31
Soybean meal, (46.5% CP)	29.62	24.98	22.21	22.20	22.19	22.21
Spray-dried animal plasma	2.50	5.00	5.00	5.00	5.00	5.00
Select menhaden fish meal	---	---	3.00	---	---	---
PEP2+	---	---	---	3.00	---	---
Peptone 50	---	---	---	---	3.00	---
PEP-NS	---	---	---	---	---	3.00
Spray-dried whey	25.00	25.00	25.00	25.00	25.00	25.00
Soybean oil	3.00	3.00	3.00	3.00	3.00	3.00
Monocalcium P, (21% P)	1.30	1.18	0.78	1.13	1.05	1.10
Limestone	0.95	1.03	0.83	1.05	1.10	1.08
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Zinc oxide	0.25	0.25	0.25	0.25	0.25	0.25
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15
Lysine HCl	0.21	0.16	0.08	0.11	0.15	0.15
DL-Methionine	0.17	0.13	0.11	0.14	0.15	0.14
L-Threonine	0.07	0.03	0.01	0.02	0.03	0.03
Total	100.00	100.00	100.00	100.00	100.00	100.00

continued

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

Ingredient, %	Negative control	5% Spay dried animal plasma	3% Select menhaden fish meal	3% PEP2+[3]	3% Peptone 50[3]	3% PEP-NS[3]
Calculated analysis						
SID amino acids, %[4]						
Lysine	1.40	1.40	1.40	1.40	1.40	1.40
Isoleucine:lysine	60	59	60	60	59	59
Methionine:lysine	32	29	30	30	30	30
Met & Cys:lysine	58	58	58	58	58	58
Threonine:lysine	63	63	63	63	63	63
Tryptophan:lysine	18.5	18.9	19.1	19.3	19.2	18.8
Valine:lysine	67	69	71	71	70	70
Total lysine, %	1.55	1.55	1.55	1.56	1.55	1.56
CP, %	22.2	22.1	22.6	22.4	22.2	22.2
ME kcal/lb	1,545	1,551	1,560	1,548	1,549	1,551
Ca, %	0.90	0.90	0.90	0.90	0.90	0.90
P, %	0.80	0.79	0.78	0.79	0.78	0.78
Available P, %	0.55	0.55	0.55	0.55	0.55	0.55

[1] A total of 360 nursery pigs (initial BW 11.8 lb) were used in a 35-d trial to determine the effects of fish meal, PEP2+, PEP50, PEP-NS on nursery pig growth performance.
[2] Phase 1 diets were fed from d 0 to 8 and were fed in pellet form.
[3] Tech Mix, Stewart, MN, and Midwest Ag Enterprises, Marshall, MN .
[4] Standardized ileal digestible.

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

	Phase 2						Phase 3
Ingredient, %	Negative control	3% Select menhaden fish meal	6% Select menhaden fish meal	6% PEP2+[3]	6% Peptone 50[3]	6% PEP-NS[3]	Corn-SBM
Corn	54.46	55.81	56.02	54.78	54.70	54.63	62.80
Soybean meal, (46.5% CP)	30.76	27.07	24.61	24.58	24.59	24.60	32.25
Select menhaden fish meal	---	3.00	6.00	---	---	---	---
PEP2+	---	---	---	6.00	---	---	---
PEP50	---	---	---	---	6.00	---	---
PEP-NS	---	---	---	---	---	6.00	---
Spray-dried whey	10.00	10.00	10.00	10.00	10.00	10.00	---
Soybean oil	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Monocalcium P, (21% P)	1.2	0.83	0.43	1.10	1.00	1.13	1.25
Limestone	0.88	0.68	0.48	0.93	1.00	0.95	1.05
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Zinc oxide	0.25	0.25	0.25	0.25	0.25	0.25	0.25
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
Lysine HCl	0.35	0.30	0.21	0.27	0.34	0.34	0.33
DL-Methionine	0.16	0.15	0.11	0.17	0.18	0.17	0.14
L-Threonine	0.14	0.13	0.10	0.12	0.14	0.14	0.13
Phzyme 600							.05
Total	100	100	100	100	100	100	100

continued

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

	Phase 2						Phase 3
Ingredient, %	Negative control	3% Select menhaden fish meal	6% Select menhaden fish meal	6% PEP2+[3]	6% Peptone 50[3]	6% PEP-NS[3]	Corn-SBM
Calculated analysis							
SID amino acids, %[4]							
Lysine	1.30	1.30	1.30	1.30	1.30	1.30	1.26
Isoleucine:lysine	60	60	62	61	60	58	61
Methionine:lysine	34	35	35	35	35	36	34
Met & Cys:lysine	58	58	58	58	58	58	59
Threonine:lysine	63	63	63	63	63	63	63
Tryptophan:lysine	17	17	17	18	17	17	17.5
Valine:lysine	65	66	69	67	65	65	68
Total lysine, %	1.44	1.43	1.43	1.45	1.43	1.45	1.39
CP, %	20.7	20.9	21.5	21.2	20.8	20.7	20.8
ME kcal/lb	1,512	1,521	1,529	1,506	1,508	1,512	1,519
Ca, %	0.75	0.75	0.75	0.75	0.75	0.75	0.76
P, %	0.69	0.68	0.67	0.68	0.67	0.67	0.66
Available P, %	0.39	0.39	0.39	0.39	0.39	0.39	0.34

[1] A total of 360 nursery pigs (initial BW 11.8 lb) were used in a 35-d trial to determine the effects of fish meal, PEP2+, PEP50, PEP-NS on nursery pig growth performance.
[2] Phase 1 diets were fed from d 0 to 7 and were in the pellet form.
[3] Tech Mix, Stewart, MN, and Midwest Ag Enterprises, Marshall, MN .
[4] Standardized ileal digestible.

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Table 4. Effects of protein source on nursery pig performance[1]

Phase 1[2]:	2.5% SDAP[4]	5% SDAP	3% SMFM	3% PEP2+	3% Peptone 50	3% PEP-NS	
Phase 2:	Corn-SBM	3% SMFM[5]	6% SMFM	6% PEP2+	6% Peptone 50	3%PEP-NS	
Phase 3[3]:	Corn-SBM	Corn-SBM	Corn-SBM	Corn-SBM	Corn-SBM	Corn-SBM	SEM
d 0 to 8							
ADG, lb	0.42	0.42	0.42	0.43	0.44	0.41	0.02
ADFI, lb	0.35	0.36	0.36	0.36	0.37	0.35	0.03
F/G	0.86	0.87	0.87	0.85	0.85	0.86	0.03
d 8 to 21							
ADG, lb	0.64^{c}	0.67^{bc}	0.69^{bc}	0.80^{a}	0.73^{b}	0.73^{ab}	0.04
ADFI, lb	0.93^{c}	0.97^{bc}	0.97^{bc}	1.05^{ab}	1.06^{b}	1.04^{ab}	0.05
F/G	1.46^{a}	1.45^{a}	1.40^{a}	1.32^{b}	1.47^{a}	1.43^{a}	0.03
d 0 to 21							
ADG, lb	0.55^{c}	0.57^{bc}	0.59^{bc}	0.66^{a}	0.62^{ab}	0.61^{ab}	0.03
ADFI, lb	0.71^{b}	0.74^{ab}	0.74^{ab}	0.79^{a}	0.79^{a}	0.78^{ab}	0.04
F/G	1.23^{a}	1.29^{a}	1.26^{a}	1.20^{b}	1.29^{a}	1.28^{a}	0.02
d 21 to 35							
ADG, lb	0.97	1.03	0.98	0.97	0.99	1.01	0.03
ADFI, lb	1.74	1.81	1.76	1.82	1.79	1.80	0.04
F/G	1.81^{ab}	1.76^{b}	1.83^{ab}	1.89^{a}	1.82^{ab}	1.80^{ab}	0.05
d 0 to 35							
ADG, lb	0.72^{b}	0.76^{ab}	0.74^{ab}	0.78^{a}	0.76^{ab}	0.77^{ab}	0.03
ADFI, lb	1.12^{c}	1.17^{abc}	1.15^{bc}	1.20^{a}	1.19^{ab}	1.19^{ab}	0.03
F/G	1.56	1.55	1.55	1.54	1.56	1.55	0.03

^{a,b,c} Within a row, means without a common superscript differ P < 0.05.

[1] A total of 360 nursery pigs (initial BW 11.8 lb) were used in a 35-d trial to determine the effects of fish meal, PEP2+, Peptone 50, and PEP-NS on nursery pig growth performance.

[2] Fed from d 0 to 8 in pellet form.

[3] Fed from d 8 to 21 in meal form.

[4] Spray dried animal plasma.

[5] Select menhaden fish meal.

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Effects of Increasing PEP-NS on Nursery Pig Performance[1]

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Summary

A total of 180 nursery pigs (PIC 1050, initially 14.2 lb and 28 d of age) were used in a 24-d study to evaluate the effects of increasing PEP-NS on nursery pig performance. PEP-NS is a combination of porcine intestinal mucosa and by-products of corn wet-milling. There were 5 pigs per pen and 6 pens per treatment. There were 6 dietary treatments: a negative control containing no specialty proteins, the negative control diet with 3, 6, 9, or 12% PEP-NS, or the negative control with 6% select menhaden fish meal (SMFM). The diet with 6% SMFM contained the same amount of soybean meal as the diet with 6% PEP-NS. A common pretest diet was fed in pellet form for the first 7 d post weaning. Experimental diets were fed in meal form from d 0 to 14, and a common diet was fed from d 14 to 24. From d 0 to 14, increasing PEP-NS increased (quadratic, $P < 0.01$) ADG, ADFI, and F/G, with the greatest response observed in pigs fed 9% PEP-NS. There were no differences ($P > 0.10$) between pigs fed 6% PEP-NS or 6% SMFM. When pigs were fed a common diet from d 14 to 24, there were no differences in performance between treatments. Overall, from d 0 to 24, pigs fed increasing PEP-NS had improved (quadratic; $P < 0.01$) ADG and F/G, with the greatest improvement seen as PEP-NS increased from 3 to 6%. These results suggest that feeding 6% to 9% PEP-NS in Phase 2 nursery pig diets is suitable replacement for 6% SMFM

Key words: fish meal, PEP-NS, nursery pig

Introduction

Previous research conducted at Kansas State University (Myers et al., 2010[5]) found that diets containing Peptone products can be used as specialty protein sources to replace select menhaden fish meal in Phase 2 nursery pig diets. Previously tested mucosal products have utilized either enzymatically processed vegetable proteins or soy proteins as carriers. A new and more economical mucosal product, PEP-NS, has recently been developed. It uses by-products from corn wet-milling as its carrier. Despite the different carrier, PEP-NS has shown similar results to those of previously tested mucosal products, PEP2+ and Peptone 50 (Myers et al., 2010[5]). Because PEP-NS is a relatively new mucosal product, little is known about the ideal dietary level to optimize growth performance. Therefore, the objective of this study was to evaluate the effects of increasing PEP-NS on nursery pig performance.

[1] Appreciation is expressed to Tech Mix Inc, Stewart, MN, and Midwest Ag Enterprises, Marshal, MN, for providing the PEP products and partial financial support.

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

[3] Tech Mix Inc, Stewart, MN.

[4] Midwest Ag Enterprises, Marshall, MN.

[5] Myers et al., Swine Day 2010, Report of Progress 1038, pp 35-43.

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Procedures

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

Diets were formulated with NRC (1998[6]) values for the SMFM and values provided by the manufacturer for the PEP-NS (Table 1). Samples of the SMFM and PEP-NS were collected and analyzed for amino acid profile, and values were similar to formulated values.

A total of 180 nursery pigs (PIC 1050, initially 14.2 lb and 28 d of age) were used in a 24-d study to evaluate the effects of SMFM and PEP-NS on nursery pig performance. After arrival at the nursery facility, pigs were fed a common pretest diet (Table 2) for the first 7 d after weaning. Pigs were then allotted to 1 of 6 dietary treatments. There were 5 pigs per pen and 6 pens per treatment. Pigs were provided ad libitum access to feed and water via a 4-hole dry self-feeder and a cup waterer in each pen (4 × 4 ft).

The 6 dietary treatments included: negative control containing no specialty protein products, the negative control diet with 3, 6, 9, or 12% PEP-NS, or the negative control with 6% SMFM (Table 3). Treatment diets were fed in meal form from d 0 to 14. From d 14 to 24, all pigs were fed a common diet. Average daily gain, ADFI, and F/G were determined by weighing pigs and measuring feed disappearance on d 0, 7, 14, and 24.

Data were analyzed as a completely randomized design with pen as the experimental unit. Analysis of variance was performed using the MIXED procedure in SAS (SAS Institute, Inc., Cary, NC). Contrast statements used were: (1) linear and quadratic effects of increasing PEP-NS, and (2) 6% PEP-NS vs 6% SMFM.

Results and Discussion

From d 0 to 14, pigs fed increasing PEP-NS had improved (quadratic; $P < 0.01$) ADG, ADFI, and F/G, with the greatest improvement observed in pigs fed 9% PEP-NS. There were no differences observed between pigs fed the diet with 6% SMFM and 6% PEP-NS. From d 14 to 24, there were no differences in ADG, ADFI, or F/G observed in pigs previously fed increasing PEP-NS.

Overall, pigs fed increasing PEP-NS had improved (quadratic; $P < 0.01$) ADG and F/G, with the greatest improvement observed in pigs fed 6% PEP-NS. Additionally, pigs fed increasing PEP-NS tended to have increased ($P < 0.10$) ADFI. There were no differences observed between pigs fed 6% PEP-NS and those fed 6% SMFM.

These results suggest that 6 to 9% PEP-NS is a suitable replacement for fish meal in Phase 2 nursery pig diets. The greatest improvement in ADG, feed intake, and F/G were seen as PEP-NS increased from 0 to 6% in the diet.

6 NRC. 1998. Nutrient Requirements of Swine, 10th Ed. Natl. Acad. Press, Washington, D.C.

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Table 1. Analyzed nutrient composition of ingredients

	Fish meal		PEP-NS[1]	
Item	Formulated[2,3,5]	Analyzed	Formulated[4]	Analyzed
CP, %	62.90	62.99	47.50	49.20
Amino Acids, %				
Cystine	0.50 (88)	0.49	0.62 (68)	0.49
Isoleucine	2.42 (94)	2.42	2.06 (83)	2.16
Leucine	4.27 (94)	4.28	3.44 (72)	3.78
Lysine	4.57 (95)	4.67	3.50 (83)	3.44
Methionine	1.66 (94)	1.55	0.97 (86)	0.95
Threonine	2.32 (88)	2.56	2.06 (77)	2.05
Tryptophan	0.59 (88)	0.56	0.59 (83)	0.67
Valine	2.82 (93)	2.78	2.56 (81)	2.60

[1] PEP-NS (Tech Mix, Stewart, MN, and Midwest Ag Enterprises, Marshall, MN).
[2] Diets were prepared using the formulated values.
[3] Nutrient values from NRC (1998).
[4] Nutrient values provided by the manufacturer.
[5] ( ) indicate standardized ileal digestible amino acid coefficients (%) used in diet formulation.

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

Ingredient, %	Pre-test diet	PEP-NS 0%	PEP-NS 3%	PEP-NS 6%	PEP-NS 9%	PEP-NS 12%	6% SMFM	Common diet
Corn	38.50	53.70	53.90	53.45	38.36	38.35	38.31	62.80
Soybean meal, (46.5% CP)	25.00	31.55	28.30	25.85	22.20	22.19	22.21	32.25
Spray-dried animal plasma	5.00	---	---	---	---	---	---	---
Select menhaden fish meal	---	---	---	---	---	---	6.00	---
PEP-NS[3]	---	---	3.00	6.00	9.00	12.00	---	---
Spray-dried whey	25.00	10.00	10.00	10.00	10.00	10.00	10.00	---
Soybean oil	3.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Monocalcium P, (21% P)	1.18	1.20	1.18	1.15	1.10	1.08	0.43	1.25
Limestone	1.03	0.88	0.93	0.93	0.98	1.00	0.48	1.05
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Zinc oxide	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-lysine HCl	0.16	0.33	0.33	0.30	0.28	0.25	0.17	0.33
DL-methionine	0.13	1.6	0.16	0.15	0.15	0.14	0.09	0.14
L-threonine	0.03	0.13	0.14	0.13	0.12	0.11	0.08	0.13
Phytase[4]	---	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Total		100.00	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis								
Standardized ileal digestible amino acids, %								
Lysine	1.40	1.30	1.30	1.30	1.30	1.30	1.30	1.26
Isoleucine:lysine	59	61	60	60	60	61	64	61
Methionine:lysine	29	34	35	35	35	35	35	34
Met & Cys:lysine	58	58	58	58	58	58	58	59
Threonine:lysine	63	63	63	63	63	63	63	63
Tryptophan:lysine	18.9	17.4	17.1	17.1	17.1	17.1	17.6	17.5
Valine:lysine	69	66	66	67	68	69	71	68
Total lysine, %	1.55	1.44	1.45	1.46	1.46	1.47	1.44	1.39
CP, %	22.1	20.9	20.9	21.1	21.3	21.5	21.9	20.8
ME kcal/lb	1,551	1,512	1,512	1,511	1,511	1,510	1,529	1,519
Ca, %	0.90	0.75	0.76	0.75	0.75	0.75	0.75	0.76
P, %	0.79	0.69	0.69	0.68	0.68	0.67	0.68	0.66
Available P, %	0.55	0.47	0.47	0.47	0.47	0.47	0.47	0.34

[1] A total of 180 nursery pigs (initial BW 14.2 lb) were used in a 24-d trial to determine the effects of increasing PEP-NS on nursery pig growth performance.
[2] The pretest diet was a common diet fed the first 7 days post weaning.
[3] Tech Mix, Stewart, MN, and Midwest Ag Enterprises, Marshall, MN.
[4] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 231 FTU/lb, with a release of 0.10% available P.

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Table 3. Effects of increasing PEP-NS on nursery pig performance[1]

	PEP-NS							Probability, *P* <		
Item	0%	3%	6%	9%	12%	6% SMFM	SEM	Linear	Quadratic	6% PEP-NS vs. 6% SMFM
d 0 to 14										
ADG, lb	0.44	0.64	0.78	0.82	0.72	0.77	0.026	<0.0001	<0.0001	0.91
ADFI, lb	0.79	0.88	0.96	1.00	0.90	0.99	0.030	0.01	0.01	0.52
F/G	1.83	1.39	1.24	1.22	1.26	1.28	0.035	<0.0001	<0.0001	0.38
d 14 to 24										
ADG, lb	1.18	1.12	1.19	1.12	1.12	1.20	0.049	0.44	0.95	0.89
ADFI, lb	1.67	1.59	1.68	1.63	1.61	1.73	0.052	0.61	0.95	0.63
F/G	1.42	1.44	1.41	1.46	1.44	1.44	0.040	0.64	0.99	0.51
d 0 to 24										
ADG, lb	0.81	0.88	0.99	0.97	0.92	0.99	0.030	0.01	0.01	0.95
ADFI, lb	1.23	1.24	1.32	1.32	1.26	1.36	0.036	0.27	0.10	0.46
F/G	1.52	1.42	1.35	1.36	1.37	1.38	0.029	0.01	0.01	0.41

[1] A total of 180 nursery pigs (initial BW 14.2 and 28 d of age) were used in a 24-d trial to determine the effects of increasing PEP-NS on nursery pig growth performance. There were 5 pigs per pen with 6 pens per treatment.

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The Influence of Hamlet Protein 300 and Fish Meal on Nursery Pig Performance

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

Summary

A total of 360 nursery pigs (PIC 1050 barrows) were used in a 24-d study to evaluate the effects on growth performance of nursery diets containing Hamlet Protein 300 (HP 300) or fish meal. Pigs were weaned at approximately 21 d of age and placed on a pretest diet for 7 d before dietary treatments began. Pens of pigs were balanced by initial weight and randomly allotted to 1 of 7 dietary treatments with 9 replications per treatment. The 7 dietary treatments included a control diet containing no specialty protein sources or the control diet with 2, 4 or 6% select menhaden fish meal; or the control diet with 2, 4, or 6% HP 300. All experimental diets were fed for 14 d, followed by a common diet for 10 d. Neither fish meal nor HP 300 influenced any growth performance criteria ($P > 0.13$) from d 0 to 14. During the common period (d 14 to 24), pigs previously fed fish meal tended to have better F/G than pigs previously fed HP 300 ($P = 0.09$). Overall (d 0 to 24), there were no differences in growth performance between treatments ($P > 0.34$). In conclusion, HP 300 and fish meal had similar effects on growth performance, but neither provided a benefit compared to the pigs fed the control diet.

Key words: fish meal, Hamlet Protein 300, nursery pig

Introduction

The nursery starter diet has been considered an important factor influencing the performance of newly weaned pigs. In these diets, the amino acid sources typically include milk-based, refined plant-derived, or animal-derived sources. These ingredients can significantly influence performance during the nursery phase because of weanling pigs' immature digestive systems and the protein sources' distinct amino acid profiles. Soy proteins have been widely used to supply amino acids for nursery pig diets. However, in previous studies, the anti-nutritional factors in soybean meal have been shown to reduce protein digestibility, be destructive to villi in the small intestine, and result in cell-mediated immune responses. Various processing technologies have been developed to reduce the level of soy protein's anti-nutritional factors and to produce more absorbable protein sources. Hamlet Protein 300 (HP 300), produced through dehydrating and enzymatic treatment, is a type of soy protein that contains a lower level of anti-nutritional components and higher protein content than raw soybean meal. Therefore, it is hypothesized that HP 300 can potentially replace animal protein, such as fish meal, in nursery diets and achieve similar performance.

The objective of our study was to evaluate the effect of increasing levels of dietary HP 300 and fish meal on the performance of weanling pigs.

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

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Procedures

The Kansas State University (K-State) Animal Care and Use Committee approved all experimental procedures.

A total of 315 nursery pigs (PIC 1050, initially 16.3 lb) were allotted to 1 of 7 treatments. There were 5 pigs per pen and 9 pens per treatment. The study was conducted at the K-State Segregated Early Weaning Facility. Each pen (5 × 5 ft) contained a 4-hole dry self-feeder and a cup waterer to provide ad libitum access to feed and water.

A common pelleted starter diet was fed for the first 7 days postweaning. Then, pigs were fed 1 of 7 experimental diets. The 7 dietary treatments included a control diet containing no specialty protein sources or the control diet with 2, 4 or 6% select menhaden fish meal; or the control diet with 2, 4, or 6% HP 300 (Table 1). Diets were formulated to contain 1.32% SID lysine and equal amounts of soybean meal at equal inclusion levels of fish meal or HP 300. The soybean meal level in the diet was reduced as the percentage of dietary HP 300 and fish meal increased. Synthetic amino acid levels varied in diets to achieve minimum SID amino acid ratios. Experimental diets were fed in meal form for 14 days. Then, a common diet was fed to all pigs from d 14 to 24. Pigs were weighed and feed disappearance was determined on d 0, 7, 14, and 24 to calculate ADG, ADFI, and F/G.

Data were analyzed using the MIXED procedure in SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit for analysis. Contrast statements were used to compare diets containing fish meal and HP 300 with the control diet and with each other. Contrasts were also used to test the linear and quadratic effects of increasing fish meal and HP 300 levels in the diets.

Results and Discussion

From d 0 to 7, pigs fed fish meal or HP 300 had similar ($P > 0.17$) ADG, ADFI and F/G to pigs fed the control diet (Table 2). Increasing the level of HP 300 in the diet tended to result in poorer F/G (quadratic, $P = 0.10$), but did not affect ($P > 0.26$) ADG or ADFI. There was no effect of increasing fish meal levels in the diet ($P > 0.12$). Also, there were no differences ($P > 0.41$) in growth performance between pigs fed HP 300 or fish meal.

From d 7 to 14, increasing dietary fish meal resulted in a quadratic improvement in ADG ($P = 0.09$), with ADG increasing to the 4% fish meal level and then returning to control levels at the 6% rate. Pigs fed fish meal tended to have greater ($P = 0.09$) ADG compared to pigs fed HP 300. Treatments did not influence ($P > 0.21$) ADFI and F/G during this period.

For d 0 to 14, there were no differences in any growth performance parameters ($P > 0.13$).

From d 14 to 24, when all pigs were fed a common diet, no differences were observed ($P > 0.56$) for ADG or ADFI. Pigs previously fed fish meal tended to have higher ($P = 0.09$) F/G than pigs previously fed HP 300 diets.

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Overall (d 0 to 24), there was no difference in growth performance between treatments ($P > 0.34$).

In conclusion, using HP 300 in nursery pig diets resulted in similar growth performance to pigs fed dietary fish meal. However, there was no benefit in our study from increasing the dietary level of either ingredient as compared to the control diet, which contained a higher level of soybean meal.

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

	Phase 1[2]							Phase 2[3]
		Fish meal			HP 300			Common
Item	Control	2%	4%	6%	2%	4%	6%	diet
Ingredient, %								
Corn	55.10	62.15	63.10	64.80	61.65	62.25	63.55	64.65
Soybean meal, 46.5%, CP	40.10	31.00	28.45	25.10	31.00	28.45	25.10	31.85
Select menhaden fish meal	--	2.00	4.00	6.00	--	--	--	--
Hamlet protein 300	--	--	--	--	2.00	4.00	6.00	--
Soybean oil	1.00	1.00	1.00	1.00	1.00	1.00	1.00	--
Monocalcium P, 21% P	1.50	1.425	1.20	1.00	1.65	1.65	1.65	1.025
Limestone	0.975	0.80	0.675	0.525	0.975	0.975	0.975	0.975
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Zinc oxide	0.25	0.25	0.25	0.25	0.25	0.25	0.25	--
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Lysine HCl	0.15	0.33	0.30	0.295	0.365	0.37	0.40	0.335
DL-methionine	0.11	0.16	0.145	0.14	0.175	0.18	0.19	0.13
L-threonine	0.05	0.135	0.135	0.135	0.14	0.15	0.15	0.13
L-tryptophan	--	--	0.0025	0.00875	--	--	0.003	--
L-isoleucine	--	--	--	--	--	--	0.0025	--
Phyzyme 600[4]	--	--	--	--	--	--	--	0.165[4]
TOTAL	100	100	100	100	100	100	100	100
Calculated analysis								
SID[5] amino acids								
Lysine, %	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.26
Isoleucine:lysine, %	69	60	60	60	60	60	60	61
Methionine:lysine, %	33	36	36	37	36	36	36	33
Met & Cys:lysine, %	60	60	60	60	60	60	60	58
Threonine:lysine, %	63	63	63	63	63	63	63	63
Tryptophan:lysine, %	19.9	17.0	17.0	17.0	17.2	17.1	17.0	17.4
Valine:lysine, %	75	67	68	67	67	67	66	68
Total lysine, %	1.47	1.45	1.45	1.45	1.45	1.45	1.44	1.39
ME, kcal/lb	1,514	1,521	1,526	1,531	1,515	1,515	1,516	1,503
SID Lysine:ME ratio, g/Mcal	3.95	3.94	3.92	3.91	3.95	3.95	3.95	3.81
CP, %	23.6	21.5	21.6	21.4	21.3	21.3	21.0	20.8
Ca, %	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.69
P, %	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.62
Available P, %	0.40	0.43	0.44	0.45	0.42	0.42	0.41	0.42

[1] A total of 315 weanling pigs (initially 16 lb and 7 d postweaning) were used in a 24-d study with 5 pigs per pen and 9 replications per treatment.
[2] Phase 1 diets were fed from d 0 to 14.
[3] Phase 2 diet was fed from d 14 to 24.
[4] Phyzyme 600 provided 231 FTU/lb, with a release of 0.10% available P.
[5] Standardized ileal digestible.

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Table 2. Effects of Hamlet Protein 300 (HP 300) and fish meal on nursery pig performance[1]

									Probability, $P <$						
		Fish meal			HP 300				Control vs. Fish meal	Control vs. HP 300	Fish meal vs. HP 300	HP 300		Fish meal	
Item	Control	2%	4%	6%	2%	4%	6%	SEM				Linear	Quadratic	Linear	Quadratic
d 0 to7															
ADG, lb	0.67	0.64	0.64	0.67	0.64	0.63	0.62	0.04	0.54	0.28	0.50	0.26	0.71	0.96	0.33
ADFI, lb	0.94	0.94	0.94	0.91	0.95	0.93	0.89	0.04	0.78	0.67	0.84	0.30	0.51	0.51	0.65
F/G	1.40	1.48	1.48	1.39	1.49	1.54	1.44	0.06	0.42	0.17	0.41	0.49	0.10	0.92	0.12
d 7 to14															
ADG, lb	1.03	1.07	1.08	1.00	1.02	0.99	1.00	0.03	0.58	0.50	0.09	0.44	0.80	0.64	0.09
ADFI, lb	1.35	1.40	1.38	1.35	1.31	1.33	1.35	0.06	0.61	0.70	0.21	0.96	0.55	0.86	0.34
F/G	1.31	1.33	1.28	1.34	1.29	1.34	1.35	0.06	0.91	0.61	0.58	0.22	0.68	0.73	0.43
d 0 to14															
ADG, lb	0.85	0.85	0.86	0.84	0.83	0.81	0.81	0.03	0.97	0.27	0.13	0.25	0.67	0.75	0.65
ADFI, lb	1.15	1.17	1.16	1.13	1.13	1.13	1.12	0.05	0.84	0.64	0.35	0.66	0.91	0.66	0.40
F/G	1.34	1.38	1.35	1.35	1.36	1.41	1.39	0.03	0.57	0.17	0.25	0.16	0.42	0.97	0.54
d 14 to24															
ADG, lb	1.17	1.22	1.14	1.16	1.20	1.15	1.20	0.06	0.94	0.81	0.81	0.80	0.75	0.56	0.76
ADFI, lb	1.79	1.86	1.76	1.80	1.79	1.76	1.80	0.09	0.78	0.90	0.57	0.99	0.68	0.77	0.77
F/G	1.53	1.53	1.55	1.55	1.50	1.53	1.51	0.02	0.64	0.46	0.09	0.72	0.79	0.39	0.88
d 0 to24															
ADG, lb	0.98	1.01	0.97	0.97	0.98	0.95	0.97	0.03	0.95	0.65	0.47	0.64	0.65	0.54	0.55
ADFI, lb	1.41	1.46	1.41	1.40	1.40	1.39	1.41	0.06	0.72	0.83	0.42	0.90	0.78	0.68	0.44
F/G	1.43	1.45	1.45	1.45	1.43	1.47	1.45	0.02	0.43	0.46	0.94	0.34	0.56	0.53	0.68

[1] A total of 315 nursery pigs (initially 16 lb and 7 d postweaning) were used in a 24-d study with 5 pigs per pen and 9 replications per treatment.

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Effects of Feeding Excess Dietary Crude Protein from Soybean Meal and Dried Distillers Grains with Solubles on Nursery Pig Performance

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

Summary

Two experiments were conducted to determine the effects of feeding excess dietary CP to nursery pigs. In Exp. 1, a total of 105 nursery pigs (PIC TR4 × 1050, initially 22.9 lb and 35 d of age) were used in a 21-d growth assay to determine the effects of feeding excess CP from soybean meal to nursery pigs. The pigs were fed a pelleted commercial starter diet for the first 14 d after weaning, and the experimental treatments were fed for the next 21 d. Treatments consisted of 3 corn-soybean meal-based diets formulated to different CP levels: (1) 22.5%, (2) 25%, and (3) 27.5% CP. Increasing CP from 22.5 to 27.5% had no effect ($P > 0.19$) on ADG, ADFI, or F/G. In Exp. 2, a total of 105 nursery pigs (PIC TR4 × 1050, initially 22.1 lb and 35 d of age) were used in a 21-d growth assay to determine the effects of excess CP from dried distillers grains with solubles (DDGS) on nursery pig growth. The pigs were fed a pelleted commercial starter diet for the first 14 d after weaning and the experimental treatments for the next 21 d. Treatments were corn-soybean meal-based diets formulated to 22.9 and 25% CP and a diet with 30% DDGS formulated to 25% CP. Increasing the CP concentration had no effect ($P > 0.12$) on ADG, ADFI, or F/G. However, pigs fed the DDGS had poorer ($P < 0.04$) F/G compared to pigs fed the corn-soybean meal-based diet formulated to 25% CP. Our data suggest that nursery pigs can tolerate CP levels up to 27.5% without negative effects on growth performance. Additionally, the inclusion of 30% DDGS in nursery pig diets did not have a significant impact on ADG or ADFI, but did negatively affect F/G.

Key words: dried distillers grains with solubles, excess crude protein, soybean meal

Introduction

Adding dried distillers grains with solubles (DDGS) to diets is a common practice in today's swine industry. As cereal starch is converted to ethanol, the other proximal components of corn (such as protein, fiber, and fat) are concentrated by about 3 times the original amount. Thus, diets formulated with moderate to high levels of DDGS will result in CP concentrations greater than with corn-soybean meal-based formulations. It has been suggested that growth performance may suffer due to excess CP in swine diets. Therefore, the objective of the experiment was to determine the impact of excess CP from both soybean meal and DDGS in diets for nursery pigs.

Procedures

In Exp. 1, a total of 105 nursery pigs (56 barrows and 49 gilts, PIC line TR4 × 1050, initially 22.9 lb and 35 d of age) were used in a 21-d growth assay to determine the effects on growth performance from feeding excess CP from soybean meal. The pigs were weaned at 21 d of age, sorted by sex and ancestry, blocked by weight, and assigned to pens. Pigs were fed a pelleted commercial starter diet for the first 14 d postwean-

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ing and the experimental treatments for the next 21 d. Treatments were corn-soybean meal-based and fed in meal form. The treatments consisted of 3 different CP levels: (1) 22.5%, (2) 25%, and 27.5% CP (Table 1). There were 7 pigs per pen and 5 pens per treatment. The pigs were housed in an environmentally controlled nursery with 4-ft x 4-ft pens and woven-wire flooring. Each pen had a self-feeder and nipple water to allow ad libitum consumption of feed and water. Pigs and feeders were weighed on d 14 and 35 postweaning to allow calculation of ADG, ADFI, and F/G.

In Exp. 2, a total of 105 nursery pigs (49 barrows and 56 gilts, PIC TR4 × 1050, initially 22.1 lb and 35 d of age) were used in a 21-d growth assay to determine the effects of excess CP from dried distillers grains with solubles (DDGS). The pigs were weaned at 21 d of age, sorted by sex and ancestry, blocked by weight, and assigned to pens. The pigs were housed and managed as in Exp. 1, with the commercial starter diet consumed for the first 14 d postweaning and the experimental treatments for the next 21 d. Treatments were corn-soybean meal-based diets formulated to 22.9 and 25% CP and a diet with 30% DDGS formulated to 25% CP. There were 7 pigs per pen and 5 pens per treatment. Pigs and feeders were weighted on d 14 and 35 postweaning to allow calculation of ADG, ADFI, and F/G.

The feed and DDGS were analyzed for concentrations of N. The DDGS were also analyzed for ether extract (EE), GE, ADF, and NDF (Table 1).

All data in Exp. 1 and 2 were analyzed as a randomized complete block design using the MIXED procedure of SAS (SAS Institute, Inc., Cary NC). In Exp. 1, linear and quadratic polynomial contrasts were used to determine the effects of increasing dietary CP. In Exp. 2, orthogonal contrasts were used to compare the corn-soy control vs. the mean of the two higher CP treatments and the 25% CP diets with or without 30% DDGS.

Results and Discussion

In Exp. 1, a corn-soybean meal-based diet that meets the amino acid requirements for nursery pigs was stated to have 23.7% CP for 11- to 22-lb pigs and 20.9% for 22- to 44-lb pigs (NRC 1998[1]). The diets in our experiment were in excess of those concentrations and, thus, should have the potential to produce negative effects. Yet, increasing the CP concentration of the diet from 22.5 to 27.5% CP had no effect ($P > 0.19$) on ADG, ADFI, or F/G (Table 2).

In Exp. 2 there was no difference ($P > 0.12$) in ADG, ADFI, or F/G when comparing the control diet with 22.9% CP versus the mean of the two higher CP diets (Table 3). However, within the 25% CP treatments, pigs fed the diet with DDGS had numerically lower ADG and ADFI and poorer ($P < 0.04$) F/G.

Our results indicate that feeding nursery pigs diets with 22.5 to 27.5% CP had no negative effects on growth performance. However, inclusion of 30% DDGS resulted in poorer F/G independent of CP concentration in the diet for the 21-d feeding period.

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

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

	Experiment 1			Experiment 2		
	CP, %			22.9% CP	25.0% CP	
Item	22.5	25.0	27.5	Control	30% DDGS	SBM
Ingredient, %						
Corn	48.32	41.71	35.44	47.30	27.30	41.67
Corn DDGS[1]	—	—	—	—	30.00	—
Soybean meal (47.5% CP)	30.23	37.44	43.95	31.35	21.65	37.51
Spray-dried whey	15.00	15.00	15.00	15.00	15.00	15.00
Menhaden fish meal	3.00	3.00	3.00	3.00	3.00	3.00
Monocalcium P (21% P)	0.74	0.60	0.46	0.72	0.21	0.60
Limestone	0.80	0.81	0.81	0.80	0.99	0.81
L-lysine HCl	0.30	0.04	—	0.26	0.46	0.04
DL- methionine	0.14	0.06	—	0.13	0.03	0.06
L-threonine	0.11	—	—	0.09	0.04	—
L-tryptophan	0.01	—	—	—	—	—
Salt	0.30	0.30	0.30	0.30	0.30	0.30
Vitamin premix	0.09	0.09	0.09	0.09	0.09	0.09
Mineral premix	0.07	0.06	0.05	0.07	0.03	0.03
Zinc oxide[2]	0.19	0.19	0.20	0.19	0.20	0.19
Antibiotic[3]	0.70	0.70	0.70	0.70	0.70	0.70
Total	100	100	100	100	100	100
Calculated analysis, %						
CP	22.5	25.0	27.5	22.9	25.0	25.0
SID lysine[4]	1.41	1.39	1.52	1.41	1.37	1.39
Ca	0.80	0.80	0.80	0.80	0.80	0.80
Total P	0.70	0.70	0.70	0.70	0.70	0.70
Chemical analysis, %						
CP	21.9	24.4	26.0	21.3	24.2	22.6

[1] Dried distillers grains with solubles.
[2] To supply 1,500 mg/kg Zn.
[3] To provide 154 g/ton oxytetracycline and 154 g/ton neomycin.
[4] Standardized ileal digestible lysine.

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Table 2. Effects of excess crude protein from soybean meal on growth performance in nursery pigs (Exp. 1)[1]

	Crude Protein, %				P value	
Item	22.5	25	27.5	SE	Linear	Quadratic
ADG, lb	1.30	1.26	1.27	0.05	—[2]	—
ADFI, lb	1.93	1.87	1.86	0.08	—	—
F/G, lb/lb	1.48	1.49	1.46	0.01	—	—

1 A total of 105 pigs (average initial BW of 22.9 lb) with 7 pigs per pen and 5 pens per treatment.
2 Dashes indicate P > 0.15.

Table 3. Effects of excess crude protein from soybean meal (SBM) and distillers dried grains with soluble (DDGS) on growth performance on nursery pigs (Exp. 2)[1]

	Treatments				P value	
Item	22.9% CP control	25% CP SBM	25% CP 30% DDGS	SE	Control vs. High CP	25% CP: SBM vs. DDGS
ADG, lb	1.29	1.29	1.20	0.04	—[2]	0.12
ADFI, lb	1.90	1.89	1.84	0.06	—	—
F/G, lb/lb	1.47	1.46	1.53	0.02	—	0.04

1 A total of 105 pigs (average initial BW of 22.1 lb) with 7 pigs per pen and 5 pens per treatment.
2 Dashes indicate P > 0.15.

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Effects of Extrusion Processing on the Nutritional Value of Dried Distillers Grains with Solubles in Diets for Nursery Pigs

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

Summary

A total of 224 pigs (PIC TR4 × 1050, initially 18.7 lb avg BW) were used in a 21-d experiment to determine the effects of extrusion processing on the nutritional value of dried distillers grains with solubles (DDGS) in diets for nursery pigs. The pigs were weaned at 21 d of age, sorted by sex and ancestry, and blocked by BW. All pigs were fed a common diet for 11 d postweaning and the experimental treatments for the next 21 d. Treatments were a corn-soybean meal-based control and 3 diets formulated with 30% DDGS. The 3 DDGS treatments were either (1) not treated, (2) dry-extruded with the barrel configured for processing cereal grain (to generate less shear and temperature rise), or (3) dry-extruded with the barrel configured for processing soybeans (to generate more shear and temperature rise). Overall, ADG and ADFI both improved ($P < 0.02$) while F/G became poorer ($P < 0.05$) for pigs fed the corn-soy control compared to those fed the DDGS treatments. Extruding the DDGS did not affect ADG or F/G ($P > 0.11$) but did reduce ADFI ($P < 0.02$). There were no differences in growth performance among pigs fed the DDGS extruded with low vs. high shear ($P > 0.20$). Pigs fed the corn-soy control diet had greater digestibility of DM, N, and GE ($P < 0.02$) compared to pigs fed the diets with DDGS. Among the DDGS treatments, extrusion improved digestibility of DM and GE ($P < 0.04$), but digestibility of N was only improved with high-shear conditions ($P < 0.05$).

Key words: DDGS, dried distillers grains with solubles, feed processing, extrusion

Introduction

Because of high corn prices, the inclusion of dried distillers grains with solubles (DDGS) in swine diets has become a common practice. However, negative effects on performance have sometimes been reported with high dietary inclusion (> 30%) of DDGS. Previous research conducted at Kansas State University (K-State) suggested that thermal processing (expanding) diets containing high levels of DDGS improved both efficiency of growth and nutrient digestibility in nursery and finishing pigs. Because of the improved nutrient utilization with these thermally processed diets, we designed an experiment to investigate the effect of an even more extreme technology, extrusion, on growth performance and nutrient digestibility in nursery pigs fed diets with high inclusion of DDGS.

Procedures

The K-State Institutional Animal Care and Use Committee approved the protocol used in this experiment. The experiment was completed at the K-State Swine Teaching and Research Center.

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A total of 224 pigs (PIC TR4 × 1050, initially 18.7 lb average initial body weight) were used in a 21-d growth assay. The pigs were weaned at 21 d of age, sorted by sex and ancestry, blocked by weight, and assigned to pens. The pigs were fed a common commercial starter diet for the first 11 d after weaning and the experimental treatments for the next 21 d. Each pen had a self-feeder and nipple water to allow ad libitum consumption of feed and water.

Treatments (Table 1) were a corn-soybean meal-based control and 3 diets formulated with 30% DDGS. The DDGS treatments were either no additional processing, dry-extruding with the barrel configured for processing cereal grain (to generate less shear and temperature rise), or dry-extruding with the barrel configured for processing soybeans (to generate more shear and temperature rise). To create the low-shear conditions, an Insta-pro 2000 dry extruder (Des Moines, IA) was fitted with a #6 steam lock, single flight screw, #6 steam lock, single flight screw, 11-R steam lock, and 15.9 mm cone opening sequence. For the high-shear conditions an 11-R steam lock, single flight screw, a blank spacer, single flight screw, 11-R steam lock, and 15.9 mm cone opening were used. Extruder barrel temperatures were collected by probes located 20 cm from the end of the extruder. The low-shear DDGS had a final temperature of 228°F and a production rate of 1,320 lbs/h while the high-shear DDGS had a final temperature of 234°F and a production rate of 1,320 lbs/h.

Pigs and feeders were weighed at d 11 and 32 postweaning to allow calculation of ADG, ADFI, and F/G. Feces were collected on d 32 postweaning from no less than 4 randomly selected pigs per pen. The fecal samples were combined within pen and stored frozen at 5°F until dried at 122°F. Feed and feces were analyzed for concentrations of DM, N, and GE. Chromium concentrations in the feed and feces were determined to allow calculation of apparent digestibility using the indirect ratio method.

Data were analyzed as a randomized complete block design using the MIXED procedure of SAS (SAS Institute, Inc., Cary NC). Orthogonal contrasts were used to separate treatment means with comparisons of: 1) the control diet vs DDGS treatments; 2) untreated vs extruded DDGS; and 3) low-shear vs high-shear extrusion.

Results and Discussion

With extrusion processing (Table 2), CP, GE, and ether extract (EE) increased as the degree of processing was increased. However, when calculated on a DM basis, only CP and EE were increased. Both NDF and ADF were decreased with extrusion processing, and extruding DDGS with high-shear conditions led to a greater reduction in NDF and ADF compared to the low-shear settings.

Overall, ADG and ADFI (Table 3) were greater for pigs fed the corn-soy control diet compared to the DDGS treatments ($P < 0.02$). However, F/G was improved when DDGS was added to the diet ($P < 0.05$). Extruding the DDGS had no effect on ADG ($P > 0.11$) or F/G ($P > 0.60$) while ADFI for pigs fed the extruded diets was less ($P < 0.02$) than for pigs fed the untreated DDGS.

Pigs fed the corn-soy control diet had greater ($P < 0.02$) digestibility of DM, N, and GE compared to pigs fed the diets with DDGS. Both DM and GE digestibility were

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improved ($P < 0.04$) by extrusion of the DDGS but N digestibility was improved ($P < 0.05$) only with the high-shear conditions.

Our results indicate that feeding nursery pigs diets with 30% DDGS decreased ADG and ADFI but improved F/G. Digestibility results showed that extruding DDGS can improve DM, N, and GE digestibility, but extrusion did not ameliorate the loss in growth performance.

Table 1. Composition of diets

Ingredient, %	Corn-soy control	30% DDGS
Corn	47.30	27.30
Corn DDGS[1]	—	30.00
Soybean meal (47.5% CP)	31.35	21.65
Spray dried whey	15.00	15.00
Menhaden fish meal	3.00	3.00
Monocalcium P (21% P)	0.72	0.21
Limestone	0.80	0.99
L-lysine HCl	0.26	0.46
DL- methionine	0.13	0.03
L-threonine	0.09	0.04
Salt	0.30	0.30
Vitamin premix	0.09	0.09
Mineral premix	0.07	0.03
Zinc oxide	0.19	0.20
Antibiotic[2]	0.70	0.70
Total	100.00	100.00
Calculated analysis, %		
Crude protein	22.9	25.0
SID lysine[3]	1.40	1.40
Ca	0.80	0.80
Total P	0.70	0.70

[1] Dried distillers grains with solubles.
[2] To provide 154 g/ton oxytetracycline and 154 g/ton neomycin.
[3] Standardized ileal digestible.

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Table 2. Chemical characteristics of dried distillers grains with solubles (DDGS)

Treatment	DM, %	CP, %	GE, Mcal/lb	Ether extract, %	NDF, %	ADF, %
As-fed basis						
DDGS	87.1	24.3	2.18	9.0	26.5	11.1
Low-shear DDGS	91.8	28.2	2.27	11.5	25.1	10.3
High-shear DDGS	91.8	27.5	2.27	10.4	23.7	8.1
Dry matter basis						
DDGS		27.9	2.49	10.3	30.4	12.7
Low-shear DDGS		30.7	2.45	12.5	27.3	11.2
High-shear DDGS		30.0	2.45	11.3	25.8	8.8

Table 3. Effects of extrusion processing on the nutritional value of dried distillers grains with solubles (DDGS) in diets for nursery pigs[1]

	Treatments					*P* value		
Item	Corn-soy control	DDGS	DDGS low-shear	DDGS high-shear	SE	Control vs DDGS	Treated vs untreated DDGS	Low- vs high- shear
ADG, lb	1.16	1.12	1.04	1.09	.04	0.02	0.11	—[2]
ADFI, lb	1.73	1.63	1.50	1.56	.07	0.001	0.02	—
F/G	1.49	1.46	1.44	1.43	.02	0.05	—	—
Apparent digestibility, %[3]								
DM	78.6	72.8	74.2	75.2	0.8	0.001	0.04	—
N	75.6	72.2	71.9	74.3	1.0	0.02	—	0.05
GE	77.9	71.9	73.9	75.1	0.9	0.001	0.02	—

[1] A total of 224 pigs (avg. initial BW of 18.7 lb) with 7 pigs per pen and 8 pens per treatment.
[2] Dashes indicate P > 0.15.
[3] Fecal samples for digestibility determinations were collected on d 32 postweaning, with chromic oxide used as an indigestible marker.

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Effects of Mat-Feeding Duration and Different Waterer Types on Nursery Pig Performance in a Wean-to-Finish Barn[1]

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Summary

A total of 3,680 weanling pigs were used in 2 experiments to determine the effects of mat-feeding strategies and different waterer types on pig performance and removal rates. In Exp. 1, a total of 24 pens (58 pigs per pen) were blocked by source farm and allotted to 1 of 4 gender (barrow or gilt) × feeding (control or mat-fed) treatments in a 27-d trial. Pigs were initially 15.4 lb. Control pigs did not receive any pelleted feed placed on mats, while pigs assigned to the mat-fed treatment were given 1.1 lb of pelleted diet on the mats 3 times daily for 6 d (with the exception of 1 pen, which was mat-fed for 5 d due to early mat disintegration). Pigs were weighed and feed intake by pen was recorded on d 0, 11, and 27 to calculate ADG, ADFI, and F/G. The numbers of removed and dead pigs were recorded, although individual pigs were not weighed. Thus, for Exp. 1, removed pig gain was not accounted for in ADG calculations. In Exp. 2, a total of 44 pens (52 pigs per pen) were allotted to 1 of 8 waterer types (swinging or pan) × gender (barrow or gilt) × mat-feeding duration (1.6 lb of pelleted feed given 3 times daily for either 3 or 7 d) treatments in a 32-d trial. Pigs were initially 13.6 lb. Waterer types evaluated in this study were a dual swinging waterer (Swinging; Trojan Plastic Waterswing, Trojan Specialty Products, Dodge City, KS) or an under-the-fence-line 14-inch pan waterer (Pan; Koca, Des Moines, IA). Pigs were weighed and feed intake by pen was recorded on d 0, 7, 20, and 32 to calculate ADG, ADFI, and F/G. Removed and dead pigs were tracked, and for Exp. 2, all removed pigs were individually weighed and included in calculations involving gain.

Results from Exp. 1 indicate a difference ($P = 0.04$) in overall (d 0 to 27) removal percentage between control and mat-fed pigs. Fewer pigs fed on mats died or were removed from pens (5.9%) than control pigs (9.8%), with most removals between treatments occurring within the first 11 d (control: 8.0% vs. mat-fed: 4.6%; $P = 0.03$).

Because of the difference in removal percentages, overall ADG and F/G tended to be improved ($P = 0.06$) for mat-fed pigs compared to the controls. However, average pig weights on d 0, 11, and 27 were not different ($P \geq 0.57$) between treatments, indicating that the ADG advantage was due to the difference in removals rather than increasing weight gain of pigs remaining in the pens. Thus, the results of Exp. 1 indicate a benefit by feeding on mats for 6 d in reducing the percentage of removed pigs, but no advantages on growth performance were observed.

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

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

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For Exp. 2, removal percentages from d 0 to 7 were similar ($P \geq 0.17$) regardless of treatment. By d 20 and through the end of the trial (d 32), a 2-way interaction ($P = 0.03$) was observed between water source and mat-feeding duration on removal percentages. Pigs that were fed on mats for 3 d and provided swinging waterers had the lowest removal rate among treatments. Biologically, it is difficult to understand why feeding on mats for 7 d would increase removals compared with 3-d mat-feeding for pigs provided with swinging waterers. Overall, there was a trend ($P \geq 0.08$) for pigs using the swinging waterer to have increased ADG and improved F/G, resulting in pigs having a 1.4-lb numeric advantage in weight at d 32 compared with pigs drinking from the pan waterer. Much of the overall effect was due to pigs using the swinging waterer having improved ($P = 0.02$) ADG and F/G compared with pigs with pan waterer access in the early stages (d 7 to 20) of the nursery period.

Overall, pigs fed on mats for 3 d had similar ($P \geq 0.12$) ADG and F/G compared with pigs fed on mats for 7 d. There was a trend ($P = 0.08$) for pigs fed on mats for 7 d to consume more feed than pigs fed on mats for 3 d, although this increased intake did not result in significant changes in growth rate. Thus, F/G was poorer ($P = 0.01$) from d 0 to 7 for pigs fed on mats for 7 d vs. those fed on mats for 3 d.

Results of these 2 experiments indicate that, in periods during these trials, performance and removal rates of pigs postweaning were able to be improved by feeding on mats and using swinging waterers instead of pan waterers.

Key words: growth, mat-feeding, waterer

Introduction

Feeding pigs a small amount of feed on floor mats (mat-feeding or floor-feeding) immediately after weaning is a common industry practice to help introduce newly weaned pigs to solid feed. It has been documented that feed intake within the first week postweaning is important to maintaining pig health. During the postweaning period a pig experiences a variety of stressors that can reduce performance, including a change in diet form, vaccination, and adaptation to a new environment and social structure. Therefore, practices that encourage feed intake and help maintain health are critical during this period. Although mat-feeding is practiced throughout the industry, the duration of this practice varies and published information on its effects on subsequent growth and removal rates is limited.

Waterer types also vary among swine facilities. Two commercially available waterers include a dual swinging waterer with guard (Trojan Plastic Waterswing, Trojan Specialty Products, Dodge City, KS), and an under-the-fence-line pan waterer (Koca, Des Moines, IA). Research indicates that using the swinging waterers results in less water disappearance compared to stationary nipple waterers or bowl-type waterers. There has been little published information on water disappearance with the pan waterer; however, reports from the field indicate disappearance is similar to that when bowl-type waterers are used. During the early postweaning period, young pigs are highly susceptible to dehydration. Therefore, water availability and learning to access the water source is critical. It is thought that pigs have easier access to water with a pan-type waterer, which may lead to a lower rate of dehydration. Also, adequate water availabil-

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ity is critical for stimulating feed intake during the weaning process. It is thought that greater access to the water source will lead to increased feed intake during the early post-weaning period. Therefore the objectives of these experiments were to: (1) determine the effects of mat-feeding on weanling pig performance, and (2) determine the effects of different durations of mat-feeding with 2 waterer types on pig performance immediately postweaning in a wean-to-finish barn.

Procedures

The Kansas State University (K-State) Institutional Animal Care and Use Committee approved procedures used in these studies. Both experiments were performed in the same double-curtain-sided commercial research facility in northeast Kansas. Pens in this barn were 10 × 18 ft and equipped with a single-sided dry, 3-hole, stainless-steel feeder (AP-3WFS-QA; Automated Production Systems, Assumption, IL), allowing pigs ad libitum access to feed. The barn was equipped with an automated feeding system (FeedPro; Feedlogic Corp., Willmar, MN), facilitating recording of feed delivery to individual pens.

For Exp. 1, each pen was equipped with a dual swinging waterer (Trojan Plastic Waterswing; Trojan Specialty Products, Dodge City, KS). Waterers varied in Exp. 2 according to the treatment assignment. Pigs were allowed to have ad libitum access to water in both experiments. All pens had a biodegradable mat and a brooder lamp placed above the mat. According to standard production procedures, all pigs were vaccinated with commercial porcine circovirus type 2 and *Mycoplasma hyopneumoniae* vaccines at 3 and 6 weeks of age.

For Exp. 1, a total of 1,392 weanling pigs (initially 15.4 lb) were placed in 24 pens (58 pigs per pen) according to gender (barrow or gilt) and blocked by source farm in a 27-d trial. Each block consisted of 2 barrow and 2 gilt pens. On d 0, pens of pigs were weighed and randomly allotted within block and gender to 1 of 2 feeding treatments (control or mat-fed) in a 2 × 2 factorial arrangement. Controls did not receive any pelleted feed on mats, while pigs on the mat-fed treatment were fed on the mats 3 times daily for 6 d (except for 1 pen which was fed on the mat for only 5 d before the mat disintegrated). Mat-feeding consisted of removing 1.1 lb of pellets from the feeder for that pen and placing it on the mats. All pigs were fed common diets in 3 phases, according to standard production procedures. Pigs were fed a pelleted diet (3 lb/pig) followed by a Phase 2 diet formulated for an average pig weight range of 15 to 25 lb (13 lb/pig). A Phase 3 diet, formulated for an average pig weight range of 25 to 50 lb, was then fed until the end of the trial. Phase 2 and 3 diets were both fed in meal form.

Pigs were weighed by pen and feed intake recorded on d 0 (weaning), 11, and 27. From these data, ADG, ADFI, and F/G were calculated. Pig removals and mortalities were recorded throughout the trial; however, mortality was not tracked on pigs after they were removed from the study. Pig removal weights and gain of removed pigs were not used in the calculation of ADG for Exp. 1. However, the days prior to removal that pigs were in test pens (pig days) were accounted for in all calculations.

For Exp. 2, a total of 2,288 pigs (52 pigs per pen) in 44 pens were used in a 32-d trial. Pigs (initially 13.6 lb) were allotted to 1 of 8 treatments in a 2 × 2 × 2 factorial arrange-

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ment in a split-plot design with waterer type (swinging or pan), gender (barrow or gilt), and mat-feeding duration (3 d or 7 d) as the factors evaluated. Waterers tested were a dual swinging waterer (Swinging; Trojan Plastic Waterswing, Trojan Specialty Products, Dodge City, KS) or an under-the-fence-line 14-inch pan waterer (Pan; Koca, Des Moines, IA). Pan waterers were placed 2 ft away from the side-edge of the feeder. A set of 2 pens (1 barrow and 1 gilt pen) was designated as the unit of replication for the waterer treatments, as 2 adjacent pens shared a pan waterer; however, a whole-plot was made of 4 pens (2 sets of 2 pens), allowing complete gender × duration treatment arrangements within each whole-plot. There were 6 whole-plots of swinging waterers and 5 whole-plots of pan waterers for a total of 44 pens on test. Waterers were distributed in pens throughout the barn such that both types of waterers were represented in each quadrant.

Pigs were supplied from multiple sources for Exp. 2. On d 0 (less than 24 hours after weaning for all sources), pigs were sorted by sex and randomly placed in pens to create whole-plots, comprising pigs from comparable sources. As each set of 2 similar waterer pens consisted of a barrow and a gilt pen, mat-feeding duration treatments were randomly assigned within gender and whole-plots. This ensured that each set of 2 pens on a similar waterer had both mat-feeding treatments (3-d and 7-d) after the split-plot treatment allotment. Average pig start weights were checked and balanced as closely as possible across both waterer and mat-feeding duration treatments.

Pens of pigs were weighed and feed intake was recorded on d 0, 7, 20, and 32 to calculate ADG, ADFI, and F/G. All pigs were mat-fed for the initial 3 d. Pigs assigned to the 7-d treatment were mat-fed for an additional 4 d. Mat-feeding procedures consisted of feeding 1.6 lb of pelleted feed on mats 3 times daily (total of 4.8 lb of feed per pen per day). For the first 2 d of feeding, bagged SEW diet was fed on the mats. For the remainder of the mat-feeding, a transition diet was removed from the feeders at each feeding and placed on the mats. All pigs were fed common diets in phases throughout the trial. Initially, 25 lb of bagged SEW diet was hand-added to each feeder (0.5 lb/pig). On top of the SEW diet, the FeedPro system was used to add approximately 3 lb/pig pelleted transition diet, followed by approximately 13 lb/pig Phase 2 diet in meal form. After feeding the Phase 2 diet, a Phase 3 diet was fed until the end of the trial. Removals and mortalities from each pen were recorded throughout the trial in a similar manner as Exp. 1. For Exp. 2, all removed pigs were weighed, and removal weights and pigs days were used for all calculations.

Data were analyzed as a randomized complete block design and a split-plot design for Exp. 1 and 2, respectively, using the GLIMMIX procedure in SAS (SAS Institute, Inc., Cary, NC). Fixed factors for Exp. 1 were feeding treatment, gender, and their interaction. Source was a random effect, and pen was the experimental unit for analysis of Exp. 1. For Exp. 2, the fixed factors were waterer type (whole-plot factor), gender (split-plot factor), mat-feeding duration (split-plot factor), and all 2-way and 3-way interactions between whole-plot and split-plot factors. For Exp. 2, the unit of replication was a set of 2 pens for analysis of the whole-plot, whereas for analysis of the split-plot, the unit of replication was an individual pen. Differences between treatments were determined by using least squares means ($P < 0.05$).

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Results and Discussion

For Exp. 1, there were no 2-way interactions ($P \geq 0.06$) between gender and treatment for any responses (Table 1). Removal percentages (including removals and mortalities) throughout the trial were not affected by gender, but were affected by treatment. There was a difference ($P \leq 0.04$) in removal percentage within the first 11 days of the trial and overall (d 0 to 27) between control and mat-fed pigs. Overall, fewer ($P = 0.04$) pigs fed on mats were removed from pens (5.9%) than control pigs (9.8%), with the majority of the removals occurring within the first 11 d (control: 8.0% vs. mat-fed: 4.6%; $P = 0.03$).

Performance of barrows and gilts throughout the trial was similar ($P \geq 0.17$), despite gilts weighing 0.5 lb less ($P < 0.01$) than barrows at weaning (d 0). On d 27, consistent with arrival weight patterns, barrows tended ($P = 0.05$) to be heavier than gilts.

From d 0 to 11, 11 to 27, and overall, there were numeric improvements ($P \geq 0.06$) in ADG and F/G for mat-fed pigs compared with control pigs. Between control and mat-fed pigs, ADFI was similar ($P \geq 0.48$). It is noteworthy that F/G was not worse for mat-fed pigs, indicating that excessive wastage of feed was not apparent in this trial.

For Exp. 1, increased removal percentage for control pigs negatively affected ADG. This was reflected in the data, as average weights of control and mat-fed pigs were similar within day ($P \geq 0.57$) on d 0, 11, and 27. Thus, the ADG and F/G advantages were due to differences in removals rather than an increase in growth rate of pigs that remained in the pens. Reasons for removal in this trial were primarily slow-starting pigs that were off-feed. Other removal reasons included lack of response to treatment for respiratory disease or scours. Thus, the results of this first trial indicate that there may be some benefit in feeding on mats for 6 d in reducing the percentage of pulled pigs. There did not appear to be any negative effects of mat-feeding on F/G, which can be a concern when considering implementation of a mat-feeding program.

In Exp. 2, removal percentages from d 0 to 7 were similar regardless of treatment. Though by d 20, there was a 2-way interaction ($P = 0.03$) between water source and mat-feeding duration on removal percentages (Table 2). Pigs fed for 3 d on the mat and using a swinging waterer were less likely ($P \leq 0.04$) to be removed from pens than pigs that were mat-fed for 7 d with a swinging waterer or 3 d mat-fed with a pan waterer. Pigs mat-fed for 7 d and with a pan waterer had intermediate removal percentages. The removal percentage differences were detectable through d 32, though the reasons for the water × mat-feeding duration interaction are not known. It is speculated that there is little biologic significance to this interaction.

There was no difference ($P \geq 0.14$; Table 3) in removal percentages between barrows and gilts, though gilts had a numerically higher rate of removal (10.1% vs. 9.8%) compared with barrows. Primary reasons for removal in this trial included light-weight pigs, which were poor-starting pigs, or illness with influenza-like symptoms, which was first detected within d 7 to 20. It is unknown what effect source of pigs had on removal percentages, as some pens were mixed with pigs from similar sources. Pigs were not tracked after removal to determine whether they remained alive or died; however, individual weights of removed pigs were recorded and used in growth-performance calculations.

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There were no 3-way or 2-way interactions with water source, gender, or mat-feeding duration for any performance responses, with the exception of d 0 to 7 ADFI. This water source × gender × mat-feeding duration interaction ($P < 0.01$) resulted from pigs mat-fed for 7 d having a 0.10-lb higher ADFI compared with pigs mat-fed for 3 d for barrows on swinging waterers (barrow-swinging-7 d: 0.44 ± 0.026 lb vs. barrow-swinging-3 d: 0.33 ± 0.026 lb; $P < 0.01$) and gilts on pan waterers (gilt-pan-7 d: 0.42 ± 0.028 lb vs. gilt-pan-3 d: 0.32 ± 0.028 lb; $P < 0.01$). Performance was similar, regardless of mat-feeding duration, for barrows on pan waterers (barrow-pan-7 d: 0.36 ± 0.028 lb vs. barrow-pan-3 d: 0.36 ± 0.028 lb; $P = 0.94$) and gilts on swinging waterers (gilt-swinging-7 d: 0.39 ± 0.026 lb vs. gilt-swinging-3 d: 0.38 ± 0.026 lb; $P = 0.69$). For the remainder of the performance responses, main effects of gender, water source, and mat-feeding duration are reported and discussed.

Barrows and gilts had similar ($P \geq 0.30$) overall ADG and ADFI. Barrows had a tendency (barrow vs. gilt: 1.37 ± 0.009 vs. 1.39 ± 0.009; $P = 0.08$) to have improved F/G compared with gilts. This trend for improved overall F/G was due to the improved (barrow vs. gilt: 1.58 ± 0.023 vs. 1.63 ± 0.023; $P = 0.03$) F/G for barrows compared with gilts from d 20 to 32. Despite this F/G improvement and a slight numeric weight advantage on d 0 (barrow vs. gilt: 13.8 ± 0.62 lb vs. 13.5 ± 0.62 lb; $P = 0.31$), barrows and gilts were of a similar (barrow vs. gilt: 36.5 ± 0.92 lb vs. 36.4 ± 0.92 lb; $P = 0.82$) weight at the end of the trial on d 32.

From d 0 to 7, water source did not affect ($P \geq 0.20$) pig performance (Table 3). From d 7 to 20, pigs with the swinging waterers had improved ($P = 0.02$) ADG and F/G, with a trend ($P = 0.10$) for higher ADFI compared with pigs using the pan waterers. Performance during d 20 to 32 was similar ($P \geq 0.30$), regardless of water source. Overall, there was a trend ($P \geq 0.08$) for pigs using swinging waterers to have increased ADG and improved F/G, resulting in pigs on the swinging waterer having a 1.4 lb numeric advantage on d 32 over pigs on the pan waterer. Although, pigs performed comparably overall regardless of waterer type, performance differences detected from d 7 to 20 appear to provide an advantage to pigs using swinging waterers in the early stages as pigs are transitioning into the nursery period.

Mat-feeding duration did not affect ADG ($P = 0.52$) during the first 7 d of the trial; however, F/G was dependent upon duration (Table 3). Pigs fed on mats for 7 d had poorer ($P = 0.01$) F/G than pigs fed on mats for 3 d. With only a 0.01 lb difference in ADG between the 2 mat-feeding treatments during this 7-d period, there is a strong likelihood that some of this feed was wasted. Each pen received 4.8 lb of feed per day throughout the assigned mat-feeding duration. This was approximately 1.5 lb more feed placed on mats than in Exp.1, with fewer pigs per pen (52 pigs per pen in Exp. 2 and 58 pigs per pen in Exp. 1). Therefore, the higher amount fed may have resulted in more wastage in Exp. 2, leading to the inconsistencies in F/G between the 2 trials for the mat-feeding period.

From d 7 to 20 and d 20 to 32, there was no difference ($P \geq 0.18$) in ADG, ADFI, or F/G between the 2 mat-feeding duration treatments. Overall, pigs fed on mats for 3 d had similar ($P \geq 0.12$) ADG and F/G compared with pigs fed on mats for 7 d. There was a trend ($P = 0.08$) for pigs fed on mats for 7 d to consume more feed than pigs fed on mats for 3 d, though this ADFI increase did not result in large changes in growth

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rate. On d 32, pigs fed on mats for 7 d had a 0.5 lb numeric advantage ($P = 0.33$) in weight over pigs fed on mats for 3 d.

Mat-feeding reduced the removal percentage in the first experiment. However, increasing the duration from 3 to 7 d did not improve the removal percentage in the second experiment, and the extended duration of mat-feeding led to numerically poorer feed efficiency. Therefore, we believe these data support limiting the duration of mat-feeding to the first few days after weaning while pigs are learning feeding behavior. Cumulative removal rate tended to be lower at d 20 and 32 postweaning for pigs using the swinging waterer. Also, growth rate and F/G were better for pigs using the swinging waterer for the d 7 to 20 period postweaning. There was no evidence that pigs performed better when provided water with the pan waterer. Therefore, additional research may be warranted to evaluate alternating or combining water sources and their effects on pig performance and water usage to optimize management and production. Strategic implementation of these tools may be used to aid in starting pigs in the nursery.

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Table 1. Main effects of gender or mat-feeding on postweaning pig performance and removal percentages (Exp. 1)[1]

	Gender			Treatment[2]			Probability, $P <$	
Item	Barrow	Gilt	SEM	Control	Mat-fed	SEM	Gender	Treatment
Pens, no.	12	12	---	12	12	---	---	---
Removals within period[3]								
d 0 to 11 removals, %	7.3	5.3	1.24	8.0	4.6	1.24	0.20	0.03
d 11 to 27 removals, %	2.0	1.2	0.50	1.9	1.4	0.50	0.27	0.48
Cumulative removals[4]								
Through d 27, %	9.2	6.5	1.23	9.8	5.9	1.23	0.13	0.04
d 0 to 11								
ADG, lb	0.26	0.30	0.025	0.25	0.30	0.025	0.24	0.15
ADFI, lb	0.45	0.47	0.017	0.46	0.47	0.017	0.17	0.64
F/G	2.01	1.69	0.169	2.04	1.67	0.169	0.20	0.14
d 11 to 27								
ADG, lb	0.92	0.90	0.013	0.90	0.92	0.013	0.30	0.26
ADFI, lb	1.24	1.22	0.023	1.24	1.22	0.023	0.45	0.48
F/G	1.35	1.35	0.022	1.38	1.32	0.022	0.99	0.09
d 0 to 27								
ADG, lb	0.64	0.65	0.016	0.63	0.66	0.016	0.58	0.06
ADFI, lb	0.91	0.91	0.019	0.91	0.90	0.019	0.95	0.80
F/G	1.43	1.40	0.031	1.46	1.37	0.031	0.51	0.06
Weight, lb								
d 0	15.6	15.1	0.27	15.4	15.4	0.27	<0.01	0.85
d 11	19.9	19.5	0.40	19.8	19.6	0.40	0.13	0.57
d 27	35.2	34.2	0.51	34.7	34.7	0.51	0.05	0.99

[1] A total of 1,392 pigs (initially 15.4 lb) with 58 pigs per pen were blocked by background and used in a 27-d trial.
[2] Treatments were no mat-feeding (control) or mat-feeding 3 times daily (1.1 lb of pelleted feed per feeding) for an average of 6 days (mat-fed).
[3] Removed pig weights were considered to be zero, assuming removed pigs did not contribute value.

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Table 2. Interactive effect of waterer type and mat-feeding duration on pig performance and removal percentages (Exp. 2)[1]

	Waterer[2]					Probability, $P <$
	Swinging		Pan			Waterer ×
Item Duration:[3]	3 d	7 d	3 d	7 d	SEM[4]	Duration
Replication, no.[5]	12	12	10	10	---	---
Within period removals						
d 0 to 7, %	3.8	6.2	6.5	6.9	1.26	0.31
d 7 to 20, %	2.3	4.0	5.3	2.5	1.13	0.03
d 20 to 32, %	0.3	1.2	0.4	1.1	0.42	0.66
Cumulative removals						
Through d 20, %	6.1[a]	9.9[b]	11.5[b]	9.2[ab]	1.43	0.03
Through d 32, %	6.4[a]	11.1[b]	11.9[b]	10.2[ab]	1.48	0.03
d 0 to 7						
ADG, lb	0.38	0.41	0.35	0.35	0.029	0.38
ADFI, lb[6]	0.35	0.41	0.34	0.39	0.022	0.86
F/G	0.94	1.02	1.00	1.16	0.066	0.43
d 7 to 20						
ADG, lb	0.73	0.75	0.65	0.66	0.025	0.73
ADFI, lb	0.87	0.90	0.83	0.84	0.025	0.47
F/G	1.20	1.21	1.29	1.28	0.026	0.73
d 20 to 32						
ADG, lb	0.89	0.91	0.88	0.90	0.032	0.91
ADFI, lb	1.43	1.48	1.40	1.40	0.045	0.23
F/G	1.61	1.64	1.59	1.57	0.034	0.36
d 0 to 32						
ADG, lb	0.71	0.73	0.66	0.67	0.022	0.71
ADFI, lb	0.96	1.00	0.92	0.94	0.026	0.53
F/G	1.36	1.38	1.39	1.40	0.013	0.62
Weight, lb						
d 0	13.7	13.6	13.5	13.7	0.91	0.54
d 7	16.5	16.7	16.2	16.4	0.85	0.98
d 20	26.1	26.6	25.0	25.0	1.08	0.50
d 32	36.8	37.6	35.7	35.9	1.36	0.58

[1] A total of 2,288 weanling pigs (52 pigs per pen) were used in a 32-d trial. Pigs were initially 13.6 lb.

[2] Waterer treatments allowed ad libitum access to water through a dual swinging waterer (Swinging; Trojan Plastic Waterswing, Trojan Specialty Products, Dodge City, KS) or a 14-inch under-the-fence-line pan waterer (Pan; Koca, Des Moines, IA).

[3] Mat-feeding duration treatments were fed 3 times daily (1.6 lb of pelleted feed each time) on mats for either 3 d or 7 d.

[4] SEM among the treatments differ because of the unbalanced design. The highest SEM among treatments is reported.

[5] Pen is the unit for replication.

[6] There was a 3-way interaction ($P < 0.01$) with gender, waterer, and mat-feeding duration for ADFI from d 0 to 7. This interaction resulted from pigs mat-fed for 7 d having a 0.10-lb higher ADFI compared with pigs mat-fed for 3 d for barrows on swinging waterers (barrow-swinging-7 d: 0.44 ± 0.026 lb vs. barrow-swinging-3 d: 0.33 ± 0.026 lb; $P < 0.01$) and gilts on pan waterers (gilt-pan-7 d: 0.42 ± 0.028 lb vs. gilt-pan-3 d: 0.32 ± 0.028 lb; $P < 0.01$), while performance was similar regardless of mat-feeding duration for barrows on pan waterers (barrow-pan-7 d: 0.36 ± 0.028 lb vs. barrow-pan-3 d: 0.36 ± 0.028 lb; $P = 0.94$) and gilts on swinging waterers (gilt-swinging-7 d: 0.39 ± 0.026 lb vs. gilt-swinging-3 d: 0.38 ± 0.026 lb; $P = 0.69$).

[ab] Results without a common superscript letter differ ($P < 0.05$).

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Table 3. Main effects of waterer type and mat-feeding duration on pig performance and removal percentages (Exp. 2)[1]

	Waterer[2]			Duration[4]			Probability, $P <$	
Item	Swinging	Pan	SEM[3]	3 d	7d	SEM	Water	Duration
Replication, no.[5]	12	10	---	22	22	---	---	---
Within period removals								
d 0 to 7, %	5.0	6.7	1.03	5.2	6.6	0.85	0.26	0.17
d 7 to 20, %[6]	3.1	3.9	0.87	3.8	3.2	0.77	0.53	0.56
d 20 to 32, %	0.8	0.7	0.34	0.4	1.2	0.28	0.93	0.03
Cumulative removals								
Through d 20, %[6]	8.0	10.4	1.07	8.8	9.6	0.97	0.12	0.56
Through d 32, %[6]	8.7	11.1	1.05	9.2	10.6	1.00	0.14	0.31
d 0 to 7								
ADG, lb	0.40	0.35	0.025	0.37	0.38	0.020	0.20	0.52
ADFI, lb[7]	0.38	0.37	0.019	0.35	0.40	0.015	0.53	<0.01
F/G	0.98	1.08	0.056	0.97	1.09	0.044	0.25	0.01
d 7 to 20								
ADG, lb	0.74	0.65	0.021	0.69	0.70	0.017	0.02	0.46
ADFI, lb	0.89	0.83	0.021	0.85	0.87	0.017	0.10	0.39
F/G	1.21	1.29	0.020	1.25	1.25	0.018	0.02	0.99
d 20 to 32								
ADG, lb	0.90	0.89	0.030	0.89	0.90	0.022	0.83	0.40
ADFI, lb	1.46	1.40	0.042	1.41	1.44	0.030	0.36	0.18
F/G	1.63	1.58	0.030	1.60	1.61	0.023	0.30	0.85
d 0 to 32								
ADG, lb	0.72	0.67	0.019	0.69	0.70	0.015	0.09	0.31
ADFI, lb	0.98	0.93	0.023	0.94	0.97	0.018	0.16	0.08
F/G	1.37	1.40	0.012	1.37	1.39	0.009	0.08	0.12
Weight, lb								
d 0	13.6	13.6	0.89	13.6	13.6	0.62	0.97	0.83
d 7	16.6	16.3	0.82	16.3	16.5	0.57	0.78	0.45
d 20	26.3	25.0	1.05	25.6	25.8	0.73	0.38	0.50
d 32	37.2	35.8	1.31	36.2	36.7	0.92	0.44	0.33

[1] A total of 2,288 weanling pigs (52 pigs per pen) were used in a 32-d trial. Pigs were initially 13.6 lb.

[2] Waterer treatments allowed ad libitum access to water through a dual swinging waterer (Swinging; Trojan Plastic Waterswing, Trojan Specialty Products, Dodge City, KS) or a 14-inch under-the-fence-line pan waterer (Pan; Koca, Des Moines, IA).

[3] SEM among the treatments differ because of the unbalanced design. The highest SEM among treatments is reported.

[4] Mat-feeding duration treatments were feeding 3 times daily (1.6 lb of pelleted feed each time) on mats for either 3 d or 7 d.

[5] A set of 2 pens was the unit of replication for the waterer treatments, while a single pen was the unit of replication for the mat-feeding duration treatments.

[6] There were 2-way interactions ($P = 0.03$) with waterer and mat-feeding duration for d 0 to 7 removal percentage, removal percentage through d 20, and removal percentage through d 32.

[7] There was a 3-way interaction ($P < 0.01$) with gender, waterer, and mat-feeding duration for ADFI from d 0 to 7. This interaction resulted from pigs mat-fed for 7 d having a 0.10-lb higher ADFI compared with pigs mat-fed for 3 d for barrows on swinging waterers (barrow-swinging-7 d: 0.44 ± 0.026 lb vs. barrow-swinging-3 d: 0.33 ± 0.026 lb; $P < 0.01$) and gilts on pan waterers (gilt-pan-7 d: 0.42 ± 0.028 lb vs. gilt-pan-3 d: 0.32 ± 0.028 lb; $P < 0.01$), while performance was similar regardless of mat-feeding duration for barrows on pan waterers (barrow-pan-7 d: 0.36 ± 0.028 lb vs. barrow-pan-3 d: 0.36 ± 0.028 lb; $P = 0.94$) and gilts on swinging waterers (gilt-swinging-7 d: 0.39 ± 0.026 lb vs. gilt-swinging-3 d: 0.38 ± 0.026 lb; $P = 0.69$).

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A Comparison of Denagard, Denagard/CTC and Pulmotil on Nursery Pig Growth Performance and Economic Return[1]

K. M. Sotak, M. D. Tokach, M. Hammer[2], J. Y. Jacela[2], S. S. Dritz[3], D. Mechler[4], R. D. Goodband, J. M. DeRouchey, and J. L. Nelssen

Summary

A total of 880 weanling pigs (initially 15.6 lb and 16 to 20 d of age) were used in a 41-d experiment to compare the effects of different antibiotic regimens on growth performance and economic return in the nursery phase. Pigs were alloted to 1 of 5 treatment groups based on weight within gender. The antibiotic regimens included: (1) control diets containing no antibiotic throughout the trial, (2) a combination of Denagard (Novartis Animal Health, Greensboro, NC) at 35g/ton and chlortetracycline at 400g/ton (Denagard/CTC) for the entire 41-d trial, (3) a Pulmotil (Elanco, Greenfield, IN) regimen of 363g/ton from d 0 to 10 followed by 181g/d from d 10 to 41, (4) Denagard 200 from d 0 to 10 followed by Denagard/CTC from d 10 to 41, and (5) Denagard/CTC from d 0 to 10, Denagard 200 from d 10 to 20, and Denagard/CTC from d 20 to 41. From d 0 to 10, ADG, ADFI, and F/G were similar ($P > 0.40$) between the pigs fed nonmedicated diets and the mean of the groups fed diets containing antibiotics. However, from d 10 to 20, 20 to 41, and for the overall trial, pigs fed diets containing antibiotics had greater ($P < 0.05$) ADG and improved ($P < 0.04$) F/G than pigs fed the control diet without antibiotics. Pigs fed diets containing Denagard/CTC had greater ($P < 0.02$) ADG and ADFI than pigs fed Pulmotil for d 0 to 10, 20 to 41, and the overall trial. No differences were found ($P > 0.18$) between pigs fed Denagard/CTC and Denagard 200 during any phase. Final pig weights were greater for pigs fed diets containing antibiotics compared with the control ($P < 0.01$) and for pigs fed Denagard/CTC compared with pigs fed Pulmotil ($P < 0.05$). Adding antibiotics to the diets increased ($P < 0.01$) feed cost per pig; however, income over feed cost (IOFC) also increased for pigs fed Denagard/CTC compared with the control ($P < 0.01$) and compared with pigs fed Pulmotil ($P < 0.01$). These results demonstrate that adding antibiotics to the nursery diet improved pig performance and economic return.

Key words: antibiotic, Denagard, Pulmotil

Introduction

In-feed antibiotics have been widely used for many years to prevent disease and increase growth rates in nursery pigs. These antibiotics have been found to increase ADG and ADFI, subsequently increasing pig weights (Steidinger et al., 2009[4]). In the Swine Day

[1] Appreciation is expressed to Novartis Animal Health, Greensboro, NC, for financial assistance for this project.

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2008 and 2009 Reports of Progress (Steidinger et al., 2008; 2009[5,6]), authors compared pigs fed different antibiotic regimens, including combinations of Denagard (Novartis Animal Health, Greensboro, NC) and chlortetracycline (Denagard/CTC) with pigs fed Mecadox (Philbro Animal Health Corp., Ridgefield Park, NJ) and oxytetracycline (Mecadox/OTC) or with pigs fed Pulmotil (Elanco Animal Health, Greenfield, IN). All of the antibiotic regimens tested improved growth performance and income over feed cost (IOFC) compared with pigs fed no antibiotic. The objective of this study was to determine the effect of several feed antibiotic regimens on growth performance and economic return in a pig flow with porcine reproductive and respiratory syndrome virus (PRRSv) circulation.

Procedures

A total of 880 weanling pigs (15.6 pounds and 16 to 20 d of age), were used in a 41-d study to determine the effect on nursery pig performance of Denagard, Denagard/CTC, and Pulmotil. Pigs used in this study originated from a PRRSv-positive herd and also tested positive for *Mycoplasma hyopneumoniae.* Serologic testing confirmed circulating PRRSv was present in the pigs during the study.

The pigs were housed in a wean-to-finish facility containing 53 pens with 22 pigs per pen (11 gilts and 11 barrows). Forty pens were used in the study with 8 replications per treatment. Each pen had slatted floors, one 5-hole feeder, and a nipple waterer. A robotic system (Feedlogic, Willmar, MN) was used to dispense and record feed. By d 14 of the trial, all pigs had seroconverted to PRRS with 100% of the samples being PCR-positive from d 14 to 42. The pigs were vaccinated for *Mycoplasma hyopneumoniae* at wks 2 and 4, and Circovirus as recommended by the veterinarian.

The pigs were all weaned on the same day (d 0) and divided into 5 treatment groups. Each of the 5 groups contained 176 pigs, for a total of 880 pigs. They were monitored daily by the farm's staff, and any critically ill or injured pigs were humanely euthanized based on Novartis Animal Health's euthanasia policies.

All treatment groups received the same 3-phase (d 0 to d 10, d 10 to d 20, and d 20 to d 41) corn-soybean meal-based diets. The only difference between diets within each phase was the antibiotic regimen. The antibiotic regimens tested included: (1) control diets containing no antibiotic throughout the trial, (2) a combination of Denagard at 35g/ton and chlortetracycline at 400g/ton (Denagard/CTC) for the entire 41-d trial, (3) Pulmotil at 363g/ton from d 0 to 10 followed by 181g/ton from d 10 to 41, (4) Denagard 200g/ton from d 0 to 10 followed by Denagard/CTC from d 10 to 41, and (5) Denagard/CTC from d 0 to 10, Denagard 200g/ton from d 10 to 20 and Denagard/CTC from d 20 to 41 (Table 1).

[5] Steidinger, M.U., M.D. Tokach, D. Dau, S.S. Dritz, J.M. DeRouchey, R.D. Goodband, and J.L. Nelssen. Comparison of different antibiotic sequences on nursery pig performance and economic return. Swine Day 2009, Report of Progress 1020, pp 122-131.

[6] Steidinger, MU., M.D. Tokach, D. Dau, S.S. Dritz, J.M. DeRouchey, R.D. Goodband, and J.L. Nelssen. Influence of antibiotic sequence in the nursery on pig performance and economic return. Swine Day 2008, Report of Progress 1001, pp. 74-81.

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Throughout the study, the pigs had ad libitum access to feed and water. Feed samples were collected at the feed mill and farm from each diet each phase and analyzed to verify that the desired antibiotic levels were present (Table 2).

All pigs and feeders were weighed on d 0, 10, 20, and 41 to determine ADG, ADFI, and F/G. Pig mortality and the number of pigs treated per pen were recorded. Actual diet costs were used to calculate the feed costs associated with each treatment. Income over feed cost (IOFC) was calculated for market prices of $0.50/lb and $1.00/lb. The $0.50/lb of gain was based on the assumption that any gain in the nursery would not increase or decrease at market, and $1.00/lb of gain assumed that each lb of gain in the nursery was equivalent to 2 lb at market (Tables 3 and 4).

The MIXED procedure was used in SAS (SAS Institute, Inc., Cary, NC) to analyze the data. Single degree of freedom contrasts were used to make comparisons between the control versus all other treatments, Denagard/CTC versus Pulmotil, Denagard/CTC versus Denagard 200 in Phases 1 and 2, and Denagard 200 versus Pulmotil in Phases 1 and 2.

Results and Discussion

Throughout the study, mortality remained constant with the source's historical averages. No adverse reactions to the antibiotic additions were observed, and their inclusion in the diets was confirmed using laboratory analysis. The analyzed levels of the antibiotics were all slightly lower than the expected values, ranging from 66% to 91% of the expected values. The presence of trace levels of Denagard (Phase 1 and 2), Chlortetracycline (Phase 1, 2, and 3), and Pulmotil (Phases 1, 2, and 3) in the control diet samples was most likely due to contamination at the time of sampling. Contamination at the time of the diet blending was not considered likely due to the control diets being mixed before the treatment diets (Table 2).

Adding antibiotics to the diet did not improve ($P > 0.40$) pig performance from d 0 to 10 (Table 3); however, pigs fed diets containing antibiotics had greater ($P < 0.05$) ADG for d 10 to 21, 21 to 42, and for the overall trial (d 0 to 42). Pigs fed diets with antibiotics also had greater ($P < 0.01$) ADFI and improved ($P < 0.01$) F/G from d 20 to 41 and for the overall trial and tended to have improved ($P<0.10$) ADFI and F/G from d 10 to 20. When comparing the response of pigs fed the control diet to those fed Pulmotil or Denagard/CTC, pigs fed Denagard/CTC had improved ($P< 0.01$) ADG, ADFI, and F/G compared with the control, but those fed Pulmotil only had improved F/G ($P <0.01$), with no effect ($P> 0.05$) on ADG or ADFI. Pigs fed diets containing antibiotics were 2.5 to 4.5 lb heavier ($P < 0.01$) at the end of the trial than pigs fed the control diet without antibiotics. Adding antibiotics to the diet increased ($P < 0.01$) feed cost per pig and feed cost per pound of gain, but also increased ($P < 0.01$) profitability as measured by IOFC (Table 4). These data clearly show the improvement in growth performance that can be achieved when health-challenged pigs are fed diets containing antibiotics.

When comparing pigs fed Denagard/CTC with those fed Pulmotil, pigs fed Denagard/CTC had increased ($P < 0.02$) ADG and ADFI from d 0 to 10, 20 to 41, and 0 to 41. The increased growth rate resulted in pigs fed Denagard/CTC through the trial being 2.5 lb heavier ($P < 0.05$) than pigs fed Pulmotil at the end of the trial. There were no

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differences ($P > 0.31$) in F/G between pigs fed diets containing Denagard/CTC and pigs fed diets containing Pulmotil during any stage. Because of higher ADFI, pigs fed the diet containing Denagard/CTC had higher ($P < 0.05$) feed cost per pig than pigs fed diets containing Pulmotil. However, pigs fed diets containing Denagard/CTC had lower ($P < 0.01$) feed costs per pound of gain and improved ($P < 0.01$) IOFC from d 10 to 20 and d 20 to 41 whether gain was valued at $0.50/lb or $1.00/lb. These results are similar to the results published in the 2009 Swine Day Report comparing performance of pigs fed Denagard/CTC to pigs fed Pulmotil.

Denagard/CTC and Denagard 200 were also compared to determine the effectiveness of Denagard as an individual antibiotic. Both antibiotic options performed similarly, with no differences in ADG ($P > 0.49$), ADFI ($P > 0.55$), or F/G ($P > 0.20$). Feed costs per pig were similar between pigs fed diets containing Denagard/CTC and Denagard 200, except pigs fed the diets containing Denagard/CTC had lower ($P < 0.01$) feed cost from d 10 to 20. Feed cost per pound of gain was lower ($P < 0.05$) for pigs fed Denagard/CTC from d 0 to 10, d 10 to 20, and overall than pigs fed Denagard 200. Pigs fed diets containing Denagard/CTC had greater ($P < 0.05$) IOFC than pigs fed Denagard 200, whether gain was valued at $0.50/lb or $1.00/lb.

While the number of individual antibiotic treatments per pen was not significantly different between Denagard/CTC versus Pulmotil ($P = 0.98$) or Denagard 200 ($P = 0.99$), pigs fed diets containing Denagard/CTC in the diet at any point during the trial required fewer individual antibiotic treatments ($P < 0.02$) than pigs fed the control diets without antibiotics (Table 2).

The overall data from this experiment are consistent with the Swine Day publications from 2008 and 2009, showing improvement in weight gain and income over feed cost for pigs fed Denagard/CTC (Steidinger et al, 2008; Steidinger et al, 2009). These results confirm the results of our first two experiments that adding antibiotics to the nursery diet improved pig performance and economic return of health-challenged pigs.

Table 1. Dietary antibiotics in each phase

Treatment	d 0 to d 10	d 10 to d 20	d 20 to d 41
1	No medication	No medication	No medication
2	Denagard/CTC[1]	Denagard/CTC[1]	Denagard/CTC[1]
3	Pulmotil, 363 g/ton	Pulmotil, 181 g/ton	Pulmotil, 181 g/ton
4	Denagard, 200 g/ton	Denagard/CTC[1]	Denagard/CTC[1]
5	Denagard/CTC[1]	Denagard, 200 g/ton	Denagard/CTC[1]

[1]Denagard at 35 g/ton and chlortetracycline at 400 g/ton.

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Table 2. Analyzed in-feed antibiotic levels

	Antibiotic level, g/ton								
	Denagard			Chlortetracycline			Pulmotil		
Diet	Expected	Analyzed	% of Expected	Expected	Analyzed	% of Expected	Expected	Analyzed	% of Expected
Phase 1									
Control	0	7.3		0	18.6		0	<45.4	
Denagard/CTC[1,2]	35	29.1	83.1	400	353	88.3	---	---	---
Pulmotil[2]	---	---	---	---	---	---	363	328	90.4
Denagard 200	200	175	87.5	---	---	---	---	---	---
Phase 2									
Control	0	3.6	---	0	11.3	---	0	<45.4	---
Denagard/CTC[1,2]	35	31.5	90.0	400	343	85.8	---	---	---
Pulmotil[2]	---	---	---	---	---	---	---	---	---
Denagard 200	200	156.7	78.4	---	---	---	---	---	---
Phase 3									
Control	0	0	---	0	3.57	---	0	<45.4	---
Denagard/CTC[1,2]	35	31.6	90.3	400	312	78.0	---	---	---
Pulmotil[2]	---	---	---	---	---	---	181	121	66.9

[1] Denagard (tiamulin) analysis conducted at CIA Laboratories, St. Joseph, MO.
[2] Chlortetracycline and Pulmotil analysis conducted at Eurofins – AvTech Laboratories, Portage, MI.

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Table 3. Influence of antibiotic additions to the diet on pig performance[1]

	Treatments[2]						Contrasts				
	1	2	3	4	5						
d 0 to 10:	No med	Den/CTC	Pulmotil	Den 200	Den/CTC						
d 10 to 20:	No med	Den/CTC	Pulmotil	Den/CTC	Den 200						
d 20 to 41:	No med	Den/CTC	Pulmotil	Den/CTC	Den/CTC	SED	No med vs all others	No med vs Pulmotil	No med vs Den/CTC	Den/CTC vs Pulmotil	Den/CTC vs Den 200[3]	Den 200 vs Pulmotil[4]
d 0 to 10												
ADG, lb	0.39	0.39	0.34	0.38	0.41	0.03	0.85	0.13	0.55	0.02	0.49	0.15
ADFI, lb	0.45	0.46	0.42	0.46	0.48	0.02	0.86	0.20	0.37	0.02	0.55	0.12
F/G	1.16	1.20	1.24	1.19	1.17	0.06	0.40	0.20	0.63	0.31	0.88	0.45
d 10 to 20												
ADG, lb	0.69	0.81	0.73	0.81	0.78	0.06	0.05	0.44	0.02	0.14	0.50	0.02
ADFI, lb	0.90	0.96	0.91	1.01	1.00	0.05	0.10	0.85	0.06	0.10	0.85	0.02
F/G	1.32	1.19	1.25	1.27	1.28	0.05	0.08	0.16	0.04	0.66	0.18	0.24
d 20 to 41												
ADG, lb	0.89	1.05	0.95	1.05	1.06	0.04	0.01	0.15	0.01	0.01	0.74	0.01
ADFI, lb	1.55	1.68	1.51	1.72	1.73	0.04	0.01	0.36	0.01	0.01	0.63	0.01
F/G	1.74	1.61	1.60	1.66	1.63	0.05	0.01	0.01	0.01	0.42	0.33	0.28
d 0 to 41												
ADG, lb	0.72	0.83	0.74	0.83	0.83	0.03	0.01	0.36	0.01	0.01	0.87	0.01
ADFI, lb	1.11	1.20	1.09	1.24	1.24	0.04	0.01	0.49	0.01	0.01	0.55	0.01
F/G	1.56	1.46	1.47	1.50	1.49	0.03	0.01	0.01	0.01	0.45	0.20	0.19
Weight, lb												
d 0	15.6	15.6	15.6	15.6	15.6	0.41	1.00	1.00	1.00	0.99	0.99	1.00
d 10	19.4	19.4	19.0	19.4	19.7	0.58	0.93	0.45	0.76	0.24	0.60	0.23
d 20	26.7	27.8	26.4	27.7	27.9	0.99	0.33	0.80	0.22	0.13	0.82	0.01
d 41	45.9	49.8	47.4	49.6	50.5	1.27	0.01	0.23	0.01	0.05	0.47	0.02
Survival, %	94.9%	98.3%	93.8%	98.9%	95.5%	--	0.20	0.20	0.11	0.14	0.70	0.15
Treatments/pen[5]	3.5	1.3	2.8	1.3	1.3	--	.06	.67	0.08	.18	.99	.17

[1] Each mean represents 8 pens with 22 pigs per pen for a total of 880 pigs.
[2] Den/CTC was a combination of Denagard at 35 g/ton and chlortetracycline at 400 g/ton. Pulmotil was 363 g/ton from d 0 to 10 and 181 g/ton from d 10 to 41. Den 200 was Denagard at 200 g/ton.
[3] Pigs fed Denagard 200 in either Phase 1 or 2 were compared to pigs receiving only Den/CTC: Phase 1 (Treatment 2 vs 4), Phase 2 (Treatment 2 vs 5), Phase 3 and overall (Treatment 2 vs 4 & 5).
[4] Pigs fed Denagard 200 in either Phase 1 or 2 were compared to pigs receiving only Pulmotil: Phase 1 (Treatment 3 vs 4), Phase 2 (Treatment 3 vs 5), Phase 3 and overall (Treatment 3 vs 4 & 5).
[5] Treatments per pen is the mean number of individual antibiotic treatments per pen. No medication vs the mean of the three treatments with Denagard had a p-value of 0.02.

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Table 4. Influence of antibiotic additions to the diet on feed economics[1]

	Treatments[2]						Contrasts				
	1	2	3	4	5						
d 0 to 10:	No med	Den/CTC	Pulmotil	Den 200	Den/CTC						
d 10 to 20:	No med	Den/CTC	Pulmotil	Den/CTC	Den 200						
d 20 to 41:	No med	Den/CTC	Pulmotil	Den/CTC	Den/CTC	SED	No med vs all others	No med vs Pulmotil	No med vs Den/CTC	Den/CTC vs Pulmotil	Den/CTC vs Den 200[3]	Den 200 vs Pulmotil[4]
Feed cost, $/pig												
d 0 to d 10	1.62	1.72	1.70	1.85	1.79	0.09	0.05	0.35	0.09	0.52	0.25	0.12
d 10 to d 20	2.13	2.40	2.36	2.53	2.79	0.137	0.01	0.11	0.01	0.38	0.01	0.38
d 20 to d 41	3.48	4.23	4.10	4.33	4.35	0.106	0.01	0.01	0.01	0.03	0.63	0.45
d 0 to d 41	7.23	8.34	8.16	8.71	8.93	0.277	0.01	0.01	0.01	0.03	0.10	0.22
Feed cost, $/lb gain												
d 0 to d 10	0.42	0.45	0.50	0.48	0.44	0.022	0.01	0.01	0.21	0.01	0.05	0.01
d 10 to d 20	0.31	0.30	0.32	0.32	0.36	0.012	0.20	0.34	0.63	0.12	0.01	0.01
d 20 to d 41	0.19	0.19	0.21	0.20	0.20	0.006	0.01	0.01	0.05	0.01	0.34	0.23
d 0 to d 41	0.25	0.25	0.27	0.26	0.26	0.01	0.01	0.01	0.04	0.01	0.01	0.99
Income over feed cost[5], $/pig												
d 0 to d 10	0.31	0.23	0.00	0.07	0.27	0.094	0.03	0.01	0.46	0.01	0.03	0.01
d 10 to d 20	1.31	1.66	1.32	1.54	1.10	0.181	0.53	0.97	0.08	0.08	0.01	0.04
d 20 to d 41	5.91	6.76	5.83	6.63	6.80	0.324	0.02	0.82	0.01	0.01	0.58	0.01
d 0 to d 41	7.48	8.59	7.03	8.18	8.06	0.318	0.06	0.17	0.01	0.01	0.24	0.01
Income over feed cost[6], $/pig												
d 0 to d 10	2.24	2.18	1.71	1.99	2.34	0.227	0.30	0.02	0.94	0.01	0.18	0.01
d 10 to d 20	4.76	5.72	5.00	5.61	4.99	0.47	0.13	0.62	0.03	0.11	0.10	0.04
d 20 to d 41	15.29	17.75	15.77	17.58	17.96	0.70	0.01	0.50	0.01	0.01	0.66	0.01
d 0 to d 41	22.19	25.53	22.23	25.07	25.05	0.823	0.01	0.96	0.01	0.01	0.72	0.01

[1] Each mean represents 8 pens with 22 pigs per pen for a total of 880 pigs.
[2] Den/CTC was a combination of Denagard at 35 g/ton and chlortetracycline at 400 g/ton. Pulmotil was 363 g/ton from d 0 to 10 and 181 g/ton from d 10 to 41. Den 200 was Denagard at 200 g/ton.
[3] Pigs fed Denagard 200 in either Phase 1 or 2 were compared to pigs receiving only Den/CTC: Phase 1 (Treatment 2 vs 4), Phase 2 (Treatment 2 vs 5), Phase 3 and overall (Treatment 2 vs 4 & 5).
[4] Pigs fed Denagard 200 in either Phase 1 or 2 were compared to pigs receiving only Pulmotil: Phase 1 (Treatment 3 vs 4), Phase 2 (Treatment 3 vs 5), Phase 3 and overall (Treatment 3 vs 4 & 5).
[5] Income over feed cost used $0.50/lb for the value of gain.
[6] Income over feed cost used $1.00/lb for the value of gain.

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Effects of Vomitoxin Concentration in Nursery Pig Diets and the Effectiveness of Commercial Products to Mitigate its Effects[1]

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Summary

A total of 180 pigs (PIC TR4 × 1050, initially 22.8 lb and 34 d of age) were used in a 21-d trial to evaluate the effects of vomitoxin concentration in nursery pig diets and the effectiveness of commercial products to mitigate vomitoxin's negative effects on performance. Pens of pigs were balanced by initial weight and were randomly allotted to 1 of 5 dietary treatments with 6 replications per treatment. Dietary treatments included a control diet consisting of corn-soybean meal and regular dried distillers grains with solubles (DDGS; low vomitoxin), a negative control diet containing 4 ppm dietary vomitoxin (from contaminated DDGS), and the negative control diet with Biofix Plus, Cel-can with bentonite clay, or Defusion Plus. All diets were fed in meal form.

From d 0 to 10, pigs fed either the negative control or diets containing Biofix Plus, Cel-can with bentonite clay, or Defusion Plus had decreased ($P < 0.05$) ADG and ADFI than pigs fed the positive control diet. Pigs fed the positive control diet had improved F/G ($P < 0.05$) compared to pigs fed the negative control diet and diets containing Biofix Plus or Cel-can with bentonite clay, with pigs fed diets containing Defusion Plus intermediate.

From d 10 to 21, pigs fed the positive control or diet containing Defusion Plus had greater ($P < 0.05$) ADG than the negative control, Biofix Plus, and Cel-can with bentonite clay diets. Additionally, pigs fed the positive control diet had a greater ($P < 0.05$) ADFI than pigs fed the negative control and diets containing Biofix Plus and Cel-can with bentonite clay, with pigs fed Defusion Plus intermediate.

Overall (d 0-21), pigs fed the positive control diet had greater ($P < 0.05$) ADG compared to pigs fed any of the vomitoxin-contaminated diets. In addition, pigs fed diets containing Defusion Plus had greater ADG ($P < 0.05$) than pigs fed the negative control diet and diets containing Biofix Plus or Cel-can with bentonite clay. Pigs fed the positive control diet had greater ADFI ($P < 0.05$) than pigs fed any other dietary treatment. Pigs fed the positive control diet had improved F/G ($P < 0.05$) compared to the negative control and diets containing Biofix Plus or Cel-can with bentonite clay. Also, pigs fed Defusion Plus had improved F/G ($P < 0.05$) compared to pigs fed the negative control. Thus, nursery pigs fed diets containing 4 ppm vomitoxin had reduced growth performance. Including Defusion Plus in the diet improved performance but not to that of pigs fed a low-vomitoxin diet.

[1] Appreciation is expressed to New Fashion Pork, Jackson, MN, and Hubbard Feeds, Mankato, MN, for supplying the contaminated DDGS.

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Key words: Biofix Plus, Cel-can with bentonite clay, Defusion Plus, vomitoxin

Introduction

Mycotoxins are toxic secondary metabolites produced by fungi that can be found in many varieties of grain and forage produced for feed. Worldwide, approximately 25% of crops are contaminated by mycotoxins annually (CAST, 1989[3]). Mycotoxin contamination has been found to reduce yield and quality of grains, to reduce the health and productivity of animals, and to represent a hazard to consumers.

Deoxynivalenol (DON), often referred to as vomitoxin, is a particularly abundant mycotoxin and is one of the most common contaminants of wheat, corn, and barley worldwide. With high levels of vomitoxin found in the 2009 corn crop, understanding its impact on swine performance is pertinent to industry productivity and animal health. To further confound the problem in swine diets, DDGS contains approximately 3 times the vomitoxin level found in the corn where it originated because vomitoxin is unaltered in the fermentation process. Thus, both corn and DDGS must be monitored for vomitoxin levels. Currently, several commercial products are marketed to help alleviate the effects of vomitoxin in swine diets. However, sparse data are available on the effectiveness of these commercial products.

Biofix Plus is a direct-fed fermented product that provides a source of yeast to potentially absorb the mycotoxins as well as break down vomitoxin by enzymatic degradation. Cel-can is a mixture of yeast components that provides a supply of fermentation metabolites in combination with clay to bind and absorb mycotoxins. Defusion Plus is a blend of antioxidants, amino acids, direct-fed microbials, and preservatives thought to absorb or break down vomitoxin in feed over a period of time.

The objectives of this trial were to determine the effect of vomitoxin in nursery pig diets and to evaluate the effectiveness of three commercial products (Biofix Plus, Cel-can, and Defusion Plus) in vomitoxin-contaminated diets for nursery pigs.

Procedures

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

A total of 180 pigs (TR4 × 1050, initially 22.8 lb and 34 d of age) were used in a 21-d growth trial to compare the effects of vomitoxin concentration in nursery pig diets and the effectiveness of commercial products to mitigate associated negative performance. Pigs were allotted to pens by initial BW, and pens were assigned to treatments in a random block design, with both weight and location in the nursery serving as blocking factors. Dietary treatments included a control diet consisting of corn-soybean meal and regular DDGS (low vomitoxin), a negative control diet containing 4 ppm dietary vomitoxin (from contaminated DDGS), the negative control diet with Biofix Plus (ADM Alliance Nutrition; Quincy, IL), Cel-can (Value-Added Science & Technologies; Mason City, IA) with bentonite clay, or Defusion Plus (North American Nutri-

[3] CAST, Council for Agricultural Science and Technology. 1989. Mycotoxins: Economic and health risks. Task Force Report No. 116.

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tion Co., Inc.; Brookville, OH) (Table 1). Diets were fed in meal form. A source of DDGS containing 12 ppm vomitoxin was included at 17% of the total ration to make the vomitoxin-contaminated diets.

Each pen contained a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water. Pens had wire-mesh floors and allowed approximately 3 ft^2 per pig. Pig weight and feed disappearance were measured on d 0, 3, 7, 10, and 21 of the trial to determine ADG, ADFI, and F/G.

Diet samples were collected from feeders between each weigh day and submitted for a complete mycotoxin analysis at the Veterinary Diagnostic Laboratory at North Dakota State University, Fargo. End-of-trial samples were also collected from the Defusion Plus and negative control treatment (Table 2) to determine if vomitoxin breakdown occurred. Samples were sent for analysis after the trial concluded.

Data were analyzed as a randomized complete block design using the GLIMMIX procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Differences between treatments were determined by using least squares means ($P < 0.05$). Pair-wise comparison was also used to test the difference between the negative control and vomitoxin mitigation treatments.

Results and Discussion

The analyzed dietary vomitoxin concentration for the positive control diet was 0.8 ppm. In addition, analyzed dietary vomitoxin concentration for the negative control, Biofix Plus, Cel-can with bentonite clay, and Defusion Plus were 4.6, 4.4, 4.3, and 5.1 ppm respectively. Also, other DON metabolites, (3-Acetyl DON and 15-Acetyl DON) were analyzed and found in small concentrations in the diets. If vomitoxin contamination is suspected, it is important to complete a full mycotoxin screening that will test for both vomitoxin and DON metabolites because these metabolites may have an additive affect. Fumonisin B1 and Zearelenone levels were tested and found in diets at or below cautionary dietary limits. Day 21 samples were collected from the negative control and Defusion Plus treatments to test for enzymatic degradation and reduction of dietary vomitoxin. Only a small reduction in dietary vomitoxin level was observed.

From d 0 to 3 and d 3 to 7, pigs fed the control diet had greater ($P < 0.05$) ADG and ADFI compared to pigs fed diets containing vomitoxin-contaminated DDGS (Table 3). There were no differences for growth criteria between the negative control and mitigation treatments for these periods. From d 7 to 10, pigs fed the positive control had greater ($P < 0.05$) ADG than pigs fed the negative control, Biofix Plus, or Cel-can with bentonite clay, while the pigs fed Defusion Plus were intermediate.

From d 0 to 10, pigs fed either the negative control or diets containing Biofix Plus, Cel-can with bentonite clay, or Defusion Plus had decreased ($P < 0.05$) BW, ADG, and ADFI compared with pigs fed the positive control diet. Pigs fed the positive control diet had improved ($P < 0.05$) F/G compared to pigs fed the negative control diet and diets containing Biofix Plus or Cel-can with bentonite clay, with pigs fed diets containing Defusion Plus intermediate.

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From d 10 to 21, pigs fed the positive control diet or the diet containing Defusion Plus had greater ($P < 0.05$) ADG than the negative control, Biofix Plus, and Cel-can with bentonite clay diets. Additionally, pigs fed the positive control diet had a greater ($P < 0.05$) ADFI than pigs fed the negative control diets containing Biofix Plus and Cel-can with bentonite clay. Pigs fed Defusion Plus were intermediate.

Overall (d 0 to 21), pigs fed the positive control diet had greater ($P < 0.05$) final BW and ADG compared to pigs fed any of the vomitoxin-contaminated diets. In addition, pigs fed diets containing Defusion Plus had greater ($P < 0.05$) ADG than pigs fed the negative control diet or diets containing Biofix Plus or Cel-can with bentonite clay. Pigs fed the positive control diet had greater ($P < 0.05$) ADFI than pigs fed any other dietary treatment. Pigs fed the positive control diet had improved F/G ($P < 0.05$) compared to the negative control and diets containing Biofix Plus or Cel-can and bentonite clay. Also, pigs fed Defusion Plus had improved F/G ($P < 0.05$) compared to pigs fed the negative control. It should be noted the pigs used in this study had good health status during the entire course of the experiment and only 1 pig was taken off test on d 9 (from the Defusion Plus treatment) due to chronic poor performance.

In summary, nursery pigs fed diets containing 4 ppm vomitoxin clearly had reduced growth performance. Including Defusion Plus improved performance but not to the level of a positive control, low-vomitoxin diet. Therefore, Defusion Plus appears to have potential for mitigating some of the negative impacts of vomitoxin on growth performance.

Results for this study found that feeding nursery diets contaminated with 4 ppm vomitoxin resulted in reduced final BW by 7.6 lb over the 21-d period. Pigs fed the Defusion Plus (5 lb per ton) were the only vomitoxin-contaminated diet group to have improved gains, which resulted in intermediate growth performance between the positive and negative control.

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

Item	Positive control	Vomitoxin, 4 ppm			
		Negative control	Biofix Plus	Cel-can with bentonite clay	Defusion Plus
Ingredient, %					
Corn	51.36	51.36	51.26	50.66	51.09
Soybean meal, 46.5% CP	28.29	28.29	28.29	28.34	28.31
DDGS	17.00	---	---	---	---
Vomitoxin DDGS[2]	---	17.00	17.00	17.00	17.00
Monocalcium P, 21% P	0.65	0.65	0.65	0.65	0.65
Limestone	1.20	1.20	1.20	1.20	1.20
Salt	0.35	0.35	0.35	0.35	0.35
Copper sulfate	0.05	0.05	0.05	0.05	0.05
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	0.40	0.40	0.40	0.40	0.40
DL-methionine	0.08	0.08	0.08	0.08	0.08
L-threonine	0.10	0.10	0.10	0.10	0.10
Phytase[3]	0.13	0.13	0.13	0.13	0.13
Cel-can	---	---	---	0.15	---
Defusion Plus	---	---	---	---	0.25
Biofix Plus	---	---	0.10	---	---
Bentonite clay	---	---	---	0.50	---
TOTAL	100.00	100.00	100.00	100.00	100.00
Calculated analysis					
Standardized ileal digestible amino acids, %					
Lysine	1.27	1.27	1.27	1.27	1.27
Isoleucine:lysine	63	63	623	63	63
Methionine:lysine	32	32	32	32	32
Met & cys:lysine	59	59	59	59	59
Threonine:lysine	63	63	63	63	63
Tryptophan:lysine	17	17	17	17	17
Valine:lysine	72	72	72	72	72
Total lysine, %	1.43	1.43	1.43	1.43	1.43
ME, kcal/lb	1,506	1,506	1,504	1,496	1,502
SID Lysine:ME, g/Mcal	3.83	3.83	3.83	3.85	3.84
CP, %	22.64	22.64	22.64	22.61	22.63
Ca, %	0.69	0.69	0.69	0.69	0.69
P, %	0.60	0.60	0.60	0.59	0.60
Available P, %	0.42	0.42	0.42	0.42	0.42

[1] Diets were fed from approximately 22.8 to 44.2 lb in meal form.
[2] Analyzed Deoynivalenol concentration in DDGS was 23.5 ppm.
[3] Phyzyme 600 (Danisco Animal Nutrition, St Louis, MO.) Provided per pound of diet: 340.5 FTU/lb and 0.13% available P released.

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Table 2. Mycotoxin analysis of diets

	Composite[1]					d 21[2]	
Items, ppm	Positive control	Negative control	Biofix Plus	Cel-can with bentonite clay	Defusion Plus	Negative Control	Defusion Plus
Deoxynivalenol (DON)	0.8	4.6	4.4	4.3	5.1	6.1	4.6
3-Acetyl DON	<0.5	<0.5	<0.5	< 0.5	<0.5	<0.5	<0.5
15-Acetyl DON	<0.5	1.0	1.0	1.0	1.1	1.3	1.0
Total DON	0.8	5.6	5.4	5.3	6.2	7.4	5.6
Fumonisin B1	2.0	2.0	2.0	1.0	<2.0	2.0	1.0
Zearelenone	<0.5	0.5	0.5	0.5	0.5	0.6	0.5

[1] Values are a mean of 6 samples collected on d 2, 5, 8, 12, 14, and 19 that were blended before being analyzed at the end of the experiment.
[2] Collected at conclusion of the study and analyzed in a separate run from other samples.

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Table 3. Effect of vomitoxin level and commercial products on nursery pig growth performance[1]

		Vomitoxin, 4ppm				
Item	Positive control	Negative control	Biofix Plus	Cel-can + bentonite clay	Defusion Plus	SEM
BW, lb						
d 0	22.7	22.8	22.9	22.9	22.8	0.42
d 3	25.3	23.6	23.7	23.7	23.7	0.44
d 7	29.7[a]	27.0[b]	26.8[b]	27.0[b]	26.8[b]	0.48
d 10	38.2[a]	33.6[b]	33.5[b]	34.3[b]	35.5[b]	0.71
d 21	49.8[a]	42.2[c]	41.8[c]	42.2[c]	44.9[b]	0.88
d 0 to 3						
ADG, lb	0.85[a]	0.28[b]	0.27[b]	0.27[b]	0.31[b]	0.056
ADFI, lb	1.30[a]	0.85[b]	0.92[b]	0.87[b]	0.83[b]	0.051
F/G	1.55[a]	3.92[b]	4.41[b]	3.35[b]	3.09[b]	0.711
d 3 to 7						
ADG, lb	1.11[a]	0.83[b]	0.76[b]	0.83[b]	0.78[b]	0.042
ADFI, lb	1.55[a]	1.15[b]	1.09[b]	1.12[b]	1.05[b]	0.052
F/G	1.40	1.40	1.44	1.36	1.37	0.057
d 7 to 10						
ADG, lb	1.24[a]	0.92[b]	0.96[b]	0.95[b]	1.04[ab]	0.078
ADFI, lb	1.86[a]	1.45[b]	1.40[b]	1.44[b]	1.46[b]	0.085
F/G	1.50	1.59	1.49	1.54	1.44	0.079
d 0 to 10						
ADG, lb	1.07[a]	0.69[b]	0.67[b]	0.70[b]	0.71[b]	0.039
ADFI, lb	1.56[a]	1.15[b]	1.13[b]	1.14[b]	1.11[b]	0.052
F/G	1.46[a]	1.67[b]	1.69[b]	1.65[b]	1.56[ab]	0.050
d 10 to 21						
ADG, lb	1.42[a]	1.10[b]	1.08[b]	1.12[b]	1.34[a]	0.050
ADFI, lb	2.26[a]	1.90[b]	1.80[b]	1.85[b]	2.05[ab]	0.089
F/G	1.62	1.72	1.69	1.67	1.55	0.066
d 0 to 21						
ADG, lb	1.29[a]	0.92[c]	0.90[c]	0.92[c]	1.03[b]	0.032
ADFI, lb	1.97[a]	1.59[b]	1.51[b]	1.54[b]	1.63[b]	0.065
F/G	1.53[a]	1.71[c]	1.68[bc]	1.67[bc]	1.57[ab]	0.044

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

[1] A total of 180 pigs (TR4 × 1050, initially 22.8 lb and 34 d of age) were used in a 21-d trial with 6 pigs per pen and 6 pens per treatment.

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The Effects of Biomin Product A and Vomitoxin on Growth Performance of Nursery Pigs[1,2]

H. L. Frobose, M.D. Tokach, K. Soltwedel[3], J. M. DeRouchey, S. S. Dritz[4], R. D. Goodband, and J. L. Nelssen

Summary

A total of 340 barrows (PIC 1050, initially 25.7 lb ± 0.2 lb BW and 35 d of age) were used in a 28-d growth trial examining the effects on nursery pig growth performance of adding Biomin Product A (Biomin; Herzogenburg, Austria) to diets contaminated with deoxynivalenol (DON), or vomitoxin on nursery pig growth performance. Also, 5% water was added in a diet with Biomin Product A as a means of potentially enhancing the activity of the product. Pigs were allotted to pens by weight, and pens were assigned to 1 of 8 treatments in a randomized complete block design with location in the barn serving as the blocking factor. There were 9 replications per treatment (pens) and 4 to 5 pigs per pen. Initial mycotoxin analyses were conducted on the primary ingredients at Romer Labs[5] and served as the basis of diet formulation. Eight dietary treatments were formulated to contain: (1) no vomitoxin or Biomin Product A, (2) 1.5 ppm vomitoxin and no Biomin Product A, (3) 1.5 ppm vomitoxin and 0.15% Biomin Product A (3 lb/ton), (4) 1.5 ppm vomitoxin and 0.30% Biomin Product A (6 lb/ton), (5) 3.0 ppm vomitoxin and no Biomin Product A, (6) 3.0 ppm vomitoxin and 0.30% Biomin Product A (6 lb/ton), (7) 3.0 ppm and 0.45% Biomin Product A (9 lb/ton), and (8) 3.0 ppm vomitoxin and 0.45% Biomin Product A with 5% water added to the diet. Dried distillers grains with solubles containing vomitoxin were used to increase concentrations in the treatment diets. After feed manufacturing, ingredients and diets were analyzed at Romer Labs and NDSU[6]. DON levels for the low- (1.5 ppm) and high- (3.0 ppm) vomitoxin diets were determined to average 2.5 and 5.2 ppm, respectively. Experimental diets were fed in meal form from d 0 to 21, and a common diet was fed from d 21 to 28 to evaluate performance immediately after removing vomitoxin from the diet. Overall (d 0 to 21), pigs fed high-vomitoxin diets had decreased ($P < 0.01$) ADG and ADFI compared to pigs fed diets lower in DON concentration. Adding Biomin Product A to diets containing vomitoxin had no effect ($P > 0.24$) on ADG; however, adding Biomin Product A to low-vomitoxin diets increased (quadratic, $P < 0.01$) ADFI, resulting in poorer (quadratic, $P < 0.01$) F/G. Furthermore, there were no differences ($P > 0.39$) in performance or feed efficiency when 5% water was added to the diet containing Biomin Product A. In conclusion, adding Biomin Product A to the diet did not improve nursery pig performance during the 3-week period during which diets containing low or high concentrations of vomitoxin were fed.

Key words: nursery pig, vomitoxin,

1 Appreciation is expressed to Biomin USA (San Antonio, TX) for financial support of this study.
2 Appreciation is expressed to Hubbard Feeds (Mankato, MN) and New Fashion Pork (Jackson, MN) for supplying the DDGS used in the study.
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Introduction

High concentrations of mycotoxins, especially vomitoxin, were present in the 2009 corn crop. Vomitoxin, also known as deoxynivalenol (DON), develops when moisture is overabundant during the flowering period of corn. Deoxynivalenol is directly associated with the plant pathogens *Fusarium graminearum (Gibberella zeae)* and *F. culmorum*, the causative agents for *Fusarium* head blight in wheat and *Gibberella* ear rot in corn. Among livestock species, pigs are particularly susceptible to deoxynivalenol consumption, which can cause reductions in performance, sub-clinical immune suppression and, in high concentrations, vomiting and feed refusal. However, swine producers are interested in finding ways to utilize vomitoxin-contaminated corn as a feedstuff. Dried distiller's grains with solubles (DDGS), a by-product of the ethanol industry, also presents significant problems for swine producers because mycotoxin levels are 2 to 3 times more concentrated than in the original corn source.

Although no FDA-approved mycotoxin inhibitors exist, some available products have shown promise in the presence of vomitoxin. Biomin Product A (Biomin, Herzogenburg Austria) is one product that might reduce the effects of DON. However, a recent study at Kansas State University by Barnes et al (2010)[7] incorporated Biofix Plus into nursery pig diets containing 4 ppm DON at 0.15% of the diet with no effect on performance. The goal of this study was to determine whether lower levels of vomitoxin or higher inclusion rates of Biomin Product A would result in improved performance when feeding DON-contaminated diets to young pigs. In addition, it was hypothesized that adding water to the diet might improve the efficacy of Biomin Product A product in diets highly contaminated with DON. That hypothesis was also tested in this trial.

Procedures

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

A total of 340 barrows (PIC 1050, initially 25.7 lb ± 0.2 lb BW and 35 d of age) were used in a 28-d growth trial. Pigs were allotted to pens by weight, and pens were assigned to 1 of 8 treatments in a randomized complete block design, with location in the barn serving as the blocking factor. There were 9 replications per treatment (pens) with 4 to 5 pigs per pen. Each pen (4 × 4 ft) contained a 4-hole dry self-feeder and 1 cup waterer to provide ad libitum access to feed and water.

To naturally incorporate vomitoxin at desired concentrations, both a clean and contaminated source of DDGS were supplied by Hubbard Feeds (Mankato, MN) to incorporate DDGS into the test diets at equivalent levels. Base corn, soybean meal, and the two sources of DDGS were tested for mycotoxin content at Romer Labs, Inc (Table 1). before diet manufacturing. These results were used in diet formulation. After diets were manufactured, each was sampled and tested again at Romer Labs and at North Dakota State University.

Initially, all pigs were fed a commercial SEW diet with a budget of 2 lb/pig followed by a commercial transition diet with a budget of 5 lb/pig for the first 7 d postweaning. At

[7] Barnes et al. Swine Day 2010. Report of Progress 1038, pp 79-85.

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d 7 postweaning, Phase 2 diets were fed for 7 days. On d 14 (d 0 of the experiment), Phase 3 diets comprising the 8 experimental treatments (Table 2) were fed to the pigs. Apart from vomitoxin and Biomin Product A content, diets were formulated to be identical in nutrient composition, and all diets contained a total of 20% DDGS. Based on the initial mycotoxin analysis of base ingredients, the 8 experimental diets were formulated to contain: (1) no vomitoxin or Biomin Product A, (2) 1.5 ppm vomitoxin and no Biomin Product A, (3) 1.5 ppm vomitoxin and 0.15% Biomin Product A (3 lb/ton), (4) 1.5 ppm vomitoxin and 0.30% Biomin Product A (6 lb/ton), (5) 3.0 ppm vomitoxin and no Biomin Product A, (6) 3.0 ppm vomitoxin and 0.30% Biomin Product A (6 lb/ton), (7) 3.0 ppm vomitoxin and 0.45% Biomin Product A (9 lb/ton), and (8) 3.0 ppm vomitoxin, 0.45% Biomin Product A and 5% water added to the diet. Experimental diets were presented in meal form and were fed from d 0 to 21. A common meal diet (<0.5 ppm DON) was fed from d 21 to 28 to evaluate the change in performance immediately after removing vomitoxin from the diet. All diets were manufactured at the Kansas State University Animal Science Feed Mill. Average daily gain, ADFI, and F/G were determined by weighing pigs and measuring feed disappearance on d 4, 7, 14, 21, and 28 of the trial.

Data were analyzed as a randomized complete block design with pen as the experimental unit. Analysis of variance used the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with treatment as a fixed effect. Treatment means were separated using the LSMEANS statement and CONTRAST statements in SAS. Means were considered significant at $P < 0.05$ and trends at $P < 0.10$.

Results and Discussion

After diet sampling, the analyzed DON concentrations from Romer Labs were higher and more variable between diets than expected. Therefore the samples at Romer Labs were tested a second time. Romer Labs indicated that their analysis procedures are less accurate for vomitoxin concentrations over 5 ppm (such as with the high-vomitoxin DDGS used in the diets). A separate set of ingredient and diet samples were sent to the North Dakota State University Veterinary Diagnostic Laboratory (NDSU) for comparative analysis. The NDSU results for the contaminated DDGS were approximately 50% higher (15.8 ppm) than the results reported by Romer Labs (10.1, 12.1 ppm), which explains why the test diets formulated to be 1.5 ppm (low-DON) and 3.0 ppm (high-DON) actually averaged approximately 2.5 and 5.2 ppm, respectively. Based on variability between labs and analyses, a composite level of DON for each diet was generated as an average of the 3 separate analyses (Table 1).

From d 0 to 4, pigs fed high concentrations of vomitoxin had reduced ($P < 0.01$) ADG, ADFI, and poorer ($P < 0.01$) F/G than those fed low concentrations. From d 4 to 7, pigs fed high-DON diets had decreased ($P < 0.01$) ADFI and tended to have lower ($P < 0.06$) ADG than pigs fed low-DON diets. From d 7 to 14, pigs fed high concentrations of DON had decreased ($P < 0.01$) ADFI compared to those fed low-vomitoxin diets. Pigs fed high-DON diets had decreased ($P < 0.01$) ADG and ADFI during d 14 to 21 when compared to pigs fed diets containing lower concentrations. For the overall test period (d 0 to 21), pigs fed diets containing high levels (3.0 ppm) of DON had reduced ($P < 0.01$) ADG and ADFI compared to pigs fed diets containing low concentrations. In the common diet period (d 21 to 28), there were no differences ($P > 0.25$)

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in ADFI or F/G between high- and low-vomitoxin diets; however, pigs previously fed high vomitoxin concentrations tended to have improved ($P < 0.09$) ADG vs. pigs than pigs fed low concentrations. For the overall trial period (d 0 to 28), pigs fed high-DON diets from d 0 to 21 had reduced ($P < 0.01$) ADG and ADFI, although they did have improved ($P < 0.05$) F/G when compared with pigs fed low concentrations. On days 4, 7, 14, 21, and 28, pigs fed high concentrations of vomitoxin weighed less ($P < 0.01$) than pigs fed low concentrations. Overall, pigs fed diets low in vomitoxin had similar performance to the positive control diet, which contained less than 0.65 ppm DON.

During d 0 to 4, pigs fed high concentrations of vomitoxin had poorer ($P < 0.02$) F/G as Biomin Product A increased in the diet. There was a Biomin Product A response from d 7 to 14, where increasing Biomin Product A resulted in quadratic response (quadratic, $P < 0.03$) in ADG in pigs fed diets containing high concentrations of vomitoxin because pigs fed 0.3% Biomin Product A had lower ADG than pigs fed 0 or 0.45% Biomin Product A. Also, F/G worsened (quadratic, $P < 0.04$) with increasing Biomin Product A. For ADFI, pigs fed high and low vomitoxin concentrations had improved (quadratic, $P < 0.05$) ADFI from d 7 to 21 with increasing Biomin Product A. This within-phase response translated into an overall increase (quadratic, $P < 0.08$) in ADFI for both high- and low-DON diets with increasing Biomin Product A. Overall (d 0 to 21), adding Biomin Product A to diets containing low or high concentrations of vomitoxin had no effect ($P > 0.24$) on ADG. In addition, pigs fed diets with the low concentration of vomitoxin had poorer (quadratic, $P < 0.01$) F/G as Biomin Product A increased in the diet. Adding Biomin Product A to the diet from d 0 to 21 did not influence ($P > 0.06$) ADG, ADFI, or F/G during the common period (d 21 to 28). Similar to the data from d 0 to 21, pigs fed low-vomitoxin diets had increased ($P < 0.01$) ADFI but poorer ($P < 0.04$) F/G as the dietary level of Biomin Product A increased.

Adding water to diets containing the high vomitoxin and Biomin Product A from d 0 to 4 improved ($P < 0.02$) F/G and tended to improve ($P < 0.07$) ADG. However, overall (d 0 to 21), adding 5% water to the high-vomitoxin diet containing 0.45% Biomin Product A did not influence ($P > 0.39$) ADG, ADFI, or F/G. However, it is important to note that significant feed quality issues were associated with the diet containing 5% added water. As the trial progressed, the diet containing added water had bridging problems in the feeders and began to spoil, as evidenced by a stale, musty odor. However, no visual mold growth was observed. As a result of these observations, samples of the water-added diet were sent to NDSU for additional mycotoxin analysis. Samples were sent from d 0, 7, 14, and 21, and a numeric increase in DON levels was observed (Table 1). The practical issues of adding water to a dry feed mix, as well as a lack of response in performance, suggest that adding water does not improve the efficacy of the Biomin Product A in highly contaminated DON diets fed to young pigs.

In conclusion, the addition of Biomin Product A to nursery pig diets containing 2 to 6 ppm of DON did not improve growth performance and seemed to have a negative effect on feed efficiency during the 3-week experimental period. The addition of water at the time of mixing feed did not affect performance and resulted in apparent feed spoilage and problems with bridging in feeders.

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Table 1. Analyzed vomitoxin (DON) content (ppm) in diet samples (as-fed basis)[1]

	Romer Labs[2]		NDSU[3]	
Item	Analysis 1	Analysis 2	Analysis 3	Avg value
Basal ingredients, ppm				
Corn	<0.5	<0.5	- - -[4]	
Soybean meal	<0.5	<0.5	- - -	
Control DDGS	0.9	- - -	0.7	
Contaminated DDGS	10.1	12.7	15.8	
Test diets[5], ppm				
Positive Control	0.6	- - -	0.7	0.65
Low-vomitoxin negative control	2.1	2.1	2.7	2.30
1.5 ppm DON, 0.15% Biomin Product A	3.0	3.0	3.0	3.00
1.5 ppm DON, 0.30% Biomin Product A	1.9	3.0	2.7	2.53
High-vomitoxin negative control	5.5	6.1	5.0	5.53
3.0 ppm DON, 0.30% Biomin Product A	4.2	6.0	5.9	5.37
3.0 ppm DON, 0.45% Biomin Product A	4.9	4.9	5.0	4.93
3.0 ppm DON, 0.45% Biomin Product A with 5% water	5.6	4.0	4.4[6]	4.80

[1] Reported vomitoxin levels as a combination of DON and 15-acetyl DON levels.
[2] Romer Labs, Union, MO. Samples were analyzed using a combination of liquid chromatography and mass spectrometry.
[3] NDSU Veterinary Diagnostic Laboratory, Fargo, ND. Samples were analyzed using a variety of mass spectrometry, ELISA, and high-pressure liquid chromatography.
[4] (- - -) indicates sample was not analyzed at this time.
[5] Test diet labels denote formulated DON levels.
[6] Additional samples were collected at d 0, 7, 14, and 21 and sent to NDSU for DON analysis. Results: d 0 (3.0 ppm), d 7 (3.4 ppm), d 14 (3.8 ppm) and d 21 (3.8ppm).

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Table 2. Diet composition for the Biomin Product A and control vomitoxin (DON) treatments (as-fed basis)[1]

		Phase 3 diets[2]							
			Low DON (1.5 ppm)[3]			High DON (3.0 ppm)[3]			5% Water[4]
Item	Common diet	Positive control	Low Neg. control	0.15% Biomin Product A	0.30% Biomin Product A	High Neg. control	0.30% Biomin Product A	0.45% Biomin Product A	0.45% Biomin Product A
Ingredient, %									
Corn	57.06	49.06	49.06	48.89	48.73	49.06	48.73	48.57	46.16
Soybean meal, 46.5%	25.90	27.63	27.63	27.65	27.66	27.63	27.66	27.67	26.27
Control DDGS 29% CP	---	20.00	10.00	10.00	10.00	---	---	---	---
Contaminated DDGS 28.5% CP	---	---	10.00	10.00	10.00	20.00	20.00	20.00	19.00
Select menhaden fish meal	4.50	---	---	---	---	---	---	---	---
Spray dried whey	10.00	---	---	---	---	---	---	---	---
Monocalcium P, 21% P	0.38	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.57
Limestone	0.58	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.19
Salt	0.30	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.33
Zinc oxide	0.25	---	---	---	---	---	---	---	---
Copper sulfate	---	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.24
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.14
L-lysine HCl	0.25	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.39
DL-methionine	0.13	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
L-threonine	0.11	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.07
Phytase[5]	0.17	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.12
Biomin Product A[6]	---	---	---	0.15	0.30	---	0.30	0.45	0.43
Water	---	---	---	---	---	---	---	---	5.00
Total	100.0	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

continued

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Table 2. Diet composition for the Biomin Product A and control vomitoxin (DON) treatments (as-fed basis)[1]

		Phase 3 diets[2]							
			Low DON (1.5 ppm)[3]			High DON (3.0 ppm)[3]			5% Water[4]
Item	Common diet	Positive control	Low Neg. control	0.15% Biomin Product A	0.30% Biomin Product A	High Neg. control	0.30% Biomin Product A	0.45% Biomin Product A	0.45% Biomin Product A
Calculated composition, %									
SID[7] amino acids, %									
Lysine	1.30	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.21
Isoleucine:lysine	61	63	63	63	63	63	63	63	63
Leucine:lysine	127	148	148	148	148	148	148	147	147
Methionine:lysine	35	30	30	30	30	30	30	30	30
Met & cys:lysine	59	58	58	58	58	58	58	58	58
Threonine:lysine	63	62	62	62	62	62	62	62	62
Tryptophan:lysine	17.0	17	17	17	17	17	17	17	17
Valine:lysine	68	72	72	72	72	72	72	72	72
CP, (N × 6.25)	21.3	22.9	22.9	22.9	22.9	22.9	22.9	22.9	21.8
Total lysine	1.43	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.37
ME, kcal/lb	1,505	1,506	1,506	1,503	1,501	1,506	1,501	1,499	1,424
SID Lysine:ME, g/Mcal	3.92	3.83	3.83	3.83	3.84	3.83	3.84	3.84	3.84
Ca	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.67
P	0.63	0.60	0.60	0.60	0.60	0.60	0.60	0.59	0.57
Available P	0.47	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.40

[1] A total of 340 pigs (Initial BW 25.7 lb ± 0.2 lb) were used with 4 to 5 pigs per pen and 9 replicates per treatment.
[2] Diets were fed for 21 d with day 14 postweaning as d 0 of the experiment. A common diet was fed from d 21 to 28 across all treatments. Diets were fed in mash form.
[3] The analyzed average DON content for the low- and high-vomitoxin diets were 2.6 and 5.3 ppm, respectively.
[4] The 5% water treatment is a duplicate of the high-vomitoxin, 0.45% Biomin Product A treatment diluted with 5% water (2.85ppm DON, 0.427% Biomin Product A).
[5] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO).
[6] Biomin Product A (Biomin USA, San Antonio, TX).
[7] Standardized ileal digestible.

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Table 3. Effects of Biomin Product A and vomitoxin (DON) on nursery pig growth performance[1]

		Low DON (1.5 ppm)[2]			High DON (3.0 ppm)[2]					Probability, P <					
										Vomitoxin	Biomin Product A low-DON diets		Biomin Product A high-DON diets		
Item	Positive control	Low Neg. control	0.15% Biomin Product A	0.30% Biomin Product A	High Neg. control	0.30% Biomin Product A	0.45% Biomin Product A	5% Water[3] 0.45% Biomin Product A	SEM	Low vs high	Linear	Quad	Linear	Quad	5% Water
d 0 to 4															
ADG, lb	0.83	0.83	0.84	0.77	0.63	0.55	0.57	0.70	0.06	0.01	0.39	0.47	0.29	0.56	0.07
ADFI, lb	1.44	1.45	1.55	1.41	1.21	1.15	1.22	1.35	0.06	0.01	0.61	0.10	0.98	0.39	0.14
F/G	1.74	1.78	1.91	1.87	1.98	2.16	2.51	2.00	0.17	0.01	0.67	0.65	0.02	0.36	0.02
d 4 to 7															
ADG, lb	0.98	1.06	1.04	1.05	0.95	0.95	0.95	1.00	0.06	0.06	0.89	0.84	0.99	0.99	0.57
ADFI, lb	1.54	1.57	1.62	1.51	1.41	1.34	1.43	1.46	0.07	<0.01	0.44	0.25	0.98	0.26	0.75
F/G	1.59	1.53	1.60	1.46	1.51	1.42	1.52	1.46	0.06	0.37	0.45	0.17	0.92	0.24	0.52
d 7 to 14															
ADG, lb	1.25	1.37	1.32	1.27	1.32	1.20	1.30	1.27	0.04	0.13	0.06	0.99	0.36	0.03	0.65
ADFI, lb	2.07	2.06	2.16	2.02	2.01	1.90	2.00	2.04	0.04	0.01	0.44	0.02	0.56	0.04	0.48
F/G	1.66	1.51	1.65	1.60	1.53	1.59	1.55	1.61	0.04	0.35	0.06	0.04	0.52	0.31	0.27
d 14 to 21															
ADG, lb	1.56	1.43	1.55	1.53	1.42	1.42	1.41	1.32	0.05	0.01	0.08	0.17	0.85	0.94	0.12
ADFI, lb	2.48	2.36	2.53	2.45	2.33	2.25	2.34	2.27	0.05	0.01	0.11	0.01	0.84	0.05	0.17
F/G	1.60	1.65	1.63	1.61	1.65	1.59	1.67	1.72	0.04	0.88	0.36	1.00	0.98	0.11	0.30
d 0 to 21															
ADG, lb	1.23	1.24	1.27	1.23	1.17	1.12	1.14	1.14	0.03	0.01	0.70	0.32	0.32	0.24	0.95
ADFI, lb	2.01	1.98	2.09	1.97	1.87	1.79	1.88	1.90	0.04	0.01	0.94	0.01	0.79	0.08	0.69
F/G[a]	1.63	1.59	1.65	1.60	1.60	1.61	1.65	1.67	0.02	0.76	0.55	0.01	0.11	0.21	0.39
d 21 to 28[4]															
ADG, lb	1.80	1.85	1.90	1.83	1.93	1.93	1.89	1.98	0.04	0.09	0.85	0.28	0.63	0.59	0.13
ADFI, lb	3.50	3.59	3.73	3.55	3.72	3.67	3.66	3.78	0.07	0.25	0.70	0.06	0.49	0.87	0.22
F/G	1.96	1.95	1.97	1.95	1.94	1.91	1.94	1.91	0.05	0.48	0.96	0.68	0.96	0.55	0.58
d 0 to 28															
ADG, lb	1.37	1.39	1.42	1.38	1.36	1.32	1.33	1.34	0.02	0.01	0.70	0.20	0.33	0.54	0.63
ADFI, lb	1.70	1.69	1.79	1.68	1.62	1.56	1.62	1.65	0.03	0.01	0.71	0.01	0.61	0.09	0.32
F/G[a]	1.24	1.21	1.26	1.21	1.20	1.18	1.22	1.23	0.02	0.05	0.97	0.04	0.56	0.15	0.62

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Table 3. Effects of Biomin Product A and vomitoxin (DON) on nursery pig growth performance[1]

		Low DON (1.5 ppm)[2]			High DON (3.0 ppm)[2]					Probability, P <					
										Vomitoxin	Biomin Product A low-DON diets		Biomin Product A high-DON diets		
Item	Positive control	Low Neg. control	0.15% Biomin Product A	0.30% Biomin Product A	High Neg. control	0.30% Biomin Product A	0.45% Biomin Product A	5% Water[3] 0.45% Biomin Product A	SEM	Low vs high	Linear	Quad	Linear	Quad	5% Water
Weights, lb															
d 0	25.87	25.63	25.82	25.65	25.64	25.50	25.64	25.54	0.17	0.31	0.93	0.28	0.84	0.39	0.60
d 4	29.19	28.95	29.20	28.73	28.18	27.72	27.91	28.34	0.31	0.01	0.52	0.25	0.35	0.37	0.23
d 7	32.12	32.12	32.30	31.86	31.04	30.58	30.77	31.35	0.39	0.01	0.55	0.42	0.45	0.47	0.20
d 14	40.87	41.72	41.53	40.74	40.41	38.99	40.02	40.25	0.45	0.01	0.12	0.57	0.29	0.04	0.70
d 21	51.78	51.74	52.40	51.48	50.37	48.92	49.89	49.84	0.56	0.01	0.71	0.18	0.29	0.07	0.94
d 28	64.35	64.65	65.67	64.32	64.12	62.44	63.14	63.93	0.63	0.01	0.69	0.11	0.15	0.17	0.35

[1] A total of 340 pigs (PIC 1050, initial BW 25.7 lb ± 0.2 lb) were used in a 28-d study to determine the effects of vomitoxin and Biomin Product A on nursery pig performance.
[2] The analyzed average DON content for the low- and high-vomitoxin diets were 2.6 and 5.3 ppm, respectively.
[3] The 5% water treatment is a duplicate of the high-vomitoxin, 0.45% Biomin Product A treatment diluted with 5% water (2.85ppm DON, 0.427% Biomin Product A).
[4] A common diet (<0.5 ppm DON) was fed across all treatments from d 21 to d 28.

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Effects of Dried Distillers Grains with Solubles and Increasing Dietary Wheat Middlings on Growth Performance, Carcass Characteristics, and Fat Quality in Growing-Finishing Pigs

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Summary

A total of 288 pigs (PIC TR4 × 1050, initially 100 lb) were used in an 84-d growth trial to evaluate the effects of dietary wheat middlings and dried distillers grain with solubles (DDGS) on growing-finishing pig growth performance, carcass characteristics, and carcass fat quality. Pens of pigs were balanced by initial weight and gender and were randomly allotted to 1 of 4 dietary treatments with 8 pigs per pen (4 barrows and 4 gilts) and 9 replications per treatment. Dietary treatments included a corn-soybean meal-based diet, a diet with 30% DDGS, or the diet with 30% DDGS with 10% or 20% wheat middlings. Treatment diets were formulated to constant standardized ileal digestible lysine:ME ratios within each phase. All treatments were fed in 4 phases. Overall (d 0 to 84), pigs fed increasing wheat middlings had decreased (linear; $P \leq 0.02$) ADG and poorer (linear; $P \leq 0.01$) F/G. There were no differences ($P = 0.12$) among treatments for ADFI. For carcass characteristics, increasing wheat middlings decreased (linear; $P < 0.01$) percentage yield and HCW and tended to decrease (linear; $P < 0.06$) loin depth. Pigs fed wheat middlings also had decreased (quadratic; $P < 0.02$) back fat and increased (quadratic; $P < 0.01$) percentage lean. Increasing DDGS from 0 to 30% decreased ($P < 0.03$) carcass yield and backfat depth ($P < 0.01$), while increasing percentage lean ($P < 0.03$) and jowl iodine value ($P < 0.001$).

Increasing wheat middlings in the diet decreased (linear; $P < 0.006$) feed cost per pig and feed cost per lb gain but also decreased (linear; $P < 0.008$) total revenue. Similarly, feeding DDGS decreased ($P < 0.001$) feed cost per pig and feed cost per lb gain; however, because total revenue was not decreased as greatly by DDGS, feeding 30% DDGS increased ($P < 0.001$) income over feed costs (IOFC). In conclusion, alternative ingredients, such as DDGS and wheat middlings, can reduce feed cost; however, the full impact on growth performance and carcass value must be known to truly understand whether they influence net profitability.

Key words: dried distillers grains with solubles, iodine value, wheat middlings

Introduction

Feed ingredient alternatives to corn and soybean meal are often used in swine diets. While these ingredients are used with the intent of lowering feed costs, it is important to know how they affect performance and carcass characteristics to predict their

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economic value. Two alternative ingredients available for use in swine diets are dried distillers grains with solubles (DDGS) and wheat middlings.

Dried distillers grains with solubles are corn by-products from ethanol production. They have approximately 3 times the crude fat, protein, and fiber of corn, with a similar energy value. Also, DDGS are known to have higher bioavailability of phosphorus when compared to corn.

One of the most common cereal by-products used in commercial pig feed is wheat middlings. Wheat middlings, often referred to as wheat midds, are by-products from the flour milling industry. Most U.S. wheat that is not exported is processed into flour, and milling by-products are widely available for use in the animal feed industry. Wheat middlings have higher crude protein and fiber but are lower in dietary energy than corn (corn ME = 1,551 kcal per lb; wheat middlings ME = 1,372 kcal per lb; NRC, 1998[2]).

Limited research is available using DDGS and wheat midds together in swine diets. Therefore, more research is needed to fully evaluate the effects on performance of those ingredients. Thus, the objective of this experiment was to evaluate the effects of dietary wheat middlings and DDGS on growing-finishing pig growth performance, carcass characteristics, and carcass fat quality to determine whether reduced diet costs make DDGS and wheat middlings viable options for grow-finish diets.

Procedures

The Kansas State University (K-State) Institutional Animal Care and Use Committee approved the procedures used in these experiments. These experiments were conducted in the growing-finishing research barn at the K-State Swine Teaching and Research Center. The facility was a totally enclosed, environmentally controlled, mechanically ventilated barn. It had 2 identical rooms containing 40 pens (8 × 10 ft) with adjustable gates facing the alleyway, allowing for 10 sq ft/pig. Each pen was equipped with a Farmweld (Teutopolis, IL), single-sided, dry self-feeder with 2 eating spaces in the fence line and a cup waterer. Pens were located over a completely slatted concrete floor with a 4-ft pit underneath for manure storage. The facility was equipped with a computerized feeding system (FeedPro; Feedlogic Corp., Willmar, MN) that delivered and recorded diets as specified. The equipment provided pigs with ad libitum access to food and water.

A total of 288 pigs (PIC TR4 × 1050), averaging 102.6 lb were used in this study. Initial weight and gender were balanced, and pens were randomly allotted to 1 of 4 dietary treatments with 8 pigs per pen (4 barrows and 4 gilts) and 9 replications per treatment. Dietary treatments included a corn-soybean meal-based diet, a diet with 30% DDGS, or that diet with 10 or 20% wheat middlings added (Tables 1 and 2). All treatments were fed in 4 phases in meal form. Pigs and feeders were weighed on d 0, 20, 36, 52, and 84 to determine ADG, ADFI, and F/G. Treatment diets were formulated to constant standardized ileal digestible (SID) lysine ME ratios within each phase. Diets were formulated to meet all requirements recommended by NRC (1998[2]). Samples of DDGS and wheat middlings were collected and analyzed for nutrient content and amino acid concentration (Table 3) at University of Missouri Agricultural Experiment Station Chemical Laboratories.

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

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At the end of the 84-d trial, pigs were weighed and transported to Triumph Foods Inc. (St. Joseph, Missouri). Pigs had been individually tattooed according to pen number to allow for data retrieval by pen and carcass data collection at the packing plant. Hot carcass weights were measured immediately after evisceration, and each carcass was evaluated for percentage yield, backfat, loin depth, and percentage lean. Also, jowl samples were collected and analyzed by Near Infrared Spectroscopy (NIR) for iodine value. Because there were differences in HCW, it was used as a covariant for backfat, loin depth, and percentage lean. Percentage yield was calculated by dividing HCW by live weight obtained before transport to the packing plant.

Data were analyzed as a completely randomized design using the PROC-MIXED procedure of the Statistical Analysis System (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Linear and quadratic polynomial contrasts were conducted to determine effects of increasing dietary wheat middlings. A single degree of freedom contrast was used for comparing pigs fed the control diet to pigs fed the diet containing 30% DDGS without wheat middlings.

Results and Discussion

Overall (d 0 to 84), pigs fed increasing wheat middlings had decreased (linear; $P \leq 0.02$) ADG and poorer (linear; $P < 0.01$) F/G. There were no differences ($P = 0.12$) among treatments for ADFI. There was a tendency for decreased (linear; $P < 0.07$) final weight as dietary wheat middlings increased. Pigs fed up to 20% wheat middlings may have experienced increased gut fill due to the high fiber content, and were therefore unable to offset the lower dietary energy from wheat middlings and gained less when compared to the pigs fed diets without wheat middlings (Table 4).

For carcass characteristics, increasing wheat middlings decreased (linear; $P < 0.01$) percentage yield and HCW and tended to decrease (linear; $P < 0.06$) loin depth. Pigs fed wheat middlings also had decreased (quadratic; $P < 0.02$) backfat and increased (quadratic; $P < 0.01$) percentage lean. Increasing DDGS from 0 to 30% decreased ($P < 0.03$) carcass yield and backfat depth ($P < 0.01$), while increasing percentage lean ($P < 0.03$) and jowl iodine value ($P < 0.001$). Past research has also shown that feeding DDGS increases carcass fat iodine value by causing it to become less saturated.

Increasing wheat middlings in the diet decreased (linear; $P < 0.006$) feed cost per pig and feed cost per lb gain, but also decreased (linear; $P < 0.008$) total revenue. Similarly, feeding DDGS decreased ($P < 0.001$) feed cost per pig and feed cost per lb gain. Because total revenue was not decreased as greatly by DDGS, feeding 30% DDGS increased ($P < 0.001$) income over feed costs (IOFC).

In conclusion, these data indicate that DDGS and wheat middlings are viable alternatives in swine diets. However, an understanding of their effect on performance and their value when considering income over feed cost is needed before deciding to use the ingredients. Also, valuing the ingredients on an IOFC basis is important to understand the value of these ingredients in diets for finishing pigs. For example, in this study DDGS reduced feed cost per lb of gain and increased IOFC. In contrast, although wheat midds reduced feed cost per lb of gain, their addition reduced IOFC.

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

		Phase 1				Phase 2			
	DDGS, % :	0	30	30	30	0	30	30	30
Ingredient, %	Wheat middlings, %:	0	0	10	20	0	0	10	20
Corn		80.0	55.6	48.3	41.0	83.4	58.9	51.7	44.2
Soybean meal, (46.5% CP)		17.43	12.12	9.34	6.57	14.29	8.95	6.17	3.48
DDGS		---	30.00	30.00	30.00	---	30.00	30.00	30.00
Wheat middlings		---	---	10.00	20.00	---	---	10.00	20.00
Monocalcium phosphate, (21% P)		0.50	-	-	-	0.35	---	---	---
Limestone		0.98	1.28	1.28	1.30	0.95	1.18	1.18	1.30
Salt		0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix		0.15	0.15	0.15	0.15	0.13	0.13	0.13	0.13
Trace mineral premix		0.15	0.15	0.15	0.15	0.13	0.13	0.13	0.13
Lysine HCl		0.29	0.35	0.39	0.43	0.26	0.32	0.36	0.40
DL-methionine		0.02	---	---	---	0.01	---	---	---
L-threonine		0.06	---	---	---	0.04	---	---	---
Phyzyme 600[2]		0.13	0.05	0.03	0.02	0.13	0.03	0.01	---
TOTAL		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

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

		Phase 1				Phase 2			
	DDGS, % :	0	30	30	30	0	30	30	30
Ingredient, %	Wheat middlings, %:	0	0	10	20	0	0	10	20
Calculate analysis									
Standardized ileal digestible amino acid %									
Lysine		0.86	0.87	0.86	0.85	0.76	0.76	0.75	0.74
Isoleucine:lysine		62	69	67	65	63	71	69	67
Leucine:lysine		151	196	191	187	161	213	207	202
Methionine:lysine		28	34	34	34	29	37	37	37
Met & Cys:lysine		57	69	69	70	59	75	75	75
Threonine:lysine		61	64	63	61	61	67	65	64
Tryptophan:lysine		17	17	17	17	17	17	16	17
Valine:lysine		72	85	84	84	75	89	89	88
Total lysine, %		0.96	1.02	1.01	0.99	0.85	0.91	0.90	0.88
ME, kcal/lb		1,515	1,520	1,503	1,486	1,518	1,523	1,506	1,487
SID Lysine:ME,g/Mcal		2.58	2.58	2.58	2.58	2.27	2.27	2.27	2.27
CP, %		15.2	18.9	18.6	18.3	14.0	17.6	17.4	17.1
Ca, %		0.55	0.55	0.55	0.56	0.50	0.50	0.50	0.55
P, %		0.45	0.45	0.51	0.56	0.41	0.44	0.49	0.55
Available P, %		0.28	0.28	0.28	0.28	0.24	0.24	0.24	0.26

[1] Phase 1 diets were fed from approximately 100 to 140 lb; Phase 2 diets were fed from 140 to 180 lb.
[2] Phyzyme 600 (Danisco Animal Nutrition, St Louis, MO.)

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

		Phase 3				Phase 4			
	DDGS, % :	0	30	30	30	0	30	30	30
Ingredient, %	Wheat middlings, %:	0	0	10	20	0	0	10	20
Corn		86.06	61.55	54.29	46.78	88.05	63.61	56.19	47.89
Soybean meal, 46.5%		11.80	6.46	3.68	1.00	9.95	4.53	1.84	0.00
DDGS		---	30.00	30.00	30.00	---	30.00	30.00	30.00
Wheat middlings		---	---	10.00	20.00	---	---	10.00	20.00
Monocalcium phosphate, 21% P		0.23	---	---	---	0.18	---	---	---
Limestone		0.98	1.13	1.14	1.29	0.95	1.08	1.15	1.28
Salt		0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix		0.10	0.10	0.10	0.10	0.08	0.08	0.08	0.08
Trace mineral premix		0.10	0.10	0.10	0.10	0.08	0.08	0.08	0.08
Lysine HCl		0.24	0.30	0.34	0.38	0.22	0.29	0.32	0.33
DL-methionine		---	---	---	---	---	---	---	---
L-threonine		0.03	---	---	---	0.03	---	---	---
Phytase 600[2]		0.13	0.02	---	---	0.13	---	---	---
TOTAL		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

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

		Phase 3				Phase 4			
	DDGS, % :	0	30	30	30	0	30	30	30
Ingredient, %	Wheat middlings, %:	0	0	10	20	0	0	10	20
Calculate analysis									
Standardized ileal digestible amino acid %									
Lysine		0.68	0.68	0.67	0.67	0.62	0.62	0.61	0.61
Isoleucine:lysine		64	74	71	69	65	76	73	73
Leucine:lysine		172	229	223	218	182	244	238	235
Methionine:lysine		30	39	39	39	32	42	42	42
Met & Cys:lysine		62	80	80	81	65	85	85	87
Threonine:lysine		62	70	68	66	64	72	71	71
Tryptophan:lysine		17	17	16	16	17	16	17	17
Valine:lysine		78	94	93	92	80	98	97	99
Total lysine, %		0.76	0.82	0.81	0.80	0.70	0.76	0.75	0.74
ME, kcal/lb		1,521	1,525	1,508	1,488	1,523	1,527	1,509	1,489
SID lysine:ME,g/Mcal		2.03	2.03	2.03	2.03	1.85	1.85	1.85	1.85
CP, %		13.0	16.7	16.4	16.1	12.3	15.9	15.7	15.7
Ca, %		0.48	0.48	0.48	0.54	0.45	0.45	0.48	0.53
P, %		0.37	0.43	0.48	0.54	0.35	0.42	0.48	0.53
Available P, %		0.21	0.21	0.23	0.26	0.20	0.20	0.23	0.26

[1] Phase 3 diets were fed from approximately 180 to 220 lb; Phase 4 diets were fed from 220 to 270 lb.
[2] Phyzyme 600 (Danisco Animal Nutrition, St Louis, MO.)

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Table 3. Analysis on dried distillers grains with solubles and wheat middlings (as-fed basis)

Item	DDGS[1]	Wheat middlings
Nutrient,%		
DM	90.98	89.72
CP	27.0 (27.7)[2]	14.7 (15.9)
Fat (oil)	11.00	3.8
Crude fiber	9.7 (7.3)	8.2 (7.0)
ADF	12.80	11.4
NDF	24.10	32.0
Ca	0.32 (0.20)	0.32 (0.12)
P	0.78 (0.77)	1.09 (0.93)
Amino acids, %		
Arginine	1.24	1.11
Histidine	0.80	0.45
Isoleucine	1.08 (1.03)	0.53 (0.53)
Leucine	3.26 (2.57)	1.03 (1.06)
Lysine	0.84 (0.62)	0.72 (0.57)
Methionine	0.53 (0.50)	0.24 (0.26)
Phenylalanine	1.38	0.64
Threonine	1.03 (0.94)	0.53 (0.51)
Tryptophan	0.21 (0.25)	0.20 (0.20)
Valine	1.47 (1.30)	0.77 (0.75)

[1] Dried distillers grains with solubles from Hawkeye Gold, Menlo, IA.
[2] Values in parentheses indicate those used in diet formulation.

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Table 4. Effects of wheat middlings and DDGS in finishing diets on growth performance and carcass characteristics[1, 2]

						Probability, $P <$		
DDGS, %:	0	30	30	30			Wheat middlings	
Wheat middlings, %:	0	0	10	20	SEM	DDGS[3]	Linear	Quadratic
Initial wt, lb	102.6	102.7	102.7	102.6	1.33	0.97	0.96	1.00
d 0 to 84								
ADG, lb	2.32	2.29	2.22	2.19	0.03	0.51	0.02	0.57
ADFI, lb	7.09	6.86	6.84	6.80	0.102	0.12	0.68	0.95
F/G	3.06	3.00	3.09	3.11	0.026	0.11	0.01	0.35
Final wt, lb	297.4	294.9	288.8	286.2	3.300	0.61	0.07	0.65
Carcass measurements[2]								
Carcass yield, %[4]	74.2	73.4	72.7	72.1	0.27	0.03	0.003	0.94
HCW, lb	220.7	216.3	210	206.4	2.48	0.22	0.01	0.65
Lean, %[5]	51.0	51.7	51.0	51.7	0.002	0.03	0.92	0.01
Backfat depth, in[5]	0.98	0.90	0.94	0.86	0.02	0.01	0.24	0.02
Loin depth, in[5]	2.41	2.42	2.36	2.36	0.02	0.73	0.06	0.17
Jowl iodine value	70.6	76.5	76.0	77.4	0.56	<0.001	0.29	0.19
Economics[6]								
Feed cost/pig, $	69.76	62.35	59.9	57.03	0.924	<0.001	<0.001	0.85
Feed cost/lb gain, $	0.268	0.243	0.238	0.231	0.002	<0.001	0.006	0.85
Total revenue, $/pig[7]	165.55	162.25	157.5	154.82	1.857	0.22	0.008	0.65
IOFC, $[8]	95.79	99.90	97.60	97.97	1.836	0.02	0.22	0.40

[1] A total of 288 pigs (TR4 × 1050) were used in this 84-d trial with 8 pigs per pen and 9 replications per diet.
[2] Includes pigs that died, were culled, and were pulled off test during the experiment.
[3] Contrast control vs 30% DDGS.
[4] Percentage yield was calculated by dividing HCW by live weight obtained prior to transport to the packing plant.
[5] Carcass characteristics were adjusted using HCW as a covariate.
[6] Diet cost was based on corn at $3.50/bu; 46.5% soybean meal at $300/ton; DDGS at $120/ton; wheat middlings at $100/ton.
[7] Value was determined based on carcass price of $75.00/ cwt.
[8] Income over feed cost = value of pig - feed costs during trial period.

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Effects of Wheat Middlings and Choice White Grease in Diets on the Growth Performance, Carcass Characteristics, and Carcass Fat Quality in Growing-Finishing Pigs

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Summary

A total of 288 pigs (PIC TR4 × 1050, initially 93.3 lb) were used in an 87-d study to determine the effects of wheat middlings and choice white grease (CWG) on growth performance, carcass characteristics, and carcass fat quality of growing-finishing pigs. Pens of pigs were randomly allotted by initial weight and gender (4 barrows and 4 gilts per pen) to 1 of 6 dietary treatments with 6 replications per treatment. Treatments were arranged in a 2 × 3 factorial arrangement with the main effects of added wheat middlings (0 or 20%) and CWG (0, 2.5, or 5%). Dietary treatments were corn-soybean meal-based diets with 15% dried distillers grains with solubles (DDGS) and fed in 4 phases. There were no CWG x wheat middlings interactions ($P \geq 0.12$) for any of the criteria evaluated. Overall, (d 0 to 87) adding 20% dietary wheat middlings decreased ($P < 0.001$) ADG and worsened ($P < 0.001$) F/G. Pigs fed diets with increased dietary CWG had increased (quadratic, $P < 0.03$) ADG and improved (linear, $P < 0.01$) F/G. Pigs fed diets containing 20% wheat middlings had decreased ($P < 0.01$) final BW; while there was a numerical increase in final BW ($P < 0.09$) as dietary fat was increased.

For carcass traits, pigs fed wheat middlings had decreased percentage yield ($P < 0.04$), HCW ($P < 0.003$), backfat depth ($P < 0.04$), and loin depth ($P < 0.001$), while jowl iodine value increased ($P < 0.001$). Additionally, pigs fed added fat had a tendency for increased backfat depth (linear; $P < 0.06$) and had a linear increase ($P < 0.01$) in jowl iodine value.

For economics, adding 20% wheat middlings to the diet decreased ($P < 0.001$) feed cost per pig and feed cost per lb gain; however, total revenue was also reduced ($P < 0.003$), resulting in a numeric decrease ($P = 0.13$) in income over feed cost (IOFC). Adding CWG increased (linear; $P < 0.001$) feed cost per pig and feed cost per lb gain, but only numerically increased ($P = 0.12$) total revenue, leading to a tendency for decreased IOFC (linear; $P < 0.09$), with increasing amounts of CWG.

Therefore, wheat middlings can be used as an alternative ingredient in swine diets to decrease feed cost and feed cost per lb of gain, but in this study the reduced performance resulted in less revenue and lower profitability.

Key words: energy, DDGS, wheat middlings

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Introduction

Feed ingredient alternatives to corn and soybean meal are often used in swine diets. While these ingredients are used with the intent of lowering feed costs, it is important to know how they can affect performance and carcass characteristics. Thus, determining the proper nutritional value and optimum utilization of alternative feedstuffs is critical to reducing diet costs. One such alternative ingredient is wheat middlings.

Wheat middlings are among the cereal by-products most commonly used in commercial pig feed. Often referred to as wheat midds, they are by-products from flour milling. Most U.S. wheat that is not exported is processed into flour, so milling by-products are widely available for use in the animal feed industry. Wheat middlings have higher crude protein and fiber but lower dietary energy than corn (corn ME = 1,551 kcal/lb; wheat middlings ME = 1,372 kcal/lb; NRC, 1998[2]).

Because of the lower ME content, producers can expect reduced gains and higher feed efficiency in finishing pigs fed wheat middlings. To mitigate this effect, dietary fat can be added to increase the diet energy level. However, limited data are available on the effects of combining wheat middlings with choice white grease (CWG) in diets for finishing pigs. Also, due to opportunities to reduce diet cost with wheat middlings, its effect on performance needs further investigation.

Therefore, the objective of this trial was to determine the effects of 20% wheat middlings and increasing levels of CWG in diets containing 15% DDGS on growth performance, carcass characteristics, and carcass fat quality of growing-finishing pigs.

Procedures

The Kansas State University (K-State) Institutional Animal Care and Use Committee approved procedures used in these experiments. These experiments were conducted in the growing-finishing research barn at the K-State Swine Teaching and Research Center. The facility was a totally enclosed, environmentally controlled, mechanically ventilated barn with 2 identical rooms, each containing 40 pens (8 × 10 ft). The pens had adjustable gates facing the alleyway that allowed for 10 sq ft/pig. Each pen was equipped with a Farmweld (Teutopolis, IL), single-sided, dry self-feeder with 2 eating spaces located in the fence line and a cup waterer. Pens were located over a completely slatted concrete floor with a 4-ft pit underneath for manure storage. The facility was also equipped with a computerized feeding system (FeedPro; Feedlogic Corp., Willmar, MN) that delivered and recorded diets as specified. The equipment provided pigs with ad libitum access to food and water.

A total of 288 (PIC TR4 × 1050, initially 93.3 lb) were used in an 87-d study. Pens of pigs (4 barrows and 4 gilts per pen) were randomly allotted by initial weight to 1 of 6 dietary treatments with 6 replications per treatment. Treatments were arranged in a 2 × 3 factorial arrangement with the main effects of added wheat middlings (0 or 20%) and CWG (0, 2.5, or 5%). Dietary treatments were corn-soybean meal-based diets with 15% DDGS and were fed in 4 phases (Tables 1 and 2). All diets were fed in meal form and balanced to a similar SID lysine:ME ratio within each phase. The ME values for

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

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dietary ingredients included: DDGS = 1,552 ME kcal per lb; wheat middlings = 1,375 ME kcal per lb; and CWG = 7,955 ME kcal per lb.

Wheat middling samples were collected at the time of feed manufacturing and a composite sample was analyzed (Table 3). Also, samples were collected from the top of each feeder and combined for a single composite sample by treatment for each phase to measure bulk density (Table 4). Bulk density of a material represents the mass per unit volume (lb per bushel).

Pigs and feeders were weighed approximately every 3 weeks to calculate ADG, ADFI, and F/G. On d 87, all pigs were weighed and transported to Triumph Foods Inc., St. Joseph, MO. Before slaughter, pigs were individually tattooed according to pen number to allow for carcass data collection at the packing plant and data retrieval by pen. Hot carcass weights were measured immediately after evisceration, and each carcass was evaluated for percentage yield, back fat, loin depth, and percentage lean. Because there were differences in HCW, it was used as a covariant for back fat, loin depth, and percentage lean. Also, jowl fat samples were collected and analyzed by Near Infrared Spectroscopy (NIR) at the plant for iodine value. Percentage yield was calculated by dividing HCW by live weight.

Data were analyzed as a completely randomized design using the PROC-MIXED procedure of the Statistical Analysis System (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. The main effects of the different treatment regimens of wheat middlings and added CWG, and their interaction were tested. Linear and quadratic contrasts were used to determine the effects of increasing dietary fat.

Results and Discussion

Bulk density tests showed that adding dietary wheat middlings decreased diet bulk density but adding CWG had no effect (Table 4).

There were no CWG x wheat middlings interactions ($P \geq 0.12$) for any of the criteria evaluated (Table 5 and 6). Overall, (d 0 to 87) adding 20% dietary wheat middlings to finishing pig diets decreased ($P < 0.001$) ADG and resulted in poorer ($P < 0.001$) F/G. Pigs fed diets with increased CWG had increased (linear; $P < 0.004$; quadratic; $P < 0.03$) ADG and improved (linear; $P < 0.01$) F/G. Feed intake was not affected by the addition of 20% dietary wheat middlings ($P > 0.40$) or added CWG ($P > 0.31$). Pigs fed diets containing 20% wheat middlings had decreased ($P < 0.01$) final BW; while there was a trend for increased (linear; $P < 0.09$) final BW as dietary fat was increased.

For carcass traits, feeding 20% dietary wheat middlings decreased percent yield ($P < 0.04$), HCW ($P < 0.003$), backfat depth ($P < 0.04$), and loin depth ($P < 0.001$). Furthermore, feeding 20% wheat middlings increased ($P < 0.001$) jowl iodine value. Additionally, pigs fed added fat had a tendency for increased backfat depth (linear; $P < 0.06$) and had a linear increase ($P < 0.01$) in jowl iodine value.

For economics, adding 20% wheat middlings to the diet decreased ($P < 0.001$) feed cost per pig and feed cost per lb gain; however the lower ADG also resulted in lighter

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carcasses and less (P < 0.003) total revenue and numerically lower ($P = 0.12$) IOFC of $3.82 per pig. Added CWG increased (linear; $P < 0.001$) feed cost per pig and feed cost per lb gain. Added CWG also numerically increased ($P = 0.12$) total revenue, but it wasn't a great enough increase to overcome the increased feed cost and resulted in a tendency for decreased IOFC (linear; $P < 0.09$) with added CWG.

The decrease in growth rate and feed intake suggest that in addition to the lower energy content, some other factor associated with feeding of wheat middlings could affect growth rate. One factor of concern is diet bulk density. Diets with high levels of wheat middlings had decreased levels of bulk density, which could result in increased gut fill. Alternatively, the high NDF levels in diets containing both dried distillers grains with solubles and wheat middlings may have limited the pigs' ability to consume enough feed to overcome the lower energy level in the wheat middling diets. Feeding 20% wheat middlings worsened ADG and F/G by 6 and 7% respectively. Interestingly, adding 5% CWG to the diet containing 20% wheat middlings resulted in similar ADG and F/G to the diet without wheat middlings or added CWG. The ME level of the high-fat, 20% wheat middlings diet would suggest that this diet should have resulted in lower F/G, indicating that energy may have been overestimated in the wheat middling diets.

Therefore, these data indicate feeding wheat middling reduced feed cost by approximately $4.00 per pig. However, due to reduced performance, IOFC was reduced by approximately $3.80 per pig. Adding 5% CWG to a diet containing 20% wheat middlings resulted in equal growth performance but poorer IOFC compared to pigs fed no wheat middlings and 2.5% CWG, due to the relatively higher cost of energy from the CWG.

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

	Phase 1						Phase 2					
Wheat midds,%:	0	0	0	20	20	20	0	0	0	20	20	20
Ingredient % Fat, %:	0	2.5	5	0	2.5	5	0	2.5	5	0	2.5	5
Corn	64.85	61.25	57.41	50.46	46.88	43.06	68.00	64.26	60.61	53.48	49.81	46.14
Soybean meal, 46.5%	17.73	18.81	20.13	12.17	13.25	14.57	14.76	16.00	17.16	9.28	10.52	11.68
DDGS	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Wheat middlings	---	---	---	20.00	20.00	20.00	---	---	---	20.00	20.00	20.00
Choice white grease	---	2.50	5.00	---	2.50	5.00	---	2.50	5.00	---	2.50	5.00
Monocalcium P, 21% P	0.30	0.30	0.30	---	---	---	0.30	0.30	0.30	---	---	---
Limestone	1.08	1.08	1.08	1.23	1.22	1.20	1.00	1.00	0.98	1.15	1.13	1.13
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.15	0.15	0.15	0.15	0.15	0.15	0.13	0.13	0.13	0.15	0.13	0.13
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15	0.13	0.13	0.13	0.15	0.13	0.13
L-lysine HCl	0.31	0.32	0.33	0.39	0.40	0.40	0.29	0.30	0.30	0.37	0.37	0.38
L-threonine	0.03	0.03	0.05	0.05	0.06	0.06	0.01	0.01	0.03	0.04	0.04	0.05
Phyzyme 600[2]	0.06	0.06	0.06	0.06	0.06	0.06	0.04	0.04	0.04	0.04	0.04	0.04
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

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

	Phase 1						Phase 2					
Wheat midds,%:	0	0	0	20	20	20	0	0	0	20	20	20
Ingredient % Fat, %:	0	2.5	5	0	2.5	5	0	2.5	5	0	2.5	5
SID amino acid %[3]												
Lysine	0.93	0.96	0.99	0.91	0.94	0.97	0.84	0.87	0.90	0.82	0.85	0.88
Isoleucine:lysine	66	65	65	62	62	61	67	66	66	63	63	62
Leucine:lysine	168	163	159	159	154	150	178	173	168	168	163	158
Methionine:lysine	30	29	28	29	29	28	31	30	30	31	30	29
Met & cys:lysine	61	59	58	61	59	58	64	62	61	64	63	61
Threonine:lysine	62	62	62	62	62	62	62	62	62	62	62	62
Tryptophan:lysine	17	17	17	17	17	17	17	17	17	17	17	17
Valine:lysine	78	76	75	77	75	74	81	79	78	79	78	77
SID Lysine:ME/Mcal	2.78	2.78	2.78	2.78	2.78	2.78	2.51	2.51	2.51	2.51	2.51	2.51
ME, kcal/lb	1,517	1,568	1,620	1,485	1,536	1,588	1,520	1,571	1,623	1,487	1,539	1,591
Total lysine, %	1.06	1.10	1.13	1.03	1.06	1.10	0.97	1.00	1.03	0.94	0.97	1.00
CP, %	18.15	18.36	18.66	17.61	17.82	18.12	17.01	17.27	17.52	16.50	16.77	17.01
Ca, %	0.55	0.55	0.55	0.55	0.55	0.55	0.51	0.51	0.51	0.51	0.51	0.51
P, %	0.47	0.47	0.47	0.52	0.52	0.51	0.46	0.46	0.46	0.51	0.50	0.50
Available P, %	0.28	0.28	0.28	0.28	0.28	0.28	0.25	0.25	0.25	0.25	0.25	0.25

[1] Phase 1 diets were fed from approximately 100 to 140 lb. Phase 2 diets were fed from 140 to 180 lb.
[2] Phyzyme 600 (Danisco Animal Nutrition, St Louis, MO.) provided per pound of diet: Phase 1 163.4 FTU/lb and 0.08 % available P released; Phase 2, 95.3 FTU/lb and 0.055 % available P released.
[3] Standardized ileal digestible.

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

	Phase 3						Phase 4					
Wheat midds,%:	0	0	0	20	20	20	0	0	0	20	20	20
Ingredient % Fat, %:	0	2.5	5	0	2.5	5	0	2.5	5	0	2.5	5
Corn	70.82	67.30	63.74	56.42	52.94	49.30	73.61	70.20	66.77	59.10	55.66	52.11
Soybean meal, 46.5%	12.04	13.04	14.12	6.51	7.48	8.60	9.35	10.27	11.19	3.95	4.87	5.91
DDGS	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Wheat middlings	---	---	---	20.00	20.00	20.00	---	---	---	20.00	20.00	20.00
Choice white grease	---	2.50	5.00	---	2.50	5.00	---	2.50	5.00	---	2.50	5.00
Monocalcium P, 21% P	0.30	0.30	0.30	---	---	---	0.30	0.30	0.30	---	---	---
Limestone	1.00	1.00	0.98	1.13	1.13	1.13	0.98	0.95	0.95	1.10	1.10	1.10
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.10	0.10	0.10	0.10	0.10	0.10	0.08	0.08	0.08	0.08	0.08	0.08
Trace mineral premix	0.10	0.10	0.10	0.10	0.10	0.10	0.08	0.08	0.08	0.08	0.08	0.08
Lysine HCl	0.27	0.27	0.28	0.35	0.35	0.36	0.25	0.25	0.26	0.32	0.33	0.33
L-threonine	0.01	0.02	0.02	0.03	0.04	0.05	---	0.01	0.01	0.02	0.03	0.04
Phyzyme 600[2]	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

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

	Phase 3						Phase 4					
Wheat midds,%:	0	0	0	20	20	20	0	0	0	20	20	20
Ingredient % Fat, %:	0	2.5	5	0	2.5	5	0	2.5	5	0	2.5	5
Caluclated analysis												
SID amino acids, %[3]												
Lysine	0.75	0.78	0.80	0.74	0.76	0.79	0.67	0.69	0.71	0.65	0.68	0.70
Isoleucine:lysine	69	68	67	64	64	63	71	70	69	66	65	65
Leucine:lysine	191	184	179	179	174	168	205	198	192	193	186	180
Methionine:lysine	33	32	31	33	32	31	35	34	33	35	34	33
Met & cys:lysine	68	66	64	68	66	65	73	71	69	74	71	69
Threonine:lysine	64	64	64	64	64	64	65	65	65	65	65	65
Tryptophan:lysine	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0
Valine:lysine	84	82	81	82	81	79	88	86	84	87	84	83
SID[3] Lysine:ME/Mcal	2.24	2.24	2.24	2.24	2.24	2.24	1.99	1.99	1.99	1.99	1.99	1.99
ME, kcal/lb	1,521	1,573	1,624	1,489	1,541	1,592	1,523	1,575	1,626	1,491	1,542	1,594
Total lysine, %	0.87	0.90	0.93	0.85	0.87	0.90	0.78	0.81	0.83	0.76	0.78	0.80
CP, %	15.96	16.14	16.34	15.44	15.60	15.82	14.92	15.07	15.21	14.44	14.59	14.78
Ca, %	0.50	0.50	0.50	0.50	0.50	0.50	0.48	0.48	0.48	0.48	0.48	0.48
P, %	0.45	0.45	0.45	0.50	0.49	0.49	0.44	0.44	0.43	0.49	0.48	0.48
Available P, %	0.23	0.23	0.23	0.23	0.23	0.23	0.22	0.22	0.22	0.22	0.22	0.22

[1] Phase 3 diets were fed from approximately 180 to 220 lb; Phase 4 diets were fed from 220 to 270 lb.
[2] Phyzyme 600 (Danisco Animal Nutrition, St Louis, MO.) provided per pound of diet: Phase 3, 54.5 FTU/lb and 0.04 % available P released; Phase 4, 47.7 FTU/lb and 0.03 % available P released.
[3] Standardized ileal digestible.

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Table 3. Analysis of dried distillers grains and wheat middlings (as-fed basis)

Item	DDGS	Wheat middlings
Nutrient, %		
DM	91.30	90.4
CP	27.7 (27.7)[1]	14.6 (15.9)
Fat (oil)	11.0	3.9
Crude fiber	9.5 (7.3)	8.4 (7.0)
ADF	11.0	10.2
NDF	27.1	34
Ca	0.15 (0.20)	0.14 (0.12)
P	0.8 (0.77)	1.0 (0.93)

[1] Values in parenthesis indicate those used in diet formulation.

Table 4. Bulk density of experimental diets (as-fed basis)[123]

	Treatments					
Wheat midds,%:	0	0	0	20	20	20
Bulk density, lb/bu[4] Fat,%:	0	2.5	5	0	2.5	5
Phase 1	48.0	46.5	46.5	42.5	40.5	40.1
Phase 2	47.7	46.2	46.2	39.4	39.1	38.8
Phase 3	47.9	47.9	47.9	38.8	38.2	38.0
Phase 4	48.4	48.2	48.2	40.7	40.1	40.5

[1] 288 pigs (TR4 × 1050, Initial BW= 93.3 lb) were used in this 84-d study with 8 pigs per pen and 6 pens per treatment.
[2] Bulk density of a material represents the mass per unit volume.
[3] Diet samples collected from the tops of each feeder during each phase.
[4] Phase 1 was d 0 to 21; Phase 2 was d 21 to 41; Phase 3 was d 41 to 60; Phase 4 was d 60 to 87.

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Table 5. Interactions of wheat middlings and fat on finishing-pig growth performance and carcass characteristics[1,2]

	0% Wheat Midds			20% Wheat Midds				Probability, $P <$
Item	0% Fat	2.5% Fat	5% Fat	0% Fat	2.5% Fat	5% Fat	SEM	Fat × Midds
Initial wt, lb	93.2	93.4	93.3	93.2	93.3	93.3	2.87	1.00
D 0 to 87								
ADG, lb	2.32	2.31	2.39	2.18	2.17	2.30	0.029	0.63
ADFI, lb	6.75	6.67	6.70	6.77	6.54	6.61	0.102	0.75
F/G	2.91	2.89	2.80	3.11	3.02	2.88	0.034	0.24
Final wt, lb	295.1	298.0	301.7	282.7	284.2	292.8	4.75	0.90
Carcass characteristics[3]								
Carcass yield, %[4]	73.3	73.9	73.4	72.8	72.9	72.8	0.41	0.82
HCW, lb	216.2	220.2	221.5	205.8	207.2	213.1	3.96	0.84
Backfat depth, in[3]	0.84	0.90	0.88	0.79	0.80	0.86	0.03	0.35
Loin depth, in[3]	2.58	2.52	2.53	2.43	2.40	2.48	0.03	0.14
Lean, %[3]	52.8	51.9	52.0	53.0	52.7	52.2	0.34	0.70
Jowl iodine value	71.6	72.4	72.3	72.3	73.7	75.1	0.34	0.12
Economics[5]								
Feed cost/pig, $	48.62	53.61	58.56	43.91	50.61	53.95	0.704	0.41
Feed cost/lb gain, $	0.28	0.31	0.34	0.26	0.28	0.31	0.006	0.54
Total revenue, $/pig[6]	162.1	165.1	166.1	154.3	155.4	159.8	2.970	0.84
IOFC[7]	113.5	111.5	107.6	110.4	104.8	105.9	2.993	0.68

[1] 288 pigs (TR4 × 1050, initial BW= 93.3 lb) were used in an 84-d study.
[2] Includes pigs that died, were culled, and were pulled off test during the experiment.
[3] Carcass characteristics other than yield and iodine value were adjusted by using hot carcass weight as a covariate.
[4] Percentage yield was calculated by dividing HCW by live weight obtained before transport to the packing plant.
[5] Diet cost was based on corn at $3.50/bu; 46.5% soybean meal at $300/ton; DDGS at $120/ton; wheat middlings at $100/ton and CWG at $30.00/cwt.
[6] Value was determined by using a base carcass price of $75.00/cwt.
[7] Income over feed cost = value of pig - feed costs during trial period.

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Table 6. Effects of dietary wheat middlings and fat on finishing pig growth performance and carcass characteristics[1,2]

	Wheat Midds, %		Fat, %			WM	Fat	Probability, $P <$			
								Main effects		Added Fat	
Item	0	20	0	2.5	5	SEM	SEM	Midds	Fat	Linear	Quadratic
Initial wt, lb	93.3	93.2	93.2	93.3	93.3	1.66	2.03	0.98	1.00	0.98	0.98
Day 0 to 87											
ADG, lb	2.34	2.21	2.25	2.24	2.34	0.029	0.020	<0.001	0.002	0.004	0.03
ADFI, lb	6.71	6.64	6.76	6.61	6.65	0.102	0.102	0.40	0.31	0.30	0.27
F/G	2.87	3.00	3.01	2.95	2.84	0.034	0.423	<0.001	<0.001	<0.001	0.36
Final wt, lb	298.3	286.6	288.9	291.1	297.2	3.36	4.75	0.01	0.21	0.09	0.64
Carcass characteristics[2]											
Carcass yield, %[3]	73.5	72.8	73.0	73.4	73.1	0.24	0.41	0.04	0.68	0.86	0.39
HCW, lb	219.3	208.7	211.0	213.7	217.3	3.96	0.24	0.003	0.29	0.12	0.89
Lean, %[4]	52.5	52.4	52.8	52.3	52.3	0.17	0.20	0.74	0.16	0.10	0.35
Back fat, in[4]	0.87	0.82	0.81	0.85	0.87	0.02	0.02	0.04	0.16	0.06	0.77
Loin depth, in[4]	2.54	2.44	2.50	2.46	2.51	0.02	0.47	<0.001	0.22	1.00	0.08
Jowl iodine value	72.1	74.2	72.7	73.1	73.7	0.02	0.24	<0.001	0.37	0.005	0.66
Economics[5]											
Feed cost/pig, $	53.60	49.49	46.26	52.11	56.25	0.406	0.498	<0.001	<0.001	<0.001	0.17
Feed cost/lb gain, $	0.31	0.28	0.27	0.30	0.32	0.003	0.004	<0.001	<0.001	<0.001	0.54
Total revenue, $/pig[6]	164.45	156.52	158.23	160.24	162.98	1.715	2.100	0.003	0.29	0.12	0.89
IOFC[7]	110.86	107.04	111.97	108.14	106.73	1.728	2.117	0.13	0.21	0.09	0.64

[1] 288 pigs (TR4 × 1050, initial BW= 93.3 lb) were used in an 84-d study.
[2] Includes pigs that died, were culled, and were pulled off test during the experiment.
[3] Percentage yield was calculated by dividing HCW by live weight obtained before transport to the packing plant.
[4] Carcass characteristics other than yield and iodine value were adjusted by using hot carcass weight as a covariate.
[5] Diet cost was based on corn at $3.50/bu; 46.5% soybean meal at $30.0/ton; DDGS at $120/ton; wheat middlings at $100/ton and CWG at $30.0/cwt.
[6] Value was determined by using a base carcass price of $75.00/cwt.
[7] Income over feed cost = value of pig - feed costs during trial period.

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Effects of Cracked Corn on Growth Performance and Stomach Lesions in Finishing Pigs

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

Summary

A total of 208 pigs (104 barrows and 104 gilts, initial average 138 lb) were used in a 63-d experiment to determine the effects of adding cracked corn to diets for finishing pigs. The pigs were sorted by ancestry and blocked by weight with 13 pigs per pen and 4 pens per treatment. Treatments were corn-soybean meal-based with none, 10, 20, or 40% roller-milled corn (mean particle size of 3,549 µm). Particle size for the none, 10, 20, and 40% cracked corn diets were 684, 926, 979, and 1,187 µm, respectively. Feed and water were offered ad libitum until slaughter (average final BW of 268 lb) at a commercial facility. Overall (d 0 to 63), increasing cracked corn from none to 40% had no effect on ADG ($P > 0.98$) and ADFI ($P > 0.41$), but F/G was numerically poorer (linear, $P < 0.11$). Adding cracked corn had no effect on HCW ($P > 0.17$) or backfat thickness ($P > 0.69$), but dressing percentage was decreased (linear effect, $P < 0.05$). For both stomach keratinization and ulcer scores, as the percentage of cracked corn increased, there was a decrease (linear, $P < 0.009$) in scores for ulcers and stomach keratinization (scale of 0 = none, 1 = mild, 2 = moderate, and 3 = severe), but even the worst treatment had an average lesion score of less than mild. Our results indicate that increasing cracked corn from none to 40% of diets for finishing pigs did not affect rate of gain but worsened F/G and dressing percentage with only slight improvements in scores for stomach lesions.

Key words: cracked corn, finishing pigs, stomach ulcers

Introduction

In finishing pigs, a 1.2 to 1.4% improvement in feed efficiency occurs for each 100-µm reduction in the particle size of corn. While decreasing particle size is an important economic factor in overall feed cost per pig, several studies have shown an increase in stomach lesions with a reduction of diet particle size. These increases in stomach lesions can lead to higher mortality from ulcer development. Colleagues in the poultry industry have suggested that feeding whole and cracked grain can improve gut health without negatively affecting growth performance in broilers. However, research is not currently available to determine if a similar strategy could be effective in swine. The objective of this experiment is to determine the effects on growth performance, carcass measurements, and stomach lesions when cracked corn is added to diets for finishing pigs.

Procedures

The Kansas State University (K-State) Institutional Animal Care and Use Committee approved the protocol used in this experiment. The experiment was completed at the K-State Swine Teaching and Research Center.

A total of 208 pigs (104 barrows and 104 gilts, initially138 lb) were used in a 63-d growth assay. The pigs were sorted by sex and ancestry, blocked by weight, and assigned

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to pens. There were 13 pigs per pen, 4 pens per treatment. The pigs were housed in a finishing facility with 6-ft x 16-ft pens and 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. Pigs were slaughtered at an average body weight of 268 lb.

Treatments were none, 10, 20, or 40% cracked corn (roller milled to a mean particle size of 3,549 μm; Table 1). Particle size for the none, 10, 20, and 40% cracked corn diets were 684, 926, 979, and 1,187 μm, respectively. All experimental diets were fed in 2 phases (d 0 to 31 and d 31 to 63).

Pigs and feeders were weighed at d 0, 31, and 63 to allow calculation of ADG, ADFI, and F/G. The pigs were harvested on d 63 (average weight of 268 lb), and carcass data were recorded. Stomachs were collected and scored for keratinization and ulcers.

All data were analyzed as a randomized complete block design using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). Polynomial regression was used to determine shape of the response to increasing concentration of cracked corn in the diet.

Results and Discussion

Overall (d 0 to 63), increasing the amount of cracked corn in the diet from none to 40% had no effect on ADG or ADFI ($P > 0.41$), but F/G tended to become worse as the percentage of cracked corn was increased (linear, $P < 0.11$; Table 2). Increasing cracked corn had no effect on HCW ($P > 0.17$) or backfat thickness ($P > 0.69$), but dressing percentage was decreased (linear effect, $P < 0.05$). For both stomach keratinization and ulcer scores, there were decreased (linear, $P < 0.01$) scores (scale of 0 = none, 1 = mild, 2 = moderate, and 3 = severe) as dietary cracked corn was increased. However, even though pigs fed diets with 40% cracked corn had the highest numerical score (i.e., the least lesion development), their scores still would be considered less than mild.

In conclusion, our results indicate that increasing cracked corn from none to 40% of the diet for finishing pigs did not affect rate of gain but worsened F/G and dressing percentage with only slight improvements in scores for stomach lesions.

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Table 1. Composition of experimental diets[1]

	d 0 to 31				d 31 to 63			
		Cracked corn, %				Cracked corn, %		
Item	Control	10	20	40	Control	10	20	40
Ingredient, %								
Corn, ground[1]	73.88	63.88	53.88	33.88	80.46	70.46	60.46	40.46
Corn, cracked[2]	---	10.00	20.00	40.00	---	10.00	20.00	40.00
Soybean meal (46.5% CP)	21.28	21.28	21.28	21.28	14.96	14.96	14.96	14.96
Soy oil	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Limestone	0.968	0.968	0.968	0.968	1.05	1.05	1.05	1.05
Monocalcium P (21% P)	0.94	0.94	0.94	0.94	0.58	0.58	0.58	0.58
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
L-lysine HCl	0.15	0.15	0.15	0.15	0.18	0.18	0.18	0.18
L-threonine	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04
Vitamin premix	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Mineral premix	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Antibiotic[3]	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis, %								
CP	16.22	16.22	16.22	16.22	13.84	13.84	13.84	13.84
SID lysine[4]	0.85	0.85	0.85	0.85	0.71	0.71	0.71	0.71
Ca	0.60	0.60	0.60	0.60	0.55	0.55	0.55	0.55
Total P	0.55	0.55	0.55	0.55	0.45	0.45	0.45	0.45

[1] Ground (in a hammermill) to 600 µm.
[2] Cracked (in a roller mill) to 3,549 µm.
[3] To provide 40 g/ton of tylosin.
[4] Standardized ileal digestible lysine.

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Table 2. Effects of cracked corn on growth performance, carcass characteristics, and stomach lesions in finishing pigs[1]

		Cracked corn, %				*P* value	
Item	Control	10	20	40	SE	Linear	Quadratic
d 0 to 63							
ADG, lb	2.02	2.10	2.06	2.04	0.05	0.98	0.43
ADFI, lb	5.67	5.99	5.90	5.96	0.28	0.41	0.46
F/G	2.81	2.85	2.86	2.91	0.08	0.11	0.86
Hot carcass weight, lb	196.7	199.8	198.3	194.0	5.43	0.23	0.17
Dress, %	74.0	73.7	73.7	72.7	0.46	0.05	0.66
Backfat thickness, in	1.05	1.05	1.06	1.05	0.04	0.93	0.69
Carcass lean, %[2]	50.9	50.9	50.8	50.9	0.47	0.93	0.72
Stomach keritinization[3]	0.21	0.18	0.08	0.05	0.04	0.008	0.48
Stomach ulceration[3]	0.22	0.04	0.02	0.00	0.04	0.009	0.05

[1] A total of 208 pigs (initial BW of 138 lb) were used.
[2] Fat-free lean index.
[3] Scored on scale: 0 = none, 1 = mild, 2 = moderate, and 3 = severe.

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Meta-analyses Describing the Variables that Influence the Backfat, Belly Fat, and Jowl Fat Iodine Value of Pork Carcasses

J. R. Bergstrom, M. D. Tokach, J. L. Nelssen, S. S. Dritz,[1] R. D. Goodband, J. M. DeRouchey, and T. A. Houser

Summary

Concern about the quality of pork fat has increased in the United States over the last decade, largely because of the increased availability and use of dried distillers grains with solubles (DDGS) in swine diets. The iodine value (IV) of pork fat is commonly used as an indicator of quality. To identify the factors associated with carcass fat IV, meta-analyses were conducted to describe the relevant variables and to develop prediction equations to assist swine nutritionists and producers in producing pork fat with an acceptable IV. Data from 21 experiments were used to develop prediction equations for carcass fat IV of pigs fed a relatively constant dietary iodine value product (IVP) throughout the feeding period, and 6 experiments were used to develop prediction equations for carcass fat IV of pigs fed a dietary IVP-reduction strategy before marketing. Backfat, belly fat, and jowl fat IV were all highly correlated among the experiments that measured the IV of the multiple fat depots ($r \geq 0.880$; $P < 0.001$). As expected, the dietary concentrations of unsaturated (primarily polyunsaturated) fatty acids were the most important in predicting carcass fat IV. However, improved prediction models were achieved by including variables to describe the pigs' initial and final BW, ADG, and carcass leanness. Increased ADG, final BW, BW range over course of the diet, and backfat depth resulted in reduced backfat IV ($P < 0.02$). Belly fat IV was also reduced with increasing final BW, BW range over course of the diet, and backfat depth ($P < 0.03$). A reduced jowl fat IV was associated with an increase in backfat depth and a lower fat-free lean index (FFLI, $P < 0.02$). Data analyzed to develop equations for predicting carcass fat IV using a dietary IVP-reduction strategy indicated that the concentrations of dietary polyunsaturated fatty acids in the initial diet were the most important. The concentrations of dietary polyunsaturated fatty acids in the reduced-IVP diet fed before marketing were also important in predicting the IV of carcass fat. However, the IV of backfat was the most amenable to change using an IVP-reduction strategy. Feeding the pigs for a longer period and to a heavier final BW resulted in a reduced backfat IV ($P \leq 0.05$). These results indicate that, although primarily determined by dietary factors, an understanding of the other variables that influence the IV of pork fat is necessary to reduce the likelihood of concerns with pork fat quality.

Key words: fat quality, fatty acids, iodine value, prediction equation

Introduction

Attention to the quality of pork fat has increased in the United States over the last decade, largely because of greater availability and use of dried distillers grains with solubles (DDGS) in swine diets. Feeding 10 to 30% or more DDGS may not affect

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carcass lean characteristics, but results in an increase in unsaturated carcass fat and the likelihood of soft bellies (Whitney et al., 2006[2]). Recent economic circumstances have encouraged pork producers to feed greater concentrations of DDGS, despite anticipated reductions in growth performance. As a result, some processors have become increasingly involved in the feeding practices employed by pork producers.

Iodine value (IV) is currently utilized as a standard indicator of carcass-fat quality in the United States. It provides an overall estimate of the unsaturated fatty acid content (greater IV = greater unsaturated fatty acid concentration), and it serves as an indicator of the fat firmness (greater IV = softer fat) and risk for rancidity (greater IV = increased risk of rancidity). However, carcass-fat quality standards can vary considerably. Various thresholds for backfat IV have ranged from 60 (Hugo & Roodt, 2007[3]) to 74 (Boyd et al., 1997[4]). Currently, one U.S. processor (Triumph Foods, St. Joseph, MO) routinely samples carcass jowl fat for IV and has established a threshold of 73. However, the IV of pork fat differs according to anatomical location, with the IV of jowl fat generally being greater than that of backfat (Benz et al., 2008[5]).

Therefore, meta-analyses were conducted to determine (1) the effects of dietary fatty acids (or dietary IVP) and variables associated with growth and carcass characteristics on the backfat, belly fat, and jowl fat fatty acids (or IV) and (2) the effects of dietary fatty acid (or IVP)- reduction strategies on the backfat, belly fat, and jowl fat fatty acids (or IV). The data for the first objective were utilized to develop equations to improve our ability to predict backfat, belly fat, and jowl fat IV. Data for the second objective were used to develop equations to improve our ability to use IVP-reduction strategies to meet acceptable fat-quality standards.

Procedures

Data Selection

The data used for the meta-analyses were obtained from numerous sources. A comprehensive search for published data was conducted via the Kansas State University (K-State) Libraries, using the Internet and the ISI Web of Knowledge/CABI search engine. Additional data were obtained through communication with authors affiliated with their studies. Data from both refereed and non-refereed publications, such as theses, technical memos, and university publications, were included.

Data interpretation

The IVP of every treatment diet was calculated as [IV of the dietary lipids] × [percentage dietary lipid] × 0.10, even when already reported, to ensure a uniform interpretation of dietary IVP across experiments. The IV of the lipid fraction of the dietary ingre-

[2] Whitney, M. H., G. C. Shurson, L. J. Johnston, D. M. Wulf, and B. C. Shanks. 2006. Growth performance and carcass characteristics of grower-finisher pigs fed high-quality corn distillers dried grain with solubles originating from a modern Midwestern ethanol plant. J. Anim. Sci. 84:3356-3363.

[3] Hugo, A., and E. Roodt. 2007. Significance of porcine fat quality in meat technology: a review. Food Rev. Intl. 23:175-198.

[4] Boyd, R. D., M. E. Johnston, K. Scheller, A. A. Sosnicki, and E. R. Wilson. 1997. Relationship between dietary fatty acid profile and body fat composition in growing pigs. PIC Technical Memo 153. PIC, Franklin, KY.

[5] Benz, J. M. 2008. Influence of dietary ingredients on pork fat quality. Ph.D. dissertation. Kansas State University, Manhattan.

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dients was calculated with the American Oil Chemists' Society (AOCS 1998) equation (IV = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723), using either the published fatty acid values for added fat sources (NRC, 1998[6]) or the analyzed profiles of the diet or diet components when reported. When analyzed values for the fat or fatty acid content were not provided for corn and soybean-based ingredients, the fatty acid profiles were calculated by using the NRC (1986) values for their fat content and the fatty acid profiles from corn oil and soybean oil (Table 1).

For treatments applied over more than one dietary phase to achieve a desired IVP or dietary fatty acid treatment, the mean IVP, mean content of fatty acids, mean ME density, and the mean percentage of dietary ME from fat of the diets were used to describe the treatment applied.

The analyzed fatty acid composition of backfat, belly fat, and jowl fat were used to calculate their IV with the AOCS (1998) equation (IV = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723) when the IV was not already reported using this equation.

Overall, 21 experiments were used to develop models for predicting the backfat, belly fat, or jowl fat IV of pigs fed a relatively constant IVP throughout the feeding period. For the analysis of IVP-reduction strategies, 6 experiments were used for modeling the backfat, belly fat, or jowl fat IV.

Statistical analyses

Each dietary IVP-treatment strategy applied within each study was considered the experimental unit (or observation) for modeling the effects of diet, duration, growth, and carcass fat/lean characteristics on backfat, belly fat, and jowl fat IV. The specific variables of interest included in the data were the experiment, genetic line, gender, dietary treatment IVP, grain source(s), protein source(s), added fat source(s), average caloric density (ME, kcal/kg), average C16:0 (%), average C18:0 (%), average C16:1+C18:1 (%), average C18:2 (%), average C18:3 (%), diet ME from fat (%), initial BW (kg), total duration (d), ADG (kg), ending BW (kg), BW range (ending BW – initial BW, kg), HCW (kg), backfat depth (mm), FFLI, and backfat IV, belly fat IV, and/or jowl fat IV.

For the meta-analysis of IVP-reduction strategies, the same dietary variables of interest were used for the diet fed during the period of reduced IVP. The total duration of the feeding period was also divided into the number of pre-reduction and actual reduction days. Interim BW was also included for the reduction analysis, and the BW range during the pre-reduction and actual reduction periods were included. An additional variable was created for the IVP-reduction analyses by multiplying the dietary IVP fed during the reduction period by the number of days in the period. This was necessary to describe the combined effect of the reduced IVP and duration that it was fed. All other variables remained the same as the previous meta-analysis of pigs fed a constant IVP.

[6] NRC. 1998. Nutrient Requirements of Swine. 10th rev. ed. Natl. Acad. Press, Washington D.C.

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The data for both meta-analyses were analyzed using the correlation, general linear models, and regression procedures of the SAS (SAS Institute, Inc., Cary, NC). The correlation procedure was used to indicate the significance of the relationship of each independent variable to the backfat IV, belly fat IV, and jowl fat IV, and to identify the significance of the relationship of IV among the 3 fat depots. The general linear models procedure was used to test the variables for significant interactions, and the regression procedure was used to develop prediction equations for backfat, belly fat, and jowl fat IV using a stepwise approach. The models were first developed without using the dummy variables for gender. Intercept-adjusted collinearity diagnostics (using the SAS syntax = COLLINOINT) and variance inflation factor (SAS syntax = VIF) were used to assist with the identification of variables with collinearity. Pairwise collinearity of variables was indicated by a condition index of ≥ 30 or a variance inflation of ≥ 10. When 2 variables were found to be collinear, the variable that provided the greatest R^2 was kept in the model, and the other variable was excluded. Additionally, plots of the residuals were examined to identify influential observations, but no observations were identified and removed for introducing bias into the models. Lastly, the dummy variables were tested with the final models to evaluate the influence of gender on backfat IV, belly fat IV, and jowl fat IV. Overall, correlations, interactions, variables, and models were considered significant at $P < 0.05$.

Results

Meta-analyses of experiments with treatments consisting of a continuous IVP throughout the feeding period

Correlations

Backfat, belly fat, and jowl fat IV were all highly correlated ($r \geq 0.887$; $P < 0.0001$) to each other (Table 2). Dietary characteristics had the highest correlations with the carcass backfat, belly fat, and jowl fat IV. For backfat IV, the total dietary concentration of C18:2 and C18:3 had the highest correlation ($r = 0.782$; $P < 0.0001$); followed by the diet IVP ($r = 0.765$; $P < 0.0001$), dietary concentration of C18:2 ($r = 0.689$; $P < 0.0001$), total dietary concentration of the unsaturated fatty acids C16:1, C18:1, C18:2, and C18:3 ($r = 0.618$; $P < 0.0001$), percentage of the diet ME from fat ($r = 0.506$; $P < 0.0001$), and dietary concentration of C18:3 ($r = 0.418$; $P < 0.0001$). For belly fat IV, the diet IVP had the highest correlation ($r = 0.882$; $P < 0.0001$); followed by the total dietary concentration of C18:2 and C18:3 ($r = 0.881$; $P < 0.0001$), total dietary concentration of the unsaturated fatty acids C16:1, C18:1, C18:2, and C18:3 ($r = 0.776$; $P < 0.0001$), dietary concentration of C18:3 ($r = 0.635$; $P < 0.0001$), percentage of the diet ME from fat ($r = 0.629$; $P < 0.0001$), dietary concentration of C18:2 ($r = 0.608$; $P < 0.0001$), total dietary concentration of C16:1 and C18:1 ($r = 0.335$; $P < 0.02$), and the ME density of the diet ($r = 0.324$; $P < 0.03$). For jowl fat IV, the dietary concentration of C18:2 had the highest correlation ($r = 0.759$; $P < 0.0001$), followed by the total dietary concentration of C18:2 and C18:3 ($r = 0.754$; $P < 0.0001$), diet IVP ($r = 0.671$; $P < 0.0001$), total dietary concentration of the unsaturated fatty acids C16:1, C18:1, C18:2, and C18:3 ($r = 0.536$; $P < 0.0001$), percentage of the diet ME from fat ($r = 0.346$; $P < 0.01$), dietary concentration of C18:3 ($r = 0.298$; $P < 0.03$), and total dietary concentration of C16:1 and C18:1 ($r = 0.256$; $P = 0.05$).

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As expected, growth and/or carcass variables were also found to be significantly correlated with backfat, belly fat, and jowl fat IV. For backfat IV, the ending BW had the highest negative correlation (r = -0.318; P < 0.01), followed by the weight range fed (r = -0.257; P < 0.02), backfat depth (r = -0.245; P < 0.02), and ADG (r = -0.242; P < 0.02). For belly fat IV, the ending BW and backfat depth had the highest negative correlation (r = -0.395; P < 0.01), followed by the weight range fed (r = -0.317; P < 0.03), with trends ($P \leq 0.06$) for a negative correlation for days fed (r = -0.271) and a positive correlation for FFLI (r = 0.272). Jowl IV was negatively correlated with backfat depth (r = -0.365; P < 0.01) and positively correlated with FFLI (r = 0.315; P < 0.02).

Prediction equations

The regression analyses of dietary and growth characteristics resulted in equations to predict backfat, belly fat, and jowl fat IV (Table 3). Equations using a single predictor demonstrated the primary influence of dietary unsaturated fatty acids on the IV of pork fat. However, improved equations were obtained by including multiple variables to describe the diet, animals, and growth.

The prediction equation for backfat IV was improved considerably by including multiple variables to characterize the diet, as well as to describe the growth and rate at which it occurred. Using the dietary concentration of C18:2 + C18:3 (*Adjusted* R^2 = 0.61) and/or backfat depth (*Adjusted* R^2 = 0.64) resulted in improvements over using the diet IVP alone (*Adjusted* R^2 = 0.58). Further improvements were obtained by adding the dietary C18:2 with or without C18:2 + C18:3 concentrations to an equation with the diet IVP, and replacing backfat depth with ADG and initial BW (*Adjusted* R^2 = 0.79). The equation that included the diet IVP, percentage dietary C18:2, percentage total dietary C18:2 + C18:3, initial BW, and ADG resulted in the greatest R^2 (*Adjusted* R^2 = 0.80). Figure 1 shows the precision with which this equation was able to predict the IV when compared to actual data.

The prediction equation for belly fat IV was improved by including multiple variables to characterize diet and growth. Adding the dietary percentage of ME from fat as an adjustment to the dietary IVP (*Adjusted* R^2 = 0.80) and/or variables to describe the weight during which the diet was fed and the ending backfat depth resulted in greater precision. The equation that included the diet IVP, percentage of ME from fat, BW range, ending BW, and backfat depth resulted in the greatest R^2 (*Adjusted* R^2 = 0.89, Figure 2).

The prediction equation for jowl fat IV was improved by including more than one dietary variable and an estimate of carcass lean. Beginning with the simple equation using dietary IVP (*Adjusted* R^2 = 0.44), replacing it with the dietary concentration of C18:2 or adding the estimated FFLI (*Adjusted* R^2 = 0.57) resulted in increased precision. Further precision was obtained by adding back the diet IVP and the percentage of ME from fat, and using either the backfat depth (*Adjusted* R^2 = 0.71) or estimated FFLI. The equation that included the diet IVP, percentage of C18:2, percentage of ME from fat, and estimated FFLI resulted in the greatest R^2 (*Adjusted* R^2 = 0.73, Figure 3).

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Meta-analyses of experiments evaluating dietary IVP-reduction strategies

Correlations

Backfat, belly fat, and jowl fat IV were all highly correlated ($r \geq 0.880$; $P < 0.001$) to each other (Table 4). As in the previous meta-analysis, dietary characteristics had the highest correlations with the carcass backfat, belly fat, and jowl fat IV. Various measures of the fatty acids in the initial dietary treatment had the highest correlations with the backfat IV, primarily the percentage of C18:2 ($r = 0.819$; $P < 0.0001$), C18:3 ($r = 0.764$; $P < 0.0001$), total C18:2 + C18:3 ($r = 0.826$; $P < 0.0001$), total unsaturated fatty acids ($r = 0.755$; $P < 0.0001$), and the diet IVP ($r = 0.815$; $P < 0.0001$). The same dietary characteristics of the IVP reduction treatment were also correlated ($r \geq 0.564$; $P < 0.0001$) with the backfat IV, as well as the ME density ($r \geq 0.605$; $P < 0.001$) and percentage of ME from fat ($r \geq 0.402$; $P < 0.03$) for both the initial and reduction-period diets. For belly fat IV, the initial dietary percentage of total C16:1 + C18:1 ($r = 0.655$; $P < 0.01$), C18:2 ($r = 0.817$; $P < 0.0001$), total C18:2 + C18:3 ($r = 0.836$; $P < 0.0001$), total unsaturated fatty acids ($r = 0.907$; $P < 0.0001$), and the diet IVP ($r = 0.915$; $P < 0.0001$) were all highly correlated. The same dietary characteristics of the IVP-reduction treatment were also correlated ($r \geq 0.635$; $P < 0.01$) with the belly fat IV, as well as the ME density ($r \geq 0.586$; $P < 0.01$) and percentage of ME from fat ($r \geq 0.523$; $P < 0.02$) for both the initial and reduction-period diets. For jowl fat IV, the percentage of C18:2 ($r = 0.901$; $P < 0.0001$), total C18:2 + C18:3 ($r = 0.878$; $P < 0.0001$), total unsaturated fatty acids ($r = 0.675$; $P < 0.01$), and the IVP ($r = 0.785$; $P < 0.0001$) of the initial diet had the highest correlations. The dietary percentage of C18:2 and total C18:2 + C18:3 of the IVP-reduction treatment were also correlated ($r \geq 0.464$; $P < 0.03$) with the jowl fat IV, as well as the percentage of ME from fat ($r = 0.511$; $P < 0.02$) in the initial diet.

Other variables were found to be correlated with the backfat and belly fat IV. The total length of the feeding period was negatively correlated with the backfat IV ($r = -0.581$; $P < 0.001$) and belly fat IV ($r = -0.518$; $P < 0.02$), and the number of days the initial diet was fed was negatively correlated with the backfat IV ($r = -0.494$; $P < 0.01$). Additionally, the initial BW ($r = 0.627$; $P < 0.0001$), overall BW range ($r = -0.594$; $P < 0.001$), reduction-period diet IVP × actual reduction-period days ($r = 0.522$; $P < 0.01$), BW at the initiation of the reduction period ($r = -0.353$; $P < 0.05$), and final BW ($r = -0.340$; $P = 0.05$) were correlated with the backfat IV. As in the previous meta-analysis, backfat depth was negatively correlated ($r = -0.629$; $P < 0.01$) with the belly fat IV. Jowl IV was not correlated with growth and carcass variables.

Prediction equations

Regression analyses of the dietary characteristics; growth, carcass, and BW data; along with feeding durations resulted in equations to predict backfat, belly fat, and jowl fat IV (Table 5.). Although the meta-analysis of diet IVP-reduction treatments was performed primarily with data not included in the previous meta-analysis, the prediction equations resulting in the greatest precision for determining the backfat, belly fat, and jowl fat IV used the same dietary variables. Similar to the previous meta-analysis, the equations with a single predictor demonstrated the primary influence of dietary unsaturated fatty acids on the IV of pork fat. However, the best single predictors were derived from the unsaturated fatty acid characteristics of the initial diet rather than the final diet.

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Improved equations for backfat IV were obtained by using either the IVP, concentration of C18:2, or concentration of C18:2 + C18:3 of the initial diet and the BW at the initiation of IVP reduction, reduction-period diet IVP × actual reduction-period days, and/or the final BW rather than the IVP of the initial diet alone. The equation that included the IVP of the initial diet, the BW at the initiation of IVP reduction, the reduction-period diet IVP × actual reduction-period days, and the final BW resulted in the greatest R^2 (*Adjusted* R^2 = 0.90). The precision with which this equation was able to predict the IV when compared to the actual data is shown in Figure 4.

Similar to the previous meta-analysis, the prediction equation for belly fat IV included the IVP of the initial diet. The precision of the equation was improved by including the reduction-period diet IVP × actual reduction-period days (*Adjusted* R^2 = 0.90, Figure 5).

The concentration of C18:2 in the initial diet was an important dietary variable for predicting jowl fat IV. The prediction equation was improved by including the number of days that the initial diet was fed (*Adjusted* R^2 = 0.87, Figure 6).

Discussion

It is well established that the fatty acid composition of pig adipose tissue can be manipulated by changing the amounts and proportions of fatty acids in the diet (Wood et al., 2003[7]). This is also evident in the meta-analyses. The equations with a single predictor, similar to the equation developed by Boyd et al. (1997), demonstrate the primary influence of the dietary unsaturated fatty acid concentration on the IV of pork fat. Madsen et al. (1992[8]) reported the positive linear relationship between the dietary and adipose tissue contents of polyunsaturated fatty acids. The diet IVP and fat IV describe the combined characteristics of the mono- and polyunsaturated fatty acid content of a particular fat. Therefore, it is not surprising that the diet IVP is a common predictor of IV across many of the prediction equations in the analyses.

Although the data from Boyd et al. (1997) were included in the meta-analyses for backfat and belly fat IV, the R^2 of the equations using a single measure of the dietary unsaturated fatty acid concentration as a predictor was considerably less than that reported by Madsen et al. (1992) and Boyd et al. (1997). The equation of Madsen et al. (1992) (IV = 47.1 + 0.14 × IVP/day, R^2 = 0.86) was derived from Danish experiments using individually housed pigs limit-fed a dietary IVP within the range of 37 to 88 (IVP/day of 42 to 190) from 20 kg BW until harvest at 90 kg BW. The equation of Boyd et al. (IV = 52.4 + 0.32 × IVP, R^2 = 0.99) was derived from a single controlled experiment, with an IVP in the range of 44 to 90 for pigs fed *ad libitum* from 43 kg BW until harvest at 118 kg BW. In the current meta-analyses, the simple equations for predicting backfat IV using the diet IVP were derived from multiple studies. The equation (backfat IV = 57.89 + 0.18 × IVP, R^2 = 0.58) from the meta-analysis of feeding a continuous IVP included data with an initial BW range of 50 to 200 lb, a final BW range of 97 to 300 lb, and a diet IVP range of 5 to 187. The equation (backfat IV = 54.20 + 0.23 × IVP of the initial diet, R^2 = 0.66) from the meta-analysis of IVP-reduction strategies included data with an initial BW range of 85 to 140 lb, a final BW range of 227

[7] Wood, J. D., R. I. Richardson, G. R. Nute, A. V. Fisher, M. M. Campo, E. Kasapidou, P. R. Sheard, and M. Enser. 2003. Effects of fatty acids on meat quality: a review. Meat Sci. 66:21-32.

[8] Madsen, A., K. Jakobsen, and H. P. Mortensen. 1992. Influence of dietary fat on carcass fat quality in pigs. A review. Acta. Agric. Scand. 42:220-225.

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to 290 lb, and a diet IVP range of 43 to 111. Nguyen et al. (2003[9]) demonstrated that the variation in the fatty acid composition of pork adipose tissue is increased when data from various experiments are pooled, resulting in weaker correlations than those obtained in an individual experiment. The increased variation results from differences in the conditions across the experiments. In the present analyses, accounting for some of these differences resulted in improved equations for predicting backfat, belly fat, and jowl fat IV.

Other variables are known to influence the amount, composition, and quality of pork fat. Several reviews have been published that describe some of these variables. Wood et al. (2008[10]) described the relationships of backfat thickness, gender, and the age, BW, or maturity of growing pigs with fat composition. Younger, lighter, and leaner pigs were found to have lower concentrations of C18:0 and C18:1 and greater concentrations of C18:2 in their subcutaneous adipose tissue; and this is also the case when intact males and gilts are compared to castrates. Fat quality defects are more common in pigs from very lean strains that are slaughtered at lower weights and with thinner backfat. The genetic influence on the fatty acid composition of adipose tissue in swine has been previously described (Wood et al., 2003), but the differences observed between genotypes are likely attributable to their differences in leanness and subcutaneous fat depth. Gender differences in fat composition are also a function of the differences in subcutaneous fat depth and leanness, and differences found between intact males and females with the same backfat thickness indicate that the adipose tissue of intact males may be less mature than that of castrates and females. The current analyses support the conclusion that the backfat depth or lean characteristics account for many of the differences observed between genotypes and genders, and that backfat depth is negatively correlated with the IV of carcass fat.

Relatively few experiments have evaluated the effects on carcass fatty acids of reducing the major dietary sources of unsaturated fatty acids for a period before slaughter. Six experiments were used in our meta-analyses of IVP-reduction treatments. Thirty of the 50 observations represented IVP-reduction treatments, or dietary strategies to reduce the effects on fat IV of the initial diet fed. The other 20 observations were the control treatments and were also used in the first meta-analyses of various levels of diet IVP fed throughout the feeding period. Nevertheless, the same characteristics of the initial diet were important for modeling the backfat IV, belly fat IV, and jowl fat IV in both sets of data.

An important finding was that the characteristics of the initial diet were most important for predicting the fat IV of pigs fed IVP-reduction treatments. The activity of lipogenic enzymes involved in the *de novo* synthesis of adipose tissue is reduced with increasing levels of dietary fatty acids (Allee et al., 1971[11]). However, data could not be

[9] Nguyen, L. Q., M. C. G. A. Nuijens, H. Everts, N. Salden, and A. C. Beynen. 2003. Mathematical relationships between the intake of n-6 and n-3 polyunsaturated fatty acids and their contents in adipose tissue of growing pigs. Meat Sci. 65:1399-1406.

[10] Wood, J. D., M. Enser, A. V. Fisher, G. R. Nute, P. R. Sheard, R. I. Richardson, S. I. Hughes, and F. M. Whittington. 2008. Fat deposition, fatty acid composition and meat quality: A review. Meat Sci. 78:343-358.

[11] Allee, G. L., D. H. Baker, and G. A. Leveille. 1971. Influence of level of dietary fat on adipose tissue lipogenesis and enzymatic activity in the pig. J. Anim. Sci. 33:1248-1254.

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found to describe the changes in activity of these enzymes after a reduction of dietary fatty acids for growing-finishing pigs. In the existing data, although not measured directly, it would appear that the changes in lipogenic enzyme activity are not easily reversed in growing-finishing pigs.

Backfat IV may be the most amenable to change using an IVP-reduction strategy; and this may be accomplished by initiating the strategy at a lighter BW and feeding to a heavier final BW. Jowl fat IV appears to be the most difficult to modify using an IVP-reduction strategy, and nutritionists and producers may be limited in their selection of ingredients when IV testing standards are based on a measurement of jowl fat.

The demand for lean pork, coupled with the increased utilization of DDGS as a swine feed ingredient, have stimulated greater interest in understanding the factors that influence pork fat quality. The meta-analyses described here provide for a greater understanding of the factors that are known to influence pork fat quality. Furthermore, the relationships described in the prediction equations obtained should prove to be useful for producing pork with acceptable fat quality.

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Table 1. Crude fat, fatty acid, IV, and IVP values used for some of the ingredients when analyzed values were not provided[1]

		Individual fatty acids of interest, % of fat									
	Crude Fat, %	C16:0	C18:0	C16:1	C18:1	C18:2	C18:3	C20:1	C22:1	IV of fat	IVP
Barley	1.9	21.8	0.9	0.3	12.8	53.0	5.8	0.0	0.0	118.4	22.5
Corn	3.9	10.9	1.8	0.0	24.2	59.0	0.7	0.0	0.0	124.8	48.7
Corn DDGS[2]	10.7	10.9	1.8	0.0	24.2	59.0	0.7	0.0	0.0	124.8	133.6
Sorghum	2.9	14.4	1.2	1.0	34.2	46.3	2.3	0.0	0.0	116.6	33.8
Sorghum DDGS	7.3	14.4	1.2	1.0	34.2	46.3	2.3	0.0	0.0	116.6	85.1
Soybean meal, 47.5% CP	3.0	10.3	3.8	0.2	22.8	51.0	6.8	0.0	0.0	125.9	37.8
Wheat, hard red winter	2.0	15.2	0.8	0.5	12.5	39.0	1.8	0.0	0.0	83.3	16.7

[1] IV = iodine value (IV = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723; AOCS, 1998); and IVP = iodine value product (IVP = [iodine value of the dietary lipids] × [percentage dietary lipid] × 0.10).

[2] DDGS = dried distillers grains with solubles.

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Table 2. Correlation coefficients of variables with backfat, belly fat, or jowl fat IV in the meta-analysis of treatments formulated to a similar dietary IVP throughout the feeding period[1]

Independent Variable	Backfat IV, n = 95	Belly fat IV, n = 49	Jowl fat IV, n = 58
Diet IVP	0.765 (P < 0.0001)	0.882 (P < 0.0001)	0.671 (P < 0.0001)
Diet C16:0, %	0.048 (P = 0.65)	0.182 (P = 0.21)	0.135 (P = 0.31)
Diet C18:0, %	-0.097 (P = 0.35)	0.005 (P = 0.98)	-0.003 (P = 0.98)
Total diet C16:1+C18:1, %	0.168 (P = 0.10)	0.335 (P < 0.02)	0.256 (P = 0.05)
Diet C18:2, %	0.689 (P < 0.0001)	0.608 (P < 0.0001)	0.759 (P < 0.0001)
Diet C18:3, %	0.418 (P < 0.0001)	0.635 (P < 0.0001)	0.298 (P < 0.03)
Total of C18:2+C18:3, %	0.782 (P < 0.0001)	0.881 (P < 0.0001)	0.754 (P < 0.0001)
Total UFA[2], %	0.618 (P < 0.0001)	0.776 (P < 0.0001)	0.536 (P < 0.0001)
ADG, kg	- 0.242 (P < 0.02)	0.171 (P = 0.24)	-0.061 (P = 0.65)
Days fed	-0.082 (P = 0.43)	-0.271 (P = 0.06)	-0.033 (P = 0.81)
ME density of diet, kcal/kg	0.016 (P = 0.88)	0.324 (P < 0.03)	0.144 (P = 0.28)
Diet ME from fat, %	0.506 (P < 0.0001)	0.629 (P < 0.0001)	0.346 (P < 0.01)
Initial BW, kg	-0.027 (P = 0.79)	0.180 (P = 0.22)	-0.054 (P = 0.68)
Final BW, kg	-0.318 (P < 0.01)	-0.395 (P < 0.01)	-0.148 (P = 0.27)
Weight range fed, kg	-0.257 (P < 0.02)	-0.317 (P < 0.03)	< -0.001 (P = 1.00)
Backfat depth, mm	-0.245 (P < 0.02)	-0.395 (P < 0.01)	-0.365 (P < 0.01)
FFLI[3]	0.005 (P < 0.96)	0.272 (P < 0.06)	0.315 (P < 0.02)
Backfat IV	---	0.907 (n = 46, P < 0.0001)	0.922 (n = 37, P < 0.0001)
Belly fat IV	0.907 (n = 46, P < 0.0001)	---	0.887 (n = 22, P < 0.0001)
Jowl IV	0.922 (n = 37, P < 0.0001)	0.887 (n = 22, P < 0.0001)	---

[1] IVP = iodine value product (IVP = [iodine value of the dietary lipids] × [percentage dietary lipid] × 0.10; Christensen, 1962); and IV = iodine value (IV = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723; AOCS, 1998).
[2] UFA = unsaturated fatty acids (C16:1 + C18:1 + C18:2 + C18:3).
[3] FFLI = fat-free lean index.

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Table 3. Regression models to describe the relationship of growth and diet variables (from treatments formulated to a similar dietary IVP throughout the feeding period) with backfat, belly fat, and jowl fat IV[1]

Dependent variable	Models	C.V.	R^2	Adjusted R^2
Backfat IV	= 76.58 + 0.08*diet IVP + 1.82*diet C18:2 (%) + 2.00*[diet C18:2 (%) + diet C18:3(%)] + 0.10*initial BW (kg) – 29.30*ADG (kg)	4.20	0.81	0.80
	= 75.28 + 0.13*diet IVP + 3.04*diet C18:2 (%) + 0.10*initial BW (kg) – 28.54*ADG (kg)	4.31	0.80	0.79
	= 77.76 + 0.06*diet IVP + 3.64*[diet C18:2 (%) + diet C18:3(%)] + 0.09* initial BW (kg) – 28.86*ADG (kg)	4.34	0.80	0.79
	= 75.63 + 0.12*diet IVP + 2.85*diet C18:2 (%) – 0.07*BW range (kg) – 18.06*ADG (kg)	4.44	0.79	0.78
	= 79.44 + 5.00*[diet C18:2 (%) + diet C18:3(%)] + 0.09*initial BW (kg) – 30.05*ADG (kg)	4.51	0.78	0.77
	= 75.38 + 4.80*[diet C18:2 (%) + diet C18:3(%)] – 19.78*ADG (kg)	5.05	0.72	0.71
	= 75.71 + 0.19*diet IVP + 0.08*initial BW (kg) – 24.58*ADG (kg)	5.25	0.70	0.69
	= 72.18 + 0.18*diet IVP – 15.71*ADG (kg)	5.61	0.65	0.65
	= 63.53 + 4.51*[diet C18:2 (%) + diet C18:3(%)] – 0.28*BF depth (mm)	5.65	0.65	0.64
	= 63.09 + 0.18*diet IVP – 0.25*BF depth (mm)	5.91	0.61	0.61
	= 57.82 + 4.59*[diet C18:2 (%) + diet C18:3(%)]	5.91	0.61	0.61
	= 57.89 + 0.18*diet IVP	6.11	0.58	0.58
Belly fat IV	= 50.36 + 0.23*diet IVP – 0.33*diet ME from fat (%) – 0.05*BW range (kg) + 0.18*final BW (kg) – 0.45*BF depth (mm)	2.78	0.90	0.89
	= 63.06 + 0.22*diet IVP – 0.33*diet ME from fat (%) + 0.05*initial BW (kg) – 0.22*BF depth (mm)	3.08	0.87	0.86
	= 57.10 + 0.22*diet IVP – 0.29*diet ME from fat (%) + 0.06*initial BW (kg)	3.27	0.85	0.84
	= 56.06 + 0.16*diet IVP + 0.05*initial BW (kg)	3.67	0.81	0.80
	= 60.11 + 0.21*diet IVP – 0.25*diet ME from fat (%)	3.70	0.81	0.80
	= 63.93 + 0.15*diet IVP – 0.22*BF depth (mm)	3.80	0.80	0.79
	= 58.85 + 0.16*diet IVP	3.96	0.78	0.77
Jowl fat IV	= 2.70 + 0.18*diet IVP + 2.15*diet C18:2 (%) – 0.33*diet ME from fat (%) + 1.10*estimated FFLI	2.71	0.75	0.73
	= 72.57 + 0.17*diet IVP + 2.01*diet C18:2 (%) – 0.32*diet ME from fat (%) – 0.69*BF depth (mm)	2.78	0.73	0.71
	= -9.82 + 0.26*diet IVP – 0.37*diet ME from fat (%) + 1.36*estimated FFLI	2.90	0.70	0.69
	= 20.65 + 4.12*diet C18:2 (%) + 0.76*estimated FFLI	3.23	0.62	0.61
	= 59.93 + 4.89*diet C18:2 (%) – 0.12*diet ME from fat (%)	3.35	0.60	0.58
	= -5.32 + 0.16*diet IVP + 1.28*estimated FFLI	3.38	0.59	0.57
	= 59.74 + 4.28*diet C18:2 (%)	3.40	0.58	0.57
	= 61.95 + 0.15*diet IVP	3.88	0.45	0.44

[1] IVP = iodine value product (IVP = [iodine value of the dietary lipids] × [percentage dietary lipid] × 0.10; Christensen, 1962); and IV = iodine value (IV = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723; AOCS, 1998).

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Table 4. Correlation coefficients of variables with backfat, belly fat, or jowl fat IV in the meta-analysis of IVP reduction strategies[1]

Independent Variable	Backfat IV, n = 33	Belly fat IV, n = 21	Jowl fat IV, n = 23
Initial diet IVP	0.815 (P < 0.0001)	0.915 (P < 0.0001)	0.785 (P < 0.0001)
Reduction-period diet IVP	0.661 (P < 0.0001)	0.818 (P < 0.0001)	0.300 (P = 0.17)
Initial diet C16:0, %	-0.416 (P < 0.02)	0.468 (P < 0.04)	-0.305 (P = 0.16)
Reduction-period diet C16:0, %	0.304 (P = 0.09)	0.414 (P = 0.06)	-0.130 (P = 0.55)
Initial diet C18:0, %	-0.642 (P < 0.0001)	0.253 (P = 0.27)	-0.459 (P < 0.03)
Reduction-period diet C18:0, %	0.252 (P = 0.16)	0.300 (P = 0.19)	-0.198 (P = 0.37)
Initial diet C16:1+C18:1, %	-0.231 (P = 0.20)	0.655 (P < 0.01)	-0.126 (P = 0.57)
Reduction-period diet C16:1+C18:1, %	0.035 (P = 0.85)	0.635 (P < 0.01)	-0.088 (P = 0.69)
Initial diet C18:2, %	0.819 (P < 0.0001)	0.817 (P < 0.0001)	0.901 (P < 0.0001)
Reduction-period diet C18:2, %	0.711 (P < 0.0001)	0.755 (P < 0.0001)	0.468 (P < 0.03)
Initial diet C18:3, %	0.764 (P < 0.0001)	0.338 (P = 0.13)	0.367 (P = 0.09)
Reduction-period diet C18:3, %	0.680 (P < 0.0001)	0.328 (P = 0.15)	0.332 (P = 0.12)
Initial diet C18:2+C18:3, %	0.826 (P < 0.0001)	0.836 (P < 0.0001)	0.878 (P < 0.0001)
Reduction-period diet C18:2+C18:3, %	0.716 (P < 0.0001)	0.763 (P < 0.0001)	0.464 (P < 0.03)
Initial diet UFA[2], %	0.755 (P < 0.0001)	0.907 (P < 0.0001)	0.675 (P < 0.01)
Reduction-period diet UFA, %	0.564 (P < 0.001)	0.862 (P < 0.0001)	0.204 (P = 0.35)
Overall ADG, kg	-0.217 (P = 0.23)	-0.018 (P = 0.94)	-0.143 (P = 0.52)
ME density of initial diet, kcal/kg	0.605 (P < 0.001)	0.626 (P < 0.01)	-0.048 (P = 0.83)
ME density of reduced IVP diet, kcal/kg	0.647 (P < 0.0001)	0.586 (P < 0.01)	0.070 (P = 0.75)
Initial diet ME from fat, %	0.402 (P < 0.03)	0.523 (P < 0.02)	0.511 (P < 0.02)
Reduction-period diet ME from fat, %	0.633 (P < 0.0001)	0.729 (P < 0.01)	0.111 (P = 0.61)
Total days	-0.581 (P < 0.001)	-0.518 (P < 0.02)	0.313 (P = 0.15)
Days initial diet fed	-0.494 (P < 0.01)	-0.119 (P = 0.61)	0.091 (P = 0.68)
Days reduction-period diet fed	0.300 (P = 0.09)	-0.072 (P = 0.76)	0.022 (P = 0.92)
Initial BW, kg	0.627 (P < 0.0001)	0.373 (P = 0.10)	-0.282 (P = 0.19)
BW at initiation of IVP reduction, kg	-0.353 (P < 0.05)	0.052 (P = 0.82)	-0.037 (P = 0.87)
Final BW, kg	-0.340 (P = 0.05)	-0.388 (P = 0.08)	0.043 (P = 0.85)
Backfat depth, mm	0.067 (P = 0.71)	-0.629 (P < 0.01)	-0.202 (P = 0.35)
FFLI[3]	-0.075 (P = 0.68)	0.410 (P = 0.06)	0.200 (P = 0.36)
Overall weight range, kg	-0.594 (P < 0.001)	-0.388 (P = 0.08)	0.290 (P = 0.18)
Weight range for reduction period, kg	0.228 (P = 0.20)	-0.098 (P = 0.67)	0.049 (P = 0.82)
Reduction-period IVP*reduction days	0.522 (P < 0.01)	0.075 (P = 0.75)	0.071 (P = 0.75)
Backfat IV	---	0.880 (n = 12, P < 0.001)	0.963 (n = 15, P < 0.0001)
Belly fat IV	0.880 (n = 12, P < 0.001)	---	0.987 (n = 6, P < 0.001)
Jowl IV	0.963 (n = 15, P < 0.0001)	0.987 (n = 6, P < 0.001)	---

[1] IVP = iodine value product (IVP = [iodine value of the dietary lipids] × [percentage dietary lipid] × 0.10; Christensen, 1962); and IV = iodine value (IV = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723; AOCS, 1998).
[2] UFA = unsaturated fatty acids (C16:1 + C18:1 + C18:2 + C18:3).
[3] FFLI = fat-free lean index.

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Table 5. Regression models to describe the relationship of variables involved in IVP-reduction strategies with backfat, belly fat, and jowl fat IV[1]

Dependent variable	Model	C.V.	R^2	Adjusted R^2
Backfat IV	= 63.57 + 0.25*initial diet IVP + 0.28*BW at initiation of IVP reduction (kg) + 0.003*(reduction-period diet IVP*reduction days) – 0.36*final BW (kg)	2.75	0.91	0.90
	= 67.66 + 0.28*initial diet IVP + 0.12*BW at initiation of IVP reduction (kg) – 0.25*final BW (kg)	4.04	0.80	0.77
	= 71.49 + 4.94*[initial diet C18:2 (%) + initial diet C18:3(%)] + 0.11*BW at initiation of IVP reduction (kg) – 0.22*final BW (kg)	4.10	0.79	0.77
	= 38.74 + 4.51*[initial diet C18:2 (%) + initial diet C18:3(%)] + 0.16*BW at initiation of IVP reduction (kg) + 0.001*(reduction-period diet IVP*reduction days)	4.38	0.76	0.74
	= 33.14 + 0.25*initial diet IVP + 0.17*BW at initiation of IVP reduction (kg) + 0.001*(reduction-period diet IVP*reduction days)	4.48	0.75	0.72
	= 78.53 + 3.97*[initial diet C18:2 (%) + initial diet C18:3(%)] – 0.16*final BW (kg)	4.62	0.72	0.71
	= 47.86 + 4.88*[initial diet C18:2 (%) + initial diet C18:3(%)] + 0.08*BW at initiation of IVP reduction (kg)	4.66	0.71	0.70
	= 76.67 + 0.22*initial diet IVP – 0.18*final BW (kg)	4.70	0.71	0.70
	= 41.85 + 0.28*initial diet IVP + 0.08*BW at initiation of IVP reduction (kg)	4.76	0.71	0.69
	= 47.05 + 5.51*initial diet C18:2 (%) + 0.07*BW at initiation of IVP reduction (kg)	4.77	0.71	0.69
	= 58.19 + 4.15*[initial diet C18:2 (%) + initial diet C18:3(%)]	4.87	0.68	0.67
	= 57.38 + 4.69*initial diet C18:2 (%)	4.96	0.67	0.66
	= 54.20 + 0.23*initial diet IVP	5.01	0.66	0.65
Belly fat IV	= 43.31 + 0.39*initial diet IVP – 0.001*(reduction-period diet IVP*reduction days)	2.65	0.91	0.90
	= 44.49 + 0.35*initial diet IVP	3.47	0.84	0.83
Jowl fat IV	= 52.43 + 4.99*initial diet C18:2 (%) + 0.06*days fed the initial diet	2.26	0.89	0.87
	= 57.89 + 4.71*initial diet C18:2 (%)	2.83	0.81	0.80
	= 58.69 + 0.19*initial diet IVP	4.04	0.62	0.60

[1] IVP = iodine value product (IVP = [iodine value of the dietary lipids] × [percentage dietary lipid] × 0.10; Christensen, 1962); and IV = iodine value (IV = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723; AOCS, 1998).

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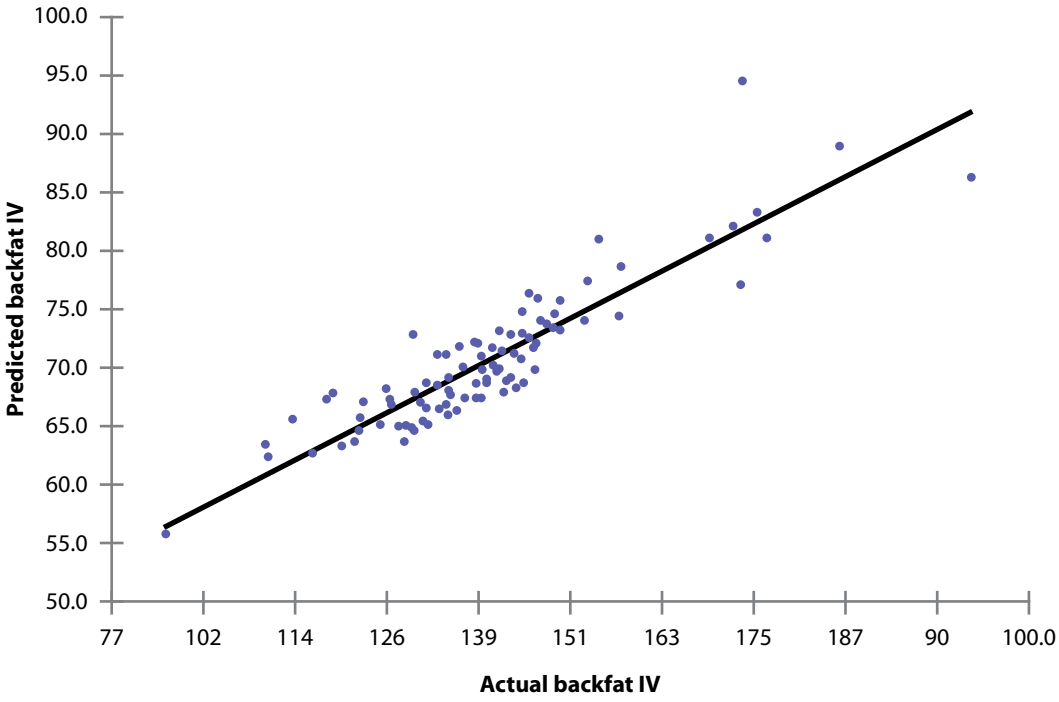

Figure 1. Predicted vs. actual backfat IV using the model [Y = 76.58 + 0.08*diet IVP + 1.82*diet C18:2 (%) + 2.00*[diet C18:2 (%) + diet C18:3(%)] + 0.10*initial BW (kg) – 29.30*ADG (kg)] and data from the meta-analysis of treatments formulated to similar dietary IVP throughout the feeding period.

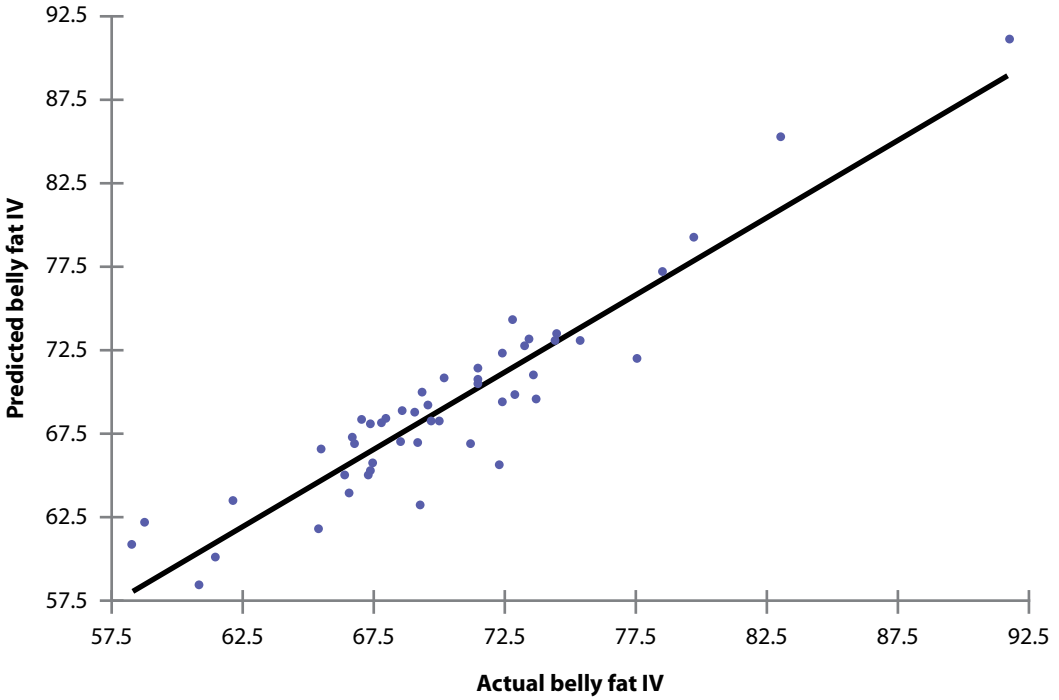

Figure 2. Predicted vs. actual belly fat IV using the model [Y = 50.36 + 0.23*diet IVP – 0.33*diet ME from fat (%) – 0.05*BW range (kg) + 0.18*final BW (kg) – 0.45*BF depth (mm)] and data from the meta-analysis of treatments formulated to similar dietary IVP throughout the feeding period.

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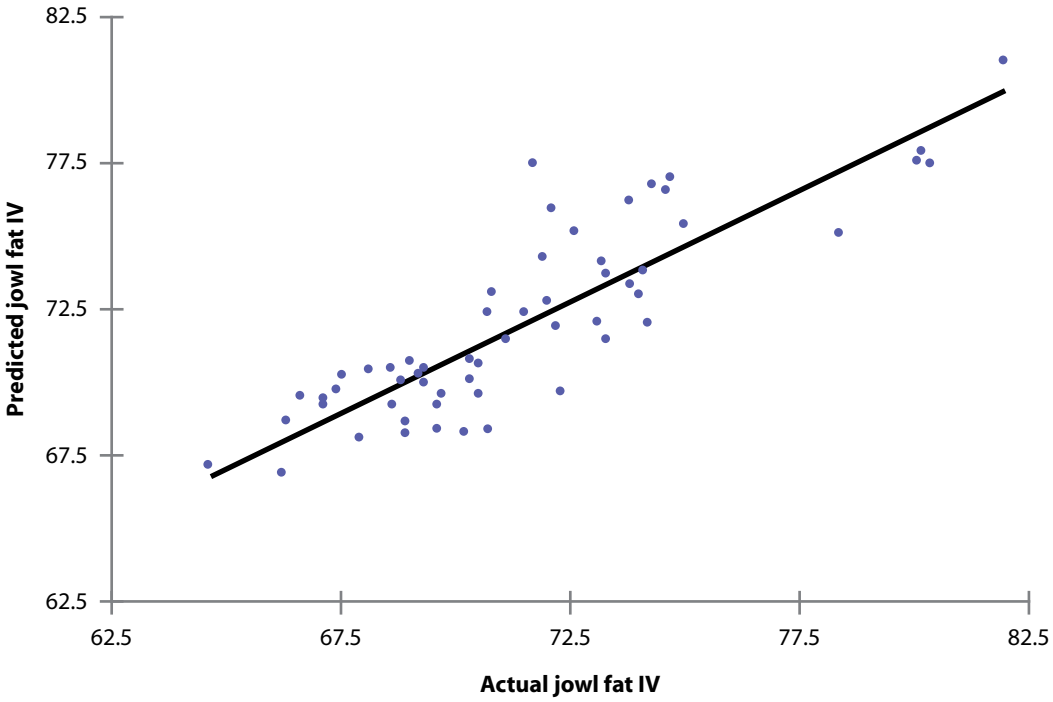

Figure 3. Predicted vs. actual jowl fat IV using the model [Y = 2.70 + 0.18*diet IVP + 2.15*diet C18:2 (%) – 0.33*diet ME from fat (%) + 1.10*estimated FFLI] and data from the meta-analysis of treatments formulated to similar dietary IVP throughout the feeding period.

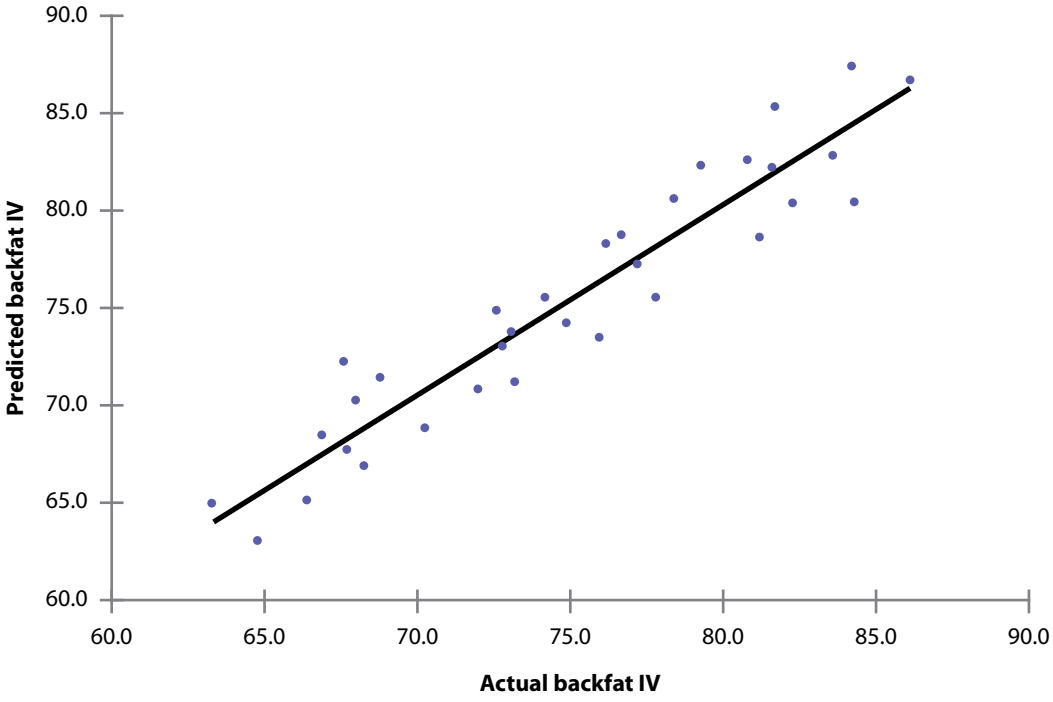

Figure 4. Predicted vs. actual backfat IV using the model [Y = 63.57 + 0.25*initial diet IVP + 0.28*BW at initiation of IVP reduction (kg) + 0.003*(reduction-period diet IVP*reduction days) – 0.36*final BW] and data from the meta-analysis of IVP-reduction strategies.

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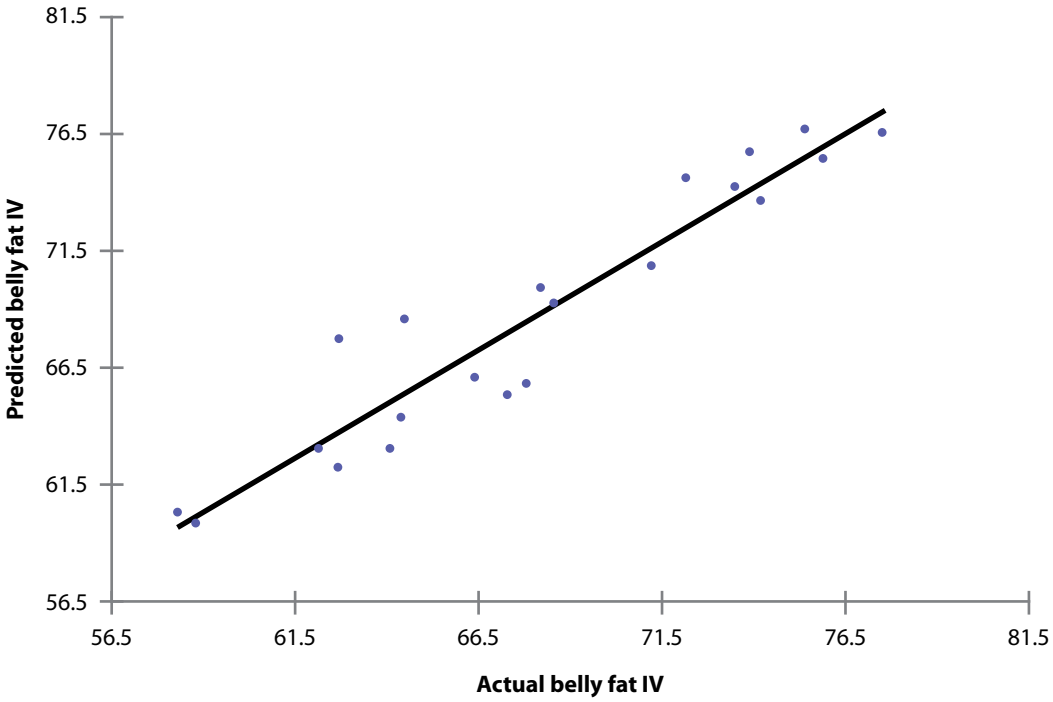

Figure 5. Predicted vs. actual belly fat IV using the model [Y = 43.31 + 0.39*initial diet IVP – 0.001*(reduction-period diet IVP*reduction days)] and data from the meta-analysis of IVP-reduction strategies.

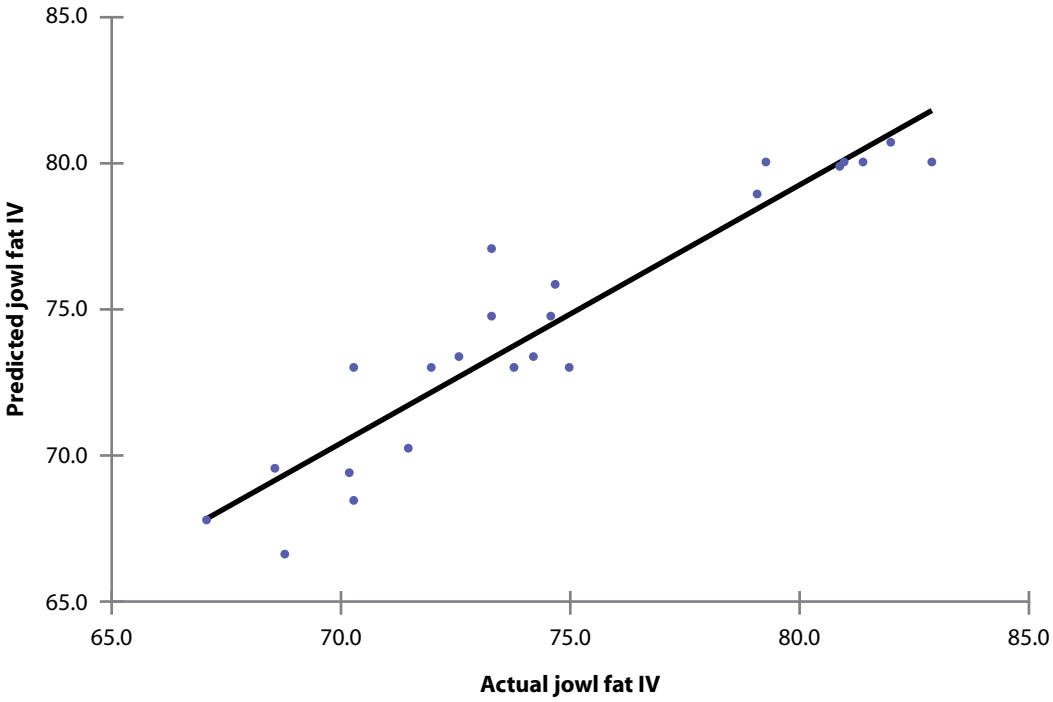

Figure 6. Predicted vs. actual jowl fat IV using the model [Y = 52.43 + 4.99*initial diet C18:2 (%) + 0.06*days fed the initial diet] and data from the meta-analysis of IVP-reduction strategies.

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Effects on Bacon Quality of Feeding Increasing Glycerol and Dried Distillers Grains with Solubles to Finishing Pigs

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Summary

A total of 84 barrows (PIC 337 × 1050, initially 68.3 lb) were fed a corn-soybean meal-based diet with added dried distillers grains with solubles (DDGS; 0 or 20%) and increasing glycerol (0, 2.5, or 5%) to determine the effects on belly quality. Criteria that were evaluated included: belly length, thickness, firmness, and slice yield; proximate and fatty acid analyses; iodine values; and sensory characteristics. There were no ($P > 0.08$) DDGS × glycerol interactions on any criteria measured. Inclusion of 20% DDGS in the diet decreased belly firmness ($P < 0.04$), as measured by the belly flop test (fat-side down method). Twenty percent DDGS decreased ($P < 0.01$) the percentage of myristic acid, palmitic acid, palmitoleic acid, stearic acid, oleic acid, vaccenic acid, total saturated fatty acids, and total monounsaturated fatty acids. In contrast, 20% DDGS increased ($P < 0.01$) the percentage of linoleic acid, α-linolenic acid, eicosadienoic acid, total polyunsaturated fatty acids, unsaturated:saturated fatty acid ratios, polyunsaturated:saturated fatty acid ratios, and iodine values. The inclusion of 0, 2.5, and 5% glycerol in swine diets did not affect any measured criteria in this study. In conclusion, feeding DDGS at a level of 20% decreased belly firmness and changed the fatty acid profile; however, it did not affect belly processing or sensory characteristics. Glycerol fed at 2.5 or 5.0% did not affect belly quality, fatty acid profile, or sensory characteristics of bacon.

Key words: belly quality, dried distiller grains with solubles, glycerol

Introduction

Increased demand for biofuel has increased the availability of feed coproducts from ethanol manufacturing. Dried distillers grains with solubles (DDGS), a coproduct that remains after ethanol is removed from fermented corn mash, contains high levels of nutrients in comparison to corn. With fluctuating corn prices, it is possible for producers to dramatically reduce feed costs by including it in swine diets. Dried distillers grains with solubles contains approximately 10% oil, which consists of 81% unsaturated fatty acids. Of that 81% unsaturated fatty acid content, 54% is linoleic acid (Xu et al., 2010[2]). It is known that feeding high levels of unsaturated fatty acids to pigs results in a lower

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

[2] Xu, G., S.K. Baidoo, L.J. Johnston, D. Bibus, J.E. Cannon, and G.C. Shurson. 2010. Effects of feeding diets containing increasing content of corn distillers dried grains with soluble to grower-finisher pigs on growth performance, carcass composition, and pork fat quality. J. Anim. Sci. 88:1398-1410.

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percentage of belly saturated fatty acids and softer bellies (Shackelford et al., 1990[3]). It has been found that belly firmness decreased linearly as dietary DDGS concentration increased. This is especially important, as bellies have become one of the most valuable pork products produced domestically. Softer bellies can result in greater variation, decreased slicing yields, a shorter shelf life, more fat separation, and more fat-smearing of bacon products (Apple et al., 2007[4]). As unsaturated fat content increases, so does softness, which can cause fat to separate from lean and be more susceptible to lipid oxidation.

At the time of this study, glycerol was an economical option to reduce feed costs in swine diets. Furthermore, it has been shown that feeding glycerol to pigs can have a beneficial effect on fat, as it lowers the concentration of unsaturated fatty acids in carcass fat (Mourot et al., 1994[5]). The objective of this study was to investigate the effect of feeding dietary glycerol and dried distillers grains with solubles on firmness, smokehouse and slice yield, bacon cooking yield, sensory characteristics of bacon, and fatty acid composition.

Procedures

The Kansas State University (K-State) Institutional Animal Care and Use Committee approved procedures used in this experiment. The K-State Institutional Review Board accepted sensory panel studies.

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

A total of 84 barrows (PIC, 337 × 1050, initially 68.4 lb) were used in this 70-d study. Pigs were blocked by weight and randomly assigned to 1 of 6 dietary treatments with 7 pens per treatment. Animals were fed corn-soybean meal-based experimental diets. Treatments were arranged in a 2 × 3 factorial, with main effects of glycerol (0, 2.5, 5.0%) and DDGS (0 or 20%). Growth performance and backfat fatty acid profile, data from this trial were previously reported by Duttlinger et al (2008[6]).

On d-70, the two heaviest barrows were visually selected, individually tattooed, and shipped to a commercial swine harvest facility (JBS SWIFT & Company, Worthington, MN) for slaughter. After slaughter and chilling (24 h), each belly was removed

[3] Shackelford, S.D., M.F. Miller, K.D. Haydon, N.V. Lovegren, C.E. Lyon, and J.O. Reagan. 1990. Acceptability of bacon as influenced by the feeding of elevated levels of monounsaturated fats to growing-finishing swine. J. Food Sci. 55 (3): 621-624.

[4] Apple, J.K., C.V. Maxwell, J.T. Sawyer, B.R. Kutz, L.K.Rakes, M.E.Davis, Z.B. Johnson, S.N. Carr, and T.A. Armstrong. 2007. Interactive effect of ractopamine and dietary fat source on quality characteristics of fresh pork bellies. J. Anim. Sci. 85: 2682-2690.

[5] Mourot, J., A. Aumaitre, A. Mounier, P. Peiniau, and A.C. Francois. 1994. Nutritional and physiological effects of dietary glycerol in the growing pig. Consequences on fatty tissues and post mortem muscular parameters. Livestock Production Science. 38:237-244.

[6] Duttlinger et al., Swine Day 2008, Report of Progress 1001, pp. 175-185.

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from the carcass according to Institutional Meat Purchasing Specification guide for a 408 fresh pork belly.

Initial belly weight (belly with skin on), length, and thickness were measured on raw bellies. Firmness was measured by centering the belly, skin-side up and skin-side down, on a stainless steel smokestick that ran perpendicular to the length of the belly. For both skin-up and skin-down orientation measurements, a measurement was taken on the dorsal and ventral sides of the belly. The measurements for firmness were measured between the 2 closest points of the flexed belly (tissue–to-tissue distance for the skin-up orientation, or skin-to-skin distance for the skin-down orientation).

Bellies were skinned and injected with a multineedle pump injector at 12% of the green weight. All bellies were weighed before and after injection, and hung on smokehouse trucks for 2 h before cooking in a smokehouse.

After chilling, cooked bellies were weighed, and the smokehouse yield of all the bellies was calculated. Bellies were placed in oxygen-impermeable vacuum-package bags (not vacuum-sealed), placed in coolers, and transferred to Jennings Premium Meats (JPM) in New Franklin, Mo., for further processing. At JPM, the cured and smoked slab bellies were pressed with a bacon press and sliced with a bacon slicer to a width of 4 mm.

Bacon slice yield was calculated by weighing the sliced bacon slab, removing the less valuable slices, then weighing the remaining #1 slices [(belly weight - (weight of #2 and #3 slices)/belly weight) × 100]. To meet the requirements for # 1 slices, the bacon strips had to have the M. *cutaneous trunci* extending more than 50% of the width of the bacon slice and slice thickness no less than 1.9 cm.

Fat samples were collected from each belly and frozen until analysis could be completed. Fatty acid results are reported as a percentage of total fatty acids in each belly sample. Iodine values, which represent the softness of the belly, were calculated by using 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). After slice-yield measurements were taken, every 10th slice, beginning from the caudal end, was collected for proximate analysis. All bacon slices were cut into small pieces, mixed into a composite sample, frozen in liquid nitrogen, pulverized in a blender, and then analyzed for protein (AOAC 990.03), moisture, fat (AOAC PVM-1:2003) and ash content (AOAC 942.05) at the K-State Analytical Laboratory. Samples for fatty acid analysis were taken from the same composite. Fatty acid results are reported as a percentage of total fatty acids in each belly sample.

Bacon slices used for sensory evaluation were removed from the belly at a point one-third the length of the belly from the cranial end. Bacon was placed on cooking racks in a Blodgett dual-air-flow oven set at 348.8°F. Slices were cooked for 5 min on each side. After cooking, slices were blotted with paper towels to remove excess grease. Bacon samples were cut into subslices and the end portions were discarded, resulting in more uniform slices. Before sensory panels began, all panelists participated in orientation sessions designed to acquaint them with the scale used for each trait. At least 8 panelists were used for each sensory evaluation session. Panelists were placed in individual booths and were required to consume a piece of apple, a piece of cracker, and water between

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each bacon sample to cleanse their palates. The panelists scored brittleness, bacon flavor intensity, saltiness, and off-flavors using an 8-point scale: Brittleness: 1 = extremely soft, 2 = very soft, 3 = moderately soft, 4 = slightly soft, 5 = slightly crisp, 6 = moderately crisp, 7 = very crisp, 8 = extremely crisp. Bacon flavor intensity: 1 = extremely bland, 2 = very bland, 3 = moderately bland, 4 = slightly bland, 5 = slightly intense, 6 = moderately intense, 7 = very intense, 8 =extremely intense. Saltiness: 1 = extremely un-salty, 2 = very un-salty, 3 = moderately un-salty, 4 = slightly un-salty, 5 = slightly salty, 6 = moderately salty, 7 = very salty, 8 = extremely salty. Off-flavor: 1 = extremely intense, 2 = very intense, 3 = moderately intense, 4 = slightly intense, 5 = slight, 6 = traces, 7 = practically none, 8 = none.

Ten additional bacon slices were removed from the belly at a point one-third the length of the belly from the cranial end. Of the 10 slices collected from each belly, six bacon slices were selected randomly and cooked using the same procedures described for sensory analysis. Pre- and post-cook weights were recorded, and cooking yield was calculated as [(cooked weight/raw weight) x100].

Data were analyzed by using the PROC GLM and PROC CORR procedures of SAS 9.1.3 (SAS Institute, Inc., Cary NC). Each pen (2 pigs per pen) selected for this experiment was an experimental unit. DDGS × glycerol interactions, DDGS main effects, and glycerol main effects were separated when f-tests were significant at a level of $P < 0.05$.

Results and Discussion

There were no DDGS × glycerol interactions ($P > 0.81$) observed for any criteria tested. There was no effect ($P > 0.22$) of DDGS on belly length, belly thickness, belly skin-on weight, or belly skin-off weight (Table 1). However, the inclusion of 20% DDGS decreased ($P = 0.04$) belly firmness by the belly flop skin-side down measurement and tended to reduce ($P = 0.07$) belly firmness with the belly flop skin-side up method. A decrease in belly firmness is expected with increased unsaturated fat. It was observed that including 20% DDGS in the diet decreased fat saturation, thereby reinforcing the observance of decreased belly firmness.

The inclusion of 20% DDGS to the diet tended to increase ($P = 0.06$) pump percentage, but did not affect ($P > 0.16$) the injected weight, belly cooked weight, belly smokehouse yield, #1 type bacon slice-yield weight, #1 type bacon slice yield, or bacon cooking yields (Table 2). Adding DDGS to the diet will cause belly fat to become more unsaturated. As a result, belly fat containing more unsaturated fatty acids will be softer. Therefore injection pressure might cause more brine to be injected and retained in the belly because the fat is more pliable.

The addition of 20% DDGS to the diet resulted in a trend ($P = 0.07$) toward increased moisture content (Table 3). However, there were no changes to protein, fat, or ash content ($P > 0.16$). It is possible that the inclusion of DDGS will affect fat content. It is generally known that protein and ash are relatively constant in meat; however, moisture and fat content are relatively mobile, in that an increase in moisture content will cause a decrease in fat content.

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Dietary addition of DDGS at 20% decreased ($P < 0.01$) myristic acid, palmitic acid, palmitoleic acid, stearic acid, oleic acid, vaccenic acid, and total SFAs (Table 4). Inclusion of DDGS at 20% increased ($P < 0.01$) linoleic acid, α-linolenic acid, eicosadienoic acid, total MUFAs, unsaturated to saturated fatty acid ratios, polyunsaturated: saturated fatty acid ratios, and iodine values. As DDGS contains 10% oil, with 81% of that oil comprising unsaturated fatty acids, the fat that will be deposited in belly fat will be more unsaturated. Furthermore, the fatty acid profile of the diet will change the triglyceride composition that is stored in adipocytes. During low energy intake, the rate of lipolysis increases, freeing fatty acids to be oxidized. The opposite is true during high energy-intake periods, as unneeded energy is stored as triglycerides. High-fat diets will inhibit fatty acid synthesis in nonruminants, essentially shutting down or limiting de novo fat synthesis. Therefore, pigs will deposit the unsaturated fat being consumed through the diet in lieu of saturated fatty acids. As a result, the total saturated fatty acid content will decrease. In contrast, unsaturated fatty acid and polyunsaturated fatty acid content would increase, thereby increasing iodine values.

The addition of 20% DDGS to swine diets did not have any effects on bacon brittleness ($P = 0.62$), bacon flavor intensity ($P = 0.24$), saltiness ($P = 0.66$), or off-flavor ($P = 0.10$; Table 5). In theory, a higher unsaturated fat level would leave bacon samples more susceptible to lipid oxidation and result in more off-flavors. However, this was not the case in this study.

Increasing dietary glycerol (not shown in tables) showed no significant effects ($P > 0.13$) on fresh belly characteristics, belly processing characteristics, proximate analysis, fatty acid composition, or sensory characteristics. Though glycerol provides a substrate for de novo fatty acid synthesis, it is likely that glycerol showed no effects on any measurements because the fat in the diet was provided from DDGS, resulting in little de novo fat synthesis. As the de novo fatty acid synthesis in pigs is limited when a fat source is added into the diet, it can be expected that glycerol will not be used as a substrate for fatty acid synthesis. Therefore, glycerol will not affect fat saturation or flavor.

In summary, feeding pigs 20% DDGS decreased belly firmness and changed the fatty acid profile but did not affect any other belly processing or sensory characteristics. Glycerol fed at 2.5 or 5% in swine diets did not affect any belly processing characteristics, belly fatty acid composition, or sensory panelist's assessment of bacon characteristics. Therefore, feeding 20% DDGS and glycerol at 0, 2.5, and 5% showed no negative or beneficial effects on bacon quality.

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Table 1. Effects of feeding dried distillers grains with solubles (DDGS) on fresh belly characteristics

	DDGS, %			
Belly Characteristics[a]	None	20	SE	P-value
Belly length, in	27.32	27.02	0.44	0.22
Belly thickness, in	1.21	1.22	0.04	0.68
Flop skin down, in	7.36	6.78	0.50	0.04
Flop skin up, in	6.34	5.95	0.37	0.07
Skin-on belly weight, lb	17.50	17.39	0.25	0.76
Skin-off belly weight, lb	14.66	14.35	0.25	0.37

[a] Values represent the mean of 42 observations.

Table 2. Effects of feeding dried distillers grains with solubles (DDGS) on belly processing characteristics

	DDGS, %			
Processing Characteristics[a]	None	20	SE	P-value
Pump %	10.35	10.79	0.16	0.06
Injected weight, lb	16.18	15.90	0.28	0.48
Belly cooked weight, lb	14.70	14.44	0.26	0.48
Smokehouse yield, %	100.15	100.50	0.22	0.26
Slice yield, lb	10.56	10.14	0.22	0.18
#1 Bacon slice yield,%	71.78	70.33	0.72	0.16
Bacon cooking yields, %	33.30	33.60	0.75	0.78

[a] Values represent the mean of 42 observations.

Table 3. Effects of feeding dried distillers grains with solubles (DDGS) on proximate analysis of bacon slices

	DDGS, %			
Composition[a]	None	20	SE	P-value
Moisture, %	40.68	42.78	0.78	0.07
Protein, %	13.12	13.53	0.30	0.33
Fat, %	43.81	41.54	1.12	0.16
Ash, %	2.56	2.18	0.33	0.42

[a] Values represent the mean of 42 observations.

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Table 4. Effect of feeding dried distillers grains with solubles on belly fatty acid composition

	DDGS, %			
Item[ab]	None	20	SE	P-value
Myristic acid (14:0),%	1.47	1.36	0.01	0.01
Palmitic acid (16:0), %	24.20	22.66	0.01	0.01
Palmitoleic acid (16:1),%	2.68	2.29	0.01	0.01
Margaric acid (17:0),%	0.47	0.46	0.01	0.68
Stearic acid (18:0), %	11.71	10.87	0.01	0.01
Oleic acid (18:1c9),%	39.88	38.34	0.01	0.01
Vaccenic acid (18:1n7),%	3.38	3.03	0.01	0.01
Linoleic acid (18:2n6),%	12.28	16.92	0.01	0.01
α- Linolenic acid (18:3n3),%	0.54	0.60	0.01	0.01
Arachidic acid (20:0), %	0.22	0.20	0.01	0.06
Eicosadienoic acid (20:2),%	0.64	0.80	0.01	0.01
Arachidonic acid (20:4n6),%	0.09	0.09	0.01	0.09
Other fatty acids, %	2.40	2.34	0.01	0.15
Total SFA, %[1]	38.42	35.81	0.01	0.01
Total MUFA,%[2]	47.02	44.57	0.01	0.01
Total PUFA, %[3]	13.06	17.94	0.01	0.01
Total TFA, %[4]	0.50	0.49	0.01	0.90
UFA:SFA ratio[5]	1.57	1.75	0.02	0.01
PUFA:SFA ratio[6]	0.34	0.50	0.01	0.01
Iodine value, g/100g[7]	63.66	69.88	0.01	0.01

[1] Total saturated fatty acids = {[C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]} where the brackets indicate concentration.
[2] Total monounsaturated fatty acids = {[C14:1] + [C16:1] + [C18:1c9] + [C18:1n7] + [C20:1] + [C24:1]} where the brackets indicate concentration.
[3] Total polyunsaturated fatty acids = {[C18:2n6] + [C18:3n3] + [C18:3n6] [C20:2] + [C20:4n6]}where the brackets indicate concentration.
[4] Total trans fatty acids = {[C18:1t] + [C18:2t] + [C18:3t]} where the brackets indicate concentration.
[5] UFA:SFA ratio = [Total MUFA + Total PUFA]/Total SFA.
[6] PUFA:SFA = Total PUFA/ Total SFA.
[7] Calculated as IV = [C16:1 x 0.95 + [C18:1] x 0.86 + [C18:2] x 1.732 + [C18:3] x 2.616 + [C20:1] x 0.785 + [C22:1] x 0.723 where the brackets indicate concentration (AOCS, 1998).
[a] Values represent the mean of 42 observations.
[b] Percentage of total fatty acid content

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Table 5. Effect of feeding dried distillers grains with solubles on bacon sensory characteristics

	DDGS, %			
Sensory characteristic[a]	None	20	SE	P-value
Brittleness[1]	5.17	5.28	0.15	0.62
Bacon flavor intensity[2]	5.87	5.67	0.12	0.24
Saltiness[3]	5.7	5.73	0.06	0.66
Off-flavor[4]	7.77	7.54	0.09	0.10

[1] Brittleness: 1 = extremely soft, 2 = very soft, 3 = moderately soft, 4 = slightly soft, 5 = slightly crisp, 6 = moderately crisp, 7 = very crisp, 8 = extremely crisp.
[2] Bacon flavor intensity: 1 = extremely bland, 2 = very bland, 3 = moderately bland, 4 = slightly bland, 5 = slightly intense, 6 = moderately intense, 7 = very intense, and 8 = extremely intense
[3] Saltiness: 1 = extremely un-salty, 2 = very un-salty, 3 = moderately un-salty, 4 = slightly un-salty, 5 = slightly salty, 6 = moderately salty, 7 = very salty, 8 = extremely salty.
[4] Off-flavor: 1 = extremely intense, 2 = very intense, 3 = moderately intense, 4 = slightly intense, 5 = slight, 6 = traces, 7 = practically none, 8 = none.
[a] Values represent the mean of 42 observations.

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Effects of Dietary Astaxanthin, Ractopamine HCl, and Gender on the Growth, Carcass, and Pork Quality Characteristics of Finishing Pigs[1]

J. R. Bergstrom, J. L. Nelssen, T. A. Houser, M. D. Tokach, R. D. Goodband, J. M. DeRouchey, and S. S. Dritz[2]

Summary

A total of 144 finishing pigs (initially 226 lb) were used to evaluate the effects of various levels and sources of added dietary astaxanthin (AX: 0, 2.5, 5, 7.5, and 10 ppm), as well as ractopamine HCl (Paylean), on growth, carcass, and pork quality characteristics of barrows and gilts. Pigs were blocked by gender and weight and randomly allotted to 1 of 9 dietary treatments fed for approximately 26 d pre-harvest. Dietary treatments consisted of a corn-soybean meal-based control, the control with 5, 7.5, or 10 ppm AX from *Phaffia rhodozyma* yeast, the control with 5 ppm synthetic AX, and the control with 9 g/ton Paylean and 0, 2.5, 5, and 7.5 ppm AX from *Phaffia rhodozyma* yeast. There were 2 pigs per pen and 8 pens per treatment (4 pens per treatment × gender combination). Overall, barrows had greater ($P < 0.01$) ADG and ADFI than gilts, while ADG and final BW increased ($P < 0.01$) and F/G improved for pigs fed Paylean. For carcass characteristics, barrows had greater ($P < 0.01$) backfat depth and less ($P < 0.01$) longissimus muscle area and fat-free lean than gilts. Pigs fed Paylean had greater ($P < 0.01$) HCW, yield, and longissimus muscle area than those that received non-Paylean treatments. Growth performance and carcass characteristics of pigs fed AX were not different than control pigs. Although there were no differences in the initial subjective color scores, the discoloration scores of longissimus chops increased (linear, $P < 0.01$) daily during 7 d of retail display, and were greater ($P < 0.01$) for barrow chops on d 7 compared to gilt chops (gender × day interaction, $P < 0.01$). Also, the overall average discoloration scores and change in d 0 to 3 objective total color were lower ($P < 0.01$) for gilts and pigs fed Paylean, although the difference between gilts and barrows was smaller when they were fed Paylean (gender × treatment interaction, $P < 0.01$). Modest differences in measures of pork color during retail display were associated with added dietary AX, but these did not result in an increase in color shelf-life or reduction in the objective measure of total color change. Collectively, these observations indicated a greater ($P < 0.01$) color shelf-life for chops from gilts and pigs fed Paylean.

Key words: astaxanthin, carcass characteristics, pork color

Introduction

Astaxanthin is a carotenoid that exists naturally in various plants, algae, and seafood. Its unique molecular structure may impart a potent antioxidant capacity. Astaxanthin is used extensively in the aquaculture feed industry for its pigmentation characteristics, but it is not currently approved for use in other food animals in the United States.

[1] Appreciation is expressed to IGENE Biotechnology, Columbia, MD, for providing the Aquasta® astaxanthin and partial funding of the trial.

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Although it is used primarily for pigmentation of farmed salmonids, astaxanthin may also be essential for their improved growth and survival.

The inclusion of astaxanthin in poultry diets has been reported to improve egg production and the general health of laying hens. In addition, improvements in chick growth and feed utilization during the first 3 wk of life, as well as resistance to Salmonella infection, have also been observed with astaxanthin supplementation (AstaReal, 2006[3]). Astaxanthin also has been found to improve the color shelf-life of poultry products, with studies reporting changes in egg yolk color and poultry muscle color that could improve consumer acceptance (Akiba et al., 2000[4]; 2001[5]; and Yang et al., 2006[6]).

In a study performed in Korea by Yang et al., (2006[6]), feeding 1.5 and 3 ppm astaxanthin to finishing pigs for 14 d before slaughter linearly improved dressing percentage and loin muscle area and decreased backfat thickness. There were no differences in meat color score. More recently, we (Bergstrom et al., 2009[7]) also observed tendencies for reduced backfat thickness and improved carcass leanness when feeding 5, 10, and 20 ppm astaxanthin. We did not observe differences in dressing percentage; however, there were trends for improvements in the instrumental color measurement of the loin muscle surface after 30 m of bloom time at 24 h postharvest. Relatively few animals were used in either of these studies, and the potential effects of astaxanthin on pork color shelf-life have only recently been reported (Carr et al., 2010[8]).

The effects of ractopamine HCl on the growth and carcass characteristics of pigs is well established, but its effects on pork quality are not as well understood. Some research indicates that pigs fed ractopamine HCl may be more prone to stress during preharvest handling, which may have implications for reduced pork quality. Further research is needed to understand those effects.

Therefore, our objective was to evaluate the effects of feeding various levels of astaxanthin, ractopamine HCl, and their combination for approximately 26 d before slaughter on finishing-pig growth performance, carcass characteristics, and pork color shelf-life.

Procedures

The Kansas State University (K-State) Institutional Animal Care and Use Committee approved the protocol used in this experiment. The project was conducted at the

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K-State Swine Teaching and Research Farm. Pigs were housed in an environmentally controlled finishing building with pens over a totally slatted floor that provided approximately 10 ft^2/ pig. Each pen was equipped with a dry self-feeder and a nipple waterer to provide *ad libitum* access to feed and water. The facility was a mechanically ventilated room with a pull-plug manure storage pit.

A total of 72 barrows and 72 gilts (PIC TR4 × C22, initially 226 lb) were used in this study. Pigs were blocked by gender and weight, and randomly allotted to 1 of 9 dietary treatments. There were 2 pigs per pen and 4 pens per treatment × gender combination (8 replications of each dietary treatment). Dietary treatments consisted of a corn-soybean meal-based control, the control with 5, 7.5, and 10 ppm astaxanthin (AX) from *Phaffia rhodozyma* yeast (Aquasta, IGENE Biotechnology, Columbia, MD), the control with 5 ppm pure synthetic AX (Carophyll Pink, F. Hoffman La Roche Ltd., Basel, Switzerland), and the control with 10 ppm ractopamine HCl (Paylean, Elanco, Greenfield, IN) and 0, 2.5, 5, and 7.5 ppm AX from *Phaffia rhodozyma* yeast. Experimental diets were fed in meal form, and AX and/or Paylean were added to the control diet at the expense of cornstarch to achieve the dietary treatments (Table 1). Pigs and feeders were weighed weekly and approximately 18 h before harvest to determine ADG, ADFI, F/G, and final BW.

To ensure that the harvest procedures would occur in accordance with Institutional Animal Care and Use Committee standards and the capabilities of the K-State Meats Lab, the barrow feeding period ended on d 22 when they were transported to the abattoir for humane slaughter. The gilt feeding period ended one week later on d 29, when they were also transported for humane slaughter. This resulted in a similar final BW for barrows and gilts.

Immediately after evisceration, HCW was measured and recorded. First-rib, 10th rib, last-rib, and last-lumbar backfat depth, as well as longissimus muscle area at the 10^{th} and 11^{th} rib interface, were collected from the right half of each carcass 24 h postmortem. After obtaining carcass measurements, an 8-in.-section of the loin, caudal to the 10^{th} and 11^{th} rib interface, was removed from the carcass of 1 randomly selected pig per pen, vacuum-packaged, and frozen at 20°C.

After 7 or 14 d of frozen storage, the loin sections were thawed for 24 h at 4°C and a 1-in.-thick boneless chop was fabricated from the center of each 8-in. loin section. Each longissimus chop was placed on a 1 S polystyrene tray (Dyne-A-Pak Inc., LAVAL, QC, Canada) with an absorbent pad and overwrapped with a polyvinylchloride film (23,250 mL of O_2/m^2/24 h oxygen permeability/flow rate). The packages were placed in an open-top retail display case (unit model DMF8, Tyler Refrigeration Corp., Niles, MI) at 2 ± 1.5°C for 7 d. The display case was illuminated with continuous fluorescent lighting (3,000 K, bulb model F32T8/ADV830/Alto, Philips, Bloomfield, NJ) that emitted an average of 2,249 lx. Packages were rotated daily to compensate for any variation in temperature and lighting within the case.

On d 0, 1, 2, and 3 of retail display, objective measures of lean color were determined for all packages using a HunterLab Miniscan™ XE Plus spectrophotometer (Model 45/0 LAV, 2.54-cm-diameter aperture, 10° standard observer, Illuminant D65, Hunter Associates Laboratory, Inc., Reston, VA) to measure CIE L* (lightness), a* (redness), and b*

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(yellowness). The spectrophotometer was calibrated daily against a standard white tile (Hunter Associates Laboratory) and 3 locations of the lean surface of each sample package were measured and averaged to determine the CIE L*, a*, and b* values. The change in total color (ΔE) from d 0 to 3 was calculated as: $\sqrt{((\Delta L^*)^2+(\Delta a^*)^2+(\Delta b^*)^2)}$ (Minolta, 1998[9]).

Additionally, subjective lean color scores (1 = white to pale pinkish gray to 6 = dark purplish red, National Pork Producers Council, 2000[10]) were determined on d 0 of retail display from the average of scores provided by 11 trained panelists. The same panelists provided scores for lean surface discoloration (1 = no discoloration, very bright pinkish red to 7 = total discoloration, extremely dark pinkish gray/tan; Hunt et al., 1991[11]) on d 0 to 7 of retail display. When an individual package received a mean discoloration score > 4 it was classified as having an unacceptable appearance and removed from display. Also, the number of days that each package maintained an acceptable appearance (≤ 4) was used to determine the color shelf-life. Packages that were removed for an unacceptable appearance were assigned a discoloration score of 5 for the remaining days of retail display.

Data were analyzed as a randomized complete block design using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) to evaluate the effects of dietary treatment, gender, and their interactions. Pen was the experimental unit. Pork quality data collected during retail display were analyzed as repeated measures, with d as the repeated variable and loin chop as the subject. Preplanned orthogonal contrasts were used to evaluate the effects of gender, AX, AX from *Phaffia rhodozyma* yeast, synthetic AX, and Paylean; and linear and quadratic polynomial contrasts were used to determine the effects of increasing AX from *Phaffia rhodozyma* yeast within the non-Paylean and Paylean treatments.

Results

The analyzed levels of AX for the experimental diets were 0.05, 4.80, 6.85, and 7.43 ppm for the non-Paylean control diet and 5, 7.5, and 10 ppm AX from *Phaffia rhodozyma* yeast treatments, respectively; 7.48 ppm for the 5 ppm synthetic AX treatment; and 0.47, 2.39, 5.64, and 7.91 ppm for the Paylean treatments with targeted levels of 0, 2.5, 5, and 7.5 ppm AX from *Phaffia rhodozyma* yeast, respectively.

No treatment × gender interactions were observed for growth and carcass characteristics during the study. Overall, barrows had greater ($P < 0.01$) ADG and ADFI than gilts (Table 2). However, the gilts achieved a similar final BW at harvest due to being fed 1 wk longer before harvesting. Pigs fed Paylean had greater ($P < 0.01$) ADG and final BW, and improved F/G ($P < 0.01$) compared with non-Paylean-fed pigs (Table 3). There were no differences in growth for pigs supplemented with AX.

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Barrows had greater ($P < 0.01$) backfat depth and reduced ($P < 0.01$) 10th-rib loin area and percentage fat-free lean compared to gilts. Pigs fed Paylean had greater ($P < 0.03$) HCW, yield, 10th-rib loin area, and fat-free lean than non-Paylean-fed pigs.

The initial subjective color scores of longissimus chops placed on retail display were not different (Table 4). However, the discoloration scores of the chops increased (linear, $P < 0.001$; quadratic, $P < 0.001$) from d 0 to 7 of retail display. Although the discoloration scores were not different among the dietary treatments or gender on d 0, the discoloration scores of chops from gilts were lower (day × gender, $P < 0.001$; barrow vs. gilt, $P < 0.001$) than those of barrows on d 3 to 7 of retail display and overall. The discoloration scores of chops from pigs fed Paylean were lower ($P < 0.001$) than those of pigs not fed Paylean on d 3 to 7 and overall, but the gender differences in discoloration score were less among the chops that originated from pigs fed Paylean (dietary treatment × gender, $P < 0.001$). Among the chops from pigs fed Paylean, the discoloration score was lowest (quadratic, $P < 0.001$) from d 3 to 7 and overall for pigs fed the highest level of 7.5 ppm AX from *Phaffia rhodozyma* yeast.

The repeated, subjective evaluations for discoloration were also utilized to determine the average color shelf-life (Figure 1). Chops from gilts had a greater ($P < 0.0001$) color shelf-life than those from barrows, and chops from pigs fed Paylean had a greater ($P < 0.001$) color shelf-life than those from non-Paylean-fed pigs.

When comparing the objective measurements of the lean color of longissimus chops, there were no differences observed in the CIE L* (measure of lightness/darkness, white = 100 and black = 0) measured over 7 d (Table 5). However, there was a dietary treatment × gender interaction ($P < 0.001$) observed for the CIE a* (measure of redness, larger value = more red). This occurred because, among the chops from pigs fed the non-Paylean diets, the decrease (linear, $P < 0.01$) in the CIE a* with increasing concentration of AX from *Phaffia rhodozyma* was more evident among barrows. A day × gender interaction ($P < 0.001$) was also observed for the CIE a* because the decrease (linear, $P < 0.001$) in CIE a* values during the 7 d of retail display was greater for barrows when compared to those of gilts. Nevertheless, the CIE a* of longissimus chops from Paylean-fed pigs was reduced ($P < 0.001$) compared to those from non-Paylean-fed pigs. Among the chops from pigs fed Paylean, the CIE a* was reduced (quadratic, $P < 0.001$) as the concentration of AX from *Phaffia rhodozyma* rose to 5 ppm before it increased at 7.5 ppm AX. The CIE b* (measure of yellowness, larger value = more yellow) of the longissimus chops decreased (linear, $P < 0.001$) during the 7 d of retail display, and was lower ($P < 0.001$) for chops from pigs fed Paylean. Among the chops from pigs fed the non-Paylean diets, the CIE b* decreased (linear, $P < 0.001$) with increasing concentration of AX from *Phaffia rhodozyma*.

Collectively, the changes in the CIE L*, a*, and b* of chops from d 0 to 3 resulted in differences in the change in total color (ΔE) from d 0 to 3 (Figure 2). Chops from pigs fed Paylean and gilts had less ($P < 0.001$) change in total color than pigs fed non-Paylean diets and barrows.

Discussion

These results agree with previous research reporting differences in growth performance and carcass characteristics between barrows and gilts, and the improvements associ-

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ated with feeding Paylean. However, unlike our previous experiment (Bergstrom et al., 2009[12]), we did not observe improvements in carcass characteristics from feeding AX. Although lower levels of AX were included in the present experiment, Yang et al. (2006[13]) reported improvements in carcass characteristics with feeding 1.5 and 3 ppm AX for 14 d. In the present experiment, it is interesting that the measures of carcass leanness were numerically improved among the pigs fed the non-Paylean diets when they received the highest level of AX from *Phaffia rhodozyma* (10 ppm) and 5 ppm synthetic AX. Likewise, measures of carcass leanness were numerically improved with feeding 7.5 ppm AX from *Phaffia rhodozyma* when the diets contained Paylean. Carr et al. (2010[14]) reported a reduction in backfat depth with feeding 66.7 ppm AX, but the AX carcasses also had a numerically lighter weight than that of the controls in that study.

Pork producers, processors, and food companies are interested in technologies that will improve consumer acceptance of pork products. The product appearance and color shelf-life are important criteria affecting both consumer and retailer preferences. Pork shelf-life is most limited by the development of brown or gray discoloration during retail display, which generally occurs long before it has spoiled. A growing number of consumers are also interested in minimally processed products that are enhanced "naturally." Astaxanthin from *Phaffia rhodozyma* yeast may qualify as a "natural" feed ingredient, and is currently used in diets for other food-animals in other parts of the world.

As expected, the day of retail display affected subjective and objective measures of the lean color of longissimus chops. The subjective discoloration scores provided by the trained panel increased during 7 d of retail display. Although there were no differences in the initial subjective color scores, the lean color of chops from gilts and pigs fed Paylean became discolored more slowly. This agreed with the reduction in the objective measure of total color change from d 0 to 3 for chops from gilts and pigs fed Paylean. Changes in the objective measure of lean color during the first 3 d of display involved reductions in the CIE a* and CIE b* measurements. The CIE a* and CIE b* measurements were also initially lower for chops from pigs fed Paylean. Collectively, the reduced discoloration and change in total color observed for chops from gilts and pigs fed Paylean were associated with a longer color shelf-life.

Although increasing concentrations of AX were associated with differences in lean color during retail display, there were no significant effects of AX on the overall color shelf-life or total color change from d 0 to 3. However, chops from pigs fed 7.5 ppm AX from *Phaffia rhodozyma* in the diets containing Paylean had the lowest discoloration scores, high CIE a* values on d 3, numerically lowest total color change from d 0 to 3, and numerically longest color shelf-life. Carr et al. (2010) have also reported that AX may improve color characteristics of pork during retail display.

In conclusion, although there were no differences in the color of fresh longissimus chops to indicate any consumer preferences initially, the color shelf-life was increased during retail display for chops from pigs fed Paylean approximately 26 d pre-harvest. Also, longissimus chops from gilts had a greater color shelf-life than chops from barrows. Although modest differences in the color of chops from pigs fed AX were observed, color shelf-life was not significantly influenced by the levels of dietary AX used in this study.

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Table 1. Composition of the experimental control diet[1]

Item	Percent
Ingredient	
Corn	72.85
Soybean meal (46.5% CP)	25.14
Monocalcium P (21% P)	0.35
Limestone	0.85
Salt	0.35
L-lysine HCl	0.15
Vitamin premix	0.08
Trace mineral premix	0.08
Cornstarch[2]	0.15
Total	100.00
Calculated analysis	
Standardized ileal digestible (SID) amino acids, %	
Lysine	0.95
Isoleucine:lysine ratio	70
Leucine:lysine ratio	156
Methionine:lysine ratio	28
Met & Cys:lysine ratio	58
Threonine:lysine ratio	61
Tryptophan:lysine ratio	19
Valine:lysine ratio	79
Total lysine, %	1.07
Protein, %	18.1
ME, kcal/lb	1,521
SID lysine:ME ratio, g/Mcal	2.83
Ca, %	0.50
P, %	0.45
Available P, %	0.20

[1] Experimental diets were fed for approximately 26 d before slaughter.
[2] Astaxanthin (10,000 ppm from *Phaffia rhodozyma*, Aquasta, IGENE Biotechnology, Columbia, MD; or pure synthetic, Carophyll Pink, F. Hoffman La Roche Ltd., Basel, Switzerland) and/or ractopamine HCl (Paylean, Elanco, Greenfield, IN) replaced cornstarch in the control diet to achieve dietary treatments with 2.5, 5, 7.5, and 10 ppm AX and/or 10 ppm ractopamine HCl.

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Table 2. Growth performance and carcass characteristics of barrows and gilts[1]

	Barrows	Gilts	SEM	*P* <
Growth performance				
Feeding period, d	22	29		
Initial BW, lb	229.1	222.0	6.92	---[2]
ADG, lb	2.69	2.51	0.034	0.001
ADFI, lb	8.42	7.65	0.142	0.001
F/G	3.15	3.08	0.043	---
Final BW, lb	289.2	294.8	5.84	---
Carcass characteristics				
HCW, lb	206.5	210.7	4.46	---
Yield, %	71.4	71.6	0.21	---
10th-rib				
backfat, in.	0.90	0.67	0.023	0.001
loin area, sq. in.	7.54	8.27	0.172	0.01
FFLI[3]	52.0	55.4	0.35	0.001

[1] A total of 144 barrows (72) and gilts (72) were blocked by gender and weight, with 2 pigs per pen and 36 pens per gender.
[2] Not significant ($P > 0.05$).
[3] FFLI = fat-free lean index

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Table 3. Growth performance and carcass characteristics of finishing pigs fed various levels of astaxanthin with or without ractopamine HCl[1]

Ractopamine HCl[2], ppm:	None					10					
Astaxanthin source:	*Phaffia rhodozyma*[3]				Synthetic[4]	*Phaffia rhodozyma*					*P* <
Astaxanthin level, ppm:	0	5	7.5	10	5	0	2.5	5	7.5	SEM	Ractopamine HCl[5]
Growth performance											
ADG, lb	2.49	2.34	2.45	2.41	2.31	2.83	2.88	2.88	2.83	0.077	0.001
ADFI, lb	8.06	8.06	8.03	8.01	7.84	8.05	8.19	8.27	7.79	0.226	---
F/G	3.24	3.44	3.28	3.35	3.40	2.86	2.85	2.88	2.76	0.075	0.001
Final BW, lb	288.9	287.6	287.4	286.2	284.2	297.1	298.6	298.8	299.1	4.55	0.001
Carcass characteristics											
HCW, lb	204.4	202.6	203.4	202.5	201.5	213.9	216.1	215.3	218.0	3.53	0.001
Yield, %	70.7	70.4	71.5	70.8	70.9	72.0	72.4	72.1	72.9	0.36	0.001
10th-rib											
-backfat, in.	0.78	0.84	0.81	0.77	0.78	0.81	0.78	0.82	0.70	0.049	---
-loin area, sq. in.	7.26	7.55	7.36	7.53	7.78	8.29	8.25	8.19	8.92	0.255	0.001
FFLI[6]	53.0	52.8	52.9	53.7	54.0	53.8	54.1	53.6	55.7	0.75	0.03

[1] A total of 144 barrows and gilts (initially 226 lb) were blocked by weight and gender to evaluate the effects of various levels of astaxanthin with or without 10 ppm ractopamine HCl.
[2] Ractopamine HCl from Paylean, Elanco, Greenfield, IN.
[3] Aquasta, IGENE Biotechnology, Columbia, MD.
[4] Carophyll Pink, F. Hoffman La Roche Ltd., Basel, Switzerland.
[5] No ractopamine HCl × astaxanthin interactions or astaxanthin effects (linear or quadratic) were observed for any of these criteria.
[6] FFLI = fat-free lean index.

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Table 4. Subjective lean color and color shelf-life evaluation of pork longissimus chops from barrows and gilts fed various levels of astaxanthin with or without ractopamine HCl[1]

Ractopamine HCl[2], ppm:	None										10								
Astaxanthin source:	*Phaffia rhodozyma*[3]								Synthetic[4]		*Phaffia rhodozyma*								
Astaxanthin level, ppm:	0		5		7.5		10		5		0		2.5		5		7.5		
Gender[5]:	B	G	B	G	B	G	B	G	B	G	B	G	B	G	B	G	B	G	SEM
Initial color[6], d 0	3.3	3.2	3.6	3.5	3.3	3.6	3.2	3.4	3.3	3.6	3.3	3.3	3.4	3.4	3.4	3.3	3.5	3.6	0.22
Discoloration[7, 8]																			
d 0	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.1	1.2	1.1	1.1	1.1	1.1	1.1	1.2	1.1	1.2	1.1	0.22
d 1	1.4	1.6	1.4	1.3	1.4	1.5	1.6	1.4	1.4	1.3	1.4	1.4	1.2	1.4	1.5	1.4	1.3	1.4	0.22
d 2	2.5	2.5	2.4	2.4	2.7	2.4	2.8	2.1	3.2	2.3	2.6	2.1	2.3	2.3	3.4	2.3	2.0	2.1	0.22
d 3	3.5	3.3	3.6	3.2	3.6	3.2	3.5	2.8	3.3	3.0	3.5	2.8	2.8	3.0	3.3	2.9	2.7	2.7	0.22
d 4	4.2	3.8	4.3	3.7	4.3	3.7	4.3	3.5	3.9	3.6	4.0	3.2	3.3	3.5	3.9	3.5	3.0	3.0	0.22
d 5	4.8	4.2	4.8	3.9	4.9	3.8	4.9	4.0	4.5	4.0	4.4	3.6	3.8	3.9	4.5	3.8	3.5	3.4	0.22
d 6	5.0	4.4	5.0	4.5	5.0	4.5	5.0	4.4	5.0	4.3	5.0	4.0	4.1	4.6	5.0	4.4	4.4	4.0	0.22
d 7	5.0	4.7	5.0	4.9	5.0	4.9	5.0	4.8	5.0	4.9	5.0	4.9	4.7	4.9	5.0	4.9	5.0	4.5	0.22
Overall	3.4	3.2	3.5	3.1	3.5	3.1	3.5	3.0	3.4	3.1	3.4	2.9	2.9	3.1	3.5	3.0	2.9	2.8	0.08
Color shelf-life, d[9]	3.3	4.5	3.0	5.0	3.0	4.3	3.0	4.8	3.8	4.8	3.5	5.5	5.3	4.5	3.8	5.3	5.3	5.5	0.54

[1] Longissimus chops from barrows (36) and gilts (36) were visually evaluated daily by a trained panel during 7 d of retail display.
[2] Ractopamine HCl from Paylean, Elanco, Greenfield, IN.
[3] Aquasta, IGENE Biotechnology, Columbia, MD.
[4] Carophyll Pink, F. Hoffman La Roche Ltd., Basel, Switzerland.
[5] B = barrow and G = gilt.
[6] Color score: 1 = white to pale pinkish gray to 6 = dark purplish red (National Pork Producers Council, 2000).
[7] Discoloration score: 1 = no discoloration, very bright pinkish red to 7 = total discoloration, extremely dark pinkish gray/tan (Hunt et al., 1991). Individual sample packages that received a mean discoloration score ≥ 4 were deemed to have an unacceptable appearance and removed from display. Sample packages removed for an unacceptable appearance were given a discoloration score of 5 for the remaining days of retail display.
[8] Discoloration statistics: dietary treatment × gender ($P < 0.001$), day × gender ($P < 0.001$), day (linear, $P < 0.001$; quadratic, $P < 0.001$), barrow vs. gilt ($P < 0.001$), ractopamine HCl vs. non-ractopamine HCl ($P < 0.001$), astaxanthin from *Phaffia rhodozyma* within ractopamine HCl (linear, $P < 0.03$; quadratic, $P < 0.01$).
[9] Color shelf-life statistics: barrow vs gilt ($P < 0.0001$), ractopamine HCl vs non-ractopamine HCl ($P < 0.001$).

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Table 5. Objective lean color measurements of pork longissimus chops from barrows and gilts fed various levels of astaxanthin with or without ractopamine HCl[1]

Ractopamine HCl[2], ppm:	None										10								
Astaxanthin source:	*Phaffia rhodozyma*[3]								Synthetic[4]		*Phaffia rhodozyma*								
Astaxanthin level, ppm:	0		5		7.5		10		5		0		2.5		5		7.5		
Gender[5]:	B	G	B	G	B	G	B	G	B	G	B	G	B	G	B	G	B	G	SEM
CIE L^* (lightness)[6]																			
d 0	54.5	57.2	57.3	54.3	55.5	54.7	57.3	55.8	56.1	54.0	55.2	54.3	55.5	55.0	55.2	55.0	54.3	54.2	1.33
d 1	54.5	55.8	55.8	53.8	55.0	53.5	55.0	54.6	55.9	53.5	54.3	54.6	54.8	53.7	54.5	54.8	52.9	53.6	1.33
d 2	54.9	56.3	56.2	54.1	55.4	53.7	55.4	54.3	55.5	53.1	54.1	53.9	54.3	53.9	54.8	53.8	52.9	53.6	1.33
d 3	54.0	56.0	55.7	54.0	55.3	53.3	55.2	53.6	55.4	53.2	53.8	54.0	53.6	54.0	54.2	54.4	53.0	54.1	1.33
Overall	54.5	56.3	56.2	54.0	55.3	53.8	55.7	54.6	55.7	53.4	54.4	54.2	54.5	54.1	54.7	54.5	53.3	53.9	0.67
CIE a^* (redness)[7,8]																			
d 0	11.5	10.0	10.4	10.2	10.7	9.1	8.9	10.4	10.2	10.0	9.9	9.2	9.7	8.8	9.1	8.4	9.9	9.1	0.44
d 1	10.6	10.2	10.0	10.1	9.9	9.1	9.0	10.4	9.8	10.0	9.5	9.1	9.6	9.0	8.7	8.4	10.0	9.4	0.44
d 2	8.6	8.9	8.4	9.0	8.3	8.4	7.6	9.5	8.6	9.3	8.4	8.7	8.9	8.4	7.8	8.0	9.2	9.1	0.44
d 3	8.4	8.5	8.1	8.7	7.6	8.2	7.3	9.4	8.2	9.0	8.1	8.7	8.7	8.3	7.5	7.8	9.4	9.0	0.44
Overall	9.8	9.4	9.2	9.5	9.1	8.7	8.2	9.9	9.2	9.6	9.0	8.9	9.2	8.6	8.3	8.1	9.6	9.1	0.22
CIE b^* (yellowness)[9,10]																			
d 0	17.5	16.9	16.3	16.5	17.3	15.7	15.9	15.9	17.1	16.4	16.1	16.0	16.5	15.4	15.7	15.5	16.3	15.6	0.42
d 1	17.0	17.1	16.6	16.6	16.4	16.0	16.4	16.3	16.5	16.3	16.1	15.8	16.3	15.7	15.6	15.5	15.9	15.7	0.42
d 2	15.8	16.5	15.7	15.8	15.4	15.2	15.7	15.9	16.1	15.8	15.5	15.7	15.6	15.3	14.9	15.3	15.2	15.5	0.42
d 3	16.0	15.9	15.6	15.2	14.9	15.2	15.0	15.8	16.0	15.7	15.4	15.6	15.7	15.2	14.6	14.9	15.1	15.3	0.42
Overall	16.6	16.6	16.1	16.0	16.0	15.5	15.8	15.9	16.4	16.0	15.8	15.8	16.0	15.4	15.2	15.3	15.6	15.5	0.21
ΔE (d 0 to 3)[11,12]	3.6	2.4	3.1	2.3	4.2	2.6	3.7	2.7	2.6	1.7	2.6	1.2	2.4	2.5	2.5	1.5	2.1	1.7	0.40

[1] Longissimus chops from barrows (36) and gilts (36) were measured daily for objective lean color analysis (CIE L*, a*, and b*) during 7 d of retail display using a HunterLab Miniscan™ XE Plus spectrophotometer (Model 45/0 LAV, 2.54-cm-diameter aperture, 10° standard observer, Illuminant D65, Hunter Associates Laboratory, Inc., Reston, VA).

[2] Ractopamine HCl from Paylean, Elanco, Greenfield, IN.

[3] Aquasta, IGENE Biotechnology, Columbia, MD.

[4] Carophyll Pink, F. Hoffman La Roche Ltd., Basel, Switzerland.

[5] B = barrow and G = gilt.

[6] CIE L^* = measure of darkness to lightness (black = 0 to white = 100).

[7] CIE a^* = measure of redness (a larger value indicates a more red color).

[8] CIE a^* statistics: dietary treatment × gender ($P < 0.001$), day × gender ($P < 0.001$), day (linear, $P < 0.001$), ractopamine HCl vs. non-ractopamine HCl ($P < 0.001$), controls vs. astaxanthin from *Phaffia rhodozyma* ($P < 0.03$), astaxanthin from *Phaffia rhodozyma* within non-ractopamine HCl (linear, $P < 0.01$), astaxanthin from *Phaffia rhodozyma* within ractopamine HCl (quadratic, $P < 0.001$).

[9] CIE b^* = measure of yellowness (a larger value indicates a more yellow color).

[10] CIE b^* statistics: day (linear, $P < 0.001$), ractopamine HCl vs. non-ractopamine HCl ($P < 0.001$), controls vs. all astaxanthin ($P < 0.001$), controls vs. astaxanthin from *Phaffia rhodozyma* ($P < 0.001$), astaxanthin from *Phaffia rhodozyma* within non-ractopamine HCl (linear, $P < 0.001$).

[11] ΔE = total color change, calculated as $\sqrt{((\text{d } 0\ L^* - \text{d } 3\ L^*)^2 + (\text{d } 0\ a^* - \text{d } 3\ a^*)^2 + (\text{d } 0\ b^* - \text{d } 3\ b^*)^2)}$.

[12] ΔE statistics: ractopamine HCl vs. non-ractopamine HCl ($P < 0.001$), barrow vs. gilt ($P < 0.001$).

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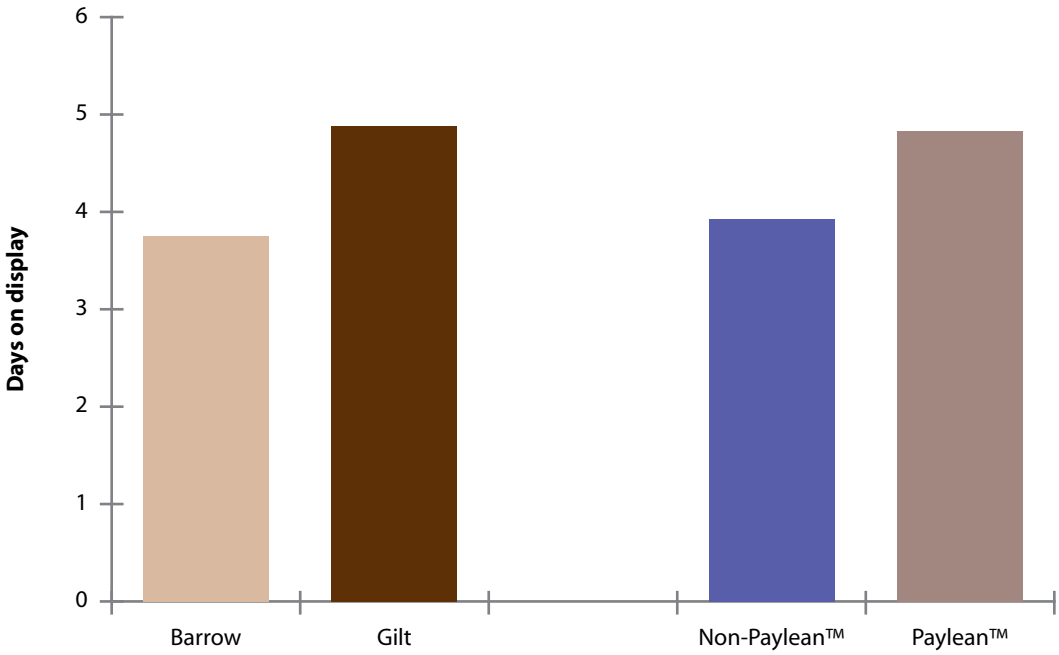

Figure 1. The effects of gender and dietary ractopamine HCl (Paylean, 9g/ton) on the color shelf-life of longissimus chops during retail display.

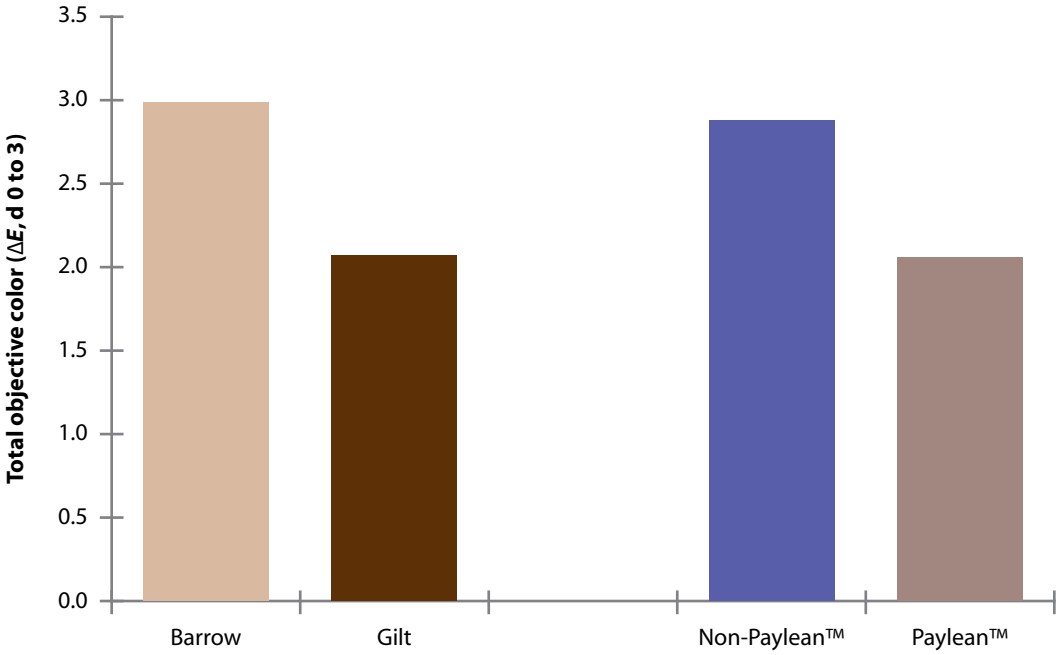

Figure 2. The effects of gender and dietary ractopamine HCl (Paylean, 9g/ton) on the change in total objective color (Δ*E*) of longissimus chops from d 0 to 3 of retail display.

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Effects of Standardized Ileal Digestible Tryptophan:Lysine Ratio in Diets Containing 30% Dried Distiller Grains with Solubles on the Growth Performance and Carcass Characteristics of Finishing Pigs in a Commercial Environment[1]

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Summary

Two experiments were performed to determine the effects of increasing standardized ileal digestible (SID) tryptophan to lysine (trp:lys) ratio in growing-finishing pig diets containing 30% dried distillers grains with solubles (DDGS). In both experiments, soybean meal replaced crystalline lysine and threonine to alter the dietary SID trp:lys concentrations while maintaining minimum ratios of other amino acids. In Exp. 1, a total of 638 pigs (PIC 1050 × 337, initially 80.0 lb) were used in a 105-d trial with 26 to 27 pigs per pen and 6 pens per treatment. Pens of pigs were randomly allotted to 1 of 4 dietary treatments with standardized ileal digestible trp:lys ratios of 14.0, 15.0, 16.5, and 18.0%. All diets were fed in meal form and treatments were fed in 4 phases. For the overall trial, ADG and ADFI increased (linear; $P < 0.001$) as trp:lys increased through 18%; however, the response tended to be quadratic from d 0 to 42, with optimal ADG and ADFI at 16.5% SID trp:lys. Feed efficiency was not influenced by SID trp:lys ratio. Although feed cost per pig increased (linear; $P < 0.001$) as SID trp:lys ratio increased, so did (linear; $P < 0.04$) final live weight, HCW, income per pig, and income over feed cost (IOFC). The results of this experiment indicated the optimal SID trp:lys ratio was 16.5% from 80 to 160 lb, but at least 18% from 160 to 265 lb.

In Exp. 2, a total of 1,214 pigs (PIC 1050 × 337, initially 146.2 lb) were used in a 73-d finishing trial with 25 to 28 pigs per pen and 9 pens per treatment. Pens of pigs were randomly allotted to 1 of 5 treatment groups. Pigs were fed common diets before the start of the experiment. Dietary treatments included corn-soybean meal-based diets with SID trp:lys ratios of 15.0, 16.5, 18.0, and 19.5, and the 15.0% diet with L-tryptophan added to achieve 18.0% SID trp:lys ratio. Overall (d 0 to 73), ADG, ADFI, F/G, final weight, and HCW improved (linear; $P < 0.03$) as dietary SID trp:lys increased through 19.5%. Increasing SID trp:lys increased (linear; $P < 0.001$) feed cost per pig, but also increased ($P < 0.01$) total income per pig. While there were no differences on an IOFC basis, pigs fed the highest level of SID trp:lys had numerically the greatest IOFC. Overall, there were no significant differences between the diet with 18.0% SID trp:lys and the diet with 15.0% SID trp:lys with added L-tryptophan to 18.0%.

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

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

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These experiments demonstrate there is opportunity to improve growth performance in late-finishing pigs with increased SID trp:lys ratios in diets containing high amounts of DDGS.

Key words: amino acid ratio, dried distillers grains with solubles, lysine, tryptophan,

Introduction

Tryptophan is one of 10 essential amino acids that is not synthesized by swine and must be supplied through diet. Today, feed alternatives to corn and soybean meal are often used by the swine industry. Determining the proper nutritional value and optimum utilization of these alternative feedstuffs, such as dried distillers grains with solubles (DDGS), is critical to reduce diet costs.

Dried distillers grains with solubles, a corn by-product from ethanol production, has approximately 3 times the crude fat, protein, and fiber as corn, with a similar energy value. Also, DDGS are known to have higher bioavailability of phosphorus than corn. Because DDGS is high in methionine and threonine, greater concentrations of crystalline lysine can be used in diets containing DDGS before other amino acids become limiting. Tryptophan is often the second limiting amino acid in diets containing high levels of DDGS.

Limited data are available on the effects of SID tryptophan level in growing-finishing pig diets containing DDGS. Also, due to the availability of synthetic tryptophan, its effects on performance also need further investigation. Therefore, the objectives of these experiments were to evaluate the SID trp:lys ratio to accurately and economically formulate growing-finishing pig diets with DDGS and crystalline amino acids.

Procedures

The Kansas State University (K-State) Institutional Animal Care and Use Committee approved the protocol used in this experiment. The experiment was conducted in a commercial research-finishing barn in southwestern Minnesota. The barns were naturally ventilated and double-curtain sided. Pens had completely slatted flooring and deep pits for manure storage. Each pen was equipped with a 5-hole stainless steel dry self-feeder and a cup waterer for ad libitum access to feed and water. Daily feed additions to each pen were accomplished through a robotic feeding system (FeedPro; Feedlogic Corp., Willmar, MN) capable of providing and measuring feed amounts for individual pens. Pigs were fed a common corn-soybean meal-based grower diet before the start of the trial that contained DDGS.

In Exp. 1, a total of 638 pigs (PIC 1050 × 337, initially 80.0 lb) were used in a 105-d growing-finishing trial. At placement, pigs were sorted by gender (barrow or gilt) and placed in pens with 26 to 27 pigs per pen. Pens of pigs were randomly allotted to 1 of 4 treatment groups with average pig weight balanced across treatments and 6 pens per treatment (3 pens of gilts and 3 pens of barrows per treatment). Dietary treatments included corn-soybean meal-based diets containing 30% DDGS, with soybean meal replacing crystalline lysine and threonine to make SID trp:lys ratios of 14.0, 15.0, 16.5, and 18.0% (Tables 1 and 2). All diets were fed in meal form and treatments were fed in all 4 phases.

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Pens of pigs were weighed and feed intake was recorded on d 0, 21, 42, 63, 76, 95, and 105. From these data, ADG, ADFI, and F/G were calculated. On d 76 of the experiment, the 3 heaviest pigs from each pen (determined visually) were weighed and sold in accordance with the farm's normal marketing procedure. At the end of the experiment, pigs were individually tattooed according to gender and pen number to allow for carcass data collection and data retrieval by pen. Pigs were transported to JBS Swift and Company (Worthington, MN) for processing and data collection. Hot carcass weights were measured immediately after evisceration, and standard carcass criteria of percent yield, HCW, percentage lean, backfat depth, loin depth, and fat-free lean index were collected.

In Exp. 2, a total of 1,214 pigs (PIC 1050 × 337, initially 146.2 lb) were used in a 73-d finishing trial. Pens were mixed gender with 25 to 28 pigs per pen, with barrows and gilts approximately equal in number within pens. Pens of pigs were randomly allotted to 1 of 5 treatment groups with average pig weight balanced across treatments, 9 pens per treatment. Pigs were fed common diets during the first two phases from approximately 80 to 146 lb. These diets were formulated to contain 18% SID trp:lys (Table 3). Dietary treatments included corn-soybean meal-based diets with SID trp:lys ratios of 15.0, 16.5, 18.0, 19.5% and the 15.0% diet with L-trypotphan added to achieve 18.0% SID trp:lys (Tables 3 and 4).

Pens of pigs were weighed and feed intake was recorded on d 0, 20, 33, 47, 62, and 73. From these data, ADG, ADFI, and F/G were calculated. On d 47 of the experiment, the 3 heaviest pigs from each pen (2 barrows and 1 gilt, determined visually) were weighed and sold in accordance with the farm's normal marketing procedure. At the end of the experiment, pigs were individually tattooed according to pen number to allow for carcass data collection and data retrieval by pen. Pigs were transported to JBS Swift and Company (Worthington, MN) for processing and data collection. Hot carcass weights were measured immediately after evisceration, and standard carcass criteria of percent yield, HCW, percentage lean, backfat depth, loin depth, and fat-free lean index were collected.

Statistical analysis was performed by analysis of variance using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). Data were analyzed as a completely randomized design with pen as the experimental unit. The main effects of the treatment were determined in both experiments. In Exp. 1, the effect of gender and gender by treatment interactions were also tested. Backfat depth, loin depth, percentage lean, and fat-free lean index were adjusted to a common carcass weight. Linear and quadratic contrasts were used to determine the effects of treatments with increasing trp:lys. In Exp.1, contrast coefficients for trp:lys percents (18.0, 16.5, 15.0, 14.0) were determined for unequally spaced treatments by using the IML procedure of SAS. In Exp. 2, contrast coefficients for trp:lys ratios (19.5, 18.0, 16.5, 15.0) and contrasts to compare the 18.0 and 15.0% with L-trp to 18.0% were used.

Results and Discussion

In Exp. 1, gender differences in growth performance were as expected, with barrows having greater ($P < 0.001$) ADG and ADFI than gilts (Table 5). Both barrows and gilts had improved ADG as SID trp:lys increased; however, the magnitude of the response was slightly greater for gilts than barrows (gender × treatment interaction $P < 0.05$).

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Gilt carcasses had lower ($P < 0.001$) backfat depth and greater ($P < 0.001$) percentage lean and fat-free lean index than barrow carcasses. Because of numerically improved F/G and lighter final weight, gilts had lower ($P < 0.001$) feed cost per pig; however, barrows had greater ($P < 0.02$) income per pig due to the heavier final weight, leading to similar income over feed cost.

From d 0 to 42, increasing SID trp:lys ratio increased ADG (linear; $P < 0.001$) and ADFI (linear; $P < 0.003$). These responses also tended to be quadratic ($P < 0.07$), with no improvement in ADG, ADFI, or weight on d 42 above a SID trp:lys ratio of 16.5%.

From d 42 to 105, increasing SID trp:lys ratio increased (linear; $P < 0.001$) ADG and ADFI. Unlike the data from d 0 to 42, the response was clearly linear through the highest SID trp:lys ratio of 18.0%. There was a tendency for a quadratic effect in F/G ($P < 0.08$) of increasing SID trp:lys ratio, with pigs fed 15.0 and 16.5% having numerically worse F/G than pigs fed either 14.0 or 18.0%.

Overall (d 0 to 105), increasing SID trp:lys increased (linear; $P < 0.001$) final BW, ADG, and ADFI. Because of the improvement in ADG, pigs fed increasing SID trp:lys had heavier (linear; $P < 0.002$) HCW.

Because of linear increases in ADFI and diet cost, increasing the SID trp:lys ratio increased (linear; $P < 0.02$) feed cost per pig and feed cost per gain. Because of the ADG response, increasing SID trp:lys ratio increased (linear; $P < 0.04$) income per pig and IOFC.

In Exp. 2, increasing the dietary SID trp:lys ratio increased final BW (linear; $P < 0.02$), overall ADG (linear; $P < 0.001$), and ADFI (linear; $P < 0.03$; Table 6)). Additionally, increasing the dietary SID trp:lys ratio improved (linear; $P < 0.01$) F/G. For carcass traits, increasing SID trp:lys resulted in increased HCW (linear; $P < 0.01$) and a tendency for a quadratic effect ($P < 0.09$) for backfat depth and percentage lean, with pigs fed diets containing 16.5 and 18.0% SID trp:lys having increased percentage lean and lower backfat depth compared to pigs fed 15.0 and 19.5% SID trp:lys. Additionally, there was also a tendency for pigs fed the crystalline tryptophan diet to have increased ($P < 0.09$) backfat depth and decreased FFLI ($P < 0.08$) compared to pigs fed the same SID trp:lys ratio without crystalline tryptophan.

Because of high feed intake, increasing SID trp:lys resulted in increased (linear; $P < 0.001$) feed cost per pig, but did not change feed cost per lb of gain. Increasing SID trp:lys increased ($P < 0.01$) total income per pig. While there were no statistical differences in IOFC, pigs fed the highest level of SID trp:lys had the numerically highest IOFC. Overall, there were no significant differences between pigs fed the diet with 18.0% SID trp:lys and pigs fed the diet with 15.0% SID trp:lys with added L-tryptophan to 18.0%.

In conclusion, these results suggest there is opportunity to improve growth performance in late-finishing pigs with increasing SID try:lys ratio. In both experiments, feeding a high-SID trp:lys ratio resulted in greater final BW, ADG, and ADFI, with a tendency for improved HCW. Finally, feeding L-tryptophan to finishing pigs resulted in similar growth performance to pigs fed a diet formulated to the same SID trp:lys ratio without L-tryptophan.

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

	Phase 1				Phase 2			
	Trp:Lys ratio, %				Trp:Lys ratio, %			
Item	14.0	15.0	16.5	18.0	14.0	15.0	16.5	18.0
Ingredient,%								
Corn	57.34	55.79	53.23	50.79	59.49	57.93	55.72	53.46
Soybean meal, 46.5% CP	10.30	11.96	14.69	17.26	8.19	9.85	12.22	14.60
DDGS[2]	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
Limestone	1.15	1.14	1.12	1.10	1.17	1.16	1.14	1.12
Salt	0.35	0.35	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	0.10	0.10
L-threonine	0.07	0.04	---	---	0.06	0.04	---	---
L-tryptophan	---	---	---	---	---	---	---	---
Liquid lysine	0.68	0.61	0.50	0.39	0.64	0.57	0.47	0.37
Phytase[3]	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis								
Standardized ileal digestible (SID) amino acids, %								
Lysine	0.95	0.95	0.95	0.95	0.87	0.87	0.87	0.87
Isoleucine:lysine	60	63	67	72	61	64	69	73
Leucine:lysine	174	178	185	191	184	189	195	202
Methionine:lysine	30	31	32	34	32	33	34	35
Met & Cys:lysine	61	63	66	68	65	66	69	72
Threonine:lysine	62	62	62	65.62	64.08	64.45	63.68	67.46
Tryptophan:lysine	14.0	15.0	16.5	18.0	14.0	15.0	16.5	18.0
Valine:lysine	0.74	0.77	0.82	0.86	0.77	0.80	0.84	0.89
Total lysine, %	1.10	1.11	1.11	1.12	1.02	1.02	1.03	1.03
ME, kcal/lb	1,525	1,525	1,525	1,525	1,525	1,525	1,525	1,525
SID Lysine:ME ratio, g/Mcal	2.83	2.83	2.83	2.83	2.59	2.59	2.59	2.59
CP, %	17.87	18.49	19.52	20.50	17.07	17.69	18.58	19.49
Ca, %	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
P, %	0.44	0.45	0.46	0.47	0.44	0.44	0.45	0.46
Available P, %	0.32	0.32	0.32	0.32	0.28	0.28	0.28	0.28

[1] Phase 1 diets were fed from approximately 80 to 120 lb; Phase 2 diets were fed from 120 to 160 lb.
[2] Dried distillers grains with solubles from Vera-Sun (Aurora, SD).
[3] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN).

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

	Phase 3				Phase 4			
	Trp:Lys ratio, %				Trp:Lys ratio, %			
Item	14.0	15.0	16.5	18.0	14.0	15.0	16.5	18.0
Ingredient,%								
Corn	61.99	60.64	58.53	56.51	64.43	63.20	61.43	59.51
Soybean meal, 46.5%	5.79	7.22	9.47	11.61	3.41	4.71	6.61	8.63
DDGS[2]	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
Limestone	1.14	1.14	1.12	1.10	1.15	1.14	1.12	1.11
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
L-threonine	0.05	0.03	---	---	0.05	0.03	---	---
L-tryptophan	---	---	---	---	---	---	---	---
Liquid lysine	0.59	0.53	0.43	0.34	0.54	0.48	0.40	0.32
Phytase[3]	0.003	0.003	0.003	0.003	0.002	0.002	0.002	0.002
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis								
Standardized ileal digestible (SID) amino acids, %								
Lysine	0.78	0.78	0.78	0.78	0.69	0.69	0.69	0.69
Isoleucine:lysine	63	66	71	75	65	69	73	78
Methionine:lysine	34	35	36	38	37	38	39	40
Met & cys:lysine	69	71	74	76	75	77	79	82
Threonine:lysine	66	66	66	70	69	69	69	73
Tryptophan:lysine	14.0	15.0	16.5	18.0	14.0	15.0	16.5	18.0
Valine:lysine	80.48	83.54	88	93	85	88	93	98
Total lysine, %	0.92	0.92	0.93	0.94	0.83	0.83	0.83	0.84
ME, kcal/lb	1,526	1,526	1,526	1,526	1,526	1,526	1,526	1,526
SID Lysine:ME ratio, g/Mcal	2.32	2.32	2.32	2.32	2.05	2.05	2.05	2.05
CP, %	16.16	16.69	17.54	18.36	15.25	15.74	16.45	17.23
Ca, %	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48
P, %	0.43	0.43	0.44	0.45	0.42	0.42	0.43	0.44
Available P, %	0.24	0.24	0.24	0.24	0.23	0.23	0.23	0.23

[1] Phase 3 diets were fed from approximately 160 to 200 lb; Phase 4 diets were fed from 200 to 240 lb.
[2] Dried distillers grains with solubles from Vera-Sun (Aurora, SD).
[3] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN).

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

			Phase 3				
	Phase 1	Phase 2	Trp:Lys ratio, %				
Ingredient, %	Common diet		15.0	16.5	18.0	19.5	15.0 to 18.0 and L-trp
Corn	51.50	54.09	60.71	58.66	56.58	54.51	60.68
Soybean meal, 46.5%	16.42	13.84	7.05	9.26	11.46	13.67	7.05
DDGS[2]	30.00	30.00	30.00	30.00	30.00	30.00	30.00
Limestone	1.12	1.14	1.14	1.12	1.10	1.08	1.14
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.10	0.10	0.09	0.09	0.09	0.09	0.09
L-threonine	---	---	0.03	---	---	---	0.03
L-tryptophan	---	---	---	---	---	---	0.02
Biolys[3]	0.50	0.47	0.63	0.52	0.41	0.30	0.63
Phytase[4]	0.01	0.01	0.003	0.003	0.003	0.003	0.003
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Standardized ileal digestible (SID) amino acids, %							
Lysine	0.95	0.87	0.78	0.78	0.78	0.78	0.78
Isoleucine:lysine	71	72	66	71	75	80	66
Methionine:lysine	33	35	35	36	37	39	35
Met & cys:lysine	68	71	71	74	77	79	71
Threonine:lysine	65	66	65	66	70	74	65
Tryptophan:lysine	18	18	15	16	18	19	18
Valine:lysine	85	88	84	88	93	98	84
Total lysine, %	1.12	1.03	0.92	0.93	0.94	0.94	0.92
ME, kcal/lb	1,526	1,526	1,528	1,527	1,527	1,526	1,528
SID Lysine:ME, g/Mcal	2.82	2.59	2.32	2.32	2.32	2.32	2.32
CP, %	20.55	19.55	17.09	17.84	18.61	19.38	17.11
Ca, %	0.51	0.51	0.48	0.48	0.48	0.48	0.48
P, %	0.47	0.46	0.43	0.44	0.45	0.46	0.43
Available P, %	0.33	0.27	0.24	0.24	0.25	0.25	0.24

[1] Phase 1 and 2 common diets were fed from 80 to 150 lb; Phase 3 diets were fed from 150 to 200 lb.
[2] Dried distillers grains with solubles from Vera-Sun (Aurora, SD).
[3] Biolys contains 50.7% L-lys (Evonik Degussa GmbH, Hanau, Germany).
[4] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN).

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

	Phase 4					Phase 5				
	Trp:Lys ratio, %					Trp:Lys ratio, %				
Ingredient, %	15.0	16.5	18.0	19.5	15.0 to 18.0 and L-trp	15.0	16.5	18.0	19.5	15.0 to 18.0 and L-trp
Corn	63.26	61.48	59.59	57.80	63.24	69.33	66.83	64.47	62.13	69.30
Soybean meal, 46.5%	4.58	6.48	8.49	10.39	4.58	13.13	15.79	18.35	20.85	13.14
DDGS	30.00	30.00	30.00	30.00	30.00	15.00	15.00	15.00	15.00	15.00
Limestone	1.13	1.12	1.10	1.08	1.13	1.10	1.12	1.10	1.08	1.10
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
DL-methionine	---	---	---	---	---	0.02	0.01	---	---	0.02
L-threonine	0.02	---	---	---	0.02	0.10	0.07	0.03	---	0.10
L-tryptophan	---	---	---	---	0.02	---	---	---	---	0.03
Biolys[2]	0.58	0.48	0.38	0.29	0.58	0.65	0.52	0.39	0.27	0.65
Optiphos 2000[3]	0.002	0.002	0.002	0.002	0.002	0.01	0.01	0.01	0.01	0.01
Ractopamine HC, 9 g/lb[4]	---	---	---	---	---	0.23	0.23	0.23	0.23	0.23
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Standardized ileal digestible (SID) amino acids, %										
Lysine	0.69	0.69	0.69	0.69	0.69	0.90	0.90	0.90	0.90	0.90
Isoleucine:lysine	68	73	78	83	68	60	65	69	74	60
Methionine:lysine	38	39	40	42	38	30	31	31	32	30
Met & cys:lysine	77	80	83	85	77	60	62	64	66	60
Threonine:lysine	68	69	73	77	68	66	66	65	66	66
Tryptophan:lysine	15	16	18	19	18	15	17	18	20	18
Valine:lysine	89	93	98	103	89	73	77	82	87	73
Total lysine, %	0.83	0.83	0.84	0.84	0.83	1.02	1.03	1.04	1.04	1.02
ME, kcal/lb	1,528	1,528	1,527	1,527	1,528	1,524	1,523	1,522	1,521	1,524
SID Lysine:ME, g/Mcal	2.05	2.05	2.05	2.05	2.05	2.68	2.68	2.68	2.68	2.68
CP, %	16.11	16.76	17.46	18.12	16.12	16.65	17.54	18.40	19.26	16.67
Ca, %	0.47	0.47	0.47	0.47	0.47	0.49	0.50	0.50	0.50	0.49
P, %	0.42	0.43	0.44	0.45	0.42	0.39	0.40	0.41	0.42	0.39
Available P, %	0.23	0.23	0.24	0.24	0.23	0.21	0.21	0.21	0.21	0.21

[1] Phase 4 diets were fed from 200 to 240 lb; Phase 5 diets were fed from 240 to 280 lb.
[2] Biolys contains 50.7% L-lys (Evonik Degussa GmbH, Hanau, Germany).
[3] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN).
[4] Ractopamine HCl (Paylean, Elanco Animal Health, Greenfield, IN) at 9.0 g/ton was added.

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Table 5. Effects of increasing tryptophan:lysine ratio on growth performance of growing-finishing pigs (Exp. 1)[1, 2]

	Trp:Lys ratio, %				TRT	Gender		Gender	Probability, *P*<		
Item	14.0	15.0	16.5	18.0	SEM	Barrows	Gilts	SEM	Gender	Linear	Quadratic
Initial wt, lb	79.8	80.1	80.2	80.0	1.95	79.7	80.4	1.13	0.69	0.96	0.89
d 42 wt, lb	152.2	157.4	161.7	161.6	2.67	157.3	157.0	1.54	0.90	0.01	0.23
Final wt, lb	258.5	265.5	275.6	286.0	2.97	276.1	266.7	2.10	0.006	<0.001	0.99
d 0 to 42											
ADG, lb	1.72	1.84	1.94	1.93	0.038	1.88	1.84	0.027	0.26	0.001	0.06
ADFI, lb	3.96	4.43	4.50	4.56	0.114	4.42	4.30	0.081	0.28	0.003	0.07
F/G	2.30	2.41	2.32	2.36	0.053	2.35	2.34	0.04	0.86	0.80	0.67
d 42 to 105											
ADG, lb	1.76	1.80	1.88	2.01	0.023	1.93	1.80	0.016	<0.001	<0.001	0.18
ADFI, lb	5.71	6.07	6.38	6.65	0.110	6.51	5.90	0.078	<0.001	<0.001	0.40
F/G	3.24	3.37	3.39	3.31	0.063	3.38	3.28	0.045	0.12	0.55	0.10
d 0 to 105											
ADG, lb	1.75	1.82	1.91	1.98	0.016	1.91	1.81	0.012	<0.001	<0.001	0.43
ADFI, lb	4.98	5.39	5.60	5.77	0.106	5.64	5.23	0.075	0.002	<0.001	0.16
F/G	2.85	2.97	2.94	2.92	0.050	2.96	2.88	0.035	0.16	0.53	0.21
Carcass characteristics											
Carcass yield, %	73.9	73.6	73.8	73.8	0.29	73.5	74.1	0.25	0.10	0.93	0.72
HCW, lb	191.7	195.6	206.0	209.6	3.75	204.4	197.0	2.29	0.03	0.002	0.60
Backfat depth, in[3]	0.67	0.67	0.59	0.58	0.04	0.71	0.56	0.01	<0.001	0.63	0.86
Loin depth, in[3]	2.45	2.43	2.43	2.43	0.03	2.4	2.4	0.03	0.41	0.11	0.79
Lean, %[3]	55.9	55.9	57.2	57.3	0.68	55.0	57.7	0.19	<0.001	0.77	0.89
Fat-free lean index[3]	50.3	50.4	51.3	51.4	0.51	49.6	51.7	0.14	<0.001	0.71	0.63
Economics[4]											
Feed cost/pig, $	43.04	46.70	51.13	51.18	1.041	50.37	45.66	0.637	<0.001	<0.001	0.01
Feed cost/lb gain, $	0.221	0.231	0.238	0.233	0.005	0.24	0.23	0.003	0.02	0.02	0.04
Income/pig, $[5]	123.44	125.95	132.64	134.97	2.413	131.65	126.85	1.418	0.02	<0.001	0.60
IOFC[6]	80.40	79.25	81.51	83.79	2.630	81.33	81.20	1.117	0.95	0.04	0.38

[1] A total of 638 pigs (PIC 1050 × 337, initially 80.0 lb) were used in a 105-d growing-finishing trial with 26 to 27 pigs per pen and 6 pens per treatment.
[2] Includes pigs that died, were culled, topped, and were pulled off test during the experiment.
[3] Carcass characteristics other than yield percentage were adjusted by using hot carcass weight as a covariate.
[4] Diet cost was based on corn at $3.50/bu; 46.5% soybean meal at $300/ton; DDGS at $120/ton; Biolys at $0.50/lb; and L-tryptophan at $15.00/lb.
[5] Value was determined by using a base carcass price of $64.40/cwt.
[6] Income over feed cost = value of pig - feed costs during trial period.

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Table 6. Effects of increasing tryptophan:lysine ratio on growth performance and carcass characteristics of finishing pigs (Exp. 2)[1,2]

	Trp:Lys, %						Probability, *P* <		
	15.0	16.5	18.0	19.5	L-trp to 18.0	SEM	Linear	Quadratic	18.0 vs. L-trp to 18.0
Initial wt, lb	146.2	146.4	146.0	146.1	146.3	3.26	0.96	0.99	0.96
D 0 to 73									
ADG, lb	1.62	1.67	1.73	1.79	1.71	0.024	<0.001	0.86	0.54
ADFI, lb	5.33	5.35	5.53	5.57	5.39	0.088	0.03	0.91	0.26
F/G	3.30	3.21	3.20	3.11	3.15	0.042	0.01	0.98	0.39
Final wt, lb	260.6	264.5	270.5	272.9	267.3	3.88	0.02	0.86	0.57
Carcass characteristics									
Farm yield, %	74.8	74.9	73.8	75.3	74.1	0.40	0.76	0.08	0.59
Carcass yield, %	75.3	75.5	75.1	75.0	75.0	0.42	0.52	0.67	0.86
HCW, lb	194.9	198.0	199.6	205.4	198.1	2.77	0.01	0.62	0.71
Backfat depth, in[3]	0.62	0.60	0.59	0.63	0.63	0.02	0.96	0.09	0.09
Loin depth, in[3]	2.31	2.38	2.31	2.32	2.34	0.03	0.80	0.29	0.39
Lean, %[3]	56.1	57.0	56.4	56.3	56.4	0.29	0.96	0.08	0.86
Fat-free lean index[3]	50.9	51.1	51.3	51.1	50.8	0.19	0.98	0.07	0.08
Economics[4]									
Feed cost/pig,$	32.16	33.15	35.14	36.61	34.68	0.562	<0.001	0.67	0.57
Feed cost/lb gain,$	0.275	0.277	0.280	0.282	0.282	0.004	0.22	1.00	0.90
Income/pig, $[5]	142.07	144.27	145.67	149.41	144.42	2.032	0.01	0.71	0.66
IOFC[6]	109.91	111.12	110.53	112.80	109.74	1.706	0.30	0.76	0.75

[1] A total of 1,214 pigs (PIC 1050 × 337, initially 146.2 lb) were used in a 73-d finishing trial, with 25 to 28 pigs per pen and 9 pens per treatment.
[2] Includes pigs that died, were culled, and were pulled off test during the experiment.
[3] Carcass characteristics other than yield percentage were adjusted by using hot carcass weight as a covariate.
[4] Diet cost was based on corn at $3.50/bu; 46.5% soybean meal at $300/ton; DDGS at $120/ton; Biolys at $0.50/lb; and L-tryptophan at $15.00/lb.
[5] Value was determined by using a base carcass price of $72.90/cwt.
[6] Income over feed cost = value of pig - feed costs during trial period.

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The Effects of Feeder Adjustment on Growth Performance of Finishing Pigs

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Summary

A total of 234 growing pigs (PIC TR4 × 1050, initially 91.4 lb) were used in an 89-d trial to determine the effects of feeder adjustment on finishing pig performance. Pigs were randomly allotted to 1 of 3 treatments. The treatments consisted of a narrow feeder adjustment (minimum gap opening of 0.50 in.), medium feeder adjustment (minimum gap opening of 0.75 in.), and wide adjustment (minimum feeder gap opening of 1.00 in.). The feeders were adjusted to the minimum gap setting, but the agitation plate could be moved upward to a maximum gap opening of 0.75, 1.00, or 1.25 in., respectively. Treatments were arranged in a completely randomized design with 9 replications of 8 pigs per pen and 1 replicate with 6 pigs. To ensure equal floor space, pen gating was adjusted to provide 8 ft^2 /pig during the study. All pens had the same feeder with 2, 14-in.-wide by 4.5-in.-deep feeder holes. Pigs had ad libitum access to feed and water. All pigs were fed a corn-soybean meal-based diet containing 20% dried distillers grains with solubles (DDGS) in 4 phases. Pen weights and feed disappearance were measured every 2 wk. Also, pictures of feeders were taken and scored by a panel to detemine percentage pan coverage. Results showed that narrow, medium, and wide feeder adjustments averaged approximately 28, 58, and 75% pan coverage, respectively. From d 0 to 28, pigs exposed to increasing feeder gap had improved (linear; $P \leq 0.05$) ADFI, with the greatest ADFI observed at 1.00 in. However, from d 28 to 56 and 56 to 89, ADG was not different among pigs fed from different feeder openings, and F/G was best for those fed from the 0.50-in. opening. Overall (d 0 to 89), there was a trend ($P = 0.08$) for increased ADG with increasing feeder opening. However, pigs fed with a 0.50-in. feeder gap had improved (linear; $P < 0.03$) F/G compared to those with a 0.75- or 1.00-in. feeder opening. These results suggest that from 90 to 150 lb, maximum ADG was observed with a feeder setting of 0.75 in (approximately 58% pan coverage). However, pigs fed from 150 to 270 lb had greater ADG and the best F/G at a setting of 0.50 in (approximately 28% pan coverage). Thus, it appears that optimum feeder-gap setting may differ with growth phase.

Key words: feeder adjustment, feeder gap opening, finishing pig

Introduction

As feed prices rise, producers have begun to consider feeder adjustments as a way to decrease feed wastage while optimizing performance. If feeder openings are adjusted too wide, increased feed wastage and poorer feed efficiency may occur. If feeder adjustment is too restricted, growth performance may be adversely affected. Previous research (Myers et al. 2010[2]) has shown that a minimum feeder gap of 1.00 in. had increased

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

[2] Myers et al., Swine Day 2010, Report of Progress 1038, pp. 172-177.

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feed disappearance and resulted in poorer F/G compared to a minimum feeder gap of 0.50 in. Currently little is known about optimal feeder adjustment for performance at various stages during the grow-finishing period. The objective of this study was to determine the ideal feeder adjustment for performance at various growth stages of finishing pigs.

Procedures

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

A total of 234 growing pigs (PIC TR4 × 1050, initially 91.4 lb) were used in an 89-d trial. Pigs were randomly alloted to 1 of 3 treatments. There were 9 pens per treatment with 8 pigs per pen and one replicate with 6 pigs per pen. Treatments were arranged in a completely randomized design with pen as the experimental unit. The treatments consisted of a narrow feeder adjustment (minimum gap opening of 0.50 in.), medium feeder adjustment (minimum gap opening of 0.75 in.), and wide adjustment (minimum gap opening of 1.00 in.). The feeders were adjusted to the minimum gap setting, but the agitation plate could be moved upward to a maximum gap opening of 0.75, 1.00, or 1.25 in., respectively. To ensure equal floor space among pens of 8 and 6 pigs, the gating was adjusted to provide 8 ft^2 per pig during the study. All pens had the same feeder with 2 14-in.-wide by 4.5-in.-deep feeder holes. Pigs were provided ad libitum access to feed and water. A common diet containing 20% DDGS was fed in 4 phases, each approximately 28 d (Table 1). The diet was formulated to meet or exceed NRC[3] requirements for finishing pigs. Average daily gain, ADFI, and F/G were determined by weighing pigs and measuring feed disappearance on d 0, 14, 28, 42, 58, 70, 84, and 89. Pictures of feeder pan coverage were taken once during each phase. The feeder pan pictures were then scored by a panel of 4 for percentage of pan coverage. Data were analyzed as a completely randomized design with repeated measures over time using the PROC MIXED procedure of SAS (SAS Institute Inc., Cary, NC). Linear and quadratic contrasts for the effects of increasing feeder gap use were evaluated. Pen was the experimental unit.

Results and Discussion

The narrow, medium, and wide feeder adjustments averaged approximately 28, 58, and 75% pan coverage, respectively (Figures 1, 2, and 3, respectively). From d 0 to 28, no differences among pigs fed from feeders with different adjustments were observed for ADG. While pigs with increasing feeder gap had increased (linear; $P < 0.05$; Table 2) ADFI, there was a tendency for pigs with increasing feeder gap to have improved ($P<0.07$) F/G.

From d 28 to 58, no differences among pigs fed from feeders with the different adjustment settings were observed for ADG. Increasing feeder gap setting increased (linear, $P < 0.05$) ADFI. This resulted in pigs with 0.50-in. feeder gap having improved (quadratic, $P < 0.04$) F/G compared to pigs with 0.75- or 1.00-in. feeder opening.

From d 58 to 89, there were no differences in ADG, ADFI or F/G among treatments.

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

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Overall (d 0 to 89), (linear; $P < 0.08$) ADG tended to improve as feeder gap setting increased, with no further benefit over the 0.75-in. setting. Also, pigs fed with either a 0.75- or 1.00-in. gap setting had increased (linear; $P < 0.01$) feed intake compared to those with 0.50-in. feeder gap. However, pigs fed with the 0.50-in. feeder gap had improved (linear; $P < 0.03$) F/G compared to pigs fed with a 0.75- or 1.00-in. feeder gap.

For carcass measurement, no significant differences were found among treatments for HCW, percentage lean, percentage carcass yield, backfat depth, or loin depth (Table 3).

These results suggest that when pigs first enter the finisher, the feeder gap should be set to at least 0.75 in. (approximately 58% pan coverage) to maximize gain without affecting feed efficiency. However, after pigs reach 150 lb, feeders should be adjusted to a 0.50-in. gap width (approximately 28% pan coverage) to minimize feed wastage and optimize both ADG and F/G. Thus, it appears that optimum feeder gap setting may differ with growth phase.

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

Item	Phase 1	Phase 2	Phase 3	Phase 4
Ingredient, %				
Corn	63.25	67.45	70.45	72.40
Soybean meal, (46.5% CP)	14.4	10.4	7.55	5.7
DDGS[2]	20	20	20	20
Limestone	1.25	1.20	1.13	1.08
Salt	0.35	0.35	0.35	0.35
Vitamin premix	0.15	0.13	0.10	0.08
Trace mineral premix	0.15	0.13	0.10	0.08
L-lysine HCl	0.34	0.29	0.27	0.26
Phytase 600[3]	0.14	0.09	0.06	0.04
Total	100	100	100	100
Calculated analysis				
Standardized ileal digestible amino acids, %				
Lysine	0.88	0.75	0.66	0.60
Isoleucine:lysine	66	69	71	73
Methionine:lysine	31	34	37	39
Met & Cys:lysine	34	70	75	80
Threonine:lysine	60	64	67	69
Tryptophan:lysine	16.5	16.5	16.5	16.6
Valine:lysine	80	85	90	94
Total lysine, %	1.02	0.88	0.78	0.72
CP, %	17.8	16.3	15.2	14.5
ME kcal/lb	1,519	1,521	1,524	1,526
Ca, %	0.55	0.52	0.48	0.46
P, %	0.42	0.40	0.39	0.38
Available P, %	0.28	0.25	0.23	0.21

[1] Each dietary phase was fed ~ 24 days.
[2] Dried distillers grains with solubles.
[3] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 231 FTU/lb, with a release of 0.10% available P.

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Table 2. Effects of feeder adjustment (gap setting) on finishing pig performance[1]

	Feeder gap, in.				*P*-value	
Item	0.50	0.75	1.00	SEM	Linear	Quadratic
d 0 to 28						
ADG, lb	1.93	2.15	2.11	0.056	0.15	0.23
ADFI, lb	4.89	5.51	5.59	0.169	0.04	0.35
F/G	2.54	2.58	2.64	0.054	0.06	0.76
d 28 to 58						
ADG, lb	2.37	2.40	2.42	0.056	0.30	0.81
ADFI, lb	6.90	7.44	7.37	0.169	0.02	0.06
F/G	2.92	3.10	3.05	0.054	0.05	0.03
d 58 to 89						
ADG, lb	1.51	1.46	1.50	0.056	0.87	0.33
ADFI, lb	5.22	5.33	5.45	0.169	0.18	0.96
F/G	3.47	3.65	3.64	0.054	0.12	0.30
d 0 to 89						
ADG, lb	1.94	2.00	2.01	0.028	0.08	0.36
ADFI, lb	5.67	6.09	6.14	0.123	0.01	0.22
F/G	2.97	3.11	3.11	0.040	0.03	0.18
Feeder coverage score, %[2]						
	27.7	58.2	75.0	7.56	0.01	0.31

[1] A total of 234 pigs (PIC TR4 ×1050, initially 91.4 lb) were used in an 89-d study to evaluate the effects of feeder adjustment on finisher growth performance. There were 8 pigs per pen and 9 pens per treatment. There was one pen per treatment with 6 pigs per pen.
[2] Pictures of feeder pan coverage were taken once during each dietary phase. A panel of 4 scored feeder pan pictures for percentage of pan coverage.

Table 3. Effects of feeder adjustment on carcass characteristics of finishing pigs[1]

	Feeder gap, in.				*P*-value	
Item	0.50	0.75	1.00	SEM	Linear	Quadratic
Live weight, lb	280	283	285	4.23	0.35	0.92
HCW, lb	208	211	208	4.95	0.37	0.58
Yield, %	74.2	74.0	74.0	0.56	0.81	0.18
Lean, %[2]	50.5	50.2	51.1	0.51	0.21	0.60
Backfat depth, in	1.07	1.07	1.00	0.91	0.25	0.89
Loin depth, in	2.50	2.39	2.48	1.34	0.61	0.17

[1] A total of 234 pigs (PIC TR4 ×1050, initially 91.4 lb) were used in an 89-d study to evaluate the effects of feeder adjustment on finisher growth performance.
[2] Percentage lean, backfat depth, and loin depth were adjusted to a common HCW.

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Figure 1. Narrow feeder adjustment (minimum feeder gap was 0.5 in. with a maximum gap of 0.75 in.) averaged 27% feeder pan coverage.

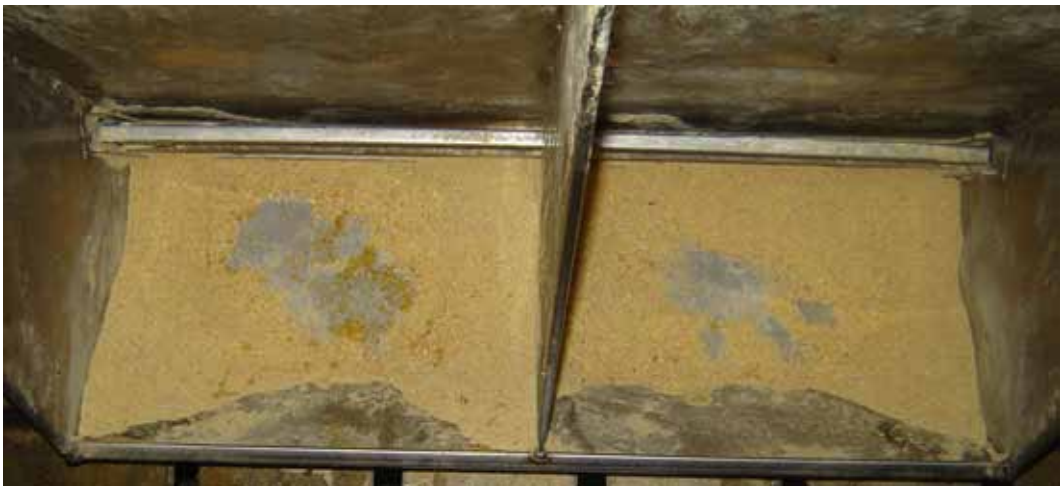

Figure 2. Medium feeder adjustment (minimum feeder gap was 0.75 in. with a maximum gap of 1.00 in.) averaged 58% feeder pan coverage.

Figure 3. Wide feeder adjustment (minimum feeder gap was 1.00 in. with a maximum gap of 1.25 in.) averaged 75% feeder pan coverage.

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The Effects of Feeder Space and Adjustment on Growth Performance of Finishing Pigs

A. J. Myers, R. D. Goodband, M. D. Tokach, S. S. Dritz,[1] J. R. Bergstrom, J. M. DeRouchey, and J. L. Nelssen

Summary

A total of 288 pigs (PIC TR4 × 1050, initially 82 lb) were used in a 91-d study to evaluate the effects of feeder trough space (1.75 vs. 3.5 in/pig) and minimum feeder-gap opening of 0.5 in. (narrow), vs. 1.0 in. (wide) on finisher pig performance. Our hypothesis was that at minimal feeder trough space (1.75 in./pig), feeders should be set at a wide gap opening to avoid limiting feed intake and ADG. The feeders were adjusted to the minimum gap setting, but the agitation plate could be moved upward to a maximum gap opening of 0.75 in. or 1.25 in., respectively. The treatments were arranged in a 2 × 2 factorial with 6 replications per treatment. All pens had the same feeder with 2, 14-in.-wide by 4.5-in.-deep feeder holes. Feeder trough space was adjusted by placing 8 or 16 pigs per pen. Gating was adjusted to give each pig 8 ft^2 of floor space. Pigs had ad libitum access to feed and water. All pigs were fed a corn-soybean meal-based diet containing 20% dried distillers grains with solubles (DDGS) in 4 phases. Pen weights and feed disappearance were measured every 2 wk. Narrow-adjusted feeders averaged approximately 48% coverage, and wide-adjusted feeders averaged approximately 85% coverage. Overall (d 0 to 91) there were no trough space × feeder adjustment interactions observed ($P > 0.10$). However, there was a tendency ($P = 0.08$) for increased ADG as feeder trough space increased from 1.75 to 3.5 in./pig. Pigs fed with the wide feeder-gap setting had increased ($P < 0.01$) feed disappearance and poorer ($P < 0.01$) F/G compared to pigs with the narrow feeder-gap setting. These results suggest that, regardless of feeder trough space, pigs with the wide feeder adjustment appeared to waste more feed, as evidenced by the poorer F/G.

Key words: feeder adjustment, finishing pig, trough space

Introduction

Continued improvements in swine genetics and nutrition have positively affected performance in the finishing stage of growth. However, to capitalize on these advancements, feed must be effectively delivered. Too little feeder space or too narrow feeder adjustment could limit feed intake and potentially decrease performance. Conversely, too much feeder space or too broad a feeder gap could increase feed wastage and decrease efficiency. Our hypothesis for this experiment was that at lower feeder trough space availability per pig, feeders should be set at a wider gap opening to avoid limiting feed intake and ADG. Therefore, the objective of this study was to evaluate the effects of feeder space and feeder setting on the growth performance of finishing pigs.

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Procedures

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

A total of 288 growing pigs (PIC TR4 × 1050 initially 82 lb) were used in a 91-d trial. Pigs were randomly alloted to 1 of 4 treatments arranged in a 2 ×2 factorial with the main effects of feeder space (1.75 in. vs. 3.5 in./pig) and feeder gap setting (narrow 0.5 in. vs. wide 1.00 in.).

For the 3.5 in. of feeder space per pig, pens were stocked with 8 pigs per pen. To achieve the 1.75 in. of feeder space per pig, 2 pens were combined with only 1 feeder for the 16 pigs. To ensure equal floor space among pens of 8 and 16, the gating was adjusted to provide 8 ft^2/pig during the study.

All pens had the same feeder with 2, 14-in.-wide by 4.5-in.-deep feeder holes. For each of the feeder gap settings, we calculated an average minimum and maximum opening. For the narrow adjustment, the minimum feeder gap was 0.5 in. with a maximum gap of 0.75 in. For the wide adjustment, the minimum feeder gap was 1.00 in. with a maximum gap of 1.25 in. We calculated maximum gap opening by taking into account the agitation plate, which can be moved upward 0.25 in. by pigs rooting around in the feeder.

Pigs were provided ad libitum access to feed and water. A common diet containing 20% DDGS was fed in four phases, each approximately 28 d in length (Table 1). The diet was formulated to meet or exceed NRC[2] requirements for finishing pigs. Average daily gain, ADFI, and F/G were determined by weighing pigs and measuring feed disappearance on d 0, 14, 28, 42, 56, 70, 84, and 91. Pictures of feeder pan coverage were taken once during each phase. A panel of 4 then scored the feeder pan pictures by percentage of pan coverage.

Data were analyzed as 2 × 2 factorial in a completely randomized design with repeated measures over time using the PROC MIXED procedure of SAS (SAS Institute Inc., Cary, NC). Repeated measures were conducted for d 0 to 56 and d 56 to 91. Pen was the experimental unit.

Results and Discussion

Results of the feeder pan coverage evaluations indicated narrow adjusted feeders averaged approximately 48% coverage (Figure 1) and wide adjusted feeders averaged approximately 85% coverage (Figure 2).

From d 0 to 56, there were no feeder adjustment × trough space interactions observed for ADG (Table 2). However, those pigs exposed to the wide feeder-gap setting increased ($P < 0.01$) ADFI, which resulted in a tendency ($P < 0.09$) for poorer F/G. This suggests that the increase in feed intake with the wider feeder-gap setting was actually an increase in feed wastage.

[2] NRC. 1998. Nutrient Requirements of Swine. 10th ed. Natl. Acad. Press, Washington, D.C.

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From d 56 to 91, there was a tendency ($P < 0.09$) for pigs with 3.5 in. feeder space to have greater ADG compared to pigs with 1.75 in. feeder space. Furthermore, pigs exposed to the wide feeder-gap setting had increased ($P < 0.0001$) ADFI and poorer ($P < 0.0001$) F/G, similar to the response seen during d 0 to 56.

An adjustment × period interaction was observed for F/G. Even though F/G was poorer for pigs with the wide feeder setting in both periods, the interaction comes from the wide feeder gap having an even poorer feed efficiency during the second period (d 56 to 91) when compared to the first period (d 0 to 56).

Overall (d 0 to 91), no feeder adjustment × trough space interactions were observed ($P > 0.10$). However, there was a tendency ($P = 0.08$) for increased ADG as feeder trough space increased from 1.75 to 3.5 in./pig. Pigs fed with the wide feeder-gap setting had increased ($P < 0.01$) feed disappearance and poorer ($P < 0.01$) F/G compared to pigs with the narrow feeder-gap setting. These results suggest that, regardless of feeder trough space, pigs with the wide feeder adjustment appeared to waste more feed, as evidenced by the poorer F/G. Further research is needed to assess optimal feeder trough space for finishing pigs.

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

Ingredient, %	Phase 1	Phase 2	Phase 3	Phase 4
Corn	63.25	67.45	70.45	72.40
Soybean meal, (46.5% CP)	14.40	10.40	7.55	5.70
DDGS[2]	20.00	20.00	20.00	20.00
Limestone	1.25	1.20	1.13	1.08
Salt	0.35	0.35	0.35	0.35
Vitamin premix	0.15	0.13	0.10	0.08
Trace mineral premix	0.15	0.13	0.10	0.08
Lysine HCl	0.34	0.29	0.27	0.26
Phytase 600	0.14	0.09	0.06	0.04
Total	100.00	100.00	100.00	100.00
Calculated analysis				
SID[3] amino acids, %				
Lysine	0.88	0.75	0.66	0.60
Isoleucine:lysine	66	69	71	73
Methionine:lysine	31	34	37	39
Met & Cys:lysine	34	70	75	80
Threonine:lysine	60	64	67	69
Tryptophan:lysine	16.5	16.5	16.5	16.6
Valine:lysine	80	85	90	94
Total lysine, %	1.02	0.88	0.78	0.72
CP, %	17.8	16.3	15.2	14.5
ME kcal/lb	1,519	1,521	1,524	1,526
Ca, %	0.55	0.52	0.48	0.46
P, %	0.42	0.40	0.39	0.38
Available P, %	0.28	0.25	0.23	0.21

[1] Each dietary phase was fed for approximately 24 days.
[2] Dried distillers grains with solubles.
[3] Standardized ileal digestible.

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Table 2. Effects of trough space and feeder-gap setting (narrow vs. wide) on finishing pig performance[1]

		Trough space/pig, in					Probability, P <		
		1.75 in.		3.5 in.			Adjustment		Trough
Item	Feeder gap:[2]	Narrow	Wide	Narrow	Wide	SED	× Space	Adjustment	space
d 0 to 56									
ADG, lb		2.22	2.27	2.26	2.31	0.046	0.91	0.13	0.18
ADFI, lb		5.99	6.30	6.09	6.45	0.145	0.80	< 0.01	0.18
F/G		2.70	2.78	2.70	2.79	0.071	0.87	0.09	0.90
d 56 to 91									
ADG, lb		2.15	2.18	2.24	2.20	0.046	0.33	0.84	0.14
ADFI, lb		7.56	8.04	7.63	8.20	0.145	0.67	< 0.01	0.33
F/G		3.51	3.70	3.41	3.73	0.071	0.21	< 0.01	0.48
d 0 to 91									
ADG, lb		2.20	2.23	2.25	2.27	0.034	0.68	0.33	0.08
ADFI, lb[3]		6.58	6.96	6.68	7.12	0.130	0.75	<0.01	0.18
F/G[3]		2.99	3.12	2.97	3.14	0.060	0.57	<0.01	0.86
Feeder coverage score, %[4]		42.9	83.3	54.1	86.5	3.76	0.30		

[1] A total of 228 pigs (PIC TR4 × 1050, initially 82 lb) were used, with either 8 (1.75 in./pig) or 16 (3.5 in./pig) per pen with 6 replications per treatment.
[2] Narrow = 0.50 in. minimum gap opening. Wide = 1.00 in. minimum gap opening.
[3] Adjustment × period interactions ($P < 0.05$).
[4] Pictures of feeder pan coverage were taken once during each dietary phase. A panel of 4 then scored feeder pan pictures for percentage of pan coverage.

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Figure 1. Narrow feeder adjustment (minimum feeder-gap opening was 0.5 in. with a maximum gap of 0.75 in.) averaged 45% feeder pan coverage.

Figure 2. Wide feeder adjustment (minimum feeder-gap opening was 1.00 in. with a maximum gap of 1.25 in.) averaged 83% feeder pan coverage.

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Effects of Feeder Design and Feeder Adjustment on the Growth Performance of Growing-Finishing Pigs[1]

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

Summary

Two experiments were performed to evaluate the effects of feeder design (conventional dry feeder vs. wet-dry feeder) and adjustment on growing-finishing pig performance. In both experiments, all pigs (PIC 337 × 1050) were fed the same corn-soybean meal diets with 15% dried distillers grains with solubles (DDGS). In Exp. 1, 1,296 pigs (initially 43 lb) were used in a 69-d study. From d 0 to 27, 3 feeder settings were evaluated for each feeder type. Numbered settings (located in each feeder) were 6, 8, and 10 for the conventional dry feeder and 6, 10, and 14 for the wet-dry feeder. An increased setting number corresponded to a greater opening. From d 27 to 69, all feeders were adjusted to an opening of approximately 1 in. (conventional dry feeder setting 8; wet-dry feeder setting 14). From d 0 to 27, pigs using a wet-dry feeder had lower ($P < 0.02$) ADFI and better F/G than pigs using a conventional dry feeder. Increasing the feeder setting improved (linear, $P < 0.01$) ADG, ADFI, and d-27 BW of pigs using a wet-dry feeder and increased (linear, $P < 0.01$) ADFI of pigs using a conventional dry feeder. From d 27 to 69, ADG and ADFI of pigs using a wet-dry feeder were greater ($P < 0.01$) than those of pigs using a conventional dry feeder, and increasing the feeder setting from d 0 to 27 resulted in greater (linear, $P < 0.01$) ADFI and poorer F/G for pigs using a wet-dry feeder. Overall (d 0 to 69), pigs using a wet-dry feeder had greater ($P < 0.05$) ADG, ADFI, final BW, and better F/G than pigs that used a conventional dry feeder. Increasing the feeder setting of a wet-dry feeder from d 0 to 27 resulted in greater (linear, $P < 0.01$) ADG and ADFI, poorer (linear, $P < 0.03$) F/G, and heavier (linear, $P < 0.01$) final BW. Feeder setting of a conventional dry feeder from d 0 to 27 did not affect overall performance. In Exp. 2, 1,248 pigs (initially 73 lb) were used in a 93-d study. Three feeder settings were evaluated throughout the study for each feeder type (conventional dry feeder set at 6, 8, and 10; wet-dry feeder set at 10, 14, and 18). Overall, pigs using a wet-dry feeder had greater ($P < 0.05$) ADG, ADFI, final BW, HCW, backfat depth, and feed cost but reduced ($P < 0.04$) fat-free lean index (FFLI) compared with pigs using a conventional dry feeder. Increasing the feeder setting of a wet-dry feeder resulted in greater (linear, $P < 0.05$) ADG, ADFI, final BW, HCW, backfat depth, and feed cost. When HCW was used as a covariate, FFLI of pigs using a wet-dry feeder decreased (linear, $P < 0.02$) with increased feeder opening. Increasing the feeder setting of a conventional dry feeder had no effect on growth performance and carcass characteristics. In conclusion, the growth rate of pigs improved with a wet-dry feeder compared with a conventional dry feeder; however, the growth of pigs using a wet-dry feeder was more sensitive to differences in feeder adjustment.

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

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

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Key words: conventional feeder, feeder adjustment, wet-dry feeder

Introduction

Previous research at Kansas State University (Bergstrom et al., 2008[3], 2009[4]) has demonstrated that using a wet-dry feeder increases the feed intake and growth rate of finishing pigs. However, pigs using wet-dry feeders in some of our recent studies have also had poorer feed efficiency. The differences in feed efficiency responses between some experiments are of concern because the additional feed cost associated with poorer efficiency may eliminate the benefits of faster growth.

Several factors may be responsible for the different feed efficiency responses among experiments. Generally, the feed efficiency differences have been most apparent during later feeding periods, and the recent studies were initiated with lighter pigs and concluded at heavier weights than earlier studies. Therefore, differences in final BW between pigs fed using conventional dry and wet-dry feeders have been greater in the most recent studies. The carcass data from some of our recent experiments indicate that pigs that are heavier from using a wet-dry feeder may also have greater backfat depth (Bergstrom et al., 2008[3]; 2009[4]).

Few studies have reported effects of feeder adjustment on the growth performance of growing pigs. Using the same conventional dry feeder used in our recent experiments, Duttlinger et al. (2008[5]) observed linear improvements in ADFI with increasing feeder opening and tendencies for quadratic improvements in ADG and F/G. These effects were the same for a corn-soybean meal diet and a corn-soybean meal diet with 15% DDGS and 5% bakery by-product. The effects of adjustment of wet-dry feeders on growth performance of growing pigs have not been reported.

Therefore, the objective of this research was to compare the effects of conventional dry and wet-dry feeders with various feeder settings on the growth performance and carcass characteristics of growing-finishing pigs.

Procedures

Procedures used in the experiments were approved by the Kansas State University Institutional Animal Care and Use Committee. The experiments were conducted at a commercial research finishing facility in southwestern Minnesota. The facility was double-curtain sided, with pit fans for minimum ventilation and completely slatted flooring over a deep pit for manure storage. Individual pens were 10 × 18 ft. One half of the pens were equipped with a single 60-in.-wide, 5-hole conventional dry feeder (STACO, Inc., Schaefferstown, PA) and a cup waterer in each pen. The remaining pens were each equipped with a double-sided wet-dry feeder (Crystal Springs, GroMaster, Inc., Omaha, NE) with a 15-in. feeder opening on both sides that provided access to feed and water. Each pen equipped with a wet-dry feeder also contained a cup waterer, but the cup waterers were shut off during the experiment. Therefore, the only source of water for pigs in these pens was through the wet-dry feeder.

[3] Bergstrom et al., Swine Day 2008, Report of Progress 1001, pp. 196-203.
[4] Bergstrom et al., Swine Day 2009, Report of Progress 1020, pp. 252-261.
[5] Duttlinger et al., Swine Day 2008, Report of Progress 1001, pp 204-214.

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Experiment 1

A total of 1,296 pigs (PIC 337 × 1050, initially 42.8 lb) were used in a 69-d experiment to evaluate the effects of feeder design (conventional dry vs. wet-dry feeder) and initial feeder adjustment on growing-finishing pig performance. Three feeder adjustment settings were evaluated for each of the 2 feeder types from d 0 to 27. Pigs were randomly placed into pens of 27; each pen had 14 barrows and 13 gilts. Pens of pigs were weighed and allotted to the 2 feeder types and 3 initial feeder settings within each feeder type. There were 24 pens per feeder type and 8 pens for each of the 3 feeder settings within each feeder type. All pigs were fed the same corn-soybean meal diets containing 15% DDGS during 2 dietary phases in the experiment (Table 1). The first diet phase was fed from d 0 to 39, and the second diet phase was fed from d 39 to 69.

The 3 settings used for the wet-dry feeders were the numbered adjustments of 6, 10, and 14 located on the adjustment mechanism inside each end of the feeder (Figures 1 to 3). The 3 settings used for the conventional dry feeder were the numbered adjustments of 6, 8, and 10 located on the adjustment mechanism inside each end of the feeder (Figures 4 to 6).

On d 19, measurements of the actual feeder opening were obtained for all feeders. For the wet-dry feeder, the mean gap opening was determined with two measurements (one from each side of the feeder) from the top of the feeder shelf to the bottom edge of the feed storage hopper. A digital photo of the pan/trough of each feeder was also taken on d 19. Afterward, the pictures were independently scored for percentage of pan coverage by a trained panel of 6 people. The mean pan coverage score of each feeder was used to determine the relationship between feeder opening and percentage of feed coverage in the pan.

On d 27, both feeder types were adjusted to a targeted feeder opening of approximately 1 in. (setting 8 for the conventional dry and setting 14 for the wet-dry) for the remainder of the experiment.

Data were analyzed to compare the effects of the 2 feeder types (wet-dry vs. conventional dry) and 3 initial feeder settings nested within each feeder type by using a completely randomized design and the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary NC). Pen was the experimental unit.

Experiment 2

A total of 1,248 pigs (PIC 337 × 1050, initially 73.0 lb) were used in a 93-d experiment to evaluate the effects of feeder design (conventional dry vs. wet-dry feeder) and adjustment on growing-finishing pig performance and carcass characteristics. Three feeder adjustment settings were evaluated for each of the 2 feeder types throughout the experiment. Pigs were randomly placed into pens of 26; each pen had 13 barrows and 13 gilts. Pens of pigs were weighed and allotted to the 2 feeder types and 3 feeder settings within each feeder type. There were 24 pens per feeder type and 8 pens for each of the 3 feeder settings within each feeder type. All pigs were fed the same corn-soybean meal diets containing 15% DDGS during 4 dietary phases in the experiment (Table 1).

The 3 settings used for the wet-dry feeders were the numbered adjustments of 10, 14, and 18 located on the adjustment mechanism inside each end of the feeder (Figures

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2, 3, and 7). The 3 settings used for the conventional dry feeder were the numbered adjustments of 6, 8, and 10 located on the adjustment mechanism inside each end of the feeder (Figures 8, 9, and 6).

On d 41 and 84, measurements of the actual feeder opening were obtained, and a photo of the pan/trough of each feeder was taken. As in Exp. 1, the pictures were scored for percentage of pan coverage, and the relationship between feeder opening and feed coverage of the pan was determined.

Data were analyzed to compare the effects of the 2 feeder types (wet-dry vs. conventional dry) and the 3 feeder settings nested within each feeder type by using a completely randomized design and the PROC MIXED procedure of SAS. Pen was the experimental unit. The carcass data were analyzed with and without using the ending HCW as a covariate.

Results

Experiment 1

The mean opening of the conventional dry feeder was greater ($P < 0.01$) than that of the wet-dry feeder on d 19 (Table 2). However, the mean percentage of pan coverage of the conventional dry feeder was less ($P < 0.01$) than that of the wet-dry feeder. The openings of both feeder types increased (linear, $P < 0.0001$) with greater feeder adjustment setting. The openings achieved were 0.59 to 0.81 in., 0.80 to 1.07 in., and 1.09 to 1.35 in. for the conventional dry feeder settings of 6, 8, and 10; and 0.50 in., 0.75 in., and 1.00 in. for the wet-dry feeder settings of 6, 10, and 14, respectively. The percentage of pan coverage of the conventional dry feeder increased (quadratic, $P < 0.01$) with greater feeder setting, as did that of the wet-dry feeder (linear, $P < 0.001$).

From d 0 to 27, pigs using the wet-dry feeder had decreased ($P < 0.02$) ADFI and better F/G than pigs using the conventional dry feeder (Table 2). Increasing the feeder setting of the wet-dry feeder increased (quadratic, $P < 0.02$) ADG, ADFI, d-27 BW, and feed cost per pig. Increasing the feeder setting of the conventional dry feeder also increased (linear, $P < 0.01$) ADFI.

After all feeders were adjusted to a common opening on d 27, ADG and ADFI of pigs using the wet-dry feeder were greater ($P < 0.0001$) than those of pigs using the conventional dry feeder from d 27 to 69. Also, increasing the feeder setting of the wet-dry feeder from d 0 to 27 resulted in increased (linear, $P < 0.0001$) ADFI and poorer F/G from d 27 to 69.

Overall (d 0 to 69), pigs using the wet-dry feeder had greater ($P < 0.05$) ADG, ADFI, final BW and feed cost per pig and poorer F/G than pigs using the conventional dry feeder. Increasing the feeder setting of the wet-dry feeder from d 0 to 27 resulted in greater (linear, $P < 0.0001$; quadratic, $P < 0.02$) ADG and ADFI, poorer (linear, $P < 0.03$) F/G, and increased (linear, $P < 0.03$) final BW and feed cost per pig. Increasing the feeder setting of the conventional dry feeder from d 0 to 27 had no effect on overall performance.

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Experiment 2

The mean openings of the conventional dry feeder and wet-dry feeder were similar on d 41 and 84 (Table 3). The openings of both feeder types increased (linear, $P < 0.001$) with greater feeder adjustment setting. The openings achieved were 0.58 to 0.82 in., 0.83 to 1.12 in., and 1.10 to 1.36 in. for the conventional dry feeder settings of 6, 8, and 10; and 0.75 in., 1.00 in., and 1.25 in. for the wet-dry feeder settings of 10, 14, and 18, respectively. The percentage of pan coverage for both feeder types increased (linear, $P < 0.001$) with greater feeder setting on both d 41 and 84. However, the mean percentage of pan coverage of the conventional dry feeder was less ($P < 0.02$) than that of the wet-dry feeder on d 41, but they were not significantly different on d 84.

Overall (d 0 to 93), pigs using the wet-dry feeder had increased ($P < 0.05$) ADG, ADFI, final BW, HCW, backfat depth, and feed cost per pig but reduced ($P < 0.04$) fat-free lean index (FFLI) compared with pigs using the conventional dry feeder. Neither feeder type nor adjustment influenced overall feed efficiency. Increasing the feeder setting of the wet-dry feeder also resulted in increased (linear, $P < 0.05$) ADG, ADFI, final BW, HCW, backfat depth, and feed cost per pig. Additionally, when HCW was used as a covariate, the FFLI of pigs fed with a wet-dry feeder decreased (linear, $P < 0.02$) with increased feeder opening. However, increasing the feeder setting of the conventional dry feeder had no effect on growth performance and carcass characteristics.

Discussion

In Exp. 1, pigs using a wet-dry feeder had increased ADG, ADFI, final weight, and income over feed cost. These results agree with those observed in our first 69-d experiment (Bergstrom et al.[3]). However, when the wet-dry feeder was adjusted to a feeder setting of 6 for the first 27 d, ADG, ADFI, and F/G were lower than those of pigs using a wet-dry feeder with a greater initial opening and pigs using the conventional dry feeder at any of the 3 initial settings. Because the feeder opening of the wet-dry feeder with a setting of 6 was frequently found to be plugged during the first 10 d of the experiment, feed intake and growth were considerably lower for these pigs than for pigs in all of the other treatments during the first 27 d. This also resulted in lower feed intake for these pigs during the remainder of the experiment. Although these pigs' ADG and F/G improved when their feeders were changed to a setting of 14 on d 27, they were unable to fully compensate for the reduced growth that was observed in the initial 27-d period.

The lack of a negative feed efficiency response with the wet-dry feeder in the current experiment is likely associated with the tighter feeder settings tested. Our earlier experiments comparing the wet-dry and conventional dry feeders used an initial wet-dry feeder setting of 18 (recommended by the manufacturer) and a conventional dry feeder setting of 8.

Similar to the observations reported by Duttlinger et al. (2008[5]), ADFI from d 0 to 27 increased as the feeder opening of the conventional dry feeder was increased. However, the magnitude of this response was not as great as that achieved by increasing the feeder opening of the wet-dry feeder, despite the relatively equal incremental changes in the mean feeder opening. This result is likely due to the larger openings tested for the conventional dry feeder, the frequent plugging of the wet-dry feeder at the lowest feeder setting, the range of opening provided by the agitation plate within each setting of the

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conventional dry feeder, and the fact that the conventional dry feeders provided twice the amount of feeder space.

Regardless of the differences in ADFI, there were no differences in ADG and F/G among the different feeder openings evaluated for the conventional dry feeder. The absence of a significant ADG and F/G response to the increased feeder opening of the conventional dry feeder during the first 27 d of this experiment might also be related to the lower voluntary feed intake relative to the experiments of Duttlinger et al. (2008). The pigs in the present experiment were initially 42.8 lb, whereas Duttlinger et al. (2008) initiated their experiments with pigs weighing 77.3 lb and 129.0 lb. The F/G of pigs using the conventional dry feeder at the greatest opening was numerically poorer during the initial 27 d of our experiment, suggesting that some of the feed intake response was feed wastage.

As in previous experiments, ADG, ADFI, and final BW were improved with the wet-dry feeder in Exp. 2. As in Exp. 1, increasing the feeder opening of the wet-dry feeder resulted in linear improvements in ADG, ADFI, and final BW. However, F/G of pigs using the wet-dry feeder was only numerically worse than that of pigs using the conventional dry feeder when the wet-dry feeder was adjusted to the widest setting of 18. Increasing the feeder opening of the conventional dry feeder did not significantly affect pig performance.

A significant observation from these studies is that income over feed cost was numerically greater with a wet-dry feeder when calculated on a live-BW basis (Exp. 1) but numerically lower when pigs were fed to a heavier BW and determined on a carcass basis using a lean premium/discount (Exp. 2). Although overall F/G was not significantly different between feeder types in Exp. 2, the greater ADG and final BW of pigs fed with a wet-dry feeder was the result of greater ADFI and total feed cost per pig. Also, pigs using a wet-dry feeder had greater backfat depth, and ADFI, total feed cost per pig, and backfat depth all increased linearly as the wet-dry feeder setting increased. The differences in backfat depth and FFLI between pigs fed with the 2 feeder types remained when HCW was used as a covariate for carcass data analysis, and FFLI decreased linearly as the wet-dry feeder setting increased.

In conclusion, compared with a conventional dry feeder with water provided separately, the wet-dry feeder improved ADG, ADFI, and final BW of growing-finishing pigs. However, a wet-dry feeder with an initial feeder setting less than 10 resulted in reduced growth performance. Feed intake and growth of pigs using a wet-dry feeder were more sensitive to differences in feeder opening and increased with greater feeder opening. The increased feed cost associated with the greater feed intake from the wet-dry feeder eliminated any net benefit from achieving a heavier final BW. Producers who want to benefit from the improved pig growth rate observed with a wet-dry feeder should determine the net benefit of achieving an optimal market weight in fewer days to market and the associated improvements in throughput and facility utilization.

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Figure 1. Wet-dry feeder at setting 6 with a 0.50-in. opening and ≈35% pan coverage.

Figure 2. Wet-dry feeder at setting 10 with a 0.75-in. opening and ≈57% pan coverage.

Figure 3. Wet-dry feeder at setting 14 with a 1.00-in. opening and ≈65% pan coverage.

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Figure 4. Conventional dry feeder at setting 6 with a 0.59- to 0.81-in. opening and ≈9% pan coverage.

Figure 5. Conventional dry feeder at setting 8 with a 0.80- to 1.07-in. opening and ≈21% pan coverage.

Figure 6. Conventional dry feeder at setting 10 with a 1.09- to 1.35-in. opening and ≈79% pan coverage.

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Figure 7. Wet-dry feeder at setting 18 with a 1.25-in. opening and ≈87% pan coverage.

Figure 8. Conventional dry feeder at setting 6 with a 0.58- to 0.82-in. opening and ≈27% pan coverage.

Figure 9. Conventional dry feeder at setting 8 with a 0.83- to 1.12-in. opening and ≈57% pan coverage.

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Table 1. Diet composition (Exp. 1 and 2)[1]

	Dietary phase			
Item	50 to 100 lb	100 to 160 lb	160 to 225 lb	225 lb to mkt.
Ingredient, %				
Corn	61.46	66.53	71.45	63.35
Soybean meal (46.5% CP)	21.43	16.64	11.85	19.80
DDGS	15.00	15.00	15.00	15.00
Monocalcium P (21% P)	0.15	---	---	---
Limestone	1.00	0.95	0.90	1.00
Salt	0.35	0.35	0.35	0.35
Liquid lysine (60% Lys)	0.45	0.40	0.35	0.35
L-Threonine	0.05	0.03	0.01	0.01
VTM + phytase[2]	0.11	0.10	0.09	0.085
Paylean, 9 g/lb	---	---	---	0.025
Total	100.00	100.00	100.00	100.00
Cost[3], $/lb	0.120	0.116	0.112	0.124
Calculated analysis				
Standardized ileal digestible (SID) amino acids				
Lysine, %	1.05	0.90	0.75	0.95
Isoleucine:lysine, %	64	66	69	68
Leucine:lysine, %	158	172	191	170
Methionine:lysine, %	28	30	33	30
Met & Cys:lysine, %	57	62	68	61
Threonine:lysine, %	62	63	64	62
Tryptophan:lysine, %	17	17	17	18
Valine:lysine, %	75	79	84	80
CP, %	19.3	17.5	15.7	18.7
Total lysine, %	1.19	1.03	0.87	1.09
ME, kcal/lb	1,523	1,527	1,529	1,526
SID lysine:ME ratio, g/Mcal	3.13	2.67	2.23	2.82
Ca, %	0.50	0.44	0.41	0.47
P, %	0.46	0.41	0.39	0.42
Available P, %	0.29	0.25	0.23	0.21

[1] Each dietary phase was formulated to meet the requirements for the BW ranges described in the table.
[2] VTM = Vitamin and trace mineral premix. Optiphos 2000 provided 0.12% available P.
[3] Ingredient prices used were: corn, $195/ton; soybean meal, $325/ton; DDGS, $160/ton; limestone, $50/ton; salt, $60/ton; liquid lysine, $1,600/ton; vitamin and trace mineral premix, $3,200/ton; phytase, $5,300/ton; Paylean, $57,000/ton; and $12/ton processing and delivery fee.

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Table 2. Effects of feeder design and initial feeder adjustment on the growth performance of growing-finishing pigs (Exp. 1)[1]

	Feeder type							Probability, P <				
	Wet-dry			Conventional dry					Wet-dry		Conventional dry	
Initial feeder setting:	6	10	14	6	8	10	SEM	Feeder type	Linear	Quadratic	Linear	Quadratic
Feeder data, d 19												
Avg. max. opening[2], in.	0.50	0.75	1.00	0.81	1.07	1.35	0.023	0.0001	0.0001	---[3]	0.0001	---
Avg. min. opening[4], in.	0.50	0.75	1.00	0.59	0.80	1.09	0.027	0.01	0.0001	---	0.0001	---
Avg. opening, in.	0.50	0.75	1.00	0.70	0.94	1.22	0.024	0.0001	0.0001	---	0.0001	---
Pan coverage, %	34.9	57.3	64.5	9.0	21.1	79.0	5.70	0.01	0.001	---	0.0001	0.01
Live performance												
d 0 to 27												
ADG, lb	1.29	1.56	1.65	1.46	1.51	1.51	0.027	---	0.0001	0.01	---	---
ADFI, lb	2.36	2.83	2.95	2.70	2.79	2.86	0.034	0.02	0.0001	0.001	0.01	---
F/G	1.83	1.81	1.79	1.84	1.85	1.89	0.019	0.01	---	---	---	---
d 27 BW, lb	77.7	84.9	87.5	82.3	83.3	84.1	0.73	---	0.0001	0.02	---	---
Feed, $/pig	13.87	16.22	16.85	15.45	15.73	15.87	0.173	---	0.0001	0.001	---	---
d 27 to 69												
Feeder setting		14			8							
ADG, lb	1.99	2.05	2.04	1.89	1.89	1.90	0.022	0.0001	---	---	---	---
ADFI, lb	4.77	5.09	5.16	4.71	4.76	4.73	0.056	0.0001	0.0001	---	---	---
F/G	2.40	2.49	2.53	2.49	2.52	2.49	0.020	---	0.0001	---	---	---
d 0 to 69												
ADG, lb	1.71	1.85	1.88	1.72	1.74	1.75	0.019	0.0001	0.0001	0.02	---	---
ADFI, lb	3.81	4.20	4.29	3.92	3.98	3.98	0.042	0.001	0.0001	0.01	---	---
F/G	2.23	2.26	2.28	2.28	2.29	2.28	0.015	0.05	0.03	---	---	---
Final BW, lb	162.6	171.2	173.5	161.5	163.9	164.3	1.36	0.0001	0.0001	---	---	---
Feed, $/pig	49.50	51.97	53.13	49.50	50.03	50.45	0.597	0.003	0.001	---	---	---
IOFC[5], $	23.32	24.46	24.69	22.82	23.21	22.89	0.985	---	---	---	---	---

[1] A total of 1,296 pigs (PIC, 337 × 1050) with an initial BW of 42.8 lb were placed in 48 pens containing 27 pigs each and used in a 69-d experiment.
[2] Measured from the bottom of the feed pan (conventional dry) or shelf (wet-dry) to the bottom of the feed agitation plate (conventional dry) or feeder hopper (wet-dry) at the narrowest position.
[3] Not significant ($P > 0.05$).
[4] Measured from the bottom of the feed pan (conventional dry) or shelf (wet-dry) to the bottom of the feed agitation plate (conventional dry) or feeder hopper (wet-dry) at the widest position.
[5] IOFC = income over feed cost; calculated by subtracting the total feed cost per pig from the estimated revenue per pig using a live price of $44.73/cwt.

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Table 3. Effects of feeder design and feeder adjustment on the growth performance of growing-finishing pigs (Exp. 2)[1]

	Feeder type							Probability, P <				
	Wet-dry			Conventional dry					Wet-dry		Conventional dry	
Initial feeder setting	10	14	18	6	8	10	SEM	Feeder type	Linear	Quadratic	Linear	Quadratic
Feeder data												
Avg. max. opening[2], in.	0.75	1.00	1.25	0.82	1.12	1.36	0.058	0.001	0.001	---[3]	0.001	---
Avg. min. opening[4], in.	0.75	1.00	1.25	0.58	0.83	1.10	0.068	0.001	0.001	---	0.001	---
Avg. opening, in.	0.75	1.00	1.25	0.70	0.97	1.23	0.059	---	0.001	---	0.001	---
d 41 pan coverage, %	52.5	63.1	84.9	23.6	58.4	83.0	5.85	0.02	0.001	---	0.001	---
d 84 pan coverage, %	52.9	72.0	82.3	40.4	66.3	83.0	5.87	---	0.001	---	0.001	---
Live performance, d 0 to 93												
ADG, lb	2.08	2.15	2.22	1.95	2.03	2.02	0.038	0.0001	0.01	---	---	---
ADFI, lb	5.53	5.81	6.10	5.24	5.41	5.34	0.149	0.0001	0.01	---	---	---
F/G	2.67	2.71	2.75	2.68	2.67	2.64	0.054	---	---	---	---	---
final live BW, lb	263.1	268.5	278.0	252.4	259.4	259.6	5.54	0.01	0.05	---	---	---
Carcass and economics[5]											---	---
HCW, lb	192.1	197.9	204.5	188.6	192.4	193.5	3.97	0.05	0.04	---	---	---
Backfat depth, in.	0.67	0.67	0.73	0.65	0.64	0.64	0.016	0.001	0.01	---	---	---
with HCW as covariate	0.67	0.67	0.72	0.65	0.64	0.64	0.016	0.001	0.02	---	---	---
Loin depth, in.	2.42	2.44	2.46	2.38	2.39	2.37	0.055	---	---	---	---	---
with HCW as covariate	2.43	2.42	2.40	2.42	2.41	2.37	0.053	---	---	---	---	---
FFLI[6]	50.1	50.2	49.8	50.2	50.4	50.5	0.21	0.04	---	---	---	---
with HCW as covariate	50.2	50.1	49.5	50.4	50.5	50.5	0.19	0.001	0.02	---	---	---
Total revenue/pig, $	110.97	113.53	117.58	108.99	111.24	111.90	2.882	---	---	---	---	---
Feed, $/pig	71.92	76.34	80.58	68.50	70.98	70.12	2.135	0.001	0.01	---	---	---
Feed, $/lb gain	0.38	0.39	0.39	0.38	0.38	0.38	0.008	---	---	---	---	---
IOFC[7], $	39.05	38.93	36.99	40.49	40.26	41.78	2.327	---	---	---	---	---

[1] A total of 1,248 pigs (PIC, 337 × 1050) with an initial BW of 73.0 lb were placed in 48 pens containing 26 pigs each.
[2] Measured from the bottom of the feed pan (conventional dry) or shelf (wet-dry) to the bottom of the feed agitation plate (conventional dry) or feeder hopper (wet-dry) at the narrowest position.
[3] Not significant ($P > 0.05$).
[4] Measured from the bottom of the feed pan (conventional dry) or shelf (wet-dry) to the bottom of the feed agitation plate (conventional dry) or feeder hopper (wet-dry) at the widest position.
[5] A total of 1,021 pigs were used to determine the carcass characteristics of the feeder treatments.
[6] FFLI = fat-free lean index.
[7] IOFC = income over feed cost; calculated by subtracting the feed cost per pig from the revenue per pig using a carcass base price of $56.03/cwt and premiums/discounts.

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Effects of Feeder Design, Wet-Dry Feeder Adjustment Strategy, and Diet Type on the Growth Performance and Carcass Characteristics of Growing-Finishing Pigs[1]

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Summary

A total of 1,287 pigs (PIC 337 × 1050, initially 82.7 lb) were used to compare the effects of a conventional dry feeder, 3 wet-dry feeder adjustment strategies, and 2 diet types on growing-finishing pig performance. There were 27 pigs per pen and 6 pens per treatment. The first wet-dry strategy consisted of maintaining a setting of 18 throughout the study (WD18). The second wet-dry strategy consisted of an initial setting of 18 until d 56 followed by a reduced setting of 14 for the remainder of the experiment (WD14). The third wet-dry strategy consisted of an initial setting of 18 until d 28, a setting of 14 until d 56, and a setting of 10 for the remainder of the experiment (WD10). The conventional dry feeder remained at a setting of 8 throughout the study. The 2 diet types evaluated in this study were a corn-soybean meal-15% DDGS diet and a corn-25% DDGS-20% bakery by-product-soybean meal diet; both diets were fed over 4 dietary phases. Overall (d 0 to 92), all pigs fed using the wet-dry feeder had greater ($P < 0.001$) ADG, ADFI, and final BW than pigs fed with the conventional dry feeder. However, within the wet-dry treatments, pigs fed with WD14 and WD10 had a reduced ($P < 0.05$) ADG compared with pigs fed with WD18. Additionally, ADFI of pigs fed using WD10 was lower ($P < 0.05$) than that of pigs fed with WD18, and ADFI of pigs fed with WD14 was intermediate. There were no differences in F/G among feeder treatments, and growth performance was similar between the 2 diet types. Pigs fed using the wet-dry feeder had greater ($P < 0.02$) HCW, yield, backfat depth, revenue per pig, and feed cost per pig than pigs fed with the conventional dry feeder. The loin depth of pigs fed using the wet-dry feeder was less ($P < 0.04$) than that of pigs fed with the conventional dry feeder. Differences in backfat and loin depth resulted in pigs using the wet-dry feeder having a lower ($P < 0.001$) fat-free lean index (FFLI) than pigs fed with the conventional dry feeder. However, within the wet-dry feeder treatments, pigs fed with WD10 had a reduced ($P < 0.05$) backfat depth and increased ($P < 0.05$) FFLI compared with pigs fed with WD18. The backfat depth and FFLI of pigs fed with WD14 were intermediate. Although not significantly different, income over feed cost was numerically greatest for pigs fed using WD10, followed by conventional dry, WD18, and WD14. In conclusion, reducing the wet-dry feeder setting in later growth periods may improve carcass leanness while maintaining the advantages in growth rate.

Key words: conventional feeder, feeder adjustment, wet-dry feeder

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Introduction

An increase in the feed intake and growth rate of pigs fed using a wet-dry feeder has been demonstrated in several experiments, including recent trials at Kansas State University (Bergstrom et al., 2008[3], 2009[4], 2010a[5]b[6]). However, in some of the experiments comparing feeder designs, pigs fed from a wet-dry feeder have had poorer feed efficiency than pigs fed from a conventional dry feeder. Management factors such as feeder adjustment (Bergstrom et al., 2010a[5]) may influence growth performance of pigs fed using a wet-dry feeder. Although a reduced feeder setting of the wet-dry feeder has generally resulted in improved feed efficiency, it also reduced (or eliminated) the growth advantage over the conventional dry feeder. Therefore, a wet-dry feeder may be more sensitive to changes in feeder adjustment.

Data from recent feeder adjustment experiments suggest that changing the feeder setting of the wet-dry feeder during the growing-finishing period may be an effective method of managing growth and F/G. A greater initial feeder opening could result in an increased growth rate during the early finishing period, and then the feeder opening could be reduced in later finishing periods, resulting in pigs with F/G similar to that of pigs fed with a conventional dry feeder. Therefore, the objective of this research was to compare the effects of a conventional dry feeder, 3 wet-dry feeder adjustment strategies, 2 diet types, and the interaction of these factors on the growth performance and carcass characteristics of growing-finishing pigs.

Procedures

Procedures used in the experiments were approved by the Kansas State University Institutional Animal Care and Use Committee. The experiments were conducted at a commercial research finishing facility in southwestern Minnesota. The facility was double-curtain sided, with pit fans for minimum ventilation and completely slatted flooring over a deep pit for manure storage. Individual pens were 10 × 18 ft. Each of 12 pens was equipped with a single 60-in.-wide, 5-hole conventional dry feeder (STACO, Inc., Schaefferstown, PA) and a cup waterer. The remaining 36 pens were each equipped with a double-sided wet-dry feeder (Crystal Springs, GroMaster, Inc., Omaha, NE) with a 15-in. feeder opening on both sides that provided access to feed and water. All pens that were equipped with a wet-dry feeder also contained a cup waterer, but the cup waterers were shut off during the experiment. Therefore, the only source of water for pigs in these pens was through the feeder.

A total of 1,287 pigs (PIC 337 × 1050, initially 82.7 lb) were used to compare the effects of a conventional dry feeder, 3 wet-dry feeder adjustment strategies, and 2 diet types on growing-finishing pig performance. There were 27 pigs per pen (13 or 14 barrows and 13 or 14 gilts) and 6 replications per treatment. Three feeder adjustment strategies were evaluated for the wet-dry feeder (Figures 1, 2, 3, and 4), and a single feeder adjustment strategy was selected and used for the conventional dry feeder as a control (Figure 5). To obtain an equal number of replications across the 4 feeder treatments, 12 pens were equipped with the conventional dry feeder, and 36 pens were

[3] Bergstrom et al., Swine Day 2008, Report of Progress 1001, pp. 196-203.
[4] Bergstrom et al., Swine Day 2009, Report of Progress 1020, pp. 252-261.
[5] Bergstrom et al., Swine Day 2010, Report of Progress 1038, pp 178-189.
[6] Bergstrom et al., Swine Day 2010, Report of Progress 1038, pp 201-208.

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equipped with a wet-dry feeder to evaluate the 3 wet-dry feeder adjustment strategies. The first wet-dry strategy consisted of maintaining a setting of 18 throughout the study (WD18). The second wet-dry strategy consisted of an initial setting of 18 until d 56 followed by a reduced setting of 14 for the remainder of the experiment (WD14). The third wet-dry strategy consisted of an initial setting of 18 until d 28, a setting of 14 until d 56, and a setting of 10 for the remainder of the experiment (WD10). The conventional dry feeders were maintained at a setting of 8 throughout the study. The 2 diet types evaluated in this study were a corn-soybean meal-15% DDGS diet (CS) and a corn-25% DDGS-20% bakery by-product-soybean meal diet (BY). Both diets were fed over 4 dietary phases (Table 1).

Pen and feeder weights were measured on d 14, 28, 42, 56, 72, and 92 to determine average BW, ADG, ADFI, F/G, and feed cost per pig. On d 72, 3 pigs (2 barrows and 1 gilt) from each pen were weighed and removed for marketing. At the conclusion of the experiment on d 92, carcass data were obtained for 1,097 pigs to determine the effects of feeder treatment and diet type on carcass characteristics and profitability.

On d 20 and 83, measurements of the actual feeder opening were obtained for all of the feeders. Methods used to determine the opening of the conventional dry feeder were the same as those reported by Duttlinger et al. (2008[7]). For the wet-dry feeder, the mean gap opening was determined with two measurements (one from each side of the feeder) from the top of the feeder shelf to the bottom edge of the feed storage hopper. A digital photo of the pan/trough of each feeder was also taken. Afterward, the pictures were independently scored for percentage of pan coverage by a panel of 6 trained people. The mean pan coverage score of each feeder was used to determine the relationship between feeder opening and percentage of feed coverage.

Data were analyzed to compare the effects of the 2 feeder types (conventional dry vs. wet dry), 3 wet-dry adjustment strategies (WD18 vs. WD14 vs. WD10), and 2 diet types (CS vs. BY) by using a completely randomized design and the PROC MIXED procedure of SAS. Pen was the experimental unit. Hot carcass weight was used as a covariate for the comparison of carcass characteristics.

Results

The mean opening of the wet dry feeder was greater ($P < 0.05$) than that of the conventional dry feeder on d 20 and 83, but the mean opening of the conventional dry feeder was greater ($P < 0.05$) than that of the WD10 setting on d 83 (Table 2). The mean opening of the wet-dry feeder decreased ($P < 0.05$) with each reduction in setting from 18 to 14 to 10. There was a feeder design × diet type interaction ($P < 0.01$) for the percentage of pan coverage on d 20. This occurred because the pan coverage of the wet-dry feeder was relatively similar between the 2 diet types but the pan coverage of the conventional dry feeder was considerably greater with the BY diet than with the CS diet. There were no significant differences in pan coverage on d 83, but the pan coverage for WD10 and the conventional dry feeder were numerically the lowest.

There were no feeder × diet type interactions for growth and carcass characteristics during the experiment. From d 0 to 28, pigs fed using the wet-dry feeder had greater

[7] Duttlinger et al. Swine Day 2008, Report of Progress 1001, pp 204-214.

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($P < 0.02$) ADG and ADFI than pigs fed with conventional dry feeder (Table 3). Also, pigs fed the CS diet had greater ($P < 0.01$) ADG than those fed the BY diet (Table 4). However, there were no differences in F/G or d-28 BW among any of the treatments.

All pigs fed using the wet-dry feeder continued to have greater ($P < 0.001$) ADG and ADFI compared with pigs fed using the conventional dry feeder from d 28 to 56, and the performance of pigs fed with a reduced setting of 14 remained similar to that of pigs fed with a wet-dry setting of 18. This resulted in a heavier ($P < 0.002$) d-56 BW for pigs fed with the wet-dry feeder compared with pigs fed using the conventional dry feeder. There were no differences in F/G among feeder treatments. Pigs fed the CS diet had greater ($P < 0.01$) ADFI and poorer ($P < 0.04$) F/G than pigs fed the BY diet, but ADG and d-56 BW were similar for the 2 diet types.

From d 56 to 92 and overall (d 0 to 92), all pigs fed using the wet-dry feeder had greater ($P < 0.001$) ADG, ADFI, and final BW than pigs fed with the conventional dry feeder. However, within the wet-dry treatments, the ADG of pigs fed with WD14 and WD10 was reduced ($P < 0.05$) compared with that of pigs fed with WD18. Additionally, ADFI of pigs fed with WD10 was lower ($P < 0.05$) than that of pigs fed with WD18, and ADFI of pigs fed with WD14 was intermediate. There were no differences in F/G among feeder treatments, and growth performance was similar between the 2 diet types.

Pigs fed using the wet-dry feeder had greater ($P < 0.02$) HCW, yield, backfat depth, revenue per pig, and feed cost per pig than pigs fed with the conventional dry feeder. The loin depth of pigs fed using the wet-dry feeder was less ($P < 0.04$) than that of pigs fed with the conventional dry feeder. The differences in backfat and loin depth resulted in pigs fed with the wet-dry feeder having a lower ($P < 0.001$) fat-free lean index (FFLI) than pigs fed with the conventional dry feeder. However, within the wet-dry feeder treatments, the backfat depth of pigs fed with WD10 was reduced ($P < 0.05$) and FFLI was increased ($P < 0.05$) compared with pigs fed with WD18. The backfat depth and FFLI of pigs fed with WD14 was intermediate. Although not significantly different, income over feed cost (IOFC) was numerically greatest for pigs fed using WD10, followed by conventional dry, WD18, and WD14.

Pigs fed the CS diet had less ($P < 0.02$) loin depth and greater ($P < 0.001$) feed cost per pig than pigs fed the BY diet. However, the FFLI of pigs fed the CS and BY diets were similar. Although not significantly different, the IOFC for pigs fed the BY diet was approximately $1.48 greater than that of pigs fed the CS diet.

Discussion

In this experiment, pigs fed using the wet-dry feeder had greater ADG and ADFI than pigs fed using the conventional dry feeder, and, unlike some previous experiments done in the same research facility, there were no differences in F/G. Also, strategies to reduce the feeder setting of the wet-dry feeder during later growth phases did not affect F/G. Although changing the wet-dry setting from 18 to 14 on d 28 (WD10) did not result in changes in growth performance, reducing the wet-dry setting from 18 to 14 (WD14) and 14 to 10 (WD10) on d 56 resulted in a subsequent reduction in ADFI and ADG compared with maintaining a wet-dry setting of 18 throughout the experiment. However, ADG and ADFI of pigs fed using any of the wet-dry settings remained

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greater than those of pigs fed with the conventional dry feeder from d 56 to 92 and overall. This resulted in pigs fed using WD18, WD14, and WD10 having 7.4%, 4.6%, and 5.2%, respectively, greater final BW on d 92 than pigs fed using the conventional dry feeder.

Unlike previous experiments, the yield of pigs using the wet-dry feeder was greater than that of pigs using the conventional dry feeder. This coincided with a greater difference between the final BW determined at the farm and the live BW determined at the slaughter plant for pigs fed with the wet-dry feeder. The final BW at the farm was determined approximately 36 h before live BW was determined at the plant. The wet-dry feeder had substantially less (≈295 lb less) feed storage capacity than the conventional dry feeder, and (on the basis of the ADFI observed just before the final weighing event) there was approximately enough feed (≈64 lb/feeder) remaining in the wet-dry feeders for an additional 9 h. The conventional dry feeders contained approximately enough feed (≈137 lb/feeder) for an additional 21 h. This indicates that pigs fed using the wet-dry feeder and conventional dry feeder may not have had access to feed for approximately 27 and 15 h, respectively, before slaughter. Therefore, the differences in yield between feeder types were likely due to differences in visceral contents and weight.

As in some previous experiments, pigs using the wet-dry feeder had greater backfat depth and lower FFLI. Although the growth rate was reduced 2.6% compared with WD18, backfat depth was reduced and FFLI increased with the WD10 feeder setting. The growth rate of pigs using WD10 was still 7.2% greater than that of pigs using the conventional dry feeder, and the increased revenue per pig obtained with the wet-dry feeder was maintained with a feed cost per pig that was numerically lower than that of pigs fed using WD18. Collectively, this resulted in pigs fed using WD10 having the greatest IOFC, although IOFC was not statistically different among the feeder treatments.

In conclusion, using a wet-dry feeder may improve ADG, ADFI, and final BW of growing-finishing pigs, regardless of diet type. Although there were no differences in F/G, staged reductions in the setting of the wet-dry feeder resulted in reductions in ADG, ADFI, and backfat depth and improvements in FFLI compared with using a wet-dry feeder at a constant setting of 18. However, the ADG, ADFI, and final BW of pigs fed using staged reductions in the wet-dry setting remained greater than those of pigs fed using the conventional dry feeder. Although IOFC was similar among treatments when determined on a fixed-time basis, the growth advantages achieved with a wet-dry feeder could be economically advantageous in pig flows with a limited number of facilities or days to market. Reducing the wet-dry feeder setting in later growth periods may improve carcass leanness while maintaining the advantages in growth rate.

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Figure 1. Feed-shelf/gap-opening adjustment mechanism located inside each end of the feed storage hopper of the wet-dry feeder.

Figure 2. Wet-dry feeder at setting 18 with a 1.25-in. opening and ≈84% pan coverage.

Figure 3. Wet-dry feeder at setting 14 with a 1.00-in. opening and ≈83% pan coverage.

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Figure 4. Wet-dry feeder at setting 10 with a 0.75-in. opening and ≈63% pan coverage.

Figure 5. Conventional dry feeder at setting 8 with a 0.74- to 1.07-in. opening and ≈67% pan coverage.

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Table 1. Diet composition

	Dietary phase[1]							
	80 to 130 lb		130 to 185 lb		185 to 235 lb		235 lb to mkt.	
Item Treatment[2]:	CS	BY	CS	BY	CS	BY	CS	BY
Ingredient, %								
Corn	65.02	37.31	68.51	40.74	72.14	44.45	63.30	35.62
Soybean meal (46.5% CP)	17.80	15.60	14.60	12.25	11.05	8.60	19.80	17.35
DDGS	15.00	25.00	15.00	25.00	15.00	25.00	15.00	25.00
Bakery by-product	---	20.00	---	20.00	---	20.00	---	20.00
Monocalcium P, 21% P	0.15	---	---	---	---	---	---	---
Limestone	1.00	1.00	0.95	1.00	0.95	1.00	1.00	1.05
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Lysine sulfate	0.54	0.62	0.48	0.56	0.42	0.51	0.42	0.51
L-Threonine	0.03	0.01	0.01	---	---	---	0.01	---
VTM + Optiphos 2000[3]	0.11	0.11	0.10	0.10	0.09	0.09	0.09	0.09
Paylean, 9 g/lb	---	---	---	---	---	---	0.025	0.025
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Cost, $/lb[4]	0.085	0.083	0.081	0.079	0.077	0.075	0.093	0.091
Calculated analysis								
Standardized ileal digestible (SID) amino acids								
Lysine, %	0.96	0.98	0.85	0.86	0.73	0.74	0.95	0.96
Isoleucine:lysine, %	64	66	66	69	69	72	68	70
Leucine:lysine, %	164	169	176	183	194	201	171	177
Methionine:lysine, %	29	30	31	33	34	36	30	32
Met & Cys:lysine, %	59	62	63	67	69	74	62	65
Threonine:lysine, %	60	60	62	62	63	66	62	63
Tryptophan:lysine, %	17	17	17	17	17	17	18	18
Valine:lysine, %	76	79	80	83	85	88	80	83
CP, %	17.9	19.4	17.1	18.5	15.7	17.1	19.0	20.4
Total lysine, %	1.10	1.13	0.98	1.01	0.85	0.88	1.09	1.12
ME, kcal/lb	1,524	1,552	1,529	1,555	1,530	1,555	1,527	1,553
SID lysine:ME ratio, g/Mcal	2.86	2.86	2.52	2.52	2.16	2.17	2.82	2.81
Ca, %	0.49	0.48	0.44	0.47	0.42	0.46	0.47	0.50
P, %	0.44	0.44	0.40	0.43	0.39	0.41	0.42	0.45
Available P, %	0.28	0.29	0.25	0.26	0.23	0.25	0.21	0.26

[1] Each dietary phase was formulated for the BW ranges described in the table.
[2] CS = Corn-soybean meal-15% DDGS, BY = Corn-DDGS-bakery by-product-soybean meal.
[3] VTM = Vitamin and trace mineral premix. Optiphos 2000 provided 0.07 to 0.12% available P.
[4] Ingredient prices used were: corn, $121/ton; soybean meal, $296/ton; DDGS, $98/ton; bakery by-product, $135/ton; limestone, $40/ton; salt, $64/ton; lysine sulfate, $1,000/ton; L-threonine, $2,580/ton; vitamin and trace mineral premix, $2,365/ton; phytase, $4,980/ton; Paylean, $66,000/ton; and $12/ton processing and delivery fee.

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Table 2. Effect of feeder design, diet type, and changing feeder adjustment of a wet-dry feeder on feeder gap opening and pan coverage during the growing-finishing period[1]

Feeder design:	Wet-dry						Conventional dry						
Feeder setting strategy:	18-18-18		18-18-14		18-14-10		8			*P* <			
Diet type[2]:	CS	BY	CS	BY	CS	BY	CS	BY	SEM	Feeder design × Diet type	Feeder design	Diet type	Wet-dry setting
Feeder data	(18 setting)		(14 setting)		(10 setting)								
Max. opening,[3,4] in.	1.25[a]		1.00[b]		0.75[c]		1.07[d]		0.014	N/A[5]	0.001	N/A	0.001
Min. opening,[6] in.	1.25[a]		1.00[b]		0.75[c]		0.74[c]		0.017	N/A	0.001	N/A	0.001
Avg. opening, in.	1.25[a]		1.00[b]		0.75[c]		0.91[d]		0.015	N/A	0.001	N/A	0.001
d 20 pan coverage, %	73	80	N/A	N/A	N/A	N/A	41	86	7.0	0.01	---[7]	0.001	N/A
d 83 pan coverage, %	76	89	78	84	64	62	58	69	10.1	---	---	---	---

[1] A total of 24 pens containing 27 pigs each.
[2] CS = Corn-soybean meal-15% DDGS, BY = Corn-DDGS-bakery by-product-soybean meal.
[3] Means within a row with different superscripts differ ($P < 0.05$).
[4] Measured from the bottom of the feed pan (conventional dry) or shelf (wet-dry) to the bottom of the feed agitation plate (conventional dry) at the narrowest position or feeder hopper (wet-dry).
[5] N/A = not applicable.
[6] Measured from the bottom of the feed pan (conventional dry) or shelf (wet-dry) to the bottom of the feed agitation plate (conventional dry) at the widest position or feeder hopper (wet-dry).
[7] Not significant ($P > 0.05$).

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Table 3. Effects of feeder design and changing feeder adjustment of a wet-dry feeder on the growth performance and carcass characteristics of growing-finishing pigs[1]

Feeder design:	Wet-dry			Conventional dry		*P* <	
Feeder setting strategy:	18-18-18	18-18-14	18-14-10	8	SEM	Feeder design	Wet-dry setting
Live performance							
d 0 to 28 feeder setting:	18	18	18	8			
ADG, lb	2.13	2.08	2.10	1.99	0.026	0.001	N/A[2]
ADFI, lb	4.68	4.71	4.70	4.53	0.056	0.02	N/A
F/G	2.20	2.26	2.24	2.28	0.22	---[3]	N/A
d 28 BW, lb	142.1	140.7	141.9	138.6	2.06	---	N/A
d 28 to 56 feeder setting:	18	18	14	8			
ADG, lb	2.19	2.16	2.18	1.96	0.024	0.001	---
ADFI, lb	6.37	6.26	6.25	5.65	0.073	0.001	---
F/G	2.90	2.90	2.86	2.89	0.025	---	---
d 56 BW, lb	203.6	201.2	203.1	193.4	2.35	0.002	---
d 56 to 92 feeder setting:	18	14	10	8			
ADG[4], lb	2.54[a]	2.41[b]	2.39[b]	2.28	0.030	0.001	0.05
ADFI, lb	7.20[a]	6.97[ab]	6.73[b]	6.46	0.086	0.001	0.05
F/G	2.84	2.89	2.82	2.83	0.027	---	---
d 0 to 92							
ADG, lb	2.30[a]	2.23[b]	2.24[b]	2.09	0.018	0.001	0.05
ADFI, lb	6.15[a]	6.04[ab]	5.94[b]	5.60	0.062	0.001	0.05
F/G	2.67	2.71	2.66	2.68	0.018	---	---
d 92 BW, lb	292.2	284.6	286.2	272.0	2.75	0.001	---
Carcass and economics							
HCW, lb	209.6	205.6	207.8	198.2	2.33	0.01	---
Yield, %	76.5	76.7	76.9	75.9	0.26	0.02	---
Backfat depth, in.	0.77[a]	0.75[ab]	0.73[b]	0.69	0.011	0.001	0.05
Loin depth, in.	2.49	2.47	2.50	2.57	0.032	0.04	---
FFLI[5]	49.3[a]	49.4[ab]	49.7[b]	50.2	0.14	0.001	0.05
Revenue/pig, $	142.56	139.68	142.49	136.61	1.699	0.02	---
Feed, $/pig	72.68	71.61	70.86	66.54	0.725	0.001	---
IOFC[6], $	69.88	68.07	71.34	70.07	1.255	---	---

[1] A total of 1,287 pigs (PIC, 337 × 1050) with an initial BW of 82.7 lb were placed in 48 pens containing 27 pigs each. Carcass data were obtained for 1,097 pigs. Hot carcass weight was used as a covariate for comparison of backfat depth, loin depth, and FFLI.
[2] N/A = not applicable.
[3] Not significant ($P > 0.05$).
[4] Means for the wet-dry feeder treatments within a row with different superscripts differ ($P < 0.05$).
[5] FFLI = fat-free lean index.
[6] IOFC = income over feed cost; calculated by subtracting feed cost per pig from revenue per pig using a carcass base price of $66.97/cwt and premiums/discounts.

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Table 4. Effects of diet type on the growth performance and carcass characteristics of growing-finishing pigs[1]

	Diet type			
	Corn-soybean meal with 15% DDGSS	Corn-soybean meal with 25% DDGS and 20% bakery by-product	SEM	*P* <
Live performance				
d 0 to 28				
ADG, lb	2.11	2.04	0.018	0.01
ADFI, lb	4.69	4.61	0.039	---[2]
F/G	2.22	2.26	0.016	---
d 28 BW, lb	141.7	139.9	1.45	---
d 28 to 56				
ADG, lb	2.14	2.11	0.017	---
ADFI, lb	6.23	6.03	0.052	0.01
F/G	2.92	2.86	0.018	0.04
d 56 BW, lb	201.7	199.0	1.66	---
d 56 to 92				
ADG, lb	2.41	2.40	0.021	---
ADFI, lb	6.85	6.82	0.061	---
F/G	2.84	2.84	0.019	---
d 0 to 92				
ADG, lb	2.23	2.20	0.013	---
ADFI, lb	5.98	5.88	0.044	---
F/G	2.68	2.68	0.013	---
d 92 BW, lb	285.3	282.2	1.94	---
Carcass and economics				
HCW, lb	207.1	203.5	1.69	---
Yield, %	76.4	76.7	0.19	---
Backfat depth, in.	0.75	0.73	0.008	---
Loin depth, in.	2.47	2.55	0.027	0.02
FFLI[3]	49.6	49.8	0.10	---
Revenue/pig, $	141.15	139.51	1.231	---
Feed, $/pig	71.91	68.94	0.513	0.001
IOFC[4], $	69.10	70.58	0.909	---

[1] A total of 1,287 pigs (PIC, 337 × 1050) with an initial BW of 82.7 lb were placed in 48 pens containing 27 pigs each. Hot carcass weight was used as a covariate for comparison of backfat depth, loin depth, and fat-free lean index.

[2] Not significant ($P > 0.05$).

[3] FFLI = fat-free lean index.

[4] IOFC = income over feed cost; calculated by subtracting the feed cost per pig from the revenue per pig using a carcass base price of $66.97/cwt and premiums/discounts.

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The Effects of Feeder Design and Changing the Availability of Water from a Wet-Dry Feeder at 4 and 8 Weeks Prior to Marketing on Growth Performance and Carcass Characteristics of Growing-Finishing Pigs[1]

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

Summary

A total of 1,296 pigs (PIC, 337 × 1050) were used to evaluate the effects on growth performance and carcass characteristics of feeder design (conventional dry feeder vs. wet-dry feeder) and changing availability of water from a wet-dry feeder at 4 and 8 wk prior to marketing. There were 27 pigs per pen (14 barrows and 13 gilts) and 24 pens per feeder-type. Pigs were fed identical corn-soybean meal diets with 15% dried distillers' grains with solubles (DDGS). Pens with a wet-dry feeder had a separate cup waterer, but the feeder provided the sole water source until d 69. The water supply to the wet-dry feeder was shut off in 8 pens on d 69 (WD8) and another 8 pens on d 97 (WD4), and the cup waterer was turned on. For the remaining 8 pens, the wet-dry feeder provided the sole water source for the entire experiment (WD0). From d 0 to 69, pigs using the wet-dry feeder had improved ($P < 0.05$) ADG, ADFI, F/G, and d 69 BW. Overall (d 0 to 124), pigs using WD0 had greater ($P < 0.05$) ADG, ADFI, final BW, and HCW than all other treatments. Pigs using WD4 had greater ($P < 0.05$) ADG than pigs that used a conventional dry feeder, and WD8 was intermediate. Pigs using WD4 had greater ($P < 0.05$) ADFI than WD8, and conventional dry was intermediate. Pigs using WD0 had poorer ($P < 0.05$) F/G than WD8 and conventional dry, and pigs using WD4 were intermediate. Backfat depth of pigs using WD8 was reduced ($P < 0.05$) compared to all other treatments, and loin depth was greater ($P < 0.05$) than that of pigs using a conventional dry feeder and WD4. Loin depth of pigs using WD0 was also greater ($P < 0.05$) than that of pigs with the conventional dry feeder. The percentage fat-free lean of pigs using WD8 was greater ($P < 0.05$) than WD4, and WD0, and pigs that used the conventional dry feeder were intermediate. Income-over-feed cost was numerically greatest for pigs using WD8. In conclusion, pigs using WD0 had better growth rates than pigs using the conventional dry feeder, WD4, or WD8. Although measures of carcass leanness were improved with WD8, the reduction in growth rate observed for this treatment during the last 8 wk eliminated any net improvement in the overall growth rate from using a wet-dry feeder.

Key words: conventional feeder, water, wet-dry feeder

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

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Introduction

Recent research at Kansas State University (Bergstrom et al., 2008[3] and 2009[4]) has demonstrated that using a wet-dry feeder improves the feed intake and growth rate of finishing pigs, but they may also have poorer feed efficiency and greater backfat depth. These differences in feed efficiency and leanness are of concern because they may eliminate the potential benefits associated with an improved growth rate.

Because the greater growth rate may be responsible for the poorer F/G and greater backfat depth, research may be beneficial to identify methods to sustain the improved growth rate obtained with a wet-dry feeder during the early finisher period and slow the late-finishing growth to a similar level as from a dry feeder. A wet-dry feeder typically provides fewer eating spaces than a conventional dry feeder because the eating behavior of pigs fed with a wet-dry feeder is different than that of pigs eating from a conventional dry feeder (Gonyou and Lou, 2000[5]). Also, as pigs grow, the number of meals and time spent at the feeder typically decreases while the rate of consumption increases (Hyun et al., 1997[6]). With 12 pigs per pen and an initial BW of 119 pounds, Amornthewaphat et al. (2000[7]) demonstrated that the performance of finishing pigs using a single-space, wet-dry feeder design with water provided separately was similar to those using a two-hole conventional dry feeder. This indicates that the increased growth observed with a wet-dry feeder may be due to the availability of water with feed, rather than the design of the feeder, and that the wet-dry feeder may provide adequate space when used as a dry feeder in late finishing. However, the effects of changing the source of water from a wet-dry feeder to a separate source (while maintaining an otherwise adequate supply) on growing-finishing pig performance have not been reported.

Therefore, the objective of this research was to evaluate the effects of feeder design and changing the availability of water from a wet-dry feeder at 4 and 8 weeks prior to marketing on growth performance and carcass characteristics of growing-finishing pigs.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved procedures used in the experiment, which was conducted in a commercial research finishing facility in southwestern Minnesota. The facility was double-curtain sided with pit fans for minimum ventilation and completely slatted flooring over a deep pit for manure storage. Individual pens were 10 × 18 ft. One-half of the pens were equipped with a single 60-in.-wide, 5-hole conventional dry feeder (STACO, Inc., Schaefferstown, PA) and a cup waterer in each pen (Figure 1). Each remaining pen was equipped with a double-sided, wet-dry feeder (Crystal Springs, GroMaster, Inc., Omaha, NE) with a 15-in.-wide feeder opening on both sides to provide access to feed and water (Figure 2). All pens that were equipped with a wet-dry feeder also contained a cup waterer. Both sources of water for the pens with a wet-dry feeder were equipped with individual shut-off valves so the water source could be selected or changed.

[3] Bergstrom et al., Swine Day 2008, Report of Progress 1001, pp. 196-203.
[4] Bergstrom et al., Swine Day 2009, Report of Progress 1020, pp. 252-261.
[5] Gonyou, H. W. and Z. Lou. 2000. Effects of eating space and availability of water in feeders on productivity and eating behavior of grower/finisher pigs. J. Anim. Sci. 78:865-870.
[6] Hyun et al. 1997. Feed intake pattern of group-housed growing-finishing pigs monitored using a computerized feed intake recording system. J. Anim. Sci. 75:1443-1451.
[7] Amornthewaphat et al. Swine Day 2000, Report of Progress 858, pp. 123-126.

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A total of 1,296 pigs (PIC, 337 × 1050, initially 42.8 lb) were used to evaluate the effects of feeder design (conventional dry vs. wet-dry feeder) and changing availability of water from a wet-dry feeder on growing-finishing pig performance. Pigs were weighed and allotted to the 2 feeder types. There were 27 pigs per pen (14 barrows and 13 gilts) and 24 pens per feeder-type. All pigs were fed the same corn-soybean meal diets with 15% DDGS during 4 dietary phases (Table 1). The last dietary phase contained ractopamine HCl (Paylean), and was initiated on d 97. Pens with a wet-dry feeder had a separate cup waterer, but the wet-dry feeder provided the sole water source until d 69. On d 69, water to the wet-dry feeder was shut off and the cup waterer turned on in 8 of the pens with a wet-dry feeder (WD8). This process was repeated with an additional 8 pens equipped with a wet-dry feeder on d 97 (WD4). For the remaining 8 pens with wet-dry feeders, the feeder provided the sole source of water for the entire experiment (WD0).

Pen and feeder weights were measured on d 14, 28, 42, 56, 69, 97, and 124 to determine average BW, ADG, ADFI, F/G, and feed cost per pig. On d 104, 3 pigs (2 barrows and 1 gilt) from each pen were weighed and removed for marketing. At the conclusion of the experiment on d 124, carcass data were obtained for 829 pigs from 38 pens (20 conventional dry and 18 wet-dry) to determine the effects of feeder treatment on HCW, yield, backfat depth, loin depth, fat-free lean index (FFLI), revenue per pig, and income-over-feed cost (IOFC).

Data were analyzed using a completely randomized design and the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) to compare the effects of the 2 feeder types (wet-dry vs. conventional dry) from d 0 to 69, and the 3 wet-dry feeder (WD0, WD4, and WD8) and single conventional dry feeder treatments from d 69 to 124 and overall (d 0 to 124). Pen was the experimental unit.

Results

During the initial period, from d 0 to 69, pigs using the wet-dry feeder had greater ($P < 0.05$) ADG, ADFI, d 69 BW, and better F/G than those using the conventional dry feeder (Table 2).

When the availability of water for WD8 was switched from the feeder to the cup on d 69, pigs fed using WD0 and WD4 had greater ($P < 0.05$) ADG, ADFI, and ending BW from d 69 to 97 than pigs that used the conventional dry feeder and WD8. Also, pigs fed using the conventional dry feeder had greater ($P < 0.05$) ADG and ADFI than that of pigs using WD8. Pigs fed with conventional dry and WD4 had improved ($P < 0.05$) F/G compared to WD8, and the F/G of WD0 was intermediate.

When the availability of water for WD4 was switched from the feeder to the cup on d 97, pigs fed using WD0 had greater ($P < 0.05$) ADG than those that used the conventional dry feeder and WD4 from d 97 to 124, and ADG of WD8 and conventional dry was also greater ($P < 0.05$) than that of WD4. Pigs fed using WD0 had greater ($P < 0.05$) ADFI and ending BW than all other treatments. The F/G of pigs fed using WD8 was improved ($P < 0.05$) when compared to WD0 and WD4. The F/G of conventional dry was intermediate to WD8 and WD0, but was improved ($P < 0.05$) compared to WD4.

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Overall (d 0 to 124), pigs fed using WD0 had greater ($P < 0.05$) ADG than all other feeder treatments. Among the other treatments, pigs fed using WD4 had greater ($P < 0.05$) ADG than pigs that used the conventional dry feeder, and that of pigs using WD8 was intermediate. The ADFI of pigs fed with WD0 was also greater ($P < 0.05$) than all other feeder treatments. However, pigs fed using WD4 had greater ADFI than those using WD8, and conventional dry feeder was intermediate. Pigs fed with WD0 had poorer ($P < 0.05$) F/G than those fed with WD8, but pigs fed with WD4 and conventional dry were intermediate. The final BW and HCW of pigs using WD0 were greater ($P < 0.05$) than that of all other feeder treatments. Backfat depth was reduced ($P < 0.05$) for pigs fed using WD8 compared to all other feeder treatments. Loin depth of pigs fed using WD8 was greater ($P < 0.05$) than that of pigs fed with WD4 and pigs that used the conventional dry feeder. Additionally, pigs fed using WD0 had greater ($P < 0.05$) loin depth than pigs that used the conventional dry feeder, with treatment WD4 being intermediate. The fat-free lean index (FFLI) of pigs fed using WD8 was greater ($P < 0.05$) than that of pigs using WD4, and WD0 and conventional dry treatments were intermediate. Despite the differences in growth and carcass characteristics, there were no significant differences in revenue per pig, feed cost per pig, and income-over-feed cost per pig (IOFC) among the treatments.

Discussion

As in previous experiments, ADG, ADFI, and final BW were increased with a wet-dry feeder during the first 69 d. However, when the availability of water was switched from the wet-dry feeder to a cup waterer, ADG and ADFI declined immediately after the switch. Although the ADFI and ADG of the pigs receiving the WD8 treatment were similar to those of pigs that used the conventional dry feeder treatment from d 97 to 124, the reduction in performance observed from d 69 to 97 eliminated the benefit of water availability in the feeder from d 0 to 69. Therefore, the overall growth performance of WD8 treatment and the conventional dry feeder were not different.

Unlike some recent experiments, backfat depth and FFLI were not different between the WD0 and conventional dry feeder treatments. Although the pigs fed with WD0 had a greater final BW and HCW, they also had a numerically greater feed cost per pig. Therefore, there was not a significant difference in IOFC. However, it is interesting that the backfat depth of pigs fed using WD8 declined, and their loin depth was greater, compared to that of pigs fed with the conventional dry feeder. This was accomplished with similar overall growth performance and final BW, but contributed to the numerically greater IOFC for pigs using WD8. The backfat depth and FFLI of pigs fed with WD0, WD4, and the conventional dry feeder were very similar, and they also had similar IOFC.

These data suggest that the availability of water with feed in the wet-dry feeder was responsible for the improved ADFI and ADG. The performance of pigs fed with WD8 was similar from d 97 to 124 to that of pigs fed with the conventional dry feeder, indicating that the wet-dry feeder design provided adequate feeder space for late-finishing pigs when used as a "dry" feeder with water provided separately. However, the abrupt change in the availability of water from WD8 to a separate cup waterer on d 69 resulted in a considerable reduction in ADG and ADFI during an apparent adaptation period from d 69 to 97. Although this feeder management strategy successfully slowed the

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late-finishing growth of pigs fed from the wet-dry feeder and resulted in reduced carcass backfat depth, the earlier benefits of using the wet-dry feeder to increase growth rate and BW were lost.

In conclusion, using the wet-dry feeder (WD0) improved ADG, ADFI, final BW, and HCW of growing-finishing pigs in this experiment. However, changing the availability of water from the wet-dry feeder to a separate cup waterer at 8 wks prior to marketing (WD8) resulted in similar overall growth performance to that of pigs fed with a conventional dry feeder, but with less carcass backfat and greater loin depth. Changing the availability of water from the wet-dry feeder to a separate waterer at 4 weeks prior to marketing (WD4) resulted in ADG that was intermediate to pigs fed with WD0 and the conventional dry feeder. Although pigs fed with WD0 had a heavier final BW, the numerically greater feed cost per pig resulted in similar IOFC to those fed using the conventional dry feeder. The FFLI and IOFC of pigs fed using WD8 were numerically greater than the other treatments. Abruptly changing the source of water from the wet dry-feeder to a separate source clearly reduced growth performance in the subsequent time period when compared to the performance of pigs fed with the conventional dry feeder. Changing the water source at 8 weeks prior to market reduced backfat depth at market compared to pigs fed with the wet-dry feeder throughout the finishing phase. Although further refinements are needed, this demonstrates that switching the water source away from the feeder during the finishing period may be a way to mitigate the negative effects of wet-dry feeders on backfat depth. Feeder design and provision of water, as well as their management, influence the growth of growing-finishing pigs.

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Table 1. Diet composition[1]

	Dietary phase			
Item	50 to 100 lb	100 to 160 lb	160 to 225 lb	225 lb to mkt.
Ingredient, %				
Corn	61.46	66.53	71.45	63.35
Soybean meal (46.5% CP)	21.43	16.64	11.85	19.80
DDGS[2]	15.00	15.00	15.00	15.00
Monocalcium P (21% P)	0.15	---	---	---
Limestone	1.00	0.95	0.90	1.00
Salt	0.35	0.35	0.35	0.35
Liquid lysine (60% Lys)	0.45	0.40	0.35	0.35
L-Threonine	0.05	0.03	0.01	0.01
VTM + phytase[3]	0.11	0.10	0.09	0.085
Paylean, 9 g/lb	---	---	---	0.025
Total	100.00	100.00	100.00	100.00
Cost, $/lb[4]	0.120	0.116	0.112	0.124
Calculated analysis				
Standardized ileal digestible (SID) amino acids				
Lysine, %	1.05	0.90	0.75	0.95
Isoleucine:lysine, %	64	66	69	68
Leucine:lysine, %	158	172	191	170
Methionine:lysine, %	28	30	33	30
Met & Cys:lysine, %	57	62	68	61
Threonine:lysine, %	62	63	64	62
Tryptophan:lysine, %	17	17	17	18
Valine:lysine, %	75	79	84	80
CP, %	19.3	17.5	15.7	18.7
Total lysine, %	1.19	1.03	0.87	1.09
ME, kcal/lb	1,523	1,527	1,529	1,526
SID lysine:ME ratio, g/Mcal	3.13	2.67	2.23	2.82
Ca, %	0.50	0.44	0.41	0.47
P, %	0.46	0.41	0.39	0.42
Available P, %	0.29	0.25	0.23	0.21

[1] Each dietary phase was formulated to meet the requirements for the BW ranges described in the table.
[2] Dried distillers grains with solubles.
[3] VTM = Vitamin and trace mineral premix. The phytase source, Optiphos 2000, provided 0.12% available P.
[4] Ingredient prices used were: corn, $195/ton; soybean meal, $325/ton; dried distillers grains with solubles, $160/ton; limestone, $50/ton; salt, $60/ton; liquid lysine, $1,600/ton; vitamin and trace mineral premix, $3,200/ton; phytase, $5,300/ton; Paylean, $57,000/ton; and $12/ton processing and delivery fee.

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Table 2. The effects of feeder design and changing the availability of water from a wet-dry feeder at 4 and 8 wk prior to marketing on growth performance and carcass characteristics of growing-finishing pigs[1]

Feeder design:	Wet-dry feeder (WD)					
Water with feed:	throughout (WD0)	to d 97 (WD4)	to d 69 (WD8)	Conventional dry (CD) w/separate cup waterer	SEM	WD vs. CD *P* <
Growth performance						
d 0 to 69						
ADG, lb	1.84	1.81	1.80	1.74	0.027	0.001
ADFI, lb	4.18	4.08	4.03	3.96	0.067	0.02
F/G	2.27	2.25	2.24	2.28	0.015	0.05
d 69 BW, lb	171.0	168.6	167.7	163.3	1.81	0.001
d 69 to 97[2]						
ADG, lb	1.93[a]	1.99[a]	1.62[b]	1.82[c]	0.037	---[3]
ADFI, lb	6.12[a]	6.07[a]	5.29[b]	5.69[c]	0.067	---
F/G	3.18[ab]	3.07[a]	3.28[b]	3.13[a]	0.052	---
d 97 BW, lb	225.3[a]	224.3[a]	213.6[b]	214.6[b]	1.76	---
d 97 to 124						
ADG, lb	2.33[a]	2.01[b]	2.24[ac]	2.18[c]	0.064	---
ADFI, lb	6.81[a]	5.86[b]	6.11[b]	6.12[b]	0.135	---
F/G	2.93[ab]	2.95[b]	2.73[c]	2.81[ac]	0.058	---
d 0 to 124						
ADG, lb	1.96[a]	1.89[b]	1.84[bc]	1.84[c]	0.017	---
ADFI, lb	5.14[a]	4.88[b]	4.73[c]	4.78[bc]	0.042	---
F/G	2.63[a]	2.58[ab]	2.56[b]	2.60[ab]	0.017	---
d 124 BW, lb	283.8[a]	274.9[b]	269.5[b]	270.1[b]	2.38	---
Carcass & economics[4]						
HCW, lb	211.7[a]	205.6[b]	201.9[b]	203.7[b]	2.26	---
Yield, %	75.4	75.4	75.4	75.9	0.41	---
Backfat depth, in.	0.77[a]	0.78[a]	0.70[b]	0.74[a]	0.019	---
Loin depth, in.	2.43[ab]	2.31[bc]	2.55[a]	2.30[c]	0.065	---
FFLI[5]	49.5[ab]	49.2[a]	50.0[b]	49.6[ab]	0.24	---
Revenue/pig, $	129.45	125.88	126.28	125.23	2.057	---
Feed cost/pig, $	75.86	73.41	70.23	72.81	2.435	---
IOFC[6], $	53.59	52.45	56.05	52.42	2.101	---

[1] A total of 1,296 pigs (PIC, 337 × 1050, initially 42.8 lb) were placed in 48 pens containing 27 pigs each.
[2] Means within the same row having different superscripts differ ($P < 0.05$).
[3] The main effects of feeder design were not compared for response criteria beginning on d 69, and the differences between feeder treatments were determined using the PDIFF option of SAS.
[4] Carcass data were obtained for 829 pigs from 38 pens (20 conventional dry and 18 wet-dry feeders) to determine the effects of feeder treatment on carcass characteristics and profitability.
[5] FFLI = fat-free lean index.
[6] IOFC = income over feed cost, calculated by subtracting the feed cost/pig from the revenue/pig determined using premiums/discounts and a base live price of $44.73/cwt.

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Figure 1. Conventional dry feeder with cup waterer.

Figure 2. Wet-dry feeder.

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The Effects of Diet Form and Feeder Design on the Growth Performance and Carcass Characteristics of Growing-finishing Pigs[1]

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

Summary

A total of 1,290 growing pigs (PIC 1050 × 337, initially 103.1 lb) were used in a 91-d study to evaluate the effects of diet form (meal vs. pellet) and feeder design (conventional dry vs wet-dry) on finisher pig performance. The treatments were arranged in a 2 × 2 factorial with 11 replications per treatment and 25 to 27 pigs per pen. Half of the pens were equipped with a 5-hole conventional dry feeder while the other half had a double-sided wet-dry feeder. All pigs were fed a corn-soybean meal-based diet containing 45 to 65% by-products in 4 phases. The only difference among treatments was diet form (meal vs. pellet). Pen weights and feed disappearance were measured on d 0, 16, 21, 43, 57, 71, and 91. Pictures of feeder pans were taken during Phase 4 and then evaluated by a panel of 4 for percentage of pan coverage. From d 0 to 91, no diet form × feeder design interactions were observed for ADG. Pigs fed pelleted diets had a tendency for improved ($P < 0.07$) ADG compared to those given meal diets. In addition, pigs fed with wet-dry feeders had improved ($P < 0.01$) ADG compared to those with conventional dry feeders. A diet form × feeder design interaction was observed ($P < 0.04$) for ADFI. When using a wet-dry feeder, pigs given meal diets had similar ADFI as those fed pelleted diets. However, when using dry feeders, pigs given pelleted diets had a much greater ADFI than pigs fed meal diets. In addition, a diet form × feeder design interaction was observed for F/G. Pigs fed both meal and pelleted diets via wet-dry feeders had similar F/G, but pigs fed pelleted diets in a conventional dry feeder had poorer F/G compared to pigs given meal diets in a conventional dry feeder. The pellets used during this experiment had average percentage fines of 35.1 ± 19% and an average pellet durability index (PDI) of 75.8 ± 8.4. We attribute the interactions to the poor pellet quality, leading to more feed wastage from the dry feeders. These results suggest that pellet quality is important to decrease feed wastage and sorting by the pigs and to optimize growth performance.

Key words: feeder, feed processing, pelleting

Introduction

With tightening profit margins, producers are looking for ways to improve feed efficiency and optimize gain without increasing diet costs. Recent research (Bergstrom et al., 2008[3]) has shown that pigs fed with wet-dry feeders have increased feed intake and gain. In addition, research has shown ADG typically increases 4 to 6% when pigs are

[1] Appreciation is expressed to New Horizon Farm for use of pigs and facilities and to Richard Brobjorg, Scott Heidebrink, and Marty Heintz for technical assistance.

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

[3] Bergstrom et al., Swine Day 2008, Report of Progress 1001, pp 196-203.

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presented pelleted diets via a conventional dry feeder. Previous research done at Kansas State University (Amornthewaphat et al., 2000[4]) has shown that feeding pelleted diets via a wet-dry feeder had little impact on growth performance in finisher pigs. This study, conducted in a university research facility, also utilized diets with no added by-products, which results in a higher quality pellet. However, since feeding diets without by-products is no longer common, it is important to determine whether feeding pelleted diets containing by-products via wet-dry feeders is beneficial. In addition, we wanted to determine whether it is practical to implement pelleted diets into a commercial operation. Therefore, the objective of the study was to evaluate the effects of diet form (meal vs. pellet) and feeder design (conventional dry vs. wet-dry) on finishing pig performance.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted in a commercial research finishing facility in southwestern Minnesota.

A total of 1,290 growing pigs (PIC 1050 × 337, initially 103.1 lb) were used in a 91-d trial. Pens were randomly allotted to treatments based on average initial weight and number of pigs per pen. There were 25 to 27 pigs per pen and 11 pens per treatment. The number of barrows and gilts within each pen was the same across all pens. The treatments were arranged in a 2 × 2 factorial with the main effects of diet form (meal vs. pellets) and feeder design (conventional dry vs. wet-dry). Half of the pens were equipped with a conventional 5-hole dry feeder (STACO, Shafferstown, PA). The other half contained a double-sided, wet-dry feeder that provided both feed and water via a 15-in feeder opening on either side (Crystal Springs, Gro Master, Omaha, NE). All pens contained cup waterers. All the wet-dry feeders were adjusted to setting 14, or 1.00-in. minimum gap width. Conventional dry feeders that contained the meal diets were adjusted to setting 8, or a minimum gap width of 1.00 in. Conventional dry feeders with pelleted diets were adjusted to setting 6, or 0.70-in. minimum gap width, for the duration of the trial.

Pigs were provided ad libitum access to feed and water. A common diet containing 45 to 65% by-products was fed in four dietary phases (Table 1). Diets differed only in form: meal vs. pellet. Average daily gain, ADFI, and F/G were determined by weighing pigs and measuring feed disappearance on d 0, 16, 29, 43, 57, 71, and 91. On d 71, 3 pigs (2 barrows and 1 gilt) from each pen were weighed and then removed for marketing. At the conclusion of the trial, d 91, carcass data were obtained for 939 pigs to determine HCW, percentage yield, backfat depth, loin depth, and fat-free lean index. Pictures of feeder pan coverage were taken during Phase 4 and then scored by a panel of 4 for percentage of pan coverage. Feed samples were taken during each phase and then analyzed for percentage fines and PDI (pellet durability index). Percentage fines were determined using a number 6 screen, while PDI was determined by tumbling 500-g samples of feed for 10 minutes, and then using a number 6 screen to sift off the fines.

[4] Amornthewaphat et al., Swine Day 2000, Report of Progress 858, pp 127-131.

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Data were analyzed as a 2 × 2 factorial in a completely randomized design using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). Pen was the experimental unit.

Results and Discussion

From d 0 to 91, no diet form × feeder design interactions were observed for ADG. Pigs fed pelleted diets had a tendency for improved ($P < 0.07$) ADG compared to those presented meal diets (Table 2). In addition, pigs with wet-dry feeders had increased ($P < 0.01$) ADG compared to those with conventional dry feeders. A diet form × feeder design interaction was observed ($P < 0.04$) for ADFI. Pigs fed meal diets with a dry feeder had lower feed intake ($P < 0.05$) compared to those fed the other treatments. In addition, we observed a diet form × feeder design interaction for F/G ($P < 0.01$). Pigs fed both meal and pelleted diets via wet-dry feeders had similar F/G, but pigs fed pelleted diets in a conventional dry feeder had poorer F/G than pigs given meal diets in a conventional dry feeder.

An interaction was observed for feeder coverage score, where pigs fed both pelleted and meal diets in wet-dry feeders had similar feeder pan coverage ($P < 0.01$; Figures 1 to 4). The interaction was because pigs presented pelleted diets in conventional dry feeders had substantially more feeder pan coverage compared to pigs fed meal diets in conventional dry feeders. We believe the increased pan coverage in the dry feeders can be attributed to increased sorting of the feed due to poorer quality pellets. The pelleted diets averaged 35.1% fines, with a PDI of 75.8. However, when feed was presented in the wet-dry feeders, pigs were unable to sort the pelleted diets due to the addition of water. This led to similar pan coverage in the wet-dry feeders between the meal and pelleted diets. Additionally, the conventional dry feeder had to be set with a wider opening for pelleted diets than for meal diets to prevent feeder plugging. This was not a problem with the wet/dry shelf feeder. We believe the pan coverage and pellet quality indexes explain why, in this trial, pigs fed the pelleted diets had poorer feed efficiency compared to those fed meal diets in the dry feeders. This is in contrast to other research that suggests that feeding pelleted diets results in improved feed efficiency.

There were no diet × feeder interactions or effects of diet detected for any of the carcass criteria evaluated (Table 3). However, pigs fed with conventional dry feeders had less ($P < 0.01$) backfat depth compared to pigs with the wet-dry feeders. This resulted in pigs fed with dry feeders having higher ($P < 0.01$) percent lean compared to those with wet-dry feeders. This difference was apparent even after adjustment to a common carcass weight. Therefore, similar to previous research findings in these same barns, feeding pigs with conventional dry feeders resulted in leaner carcasses compared to pigs with wet-dry feeders.

Similar to other studies in these barns, the wet-dry feeders improved both ADG and feed intake compared to conventional dry feeders but resulted in pigs with fatter carcasses. As expected, feeding pelleted diets tended to improve ADG. However, with the dry feeders, feeding pelleted diets unexpectedly led to poorer feed efficiency when using conventional dry feeders and no difference between meal and pellet feeding when using wet-dry feeders. We believe the poorer feed efficiency was the result of increased

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feed wastage. We attribute the increased feed wastage with the dry feeders to increased sorting by the pigs due to poorer quality pellets.

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

Item	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Ingredient, %					
Corn	33.32	22.15	21.11	27.71	28.18
Soybean meal, (46.5% CP)	16.70	12.10	9.05	9.20	13.60
DDGS[3]	45.00	45.00	35.00	30.00	25.00
Bakery meal	---	15.00	30.00	30.00	30.00
Limestone	1.30	1.25	1.07	1.04	0.99
Salt	0.38	0.14	0.20	0.20	0.20
Vitamin premix	0.09	0.09	0.08	0.08	0.08
Liquid lysine, 60%	---	---	0.54	0.54	0.59
Lysine sulfate	0.64	0.65	---	---	---
Threonine	---	---	---	0.01	0.12
Phytase[4]	0.01	0.01	0.01	0.01	0.01
Tylan 40	0.01	0.01	0.01	0.01	---
Paylean[5]	---	---	---	---	0.03
Total	100	100	100	100	100
Calculated analysis[6]					
Standardized ileal digestible amino acids,%					
Lysine	1.06	0.95	0.84	0.84	0.97
Isoleucine:lysine	76	78	76	73	68
Methionine:lysine	34	35	35	34	30
Met & Cys:lysine	68	72	72	69	61
Threonine:lysine	66	67	65	64	70
Tryptophan:lysine	19.7	19.9	19.3	18.6	17.8
Total lysine, %	1.19	1.07	0.94	0.94	1.08
CP, %	23.5	22.0	19.3	18.6	19.5
ME kcal/lb	1,453	1,499	1,532	1,510	1,523
Ca, %	0.65	0.63	0.55	0.53	0.52
P, %	0.56	0.53	0.47	0.45	0.44
Available P,%	0.42	0.42	0.36	0.33	0.31

[1] Phase 1, 2, 3, 4, and 5 diets were fed from 95 to 135, 135 to 175, 175 to 205, 205 to 230, and 235 to 280 lb BW, respectively.
[2] All dietary phases were fed in both diet forms to each feeder type.
[3] Dried distillers grains with solubles
[4] OptiPhos 2000; Enzyvia LLC, Sheridan, IN.
[5] Paylean; Elanco Animal Health, Greenfield, IN.
[6] NRC. 1998. Nutrient Requirements of Swine. 10th ed. Natl. Acad. Press, Washington, D.C.

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Table 2. Effects of diet form and feeder design on finishing pig performance[1]

	Conventional-dry		Wet-dry			*P*-values		
Item	Meal	Pellet	Meal	Pellet	SEM	Diet	Feeder	Diet × Feeder
d 0 to 91								
ADG, lb	1.86	1.88	1.96	1.99	0.014	0.07	0.01	0.70
ADFI, lb	5.05[a]	5.40[b]	5.51[b]	5.54[b]	0.052	0.01	0.01	0.04
F/G	2.72[a]	2.87[c]	2.81[b,c]	2.77[a,b]	0.033	0.07	0.91	0.01
Feeder coverage score, %[2]	59[a]	90b[c]	74[ab]	78[b]	5.70	0.01	0.79	0.02

[1] A total of 1,290 growing pigs (PIC 1050 × 337, initially 103.1 lb) were used, with 25 to 27 pigs per pen and 11 pens per treatment.

[2] Pictures of feeder pan coverage were taken once during Phase 4. A panel of 4 then scored feeder pan pictures for percentage of pan coverage.
[a,b,c] Means lacking a common superscript within row differ ($P < 0.06$)

Table 3. Effects of diet form and feeder design on carcass characteristics[1]

	Conventional-dry		Wet-dry feeder			*P*-value		
Item	Meal	Pellet	Meal	Pellet	SEM	Diet	Feeder	Diet × Feeder
HCW, lb	202.3	204.3	207.55	206.9	2.56	0.77	0.09	0.54
Yield, %	75.6	75.3	75.6	76.0	0.003	0.95	0.19	0.24
Backfat depth, in.[2]	0.68	0.68	0.74	0.72	0.02	0.40	0.01	0.57
Loin depth, in.[2]	2.44	2.38	2.35	2.33	0.04	0.39	0.11	0.64
Lean, %[2]	55.8	55.7	54.4	54.6	0.46	0.97	0.01	0.77
Income/pig,$	147.72	148.52	148.87	148.84	1.75	0.80	0.63	0.79
Sort loss[3]	-0.79	-0.99	-1.10	-1.21	0.27	0.49	0.26	0.86

[1] A total of 1,290 growing pigs (PIC 1050 × 337, initially 103.1 lb) were used, with 25 to 27 pigs per pen and 11 pens per treatment. Carcass data were obtained for 939 pigs from 44 pens to determine the effects of diet form and feeder design on carcass characteristics.
[2] Percentage lean, backfat depth, loin depth, and percentage fat-free lean were adjusted to a common HCW.
[3] Sort loss was calculated based upon carcass weight.

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Figure 1. Conventional dry feeder with meal diets averaged 59% feeder pan coverage.

Figure 2. Conventional dry feeder with pelleted diets averaged 90% feeder pan coverage.

Figure 3. Wet-dry feeders with meal diets averaged 74% feeder pan coverage.

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Figure 4. Wet-dry feeder with pelleted diets averaged 78% feeder pan coverage.

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Effects of Increasing Stocking Density on Finishing Pig Performance[1]

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Summary

A total of 1,201 finishing pigs (initially 63 lb) were used in a 99-d growth trial to evaluate the effects of increasing stocking density on finishing pig growth performance. Single-sex pens of barrows and gilts were blocked to minimize variation due to gender and barn location. There were 12 pens per block with 3 replication pens per treatment within each block. Pens of pigs were randomly allotted to 1 of 4 treatments with 12 pens per treatment. Treatments were stocking pens with 22, 24, 26, or 28 pigs each, allowing 8.2, 7.5, 6.9, and 6.4 ft^2 per pig, respectively. Pens of pigs were weighed and feed intake was determined on d 0, 14, 28, 42, 56, 70, 84, and 99 to calculate ADG, ADFI, and F/G. Pigs were fed common diets throughout the trial. No adjustments were made at the pen level to account for space increases because of removed pigs.

Overall, as stocking density increased, ADG and ADFI decreased (linear; $P < 0.001$), but there were no differences (linear; $P = 0.99$) in F/G. These performance differences resulted in off-test (d 99) pig weights decreasing (linear, $P < 0.001$) as stocking density increased. These data indicate that in this commercial barn, finisher pig ADG and ADFI improved as the number of pigs in each pen was reduced. However, based on an economic model, income over feed and facility cost per pig placed was numerically optimized when pens were stocked with 24 pigs each, allowing 7.5 ft^2 of floor space per pig.

Key words: growth, space allowance, stocking density

Introduction

Recommendations for finishing pig stocking density vary from approximately 6.0 to 9.0 ft^2 per pig, depending on factors to be optimized. Pig performance is improved with more space per pig, while facility cost per pig, economic return, and overall efficiency are likely to be improved with less space allowed. Other factors, including pig flow and facility availability, also affect practicality of achieving an optimum stocking density. A report by the National Pork Board indicated that, on average, swine operations stock pens at approximately 7.2 ft^2 per pig (2005[3]). In the facilities used for this experiment, stocking 25 pigs per pen allowed 7.2 ft^2 per pig. Understanding the effects of different stocking densities on performance can aid pig flow decision-making and help producers maximize income by balancing fixed costs with effects on performance. The objective of this experiment was to determine the effects of different stocking densities (6.4, 6.9, 7.5, or 8.2 ft^2 per pig) on performance of finisher pigs.

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

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

[3] Kliebenstein, J., M. Brumm, B. Buhr, and D. Holtkamp. 2005. Economic analysis of pig space: Comparison of production system impacts. pp. 1-38. National Pork Board (NPB #04-177).

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Procedures

The Kansas State University (K-State) Institutional Animal Care and Use Committee approved procedures used in this study. This experiment was conducted in a standard, double-curtain-sided, research finishing barn in northeast Kansas. There was slatted concrete flooring throughout the barn. Pens were 10 × 18 ft and equipped with a single-sided dry, 3-hole, stainless steel feeder (AP-3WFS-QA; Automated Production Systems, Assumption, IL) and a dual swinging waterer (Trojan Plastic Waterswing; Trojan Specialty Products, Dodge City, KS), allowing pigs to have ad libitum access to feed and water. Each hole in the feeder was 14 inches long. The barn was equipped with an automated feeding system (FeedPro; Feedlogic Corp., Willmar, MN) to allow recording of feed delivery to individual pens.

A total of 1,201 pigs were used to determine the effects of increasing pen-stocking density of commercial finishing pigs. Pens were allotted to 1 of 4 stocking density treatments and gender assignment (barrow or gilt) to distribute treatments around the barn. Treatments were stocking pens with 22, 24, 26, or 28 pigs per pen, allowing 8.2, 7.5, 6.9, and 6.4 ft^2 per pig, respectively. A set of 12 pens constituted a generalized block to minimize variation due to gender and barn location. Although barrows and gilts were penned separately, gender was likely confounded with age: The 12 gilt pens contained pigs that may have been younger than the barrows in the remaining 36 pens.

Pens of pigs were double-stocked in a second barn on the research site before the trial began. At the start of the trial (d 0), pigs were moved from the second finisher barn to the trial barn. Within gender, multiple pens of pigs were allowed to mix within the alley of the second barn. After mixing, pigs were gate-cut by stocking density treatment into their trial pens. These procedures ensured that all trial pens had initial disruption of social order as well as a random assortment of pig weights. Pens of pigs were weighed and feed intake was determined on d 0 and every 2 wk thereafter until pigs were taken off test (d 99). Pigs were fed common diets throughout the trial. If a pig died or was removed because of illness or injury, no adjustment was made to the pen to account for the additional space per pig. For the overall trial, removed pigs by treatment (1.9%, 1.0%, 1.6%, and 1.5% for the 22, 24, 26, and 28 pigs per pen treatments, respectively) were within normal production criteria for this commercial system.

Data were analyzed as a generalized blocked design with stocking-density treatment as a fixed effect and block as a random effect using the GLIMMIX procedure in SAS (SAS Institute, Inc., Cary, NC). Pen was the experimental unit for an analysis. The effects of increasing stocking density on performance and economic response criteria were determined by linear and quadratic polynomial contrasts.

Results and Discussion

Stocking density did not affect (linear; $P \geq 0.20$) ADG, ADFI, or F/G within the first 14 d of this trial (Table 1). In all subsequent periods, ADFI decreased (linear, $P < 0.001$) as stocking density increased, which led to a decrease (linear, $P \leq 0.02$) in ADG in all periods except from d 56 to 70. Stocking density did not change feed efficiency except for a small linear improvement ($P = 0.02$), from d 56 to 70, as density increased.

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Overall, as stocking density increased ADG and ADFI decreased (linear; $P < 0.001$), and F/G was not affected (linear; $P = 0.99$). On d 99, pig weights decreased (linear; $P < 0.001$) as stocking density increased, which resulted in a 13.2 lb increase in pig weight due to pens being stocked with 22 pigs compared to the pens loaded with 28 pigs. These data indicate that in this commercial barn, finisher pig ADG and ADFI was improved as stocking density was reduced.

The relationship between space allowed per pig (m^2 or ft^2) and weight in kg raised to the two-thirds power ($BW^{0.67}$) can be determined using a value defined as the *k*-value ($m^2 = k \times BW(kg)^{0.67}$) (Whittemore 1998[4]). After a review of published studies, Gonyou et al. (2006[5]) reported a range of *k*-values (range: 0.0335 to 0.0358 $m^2/BW^{0.67}$) below which feed intake was reduced for pigs on either fully or partially slatted floors. Thus, representative value of 0.035 $m^2/BW^{0.67}$ defines a critical limit below which feed intake is reduced due to inadequate space allowance per pig (Torrallardona and Roura, 2009[5]).

According to the *k*-value calculations (Table 2) for each stocking density and average pig weight from the present trial, the negative effects on feed intake should have started as pigs reached average body weights of 218.1, 191.5, 169.9, and 152.1 lb for the 22, 24, 26, and 28 pigs per pen treatments, respectively. These weight limits were not reached, and similarly feed intake should not have decreased until after d 70 for the 22 pigs-per-pen treatment, d 56 for the 24 pigs-per-pen treatment, and d 42 for both the 26 and 28 pigs-per-pen treatments. However, based on the feed consumption data recorded during this trial, after d 14, feed intake decreased linearly as stocking density increased.

The differences in trial performance compared with expected outcomes based on published responses may have been attributable to factors other than stocking density, which could have affected feed intake and subsequent growth rate. Potential influencing factors include feeder space or water access. Feeder space for the 22, 24, 26, and 28 pigs-per-pen treatment were as follows: 1.91, 1.75, 1.62, or 1.50 in. respectively, per pig. Though all pens were stocked at densities below manufacturer-recommended maximums for the feeder and waterer types, the feeder space was below that of other recommendations. It is unknown whether the amount of feeder space per pig or water access contributed to the negative effects on performance as the number of pigs per pen increased.

Regardless of potential other contributing factors, results of this trial indicate that growth rate and feed intake increased as stocking density per pen decreased. However, based on an economic model of these data (Table 3), income over feed and facility cost per pig placed was numerically highest (quadratic; $P = 0.64$) when pens were stocked with 24 pigs. Therefore, in this commercial barn the negative effects on performance from higher stocking and reduction of space per pig could not be overcome by throughput alone. Similarly, numbers and weight of pigs when stocked at 22 pigs per pen were low enough that even the improvements in ADG, compared with pigs from higher-stocked pens, could not overcome the increased facility cost per pig placed compared

[4] Whittemore, C. T. 1998. The science and practice of pig production. 2nd ed. Blackwell Science, Oxford; Malden, Mass.

[5] Torrallardona, D., and E. Roura. 2009. Voluntary feed intake in pigs. Wageningen Academic Publ, Wageningen.

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to stocking at higher densities. Therefore, these results indicate that ADFI and ADG of pigs linearly improved as stocking density was reduced from 28 to 22 pigs; however, income over feed and facility cost appeared to be numerically optimized when pens were stocked at 24 pigs per pen, allowing 7.5 ft^2 of floor space per pig.

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Table 1. Effect of stocking density on performance of commercial finishing pigs[1]

	Stocking density, pigs per pen[2]					Probability, $P <$	
Item	22	24	26	28	SEM	Linear	Quadratic
Pens, no.	12	12	12	12	---	---	---
d 0 to 14							
ADG, lb	2.07	2.08	2.05	2.04	0.065	0.20	0.82
ADFI, lb	3.56	3.57	3.54	3.53	0.132	0.59	0.77
F/G	1.71	1.72	1.73	1.73	0.019	0.45	0.86
d 14 to 28							
ADG, lb	1.94	1.83	1.77	1.77	0.065	<0.001	0.07
ADFI, lb	4.24	4.09	3.90	3.91	0.160	<0.001	0.20
F/G	2.18	2.24	2.21	2.22	0.024	0.37	0.24
d 28 to 42							
ADG, lb	2.32	2.27	2.26	2.20	0.062	<0.001	0.87
ADFI, lb	5.26	5.08	5.02	4.89	0.241	<0.001	0.65
F/G	2.26	2.23	2.22	2.22	0.053	0.13	0.52
d 42 to 56							
ADG, lb	2.10	2.06	2.03	1.95	0.107	0.008	0.66
ADFI, lb	5.91	5.75	5.68	5.53	0.289	<0.001	0.92
F/G	2.81	2.80	2.82	2.85	0.090	0.68	0.72
d 56 to 70							
ADG, lb	2.51	2.47	2.45	2.46	0.089	0.34	0.46
ADFI, lb	6.35	6.06	5.98	5.94	0.251	<0.001	0.07
F/G	2.54	2.46	2.44	2.42	0.075	0.02	0.49
d 70 to 84							
ADG, lb	2.10	2.03	2.04	1.95	0.066	0.02	0.79
ADFI, lb	6.64	6.34	6.27	6.24	0.248	<0.001	0.05
F/G	3.18	3.12	3.08	3.22	0.104	0.75	0.09
d 84 to 99							
ADG, lb	2.09	1.99	1.96	1.85	0.072	0.003	0.96
ADFI, lb	6.86	6.49	6.48	6.31	0.215	<0.001	0.25
F/G	3.28	3.30	3.34	3.45	0.157	0.16	0.59
d 0 to 99							
ADG, lb	2.16	2.10	2.08	2.03	0.050	<0.001	0.65
ADFI, lb	5.55	5.35	5.28	5.20	0.210	<0.001	0.12
F/G	2.56	2.54	2.54	2.56	0.045	0.99	0.24

continued

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Table 1. Effect of stocking density on performance of commercial finishing pigs[1]

	Stocking density, pigs per pen[2]					Probability, *P* <	
Item	22	24	26	28	SEM	Linear	Quadratic
Weight, lb							
d 0	62.9	63.0	62.6	63.0	2.41	0.95	0.86
d 14	91.9	92.1	91.3	91.6	3.27	0.73	0.96
d 28	119.4	117.7	116.0	116.4	4.11	0.05	0.39
d 42	151.8	149.5	147.7	147.2	4.86	0.007	0.46
d 56	181.3	178.2	176.3	174.7	6.04	<0.001	0.58
d 70	216.6	212.7	210.6	209.1	6.88	<0.001	0.35
d 84	246.0	241.2	239.1	236.4	7.27	<0.001	0.43
d 99	277.4	271.0	268.6	264.2	7.14	<0.001	0.52

[1] A total of 36 barrow pens and 12 gilt pens with 22 to 28 pigs per pen were used in a 99-d growth trial.
[2] Stocking density treatments (12 pens per treatment: 3 gilt pens and 9 barrow pens) were 22, 24, 26, and 28 pigs per pen, providing approximately 8.2, 7.5, 6.9, and 6.4 ft^2 per pig, respectively.

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Table 2. Determination of *k*-values for different stocking densities and pig weights[1]

	Stocking density, pigs per pen[2]				*k*-value[3,4]			
Item	22	24	26	28	22 pigs	24 pigs	26 pigs	28 pigs
Space per pig, ft^2	8.18	7.50	6.92	6.43	---	---	---	---
BW when *k* = 0.035, lb[5]	218.1	191.5	169.9	152.1	---	---	---	---
Weight, lb								
d 0	62.9	63.0	62.6	63.0	0.080	0.074	0.068	0.063
d 14	91.9	92.1	91.3	91.6	0.062	0.057	0.053	0.049
d 28	119.4	117.7	116.0	116.4	0.052	0.049	0.045	0.042
d 42	151.8	149.5	147.7	147.2	0.045	0.041	0.038	0.036
d 56	181.3	178.2	176.3	174.7	0.040	0.037	**0.034**	**0.032**
d 70	216.6	212.7	210.6	209.1	0.035	**0.033**	**0.030**	**0.028**
d 84	246.0	241.2	239.1	236.4	**0.032**	**0.030**	**0.028**	**0.026**
d 99	277.4	271.0	268.6	264.2	**0.030**	**0.028**	**0.026**	**0.024**

[1] Average pig weight reported for each stocking density and weigh day.
[2] Stocking density treatments were 22, 24, 26, and 28 pigs per pen providing approximately 8.2, 7.5, 6.9, and 6.4 ft^2 per pig, respectively.
[3] *k*-Values calculated using a formula reported by Whittemore (1998): Space per pig (m^2) = *k*×BW (kg)$^{0.67}$ or Space per pig (ft^2)/10.7639) = *k*×((BW (lb)/2.2046)$^{0.67}$.
[4] Bold type with shaded background indicate *k*-values below 0.035, the critical *k*-value for adequate feed intake (Torrallardona and Roura, 2009).
[5] Calculated body weight for each stocking density when *k* = 0.035, the critical *k*-value for adequate feed intake (Torrallardona and Roura, 2009).

Table 3. Economic impact of different stocking densities on pig performance[1]

	Stocking density, pigs per pen[2]					Probability, *P* <	
Item	22	24	26	28	SEM	Linear	Quadratic
Total weight[3]							
Pig weight produced, lb/pen	5985.4	6437.3	6890.5	7283.7	169.75	<0.001	0.65
Revenue[4]							
Pen revenue, $/pen	3292	3541	3790	4006	93.36	<0.001	0.65
Total feed consumption							
Feed usage, lb/pen	11,925	12,652	13,514	14331	505.5	<0.001	0.65
Costs							
Feed cost, $/pen[5]	954	1012	1081	1146	40.439	<0.001	0.65
Facility cost, $/pen[6]	272	272	272	272	---	---	---
Income over feed and facility cost							
IOFAFC, $/pen[7]	2065.75	2256.14	2436.40	2587.29	55.763	<0.001	0.51
IOFAFC, $/pig placed[8]	93.90	94.01	93.41	92.40	2.223	0.34	0.64

[1] A total of 1,201 pigs, initially 63 lb, were used in a 99-d trial with 22 to 28 pigs per pen and 12 pens per treatment.
[2] Stocking density treatments were 22, 24, 26, and 28 pigs per pen, providing approximately 8.2, 7.5, 6.9, and 6.4 ft2 per pig, respectively.
[3] Total weight produced; calculated as (initial weight × initial no. pigs per pen) + [(off-test weight × no. pigs per pen at off-test) - (initial weight × initial no. pigs per pen)]
[4] Based on live value of $55/cwt.
[5] Based on diet cost of $160/ton.
[6] Based on $0.11/pig/day × 25 pigs/pen × 99 days.
[7] Income over feed and facility cost (IOFAFC); calculated as (revenue - feed cost - facility cost).
[8] Income over feed and facility cost (IOFAFC) per pig placed; calculated as (revenue - feed cost - facility cost)/initial no. pigs placed.

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Effects of Mixing Late-Finishing Pigs Just Before Marketing on Growth Performance[1]

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

Summary

A total of 512 commercial finishing pigs were used in a 15-d trial to determine the effects of mixing late-finishing pigs from 1 or 2 barns at different stocking densities on pig performance prior to marketing. Close-to-market-weight pigs from 2 barns (north barn or south barn) were placed in 32 single-sex pens in the north barn at densities of either 12 or 20 pigs per pen. Pens of pigs were allotted to 1 of 4 mixing treatments (8 pens per treatment). Mixing treatments were: (1) nonmixed pens with 12 north barn pigs (control), (2) mixing 6 north barn pigs with 6 south barn pigs (Mix 1), (3) mixing 10 north barn pigs with 10 south barn pigs (Mix 2), and (4) mixing 10 north barn pigs with 10 more north barn pigs (Mix 3). All pigs were fed a common diet during the trial. Pens of pigs were weighed and feed disappearance determined on d 0, 8, and 15 to determine ADG, ADFI, and F/G. All response criteria were adjusted to a common initial weight in the analysis. Results from this trial indicate that pen inventories had a large impact on performance, with pigs stocked at 12 pigs per pen having greater ADG ($P \leq 0.06$) and ADFI ($P \leq 0.02$) than those stocked at 20 pigs per pen. Overall, there was no difference in performance for nonmixed control pigs and mixed pigs when stocked at a similar density (12 pigs per pen). These data indicate, in the 2 wk prior to market, increasing the number of pigs per pen had a larger effect on performance than mixing pigs. Although performance was negatively affected immediately after mixing, overall performance of mixed pigs was not different than that of nonmixed pigs. Therefore, given adequate time to adjust to a new environment and establish a new social order, mixing pigs does not appear to affect overall performance.

Key words: growth, management at marketing, mixing

Introduction

Variation in pig weights within barns managed on an all/in-all/out basis has led to adoption of strategies to minimize profit loss due to marketing of lightweight pigs. Mixing or combining pens of pigs around the time of marketing has become a common practice to assist with pig flow. This allows space to be emptied for washing and refilling while allowing remaining pigs to be held for additional weight gain. Past research has shown that mixing of grow-finish pigs negatively affects ADG immediately after mixing. Some reports also indicate that, with enough time allowed, mixed pigs may experience compensatory gain that mitigates the negative effects of mixing.

The objective of this trial was to determine the effects on pig performance of mixing different numbers of close-to-market-weight pigs from 1 or 2 barns prior to marketing.

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

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Procedures

The Kansas State University (K-State) Institutional Animal Care and Use Committee approved procedures used in this study. This trial was conducted in a double-curtain-sided research finishing barn (north barn) in northeast Kansas. Pens were 10 × 18 ft and equipped with a single-sided dry, 3-hole, stainless-steel feeder (AP-3WFS-QA; Automated Production Systems, Assumption, IL) and a double-nipple swinging waterer (Trojan Plastic Waterswing, Trojan Specialty Products, Dodge City, KS), allowing pigs to have ad libitum access to water and feed. The barn was equipped with an automated feeding system (FeedPro; Feedlogic Corp., Willmar, MN) that recorded feed delivery to individual pens. Pigs for this trial were sourced from 2 barns (north barn and south barn), each stocked with pigs of similar ages. The second barn (south barn) was identical to the north barn in construction and equipment and was connected to the north barn by a curtain-sided hallway containing a pen-sized scale.

A total of 512 late-finishing pigs (average initial BW: 256 lb) were used in a 15-d trial to determine the effects of mixing pigs at different stocking densities on growth performance of pigs remaining in the barn after topping (first marketing) and second marketing. Pigs used in this trial were from 2, 50-pen barns on the same site, with pigs from 2 sources (south barn: maternal line only; north barn: terminal and maternal lines). Pigs had been previously marketed out of both barns, with the last loads having been marketed the morning the trial began (d 0). A total of 32 pens of pigs were allotted to 1 of 4 mixing treatments on d 0, and no additional marketing occurred from the barn until the trial was completed. Mixing treatments were: (1) nonmixed pens with 12 north barn pigs (control), (2) mixing 6 north barn pigs with 6 south barn pigs within a pen (Mix 1), (3) mixing 10 north barn pigs with 10 south barn pigs within a pen (Mix 2), and (4) mixing 10 north barn pigs with 10 north barn pigs within a pen (Mix 3). There were 4 barrow and 4 gilt pens per treatment (8 pens per mixing treatment).

On d 0, pigs remaining in each barn were inventoried, and control pens were determined by using 8 north barn pens (4 barrow and 4 gilt pens), which contained a minimum of 12 remaining pigs. When necessary, some pigs were removed from these pens to create stocking densities of 12 pigs per pen. Mixing within gender an equal number of north or south barn pigs, in accordance with the appropriate sources and stocking density for the assigned treatment, created the pens for the 3 mixed-pen treatments. There were no standard conditions set on how many pens of pigs could be mixed to make the required numbers, so some variation occurred in the number of original pens used to create the new mixed pens. However, each new pen was sourced from a minimum of 2 pens, ensuring that social rank in each mixed pen was disrupted.

For the duration of the trial, a common diet was fed in meal form without the addition of ractopamine hydrochloride. Pens of pigs were weighed and feed disappearance determined on d 0, 8, and 15. From these data, ADG, ADFI, and F/G were calculated.

Data were analyzed using the GLIMMIX procedure in SAS (SAS Institute, Inc., Cary, NC), with pen as the experimental unit. The model included mixing treatment as a fixed effect and initial average pen weight as a covariate because there were numeric differences in initial average pig weight. For this study, gender was potentially confounded with genetic background, thus gender was used as a random effect to

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account for variation between barrow and gilt pens. Differences between treatments were determined by using least squares means ($P < 0.05$).

Results and Discussion

In the 8 d after mixing pigs, despite ADG being similar ($P = 0.13$; Table 1) among the treatments, all 3 mixed-pig treatments demonstrated numerically lower ADG than the nonmixed control pigs. Some of the numerical reduction in growth rate can be attributed to the differences in ADFI during the first 8 d. Control pigs had increased ($P < 0.01$) ADFI compared with Mix 2 or Mix 3 pigs, while the Mix 1 pigs had intermediate feed intake. Feed to gain, although similar ($P = 0.50$) among treatments, was numerically poorer for the 3 mixed-pig treatments compared with the control pigs. The intake reduction coupled with a poorer feed efficiency explains the numerically lower ADG for the mixed pigs in the first few days after mixing, as pigs established their new social order and adapted to new surroundings. In addition, a portion of the negative effects on ADG, ADFI, and F/G may be attributable to the higher stocking density or reduced feeder space per pig for the Mix 2 and Mix 3 treatments compared with the control and Mix 1 treatments. Pens stocked with 12 pigs had 3.5 in. of feeder space and 15.0 ft^2 of pen space per pig. In contrast, pens stocked with 20 pigs allowed 2.1 in. of feeder space per pig and 9.0 ft^2 per pig of pen space.

From d 8 to 15, control and Mix 1 pigs had greater ($P \leq 0.04$) ADG than the Mix 3 pigs, with Mix 2 pigs intermediate. Pens stocked at 12 pigs each (the non-mixed control and Mix 1 pens) had increased ($P \leq 0.02$) ADFI compared with both mixed pens stocked at 20 pigs per pen. These differences may be associated with stocking density, because the low-density mixed pens (Mix 1) had similar ($P = 0.69$) intake compared with the non-mixed control pens. There was no treatment ($P = 0.13$) effect on F/G from d 8 to 15, though F/G was numerically improved from the previous period.

The results from d 0 to 8 and d 8 to 15 suggest that the number of pigs per pen had a large impact on performance. Overall, ADFI was lower ($P \leq 0.02$) for the higher stocking-density pens (20 vs. 12 pigs per pen). Because of the difference in ADFI, overall ADG was decreased ($P < 0.01$) and off-test weight lighter ($P \leq 0.005$) for the Mix 3 treatment (20 pigs per pen) than for the control and Mix 1 (both stocked at 12 pigs per pen). Mix 2 (20 pigs per pen) tended to have lower ($P \leq 0.06$) ADG and weigh less ($P \geq 0.07$) compared with treatments stocked at 12 pigs per pen.

These data indicate that increasing the number of pigs per pen had a greater effect on performance than mixing pigs. Despite early numerical negative effects of mixing, overall, there was no difference in performance for mixed pigs and nonmixed control pigs when stocked at a similar density (12 pigs per pen). Therefore, mixing of pigs prior to market does not appear to affect overall performance as long as pigs are allowed time to adjust to the environment and establish a new social structure.

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Table 1. Effect of mixing pigs from multiple barn sources on performance of late-finishing pigs just before marketing[1]

Item	Control[2]	Mix 1	Mix 2	Mix 3	SEM[3]	Probability, $P <$
Counts						
Pens, no.	8	8	8	8	---	---
Pigs per pen, no.	12	12	20	20	---	---
Source barns per pen, no.	1	2	2	1	---	---
d 0 to 8[4]						
ADG, lb	1.90	1.76	1.58	1.46	0.201	0.13
ADFI, lb	7.29[a]	6.82[ab]	6.25[b]	6.35[b]	0.282	0.02
F/G	3.85	4.06	4.29	4.44	0.410	0.50
d 8 to 15[4]						
ADG, lb	2.16[ab]	2.32[a]	1.97[bc]	1.87[c]	0.097	0.01
ADFI, lb	7.92[a]	8.04[a]	7.23[b]	7.11[b]	0.234	0.003
F/G	3.71	3.50	3.70	3.82	0.138	0.41
d 0 to 15[4]						
ADG, lb	2.02[a]	2.02[a]	1.76[ab]	1.65[b]	0.123	0.01
ADFI, lb	7.59[a]	7.39[a]	6.70[b]	6.71[b]	0.251	0.006
F/G	3.78	3.67	3.89	4.08	0.152	0.13
Weight, lb[5]						
d 8	271.0	269.9	268.4	267.4	1.60	0.12
d 15	286.2[a]	286.1[a]	282.6[ab]	280.5[b]	1.74	0.01

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

[1] Initially, a total of 512 late-finishing pigs (barrows and gilts with initial average BW of 256 lb) with 12 or 20 pigs per pen sourced from 1 or 2 barns (north barn or south barn) were used in a 15-d growth trial.

[2] Mixing treatments were: (1) nonmixed control pens with 12 north barn pigs (control), (2) mixing 6 north barn pigs with 6 south barn pigs (Mix 1), (3) mixing 10 north barn pigs with 10 south barn pigs (Mix 2), and (4) mixing 10 north barn pigs with 10 more north barn pigs (Mix 3).

[3] Due to initial weight adjustment, the SEM varied among treatments. The highest SEM among the treatments is reported.

[4] ADG, ADFI, and F/G were adjusted to a common d 0 weight.

[5] Weights for d 8 and 15 were adjusted to a common d 0 weight.

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Effects of Switching Diet Formulations on Finishing Pig Performance[1]

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

Summary

A total of 1,239 finishing pigs (initially 43 lb) were used in a 41-d trial to determine the effects on ADG, ADFI, and F/G of switching every 2 wk from a corn-soybean meal-based diet to a diet containing alternative ingredients. Pens of pigs were weighed and allotted randomly to 1 of 4 dietary treatments. Dietary treatments were: (1) feeding a corn-soybean meal-based diet; (2) feeding an alternative ingredient-based diet; (3) feeding both diets in succession by feeding 2 wk of the corn-soybean meal-based diet followed by 2 wk of the diet with alternative ingredients, then feeding the corn-soybean meal-based diet again for 2 wk (Switch 1); or (4) feeding both diets in succession by feeding 2 wk of the diet with alternative ingredients followed by 2 wk of the corn-soybean meal-based diet, then feeding the diet with alternative ingredients again for 2 wk (Switch 2). Nutrient specifications of the corn-soybean meal-based diet and alternative ingredient-based diet were similar within phase, and diets were fed in 2 phases (Phase 1: 4 wk, and Phase 2: 2 wk). Pigs were weighed and feed intake was recorded by pen on d 0, 13, 27, and 41 to determine ADG, ADFI, and F/G.

Although performance among pigs fed the different dietary treatments was variable throughout the testing periods, dietary treatment did not affect ($P \geq 0.07$) overall ADG or ADFI. This resulted in pigs being of similar ($P = 0.41$) off-test weight, regardless of the diet (corn-soybean meal-based or alternative ingredient-based diets) or diet sequence (Switch 1 or Switch 2). Therefore, in this study with diets formulated to similar nutrient specifications but having different ingredients, pigs had comparable performance regardless of whether a corn-soybean meal-based diet or an alternative ingredient-based diet was fed continuously or whether pigs were fed these same 2 diets alternated every 2 wk.

Key words: alternative ingredients, diet formulation, diet switching

Introduction

Swine diets are formulated with available ingredients to optimize profitability through reduced cost or improved performance. Historically, swine diets in the Midwestern United States have been based on corn and soybean meal; however, with large amounts of corn by-products available, more alternative ingredients are being used to lower diet cost. Some examples of alternative ingredients used in swine diets are dried distillers grains with solubles (DDGS), and hominy feed. The pricing of these alternative ingredients is sometimes more volatile than that of corn and soybean meal. Thus, as prices fluctuate, so do the optimum diet formulation and inclusion percentages. As ingredi-

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

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ents are substituted, pig diet formulations often shift abruptly, even though nutrient specifications remain consistent. Nonnutritive characteristics of ingredients, such as palatability or odor, may affect feed intake and growth performance with changes in diet formulation. Sudden and frequent formulation changes may exacerbate the effects. Little work has been done to determine what effects abrupt changes in diet formulations may have on finishing-pig performance. Objectives of this trial were to determine the effects on finishing-pig performance of switching diet formulation extremes between a corn-soybean meal-based diet and a diet containing alternative ingredients (DDGS and hominy feed).

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved procedures used in this study. The study was conducted at a commercial research facility in northeastern Kansas. The barn was double-curtain-sided and naturally ventilated, with deep pits for manure storage. All 44 pens used for the trial were 10 × 18 ft with totally slatted flooring and equipped with a single-sided dry, 3-hole, stainless-steel feeder (AP-3WFS-QA; Automated Production Systems, Assumption, IL) and a double-nipple swinging waterer (Trojan Plastic Waterswing, Trojan Specialty Products, Dodge City, KS), allowing pigs ad libitum access to feed and water. The barn was equipped with an automated feeding system (FeedPro; Feedlogic Corp., Willmar, MN), which recorded feed delivery to individual pens.

A total of 1,239 finishing pigs (initially 43 lb) were used in a 41-d trial to determine the effects on pig performance of switching diet formulations. Pigs were stocked with 27 to 29 barrows or gilts in single-sex pens. Pigs were sourced from farms having 1 of 2 genetic backgrounds (maternal or terminal). Pigs were penned by source, and sources were distributed across the dietary treatments. There were 12 pens per corn-soybean meal-based diet and alternative-ingredient diet only treatments and 10 pens per treatment with switching diets (Switch 1 and Switch 2).

On d 0, pens of pigs were weighed and allotted to 1 of 4 dietary treatments. Dietary treatments were: (1) feeding a corn-soybean meal-based diet; (2) feeding an alternative ingredient-based diet; (3) feeding both diets in succession by feeding 2 wk of the corn-soybean meal-based diet followed by 2 wk of the alternative ingredient-based diet, and then 2 wk of the corn-soybean meal-based diet (Switch 1); or (4) feeding both diets in succession by feeding 2 wk of the alternative ingredient-based diet followed by 2 wk of the corn-soybean meal-based diet, followed by 2 wk of the alternative ingredient-based diet (Switch 2). Diets were fed in 2 phases (Table 1). Phase 1 diets were fed during the first 4 wk of the trial, and Phase 2 diets were fed during the last 2 wk of the trial. Pigs were weighed by pen on d 0, 13, 27, and 41. Feed intake data were recorded on weigh days, and from these data, ADG, ADFI, and F/G were calculated.

Data were analyzed as a completely randomized design using the GLIMMIX procedure of SAS (SAS Institute Inc., Cary, NC), with pen as the experimental unit. In addition to dietary treatment, the effects of gender (barrow or gilt), source, and all interactions were included as fixed effects in the model. Differences between treatments were determined by using least squares means ($P < 0.05$).

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Results and Discussion

Dietary treatment did not affect ($P \geq 0.09$) ADG, ADFI, or F/G from d 0 to 13 (Table 2). From d 13 to 27, pigs continuously fed the alternative ingredient-based diet or switched on d 13 to the alternative ingredient-based diet (Switch 1) had improved ($P \leq 0.007$) ADG compared to pigs fed the corn-soybean meal-based diet or switched to the corn-soybean meal-based diet on d 13 (Switch 2). This improved ADG was a result of pigs continuously fed the alternative ingredient-based diet or switched on d 13 to the alternative ingredient-based diet (Switch 1) having increased ($P \leq 0.001$) ADFI from d 13 to 27, compared to pigs fed the corn-soybean meal-based diet, and pigs on the Switch 2 treatment had intermediate ADFI. From d 27 to 41, dietary treatment tended ($P = 0.06$) to affect ADG and ADFI, with pigs fed the corn-soybean meal-based diet or switched to the corn-soybean meal-based diet on d 27 having numerically increased ADG and ADFI compared with pigs fed the alternative ingredient-based diet during that period (alternative ingredient-based diet treatment and Switch 2).

There was a 2-way interaction ($P = 0.03$) between diet and gender for d 27 to 41 F/G. Gilts fed the Switch 1 diet sequence had poorer (2.47 ± 0.042 vs. 2.34 ± 0.042; $P = 0.04$) F/G than barrows fed the Switch 1 diet sequence. Within other diet treatments, barrows and gilts had similar ($P \geq 0.10$) F/G.

These variable growth rate and performance differences across the trial periods resulted in no overall difference ($P \geq 0.07$) in ADG or ADFI or off-test weight among dietary treatments. Differences within phases suggest that characteristics of the diets caused differences in performance. These results indicate that overall pig performance was similar, regardless of whether corn-soybean meal-based diets or alternative ingredient-based diets were fed continuously or pigs were fed these diets in an alternating manner, as long as diets were formulated to similar nutrient specifications. Therefore, on this commercial farm, as ingredient availability or costs change, there appear to be no negative effects on performance if pigs must be switched between corn-soybean meal-based diets and alternative ingredient-based diets.

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

	Phase 1		Phase 2	
Item	Corn-soybean meal-based	Alternative ingredient-based	Corn-soybean meal-based	Alternative ingredient-based
Ingredient, %				
Corn	75.73	38.95	78.20	41.20
Soybean meal (46.5% CP)	21.75	11.95	19.60	9.75
Corn hominy feed	---	32.50	---	32.50
DDGS	---	15.00	---	15.00
Monocalcium phosphate (21% P)	0.55	---	0.33	---
Limestone	0.70	0.58	0.65	0.58
Salt	0.35	0.28	0.35	0.28
Vitamin premix with phytase	0.15	0.12	0.15	0.12
Phytase	0.05	0.03	0.05	---
Trace mineral premix	0.15	0.12	0.15	0.12
Copper sulfate	0.05	0.05	0.05	0.05
L-lysine HCl	0.37	0.40	0.35	0.37
DL-methionine	0.06	---	0.04	---
L-threonine	0.09	0.05	0.09	0.04
Total	100.00	100.00	100.00	100.00
Calculated analysis				
SID[3] amino acids, %				
Lysine	1.03	1.02	0.96	0.95
Isoleucine:lysine	59	62	59	63
Leucine:lysine	136	155	141	161
Methionine:lysine	30	30	29	31
Met & Cys:lysine	55	58	55	60
Threonine:lysine	60	60	61	61
Tryptophan:lysine	16	16	16	16
Valine:lysine	67	76	68	77
SID Lysine:ME ratio, g/Mcal	3.08	3.08	2.86	2.87
ME, kcal/lb	1,519	1,501	1,523	1,502
Total lysine, %	1.14	1.17	1.07	1.08
CP, %	17.00	19.22	16.18	18.37
Ca, %	0.52	0.54	0.46	0.53
P, %	0.48	0.53	0.42	0.52
Available P, %	0.29	0.30	0.24	0.28

[1] Phase 1 diets were fed during the first 4 wk of the trial and formulated for a weight range of 50 to 80 lb. Phase 2 diets were fed during the last 2 wk of the trial and formulated for a weight range of 80 to 110 lb.

[2] Treatment diets were corn-soybean meal-based diets or alternative ingredient-based diets containing 47.5% alternative ingredients.

[3] Standardized ileal digestible.

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Table 2. Effects of diet formulation treatment on performance of commercial finishing pigs[1,2]

Item	Corn-soybean meal-based diet	Alternative ingredient-based diet	Switch 1[3]	Switch 2[4]	SEM[5]	Probability, $P <$
Pens, no.	12	12	10	10	---	---
d 0 to 13						
ADG, lb	1.55	1.52	1.57	1.55	0.025	0.56
ADFI, lb	3.24	3.12	3.27	3.08	0.064	0.13
F/G	2.09	2.05	2.09	1.99	0.032	0.09
d 13 to 27						
ADG, lb	1.73[a]	1.85[b]	1.84[b]	1.73[a]	0.027	0.002
ADFI, lb	3.81[a]	4.11[bc]	4.20[c]	3.96[ab]	0.059	<0.001
F/G	2.21	2.22	2.28	2.28	0.028	0.10
d 27 to 41						
ADG, lb	2.10	1.99	2.11	2.09	0.034	0.06
ADFI, lb	4.98	4.77	5.07	4.87	0.080	0.06
F/G[6]	2.37	2.39	2.40	2.34	0.029	0.44
d 0 to 41						
ADG, lb	1.80	1.79	1.85	1.79	0.023	0.30
ADFI, lb	4.03	4.02	4.20	3.99	0.059	0.07
F/G	2.24	2.24	2.27	2.22	0.019	0.35
Weight, lb						
d 0	43.2	43.2	43.3	43.1	0.60	0.99
d 13	63.4	63.0	63.7	63.2	0.81	0.94
d 27	87.7	88.9	89.5	87.6	1.04	0.49
d 41	117.0	116.8	119.4	117.0	1.27	0.41

[abc] Results without a common superscript letter differ ($P < 0.05$).

[1] A total of 1,239 pigs with 27 to 29 pigs per pen were used in a 41-day trial. Pigs were weighed on d 0, 13, 27, and 41.

[2] Treatments were: (1) feeding a corn-soybean meal-based diet; (2) feeding an alternative ingredient-based diet; (3) feeding both diets by switching every 2 wk, with pigs starting on the corn-soybean meal-based diet (Switch 1); or (4) feeding both diets by switching every 2 wk, with pigs starting on the alternative ingredient-based diet (Switch 2).

[3] Pigs assigned to the Switch 1 treatment were fed the corn-soybean meal-based diet from d 0 to 13 and 27 to 41 and the alternative ingredient-based diet from d 13 to 27.

[4] Pigs assigned to the Switch 2 treatment were fed the alternative ingredient-based diet from d 0 to 13 and 27 to 41 and the corn-soybean meal-based diet from d 13 to 27.

[5] SEM among treatment groups differed because of unbalanced design. The highest SEM among the treatment groups is reported.

[6] The diet × gender interaction ($P = 0.03$) for F/G from d 27 to 41 resulted from gilts fed the Switch 1 diet sequence having poorer (2.47 ± 0.042 vs. 2.34 ± 0.042; $P = 0.04$) F/G than barrows fed the Switch 1 diet sequence, while within diet treatments, barrows and gilts had similar ($P \geq 0.10$) F/G.

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Evaluation of Feed Budgeting, Complete Diet Blending, and Corn-Supplement Blending on Finishing-Pig Performance

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Summary

A total of 283 pigs (PIC TR4 × 1050, initially 77.2 ± 1.4 lb BW) were used to compare phase feeding with blending finishing diets by using the FeedPro system (Feedlogic Corporation, Willmar, MN). There were 3 experimental treatments: (1) a standard 4-phase complete feed program, (2) blending high- and low-lysine complete diets over the entire experiment, and (3) blending ground corn and a separate complete supplement within each phase. FeedPro is an integrated feed dispensing system that can deliver and blend 2 separate diets while dispensing. The 4 phases were 77 to 120, 120 to 175, 175 to 221, and 221 to 278 lb. Each treatment had 12 replicate pens and 8 pigs per pen. Overall (77 to 278 lb), ADG and ADFI were similar ($P > 0.24$) across treatments. However, pigs fed the ground corn-supplement blend had poorer ($P < 0.01$) F/G than pigs fed diets blended in multiple phases and tended to have poorer ($P < 0.09$) F/G than pigs fed the standard phase diets. There were no differences ($P > 0.70$) in HCW, percentage yield, and loin depth across treatments. Pigs fed using phase feeding of the ground corn-supplement blend had greater ($P < 0.02$) percentage lean and lower ($P < 0.04$) fat depth than pigs fed using phase feeding of complete diets or diet blending. There were no ($P > 0.28$) statistical differences in total revenue and income over feed costs (IOFC) across treatments. However, the highest IOFC was obtained from diet blending, which had a numeric advantage of $1.44 to $2.32/pig over other treatments. In conclusion, the FeedPro system blended separate complete diets and a ground corn-supplement combination without adversely affecting growth performance and carcass characteristics.

Key words: carcass characteristics, feed blending, growth

Introduction

Pig growth and efficiency are maximized and nutrient excretion is reduced when pigs are fed diets that match their nutrient requirements. The optimal concentration of nutrients required by growing pigs generally decreases over the growing-finishing period, and phase feeding is practiced to accurately adjust to these requirements. In commercial production, phase feeding commonly involves feeding a series of 2 to 5 diets, each differing in energy or amino acid balance to match nutrient requirements at each phase. Increasing the number of feeding phases has economic and environmental

[1] Feedlogic Corporation, Willmar, MN. Appreciation is expressed to Feedlogic Corporation for financial support for this study.

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benefits (Van der Peet-Schwering et al, 1999[3]); however, it may concomitantly increase costs of feed storage and management.

Blend feeding, which involves mixing 2 base diets in proportionate ratios, can potentially increase the number of phases to more accurately meet pigs' nutrient requirements. Recent automatic feeding systems, such as the FeedPro system, have diet-blending capabilities that provide a practical means of feeding diets in multiple phases. However, few studies have been conducted to evaluate the benefits of complete diet blending in multiple phases by using an automatic feeding system.

The objective of this study was to compare the effects (i.e., growth performance, carcass characteristics, and economics) of feeding finishing pigs blended diets made from 2 base diets fed to a set lysine curve using the FeedPro system with the effects of feeding pigs a standard 4-phase feeding program. To further test the blending capabilities of the FeedPro system, we compared phase-feeding of blended complete diets with phase-feeding of a blended ground corn-supplement diet that provided a diet composition identical to that in the standard 4-phase feeding program.

Procedures

Procedures used in this study were approved by the Kansas State University (K-State) Institutional Animal Care and Use Committee. The experiment was conducted at the K-State Swine Teaching and Research Center growing-finishing facility.

A total of 283 pigs (PIC TR4 × 1050, initially 77.2 ± 1.4 lb BW) were allotted to 1 of 4 experimental treatments in a completely randomized design. Barrows and gilts were equally distributed among the treatments. Each treatment had 12 replicate pens and 8 pigs per pen (4 barrows and 4 gilts). Each pen was 8 × 10 ft and equipped with a Farmweld (Teutopolis, IL) dry, single-sided self-feeder with 2 feeding spaces. The facility also had the FeedPro system (Feedlogic Corp., Willmar, MN), an integrated feed dispensing system, and 12 feed storage bins.

There were 3 experimental treatments: (1) a standard 4-phase complete feed program (phase feeding), (2) blending high- and low-lysine complete diets over the entire experiment (diet blending), and (3) blending ground corn and a separate complete supplement within each phase (corn-supplement). All diets were dispensed using the FeedPro system, which provided ad libitum access to feed. For the standard 4-phase feeding program, 4 finishing diets (Table 1) were formulated to provide 2.72, 2.30, 2.00, and 1.81 g standardized ileal digestible (SID) lysine/Mcal ME and were fed from 77 to 120 (Phase 1), 120 to 175 (Phase 2), 175 to 221 (Phase 3), and 221 to 278 lb (Phase 4), respectively. For the diet-blending treatment, complete high-lysine and low-lysine diets (Table 1) were formulated to provide 3.15 and 1.63 g SID lysine/Mcal ME, respectively. The 2 diets were blended in varying ratios on a daily basis (Figure 1) to meet a lysine requirement curve that was set using Feedlogic feed intake data. For the corn-supplement treatment, 4 complete supplements were formulated (Table 2) and were stored separately from ground corn in feed storage bins. The FeedPro system

[3] Van der Peet-Schwering, C. M. C., A. W. Jongbloed, and A. J. A. Aarnink. 1999. Nitrogen and phosphorus consumption, utilization, and losses in pig production : The Netherlands. Livest. Prod. Sci. 58:213-224.

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blended ground corn and the complete supplement in calculated ratios (Table 2) to be identical in dietary nutrient composition to those fed the standard phase-feeding program for each growing phase. The SID lysine:ME ratios (g/Mcal) provided by the 3 feeding programs to pigs throughout the finishing period are shown in Figure 2. The figure illustrates the stair-step reduction of lysine:calorie ratios used for the phase feeding and corn-supplement treatments and the more gradual reduction in lysine:calorie ratio used in the diet-blending treatment. The gradual reduction in lysine:calorie ratio was achieved by changing the ratio of the 2 diets provided on a daily basis. All complete diets, ground corn, and supplements were manufactured at the K-State Animal Science Feed Mill.

Pigs were weighed and feed disappearance was determined at the end of each phase to calculate ADG, ADFI, and F/G. At the end of the study, pigs were tattooed and sent to Triumph Foods, LLC (St. Joseph, MO), where standard carcass criteria of hot carcass weight (HCW), carcass yield, percentage lean, and loin and backfat depth were measured. Feed cost was calculated as the sum of diet cost and grinding, mixing, and delivery (GMD) costs. The individual components of the GMD charges used were (1) grinding = $5/ton, (2) mixing = $3/ton, and (3) delivery = $7/ton. The complete diets used in phase feeding and diet blending received all 3 charges (grinding, mixing, and delivery). For the corn-supplement treatment, grinding was charged to the ground corn, mixing was charged to the supplement, and delivery was charged to both components. Feed cost per pig and feed cost per pound of gain were calculated for each phase and for the overall period of the experiment. Total revenue and income over feed cost (IOFC) were also determined under 2 scenarios (carcass base prices of $51.99 and $67.95 for Scenario 1 and 2, respectively).

Data were analyzed as a completely randomized design using the GLM procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Hot carcass weight was used as a covariate for yield, fat depth, loin depth, and percentage lean. When treatment effect was a significant source of variation, means were separated using the PDIFF option of SAS. Least square means were calculated for each independent variable. Statistical significance and tendencies were set at $P < 0.05$ and $P < 0.10$, respectively, for all statistical tests.

Results and Discussion

Average daily gain and pig weights were similar ($P > 0.13$) across treatments in each of the individual 4 phases (Table 3). In phases 1 to 3, ADFI was also similar ($P > 0.30$) across treatments; however, pigs fed using diet blending had lower ($P < 0.03$) ADFI during Phase 4 than pigs fed using phase feeding of complete diets or the corn-supplement blend. For Phase 1 (77 to 120 lb), pigs fed the corn-supplement blend had lower ($P < 0.03$) F/G than pigs fed using phase feeding of complete diets and diet blending. However, for Phase 3 (175 to 221 lb), F/G was higher ($P < 0.05$) for pigs fed the corn-supplement blend than for pigs fed with phase feeding of complete diets or with diet blending. In Phase 4 (221 to 278 lb), pigs fed using diet blending had lower ($P < 0.05$) F/G than pigs fed using phase feeding of complete diets or the corn-supplement blend.

Overall (77 to 278 lb), ADG, ADFI, and final weights were similar ($P > 0.51$) across treatments. However, pigs fed the corn-supplement blend had poorer ($P < 0.01$) F/G

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than pigs fed diets blended in multiple phases and tended to have poorer ($P < 0.09$) F/G than pigs fed using the standard phase-feeding program. These results agree with similar studies in which growth performance of finishing pigs fed using standard phase-feeding programs or multiphase programs was compared. Pomar et al. (2007[4]) compared, for pigs weighing 55 to 230 lb, a 3-phase feeding program with a daily multiphase system in which diets were blended using an automatic feeding system. In that study, pigs fed in multiple phases tended to have greater ADG than pigs fed using the standard phases; however, ADFI and F/G were similar for both groups of pigs. Moore and Mullan (2009[5]) also compared, for pigs weighing 50 to 195 lb, a conventional 3-phase feeding program with a 2-diet blend fed in weekly phases using a similar Feedlogic system and found no differences in growth performance.

In terms of carcass characteristics, there were no differences ($P > 0.70$) in HCW, percentage yield, and loin depth across treatments (Table 4). Pigs fed using phase feeding of the corn-supplement blend had greater ($P < 0.02$) percentage lean and lower ($P < 0.04$) fat depth than pigs fed using phase feeding of complete diets or diet blending in multiple phases. These results are similar to those of Moore and Mullan (2009), who showed that pigs fed in 3 phases or fed blended diets in weekly phases had similar HCW, yield, and fat depth. However, the greater lean percentage and lower fat depth observed in pigs fed the corn-supplement blend was not expected because the blend was formulated and mixed to contain the same nutrient levels and followed the same program as the standard phase feeding. Though not significant, HCW and carcass yield of pigs fed the corn-supplement blend were 2.4 to 3.5 lb lower than those of pigs fed using standard phase feeding and diet blending; this result suggests that pigs fed the corn-supplement blend were lighter at slaughter and also may have contributed to the differences observed in percentage lean and fat depth.

Feed cost per pig was $1.92 and $1.20 less for diet blending in multiple phases and phase feeding using the corn-supplement blend, respectively, than the standard phase-feeding program, but this difference was not significant (Table 5). The majority of the difference in cost for diet blending and phase feeding was due to the lower ADFI and better F/G observed in Phase 4, which resulted in a $0.98 decrease ($P < 0.05$) in feed cost per pig. For the corn-supplement blend, the cost of mixing ($3/ton) was not assessed for ground corn, which contributed to the lower GMD cost and feed cost per pig. Feed cost per pound of gain was lower ($P < 0.05$) for pigs fed the corn-supplement blend in Phase 1 and pigs fed with diet blending in phases 3 and 4, but overall, no differences were observed across the treatments. We evaluated total revenue and IOFC by using 2 carcass base prices: Scenario 1 = $51.99, October 2009 price; and Scenario 2 = $67.95, October 2008 price. In both scenarios, there were no ($P > 0.28$) statistical differences in total revenue and IOFC across treatments. However, the highest IOFC was obtained from diet blending in multiple phases; the numeric advantage over other treatments ranged from $1.44 to $2.32/pig depending on the scenario. This conforms

[4] Pomar, C., J. Pomar, D. Babot, and F. Dubeau. 2007. The impact of daily multiphase feeding on animal performance, body composition, and nitrogen and phosphorous excretion in growing-finishing pigs. Journées de la Recherche Porcine en France, 39:23-30.

[5] Moore, K., and B. Mullan. 2009. Evaluation of feeding strategies and measurement of feed consumption using the Feedlogic system: Final report. Cooperative Research Centre for an Internationally Competitive Pork Industry, Department of Agriculture and Food, Australia. http://www.porkcrc.com.au/2A-104_Final_Report_0902.pdf. Accessed November 25, 2009.

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with results of Moore and Mullan (2009), who showed that feeding pigs in weekly phases improved net return (about $3.00/pig, Australian dollars) compared with feeding pigs a standard 3-phase feeding program.

In conclusion, blending 2 complete diets in multiple phases or a blending ground corn and a complete supplement with the FeedPro system did not affect growth performance and carcass characteristics. Diet blending may provide higher net returns than standard phase feeding by effecting small improvements in feed efficiency. Although blending the ground corn and supplement resulted in poorer F/G during the last phase of the trial, the practical advantage of this feeding approach suggests that it should be investigated further.

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Table 1. Diet composition for the phase-feeding and diet-blending treatments (as-fed basis)

	Phase feeding[1]				Diet blending[2]	
Item	Diet 1	Diet 2	Diet 3	Diet 4	High Lysine	Low Lysine
Ingredient, %						
Corn	78.42	83.11	86.54	88.45	73.75	90.53
Soybean meal (46.5%)	18.95	14.61	11.40	9.63	23.30	7.70
Monocalcium phosphate (21% P)	0.50	0.30	0.23	0.15	0.70	0.05
Limestone	0.95	0.95	0.90	0.90	0.96	0.89
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.15	0.13	0.10	0.08	0.16	0.07
Trace mineral premix	0.15	0.13	0.10	0.08	0.16	0.07
Lysine HCl	0.30	0.26	0.24	0.22	0.34	0.20
DL-Methionine	0.03	0.00	0.00	0.00	0.05	0.00
L-Threonine	0.07	0.04	0.03	0.03	0.10	0.03
Phytase 600	0.13	0.13	0.13	0.13	0.13	0.13
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated composition, %						
SID[3] amino acids						
Lysine	0.91	0.77	0.67	0.61	1.05	0.55
Isoleucine:lysine	61	63	64	66	60	67
Methionine:lysine	29	28	30	32	29	34
Met & Cys:lysine	56	58	62	66	55	70
Threonine:lysine	62	62	63	65	62	66
Tryptophan:lysine	16.5	16.5	16.5	16.5	16.5	16.5
Valine:lysine	71	74	78	81	68	84
CP (N × 6.25)	15.83	14.14	12.90	12.22	17.53	11.48
Total lysine	1.01	0.86	0.75	0.69	1.16	0.63
ME, kcal/lb	1,515	1,519	1,522	1,525	1,511	1,527
SID lysine:ME, g/Mcal	2.72	2.30	2.00	1.81	3.15	1.63
Ca	0.54	0.49	0.45	0.43	0.60	0.40
P	0.46	0.40	0.37	0.35	0.51	0.32
Available P[4]	0.28	0.23	0.21	0.19	0.33	0.17

[1] Standard 4-phase complete diet feeding program; Phase 1 was from 77 to 120 lb BW, Phase 2 was from 120 to 175 lb BW, Phase 3 was from 175 to 221 lb BW, and Phase 4 was from 221 to 278 lb BW.

[2] Feed delivery was based on a lysine requirement curve; complete high- and low-lysine diets were blended throughout the duration of the experiment.

[3] Standardized ileal digestible.

[4] Phytase provided 0.10% available P to the diet.

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Table 2. Composition of the complete supplements (as-fed basis) and the proportion of ground corn and supplement by phase[1,2]

	Complete supplement			
Ingredient, %	1	2	3	4
Soybean meal (46.5%)	87.85	86.51	84.66	83.37
Monocalcium phosphate (21% P)	2.32	1.78	1.67	1.30
Limestone	4.40	5.63	6.69	7.80
Salt	1.62	2.07	2.60	3.03
Vitamin premix	0.70	0.74	0.74	0.65
Trace mineral premix	0.70	0.74	0.74	0.65
Lysine HCl	1.39	1.54	1.75	1.86
DL-Methionine	0.12	---	---	---
L-Threonine	0.34	0.25	0.22	0.26
Phytase 600	0.58	0.74	0.93	1.08
Total	100.00	100.00	100.00	100.00
Blend				
Ground corn, %	78	83	87	88
Complete supplement, %	22	17	13	12

[1] Diets were blended and feed budgeted to be identical in composition and nutrient analyses for each phase to those fed in the standard 4-phase feeding program.
[2] Phase 1 was from 77 to 120 lb BW, Phase 2 was from 120 to 175 lb BW, Phase 3 was from 175 to 221 lb BW, and Phase 4 was from 221 to 278 lb BW.

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Table 3. Effects of diet blending using the FeedPro system on finishing pig growth performance[1]

	Treatment[2]			
Item	Phase feeding	Diet blending	Corn-supplement	SEM
Pig weights, lb				
Initial	77.2	77.2	77.2	1.4
End of phase 1	120.2	120.2	120.6	1.6
End of phase 2	176.5	173.4	175.6	2.2
End of phase 3	223.2	220.9	219.7	2.6
End of phase 4	280.4	277.6	277.5	3.1
Phase 1 (77 to 120 lb)				
ADG, lb	2.05	2.05	2.07	0.02
ADFI, lb	4.68	4.72	4.59	0.06
F/G	2.29[a]	2.30[a]	2.22[b]	0.02
Phase 2 (120 to 175 lb)				
ADG, lb	2.16	2.05	2.11	0.04
ADFI, lb	5.83	5.69	5.88	0.09
F/G	2.70	2.79	2.79	0.04
Phase 3 (175 to 221 lb)				
ADG, lb	1.96	1.98	1.84	0.05
ADFI, lb	6.10	5.92	6.02	0.11
F/G	3.13[a]	3.02[a]	3.28[b]	0.06
Phase 4 (221 to 278 lb)				
ADG, lb	2.20	2.18	2.22	0.04
ADFI, lb	7.71[a]	7.37[b]	7.78[a]	0.05
F/G	3.51[a]	3.39[b]	3.51[a]	0.04
Overall (77 to 278 lb)				
ADG, lb	2.10	2.07	2.06	0.02
ADFI, lb	6.14	5.99	6.14	0.07
F/G	2.93[ax]	2.90[a]	2.98[by]	0.02

[1] A total of 288 pigs (initially 77.2 ± 1.4 lb BW) were used with 12 replicate pens per treatment and 8 pigs per pen.
[2] Phase feeding = complete diets in each phase; diet blending = blending of high- and low-lysine diets fed to a set lysine curve; corn-supplement = blending of ground corn and complete supplement.
[a,b] $P < 0.05$, [x,y] $P < 0.09$.

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Table 4. Effects of diet blending using the FeedPro system on carcass characteristics of finishing pigs[1]

	Treatment[2]			
Item	Phase feeding	Diet blending	Corn-supplement	SEM
HCW, lb	207.3	206.6	204.2	2.65
Yield[3], %	73.92	74.44	73.61	0.44
Lean[3], %	52.13[a]	52.25[a]	52.90[b]	0.19
Fat depth[3], in.	0.85[a]	0.81[a]	0.76[b]	0.02
Loin depth[3], in.	2.41	2.40	2.38	0.03

[1] Carcass data from 283 pigs (6 to 8 pigs per treatment).
[2] Phase feeding = complete diets in each phase; Diet blending = blending of high- and low-lysine diets fed to a set lysine curve; Corn-supplement = blending of ground corn and complete supplement.
[3] Adjusted with HCW as covariate.
[a,b] $P < 0.05$.

Table 5. Economics of diet blending using the FeedPro system[1]

	Treatment[2]			
Item	Phase feeding	Diet blending	Corn-Supplement	SEM
Feed cost/pig, $				
Phase 1	9.53	9.62	9.25	0.14
Phase 2	13.53	13.02	13.38	0.20
Phase 3	12.30	11.77	11.70	0.23
Phase 4	16.20[a]	15.22[b]	16.03[a]	0.22
Total	51.56	49.64	50.36	0.62
Feed cost/lb gain[3], $				
Phase 1	0.221[a]	0.221[a]	0.213[b]	0.002
Phase 2	0.239	0.246	0.244	0.004
Phase 3	0.260[a]	0.250[b]	0.265[a]	0.005
Phase 4	0.281[a]	0.269[b]	0.278[a]	0.003
Overall	0.250	0.246	0.250	0.002
Scenario 1[4]				
Total revenue, $/pig[5]	106.85	106.49	105.28	1.37
IOFC[6]	55.29	56.86	54.91	1.03
Scenario 2[4]				
Total revenue, $/pig[5]	140.84	140.37	138.77	1.80
IOFC[6]	89.29	90.73	88.41	1.44

[1] Data collected from 283 pigs (6 to 8 pigs per treatment).
[2] Phase feeding = complete diets in each phase; diet blending = blending of high- and low-lysine diets fed to a set lysine curve; corn-supplement = blending of ground corn and complete supplement.
[3] Feed cost/lb gain = (Direct feed cost + GMD cost/pig) / total live gain. Assumed grinding (G) = $5/ton; mixing (M) = $3/ton; delivery and handling (D) = $7/ton.
[4] Scenario 1: carcass base price = $51.55 (October 2009 price); Scenario 2: carcass base price = $67.95 (October 2008 price).
[5] Total revenue = carcass base price × HCW.
[6] IOFC, income over feed cost = total revenue/pig - feed cost/pig.
[a,b] $P < 0.05$.

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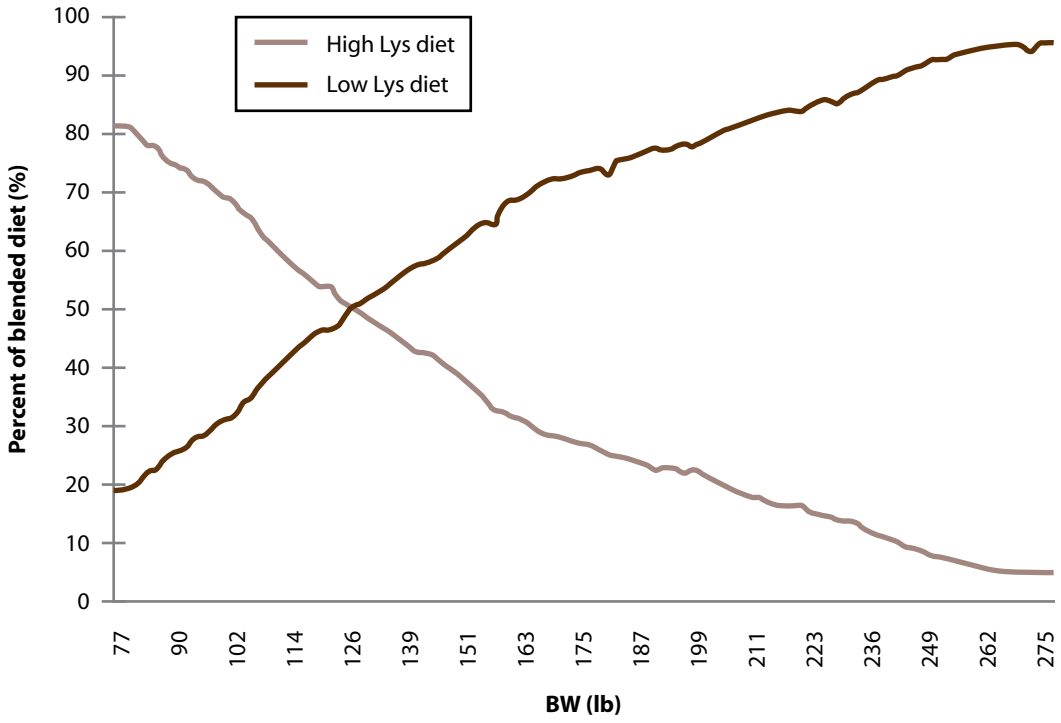

Figure 1. Percentage of the high- and low-lysine diets blended to a set lysine requirement curve with the FeedPro system.

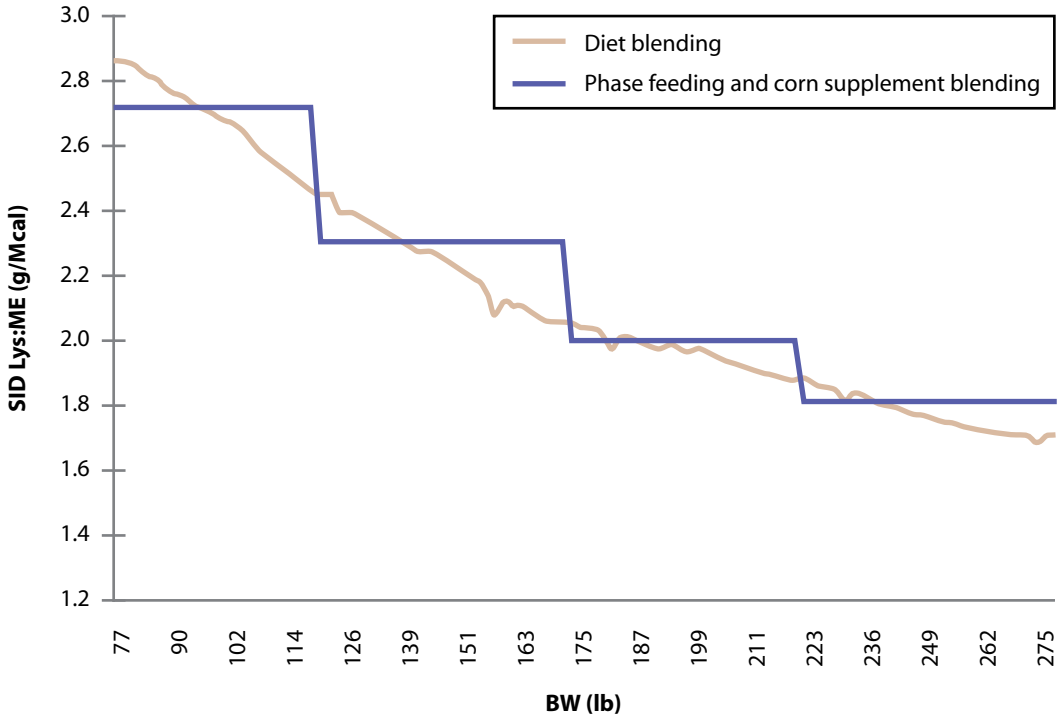

Figure 2. Standardized ileal digestible (SID) lysine:ME ratio (g/Mcal) provided to pigs in a 4-phase feeding program using complete finishing diets or a blend of ground corn and supplement and a diet made by blending complete high- and low-lysine diets to a set lysine curve with the FeedPro system.

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The Effects of Feed Budgeting, Complete Diet Blending, and Corn Supplement Blending on Finishing Pig Growth Performance in a Commercial Environment[1]

H. L. Frobose, J. M. DeRouchey, D. Ryder[2], M. D. Tokach, S. S. Dritz[3], R. D. Goodband, and J. L. Nelssen

Summary

A total of 808 pigs (PIC 337 x 1050, initially 78.4 ± 1.4 lb BW) were used to compare different feed-blending strategies for finishing pigs using the FeedPro system (Feedlogic Corp., Willmar, MN). There were 3 experimental treatments: (1) a standard-phase complete feed program, (2) blending a high- and low-lysine complete diet (curve), and (3) blending ground corn and a supplement. FeedPro is an integrated feed dispensing system that can deliver and blend 2 separate diets while dispensing. Treatment diets were fed over 4 phases (78 to 231 lb BW) with a common complete diet containing Paylean fed during the fifth phase. The 5 phases were from 78 to 115, 115 to 157, 157 to 191, 191 to 239, and 239 to 281 lb. Each treatment had 10 replicate pens and 26 to 27 pigs per pen. Overall (d 0 to 78), pigs phase-fed complete diets had greater ($P < 0.01$) ADG than pigs fed blended diets and tended to have greater ($P < 0.07$) ADG than those fed the ground corn-supplement blend. Pigs fed the blended diets had lower ($P < 0.001$) ADFI than pigs phase-fed complete diets or fed the corn-supplement blend. However, pigs fed blended diets had improved ($P < 0.001$) F/G compared to pigs phase-fed a ground corn-supplement blend and tended to have improved ($P < 0.07$) F/G compared to pigs fed standard-phase diets. Pigs fed standard-phase diets had heavier ($P < 0.03$) HCW than pigs fed the corn-supplement blend and tended to have heavier ($P < 0.03$) HCW than pigs fed diets on a lysine curve. However, there were no differences ($P \geq 0.11$) in percentage yield, percentage lean, fat depth, or loin depth among treatments. There were no differences ($P \geq 0.11$) in total revenue or income over feed costs (IOFC) across treatments. However, standard phase-fed pigs held a numerical advantage in total revenue, mainly driven by a heavier HCW over other treatments. Also, pigs fed a ground corn-supplement blend had numerically the lowest IOFC compared to other treatments. In conclusion, feeding using the FeedPro system is competitive with standard phase-fed diets on a net return basis, while feeding a ground corn-supplement blend adversely affected net returns.

Key words: carcass characteristics, feed blending, growth

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

[2] Feedlogic Corp., Willmar, MN. Appreciation is expressed to Feedlogic Corp. for financial support of this study.

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

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Introduction

When pigs are fed diets that accurately match their nutrient requirements, growth and efficiency are maximized while nutrient excretion is minimized. The ideal concentration of nutrients required by growing pigs generally decreases over the growing-finishing period, and to accurately adapt to these requirements, phase feeding is the industry standard. In commercial production, phase feeding frequently involves feeding a sequence of 2 to 5 diets, each differing in energy and amino acid levels to match nutrient requirements of that phase.

Blend feeding incorporates 2 complete diets and has the potential to more accurately match the pigs' nutrient requirements by increasing the number of phases. Recent automatic feeding systems, such as the FeedPro system, have diet-blending capabilities and can effectively deliver different ratios of 2 base diets without added labor. However, studies evaluating the benefits of complete diet blending in multiple phases using an automatic feeding system have been limited.

A recent study was conducted at Kansas State University (K-State) by Sulabo et al (2010[4]) to compare different feeding strategies using the FeedPro system. The focus of the current study was to replicate the study conducted by Sulabo et al (2010) in a commercial environment. More specifically, the objectives were: (1) to compare the effects of feeding finishing pigs with 2 base diets blended according to a set lysine curve using the FeedPro system with a standard phase-feeding program on growth performance, carcass characteristics, and economics, and (2) to further assess the blending abilities of the FeedPro system, phase-feeding of blending complete diets was compared with blending ground corn and a complete supplement that provided the identical diet composition as the standard phase-feeding program.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved all procedures used in this study. The experiment was conducted in a commercial research-finishing barn in southwestern Minnesota.

The barns were naturally ventilated and double curtain-sided. Pens had completely slatted flooring and deep pits for manure storage. Each pen was equipped with a 5-hole stainless steel dry self-feeder and a cup waterer for ad libitum access to feed and water. Feed was added to each pen daily with a robotic feeding system (FeedPro; Feedlogic Corp., Willmar, MN) capable of providing and measuring feed amounts by individual pen.

A total of 808 pigs (PIC 337 x 1050, initially 78.4 ± 1.4 lb BW) were randomly assigned to 1 of 3 experimental treatments according to average BW within pen. There were 26 to 27 pigs per pen (mixed sex) with 10 replicates per treatment. The 3 experimental treatments were: (1) a standard 4-phase complete feed program, (2) blending a high- and low-lysine complete diet (Curve), and (3) blending ground corn and a supplement. For the standard 4-phase feeding program, 4 finishing diets (Table 1) were formulated to provide 2.83, 2.59, 2.32, and 2.05 g SID Lys/Mcal ME and were fed from

[4] Sulabo, R.C. et al., Swine Day 2010. Report of Progress 1038, pp. 232-241.

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78 to 115 (Phase 1), 115 to 157 (Phase 2), 157 to 191 (Phase 3), and 191 to 239 lb (Phase 4), respectively.

A common complete diet containing 4.5 g/ton ractopamine HCl (RAC; Paylean, Elanco Animal Health, Greenfield, IN) was fed across all treatments for 22 days from 239 to 281 lb BW prior to marketing. This diet was formulated to contain RAC at 9g/ton and 2.67g SID Lys per Mcal ME. For the diet blending treatment, a complete high-lysine and low-lysine diet (Table 1) was formulated to provide 2.98 and 1.93 g SID Lys per Mcal ME, respectively. These 2 diets were incorporated in different ratios daily (Figure 1) to meet a lysine requirement curve that was determined using Feedlogic feed intake data. For the ground corn-supplement treatment, four complete supplements were formulated (Table 2) and were stored separately from ground corn. The FeedPro system blended ground corn and the complete supplement in calculated ratios (Table 2) to be identical in dietary nutrient composition to the standard phase-feeding program for each growing phase. Figure 2 illustrates the stair-step reduction of lysine to calorie ratios used for the phase-feeding and corn-supplement treatments and the more gradual reduction in lysine to calorie ratio for the diet-blending treatment. The gradual reduction in lysine to calorie ratio was achieved by changing the ratio of the 2 diets provided on a daily basis. Pigs from each pen were weighed as a group, and feed disappearance was determined approximately every 3 wk to determine ADG, ADFI, and F/G.

On d 88 of the experiment, the 4 heaviest pigs from each pen (determined visually) were weighed and removed in accordance with the farm's normal marketing procedure. On d 109, up to 4 of the heaviest pigs (determined visually) per pen were again weighed, removed, and marketed. At the end of the experiment, pigs were individually tattooed by pen number to allow for carcass data collection at the packing plant and data retrieval by pen. Pigs were transported to JBS Swift and Company (Worthington, MN) for processing. Standard carcass criteria of loin and backfat depth, HCW, percentage lean, and percentage yield were collected. As a result of misidentification of pigs by plant personnel, of the original 10 replicates per treatment, authors were able to utilize 6 pens from the standard phase-fed treatment, 10 pens from the diet-blending group, and 7 pens from the group phase-fed a corn-supplement blend.

Feed cost was calculated as the sum of diet cost and grind, mixing, and delivery (GMD) costs. The individual components of the GMD charges used were (1) grinding = $5 per ton; (2) mixing = $3 per ton; and (3) delivery = $7 per ton. All three charges (grinding, mixing, and delivery) were applied to the complete diets used in phase feeding and diet blending. For the corn-supplement treatment, grinding was charged to the ground corn, mixing was charged to the supplement, and delivery was charged to both components. Feed cost per pig and feed cost per pound of gain were calculated for each phase and overall. Total revenue and income over feed cost (IOFC) were also determined.
Data were analyzed as a completely randomized design using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC), with pen as the experimental unit. Hot carcass weight was used as a covariate for fat depth, loin depth, and lean percentage. When treatment effect was a significant source of variation, means were separated using CONTRAST statements in SAS. Least square means were calculated for each independent variable. For all statistical tests, significance and tendencies were set at $P < 0.05$ and $P < 0.10$, respectively.

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Results and Discussion

There were no differences ($P \geq 0.37$) in pig weights across all treatments in phases 1 to 3 (Table 3). However, in Phase 4, pigs given standard phase-fed diets tended to be heavier ($P < 0.10$) than those fed the corn-supplement blended diets. In Phase 5 (239 to 281 lb), pigs fed standard phase diets tended to be heavier ($P < 0.10$) than pigs fed a ground corn-supplement blend. In Phase 1 (78 to 115 lb), there were no differences ($P \geq 0.29$) in performance across all treatments. In Phase 2 (115 to 157 lb), ADG and F/G were similar across all treatments; however there was a tendency for increased ($P < 0.10$) ADFI for pigs fed the ground corn-supplement blend as compared to pigs fed blended diets. For Phase 3 (157 to 191 lb), ADG was similar ($P \geq 0.19$) across all treatments. For ADFI, pigs fed diets blended on a set lysine curve had lower ($P < 0.001$) ADFI than pigs fed either standard phase diets or those fed a corn-supplement blend. However, pigs fed blended diets tended to have improved ($P < 0.08$) F/G compared to pigs fed a corn-supplement blend. In Phase 4 (191 to 239 lb), pigs fed using the corn-supplement blend had poorer ($P < 0.01$) ADG than pigs fed using either standard phase feeding or blended diets on a lysine curve. Additionally, pigs phase-fed using complete diets had improved ($P < 0.01$) ADFI as compared to pigs fed blended diets in Phase 4. Finally, pigs fed diets blended on a lysine curve had improved ($P < 0.02$) F/G compared to pigs fed using phase-feeding of either complete diets or the ground corn-supplement blend. In Phase 5 (239 to 281 lb), pigs previously fed the corn-supplement blended diets had higher ($P < 0.05$) ADG and ADFI than those previously fed using diet blending.

Overall (78 to 281 lb), pigs fed blended diets on a lysine curve had poorer ($P < .01$) ADG and ADFI than pigs using phase feeding of complete diets. Additionally, pigs fed blended diets had lower ($P < .001$) ADFI and improved ($P < .001$) F/G than pigs fed a ground corn-supplement blend. Finally, pigs consuming the standard phase-feeding diet tended ($P < .07$) to have higher ADG but also poorer F/G ($P < .07$) than those fed a corn-supplement blend. These results are consistent with the results of Sulabo et al (2008[5]).

For carcass characteristics, there were no differences ($P \geq 0.11$) in percentage yield, percentage lean, backfat depth or loin depth across all treatments (Table 4). However, pigs phase-fed complete diets had heavier ($P < 0.03$) HCW than pigs fed blended diets on a lysine curve and tended to have heavier ($P < 0.07$) HCW than those fed a ground corn-supplement blend. These results were similar to Sulabo et al (2008), where pigs were fed based on similar treatments to the current study showed no differences in percentage yield or loin depth but did show a numerical advantage in HCW for the standard phase-fed treatment. The improvement in HCW for the standard phase-fed diet corresponds to the increased ADG seen in the overall growth data.

Feed costs on a per-pig basis were similar ($P \geq 0.27$) across all treatments within phases 1 and 2 (Table 5). However, in phases 3 and 4, feed costs per pig were lower ($P < 0.01$) for diets blended on a set lysine curve as compared to phase-feeding of either complete diets or a ground corn-supplement blend. In Phase 5, where a common Paylean diet was fed across all treatments, pigs that had been fed blended diets had decreased ADFI and improved F/G which translated into a lower ($P < 0.01$) feed cost per pig than those that had been fed a ground corn-supplement blend in the first four phases. Overall, feed

[5] Sulabo, R.C. et al. Swine Day 2008. Report of Progress 1001, pp. 231-235.

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cost on a per-pig basis was lower ($P < 0.01$) for pigs fed blended diets than pigs fed the standard diets or a ground corn-supplement blend.

Feed cost per lb gain was lower ($P < 0.05$) in Phase 3 for diets blended on a lysine curve as compared to those fed a ground corn-supplement blend. During Phase 4, feed cost per lb gain was lower ($P < 0.02$) for pigs fed blended diets than those phase-fed complete diets or a ground corn-supplement blend. Overall, pigs fed blended diets tended to have lower ($P < 0.07$) feed cost per lb gain than pigs phase-fed a corn-supplement blend.

Total revenue per pig was similar ($P \geq 0.23$) across all treatments, although standard phase-fed pigs had a numeric advantage over other treatments, which can be primarily attributed to tendency for increased ($P < 0.07$) HCW seen in the standard phase-fed pigs. There were no differences ($P \geq 0.17$) in IOFC across treatments, although pigs fed a ground corn-supplement blend had a numerically lower IOFC compared to other treatments. Although pigs fed a blended diet had decreased ($P < 0.01$) ADG, and thus tended to have a lighter ($P < 0.07$) HCW compared to those phase fed a standard complete diet, the fact that they still had a numeric advantage in IOFC is noteworthy. These results agree withthose of Sulabo et al (2010), in which pigs fed blended diets had improved net returns when compared to those phase-fed either complete diets or a ground corn supplement blend.

In conclusion, diets blended on a set lysine curve experienced a decrease in growth but an improvement in feed efficiency without affecting carcass characteristics. These results confirm results by Sulabo et al (2010) that diet blending may provide higher returns due to feed efficiency improvement. Phase-feeding a ground corn-supplement blend may have practical application in commercial production, but the increased F/G and similar feed cost per lb gain in relation to standard phase-fed diets does not support its use with the FeedPro delivery system.

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Table 1. Diet composition for the phase-feeding and diet-blending treatments (as-fed basis)

	Phase feeding[1]					Diet blending[2]	
Item	Diet 1	Diet 2	Diet 3	Diet 4	Paylean	High Lysine	Low Lysine
Ingredient, %							
Corn	52.32	54.98	57.92	60.83	61.45	50.74	61.56
Soybean meal (46.5%)	15.43	12.84	10.06	7.18	16.56	17.01	6.50
Dried distillers grains with solubles	30.00	30.00	30.00	30.00	20.00	30.00	30.00
Limestone	1.25	1.20	1.10	1.10	1.03	1.23	1.10
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin and trace mineral premix	0.10	0.10	0.09	0.09	0.09	0.10	0.09
L-threonine	---	---	---	---	0.02	---	---
Biolys	0.55	0.52	0.48	0.45	0.45	0.57	0.40
Phytase[3]	0.01	0.01	---	---	0.00	0.01	---
Ractopamine HCl, 9 g/lb[4]	---	---	---	---	0.05	---	---
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Calculated composition							
SID[5] amino acids, %							
Lysine	0.95	0.87	0.78	0.69	0.90	1.00	0.65
Isoleucine:lysine	69	70	72	75	69	68	78
Methionine:lysine	33	34	37	40	32	32	41
Met & cys:lysine	67	70	75	81	65	65	85
Threonine:lysine	63	65	67	71	65	62	73
Tryptophan:lysine	17	17	17	17	18	17	17
Valine:lysine	83	86	90	95	83	82	99
CP , %	20.19	19.20	18.12	17.00	18.71	20.81	16.71
Total lysine, %	1.11	1.03	0.93	0.83	1.04	1.17	0.79
ME, kcal/lb	1,524	1,525	1,527	1,528	1,526	1,524	1,528
SID Lysine:ME, g/Mcal	2.83	2.59	2.32	2.05	2.67	2.98	1.93
Ca, %	0.55	0.53	0.48	0.47	0.47	0.55	0.47
P, %	0.47	0.46	0.45	0.43	0.43	0.47	0.43
Available P, %[6]	0.30	0.27	0.24	0.22	0.21	0.30	0.22

[1] Phases 1, 2, 3, 4, and 5 were fed from approximately 80 to 120, 120 to 160, 160 to 200, and 200 to 240, and 240 to 250 lb BW, respectively.
[2] Feed delivery based on a lysine requirement curve where a complete high- and low-lysine diet was blended for the duration of the experiment.
[3] Optiphos 2000 (Enzyvia LLC, Sheridan, IN)
[4] Paylean (Elanco Animal Health, Greenfield, IN)
[5] Standardized ileal digestible.
[6] Phytase provided 0.10% available P in diets 1, 2 and the high-lysine blending diet .

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Table 2. Composition of the complete supplements (as-fed basis) and the proportion of ground corn and supplement by phase[1,2]

	Complete supplement			
Ingredient, %	1	2	3	4
Soybean meal (46.5%)	32.35	28.53	23.90	18.34
DDGS	62.92	66.64	71.29	76.59
Limestone	2.62	2.67	2.61	2.81
Salt	0.73	0.78	0.83	0.89
Vitamin and trace mineral premix	0.21	0.22	0.21	0.23
L-lysine HCl	1.15	1.16	1.14	1.14
Phytase[3]	0.02	0.01	0.01	---
Total	100.00	100.00	100.00	100.00
Blend:				
Ground corn, %	52	55	58	61
Complete supplement, %	48	45	42	39

[1] Diets were blended and feed budgeted to be identical in composition and nutrient analyses for each phase to those fed the standard 4-phase feeding program.
[2] Phases 1, 2, 3, 4, and 5 were fed from approximately 80 to 120, 120 to 160, 160 to 200, 200 to 240, and 240 to 250 lb BW, respectively.
[3] Optiphos 2000 (Enzyvia LLC, Sheridan, IN)

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Table 3. Effects of diet blending using the FeedPro system on finishing-pig growth performance[1]

	Treatment[2]			
Item	Phase feeding	Diet blending	Corn-supplement	SEM
Pig weights, lb				
Initial	78.5	78.5	78.3	1.4
End of phase 1	115.5	114.8	114.9	1.6
End of phase 2	157.3	155.7	156.6	2.3
End of phase 3	192.3	189.4	190.8	2.3
End of phase 4	242.1^{y}	237.8^{ab}	236.8^{x}	2.2
End of phase 5	284.7^{b}	280.3^{ab}	277.9^{a}	2.2
Phase 1 (78 to 115 lb)				
ADG, lb	1.76	1.72	1.74	0.03
ADFI, lb	3.89	3.80	3.87	0.07
F/G	2.21	2.21	2.23	0.03
Phase 2 (115 to 157 lb)				
ADG, lb	1.99	1.95	1.98	0.03
ADFI, lb	5.14^{xy}	5.00^{y}	5.20^{x}	0.08
F/G	2.59	2.57	2.62	0.04
Phase 3 (157 to 191 lb)				
ADG, lb	1.66	1.59	1.63	0.04
ADFI, lb	5.91^{b}	5.44^{a}	5.92^{b}	0.08
F/G	3.57^{xy}	3.43^{x}	3.63^{y}	0.08
Phase 4 (191 to 239 lb)				
ADG, lb	1.98^{b}	1.93^{b}	1.83^{a}	0.02
ADFI, lb	6.11^{b}	5.78^{a}	5.97^{ab}	0.08
F/G	3.09^{a}	3.00^{a}	3.25^{b}	0.05
Phase 1 to 4 (78 to 239 lb)				
ADG, lb	1.86^{b}	1.80^{a}	1.81^{a}	0.014
ADFI, lb	5.30^{b}	5.27^{b}	5.04^{a}	0.057
F/G	2.86^{b}	2.93^{c}	2.79^{a}	0.029
Phase 5 (239 to 281 lb)				
ADG, lb	2.06^{ab}	1.94^{a}	2.09^{b}	0.05
ADFI, lb	6.28^{ab}	6.16^{a}	6.42^{b}	0.06
F/G	3.05	3.19	3.09	0.08
Overall (0 to 281 lb)				
ADG, lb	1.89^{by}	1.83^{axy}	1.85^{abx}	0.02
ADFI, lb	5.47^{b}	5.23^{a}	5.47^{b}	0.05
F/G	2.90^{abx}	2.86^{axy}	2.95^{by}	0.02

$^{a,b\ x,y}$ Within a row, means without a common superscript differ $P < 0.05$ for statistical significance and $P < 0.10$ for trends.

[1] A total of 808 pigs (initially 78.4 ± 1.4 lb BW) were used with 10 replicate pens per treatment and 27 pigs per pen.

[2] Phase feeding = complete diets in each phase; diet blending = blending of high- and low-lysine diet fed to a set lysine curve; corn-supplement = blending of ground corn and complete supplement.

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Table 4. Effects of diet blending using the FeedPro system on carcass characteristics of finishing pigs[1]

	Treatment[2]			
Item	Phase feeding	Diet blending	Corn-supplement	SEM
HCW, lb	210.2[by]	206.6[abx]	204.2[a]	1.72
Yield, %	75.7	76.0	76.0	0.344
Lean, %[3]	53.0	53.6	53.1	0.02
Fat depth, in.[3]	0.80	0.78	0.81	0.245
Loin depth, in.[3]	2.22	2.30	2.24	0.047

[a,b x,y] Within a row, means without a common superscript differ $P < 0.05$ and $P < 0.10$, respectively.

[1] Carcass data from 483 pigs. Phase feeding (6 pens); diet blending (10 pens); corn-supplement (7 pens).

[2] Phase feeding = complete diets in each phase; diet blending = blending of high- and low-lysine diet fed to a set lysine curve; corn-supplement = blending of ground corn and complete supplement.

[3] Adjusted with HCW as covariate

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Table 5. Economics of diet blending using the FeedPro system[1]

	Treatment[2]			
Item	Phase feeding	Diet blending	Corn-supplement	SEM
Feed cost/pig, $				
Phase 1	6.99	6.78	6.81	0.13
Phase 2	9.00	8.78	8.95	0.14
Phase 3	9.86a	9.18[b]	10.03[a]	0.13
Phase 4	12.33[a]	11.42[b]	11.64[b]	0.17
Phase 5[3]	14.19[ab]	13.91[b]	14.50[a]	0.14
Total	52.38[a]	50.06[b]	51.94[a]	0.47
Feed cost/lb gain, $[4]				
Phase 1	0.189	0.188	0.186	0.002
Phase 2	0.216	0.214	0.215	0.003
Phase 3	0.283[ab]	0.275[b]	0.293[a]	0.006
Phase 4	0.297[a]	0.282[b]	0.302[a]	0.004
Phase 5	0.329	0.344	0.333	0.008
Total	0.265[xy]	0.262[y]	0.268[x]	0.002
Total revenue, $/pig[5,6]	147.35	145.94	144.87	1.36
IOFC[7]	94.40	95.88	93.45	1.25

[a,b x,y] Within a row, means without a common superscript differ P < 0.05 for statistical significance and P < 0.10 for trends.

[1] Data collected from 808 pigs (approximately 270 pigs per treatment).

[2] Phase feeding = complete diets in each phase; diet blending = blending of high- and low-lysine diet fed to a set lysine curve; corn-supplement = blending of ground corn and complete supplement.

[3] Paylean diet delivered in same form across all treatments. Differences are due to variation in performance.

[4] Feed cost/lb gain = (direct feed cost + GMD cost/pig) ÷ total live gain; assumed grinding = $5/ton; mixing = $3/ton; delivery and handling = $7/ton.

[5] Carcass base bid = $70.81 (June 2010)

[6] Total revenue = carcass price (including premiums/discounts for lean and yield) × HCW.

[7] IOFC, income over feed cost = total revenue/pig - feed cost/pig.

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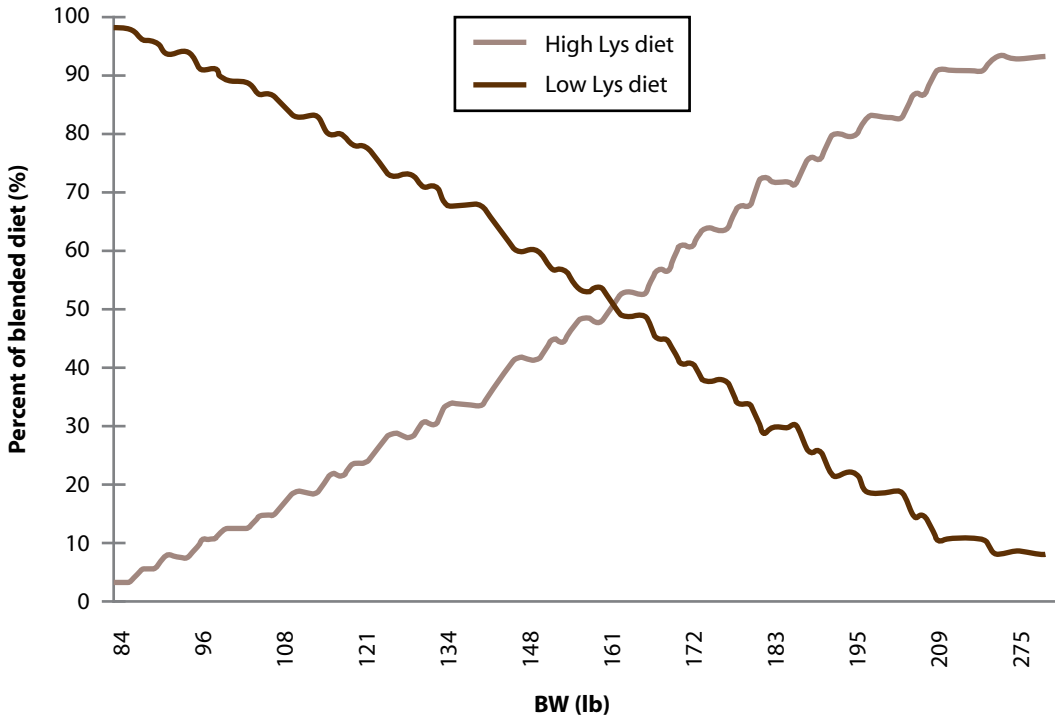

Figure 1. Percentage of the high- and low-lysine diets blended to a set lysine requirement curve using the FeedPro system.

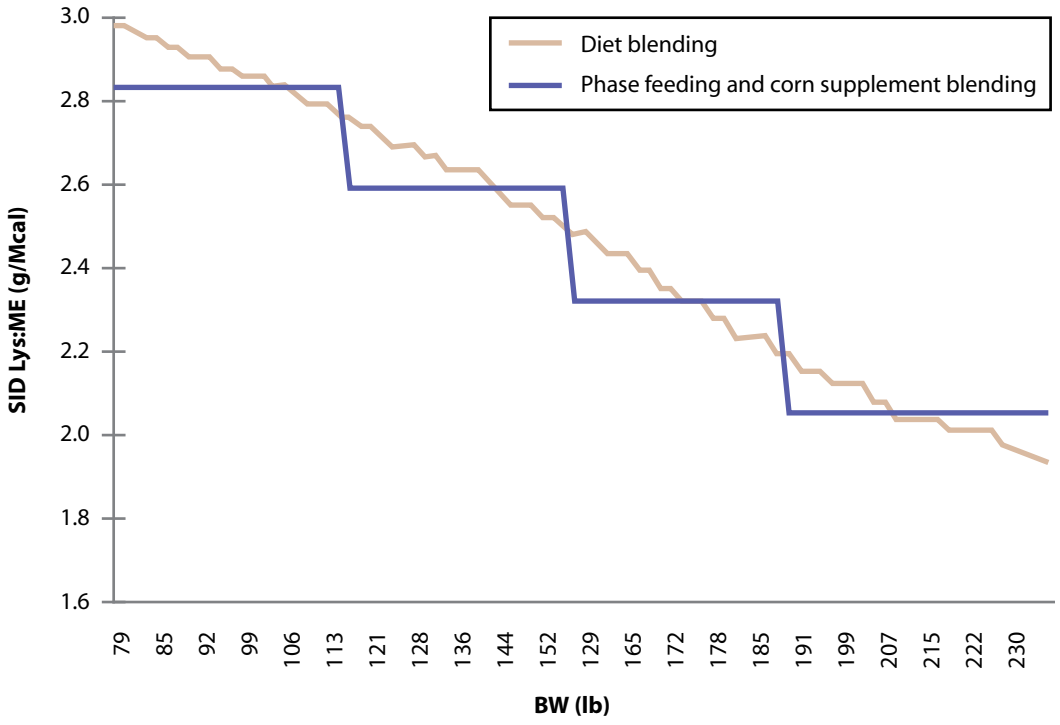

Figure 2. Standardized ileal digestible Lys:ME ratio (g/Mcal) delivered to pigs (78 to 239 lb BW) based on a 4-phase feeding program utilizing either complete finishing diets or a ground corn-supplement blend compared to blending of high- and low-lysine diets based on a predetermined lysine curve using the FeedPro system.

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Effects of Feed-Withdrawal Time on Finishing-Pig Carcass Characteristics and Economics in a Commercial Environment[1,2]

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Summary

The effects of feed-withdrawal time on finishing-pig carcass composition and net returns were determined in 2 studies. In Exp. 1, a total of 728 pigs (BW = 286.4 ± 2.7 lb, 10 to 19 pigs per pen) were marketed from 48 pens that were randomly assigned to 1 of 4 treatments: feed withdrawal times of 7, 24, 36, or 48 h before harvest. Pigs were fed a common corn-soybean meal diet containing dried distillers grains with solubles (DDGS) and bakery co-products. As expected, increased feed withdrawal time decreased (linear; $P < 0.001$) live weight. Withholding feed also decreased (linear; $P < 0.03$) HCW and backfat depth. Percentage yield increased (quadratic; $P < 0.01$) with longer withdrawal periods, as did percentage lean (linear; $P < 0.01$). Withholding feed increased (quadratic; $P < 0.01$) live price and, accordingly, also increased (linear; $P < 0.001$) carcass price. These results were due in part to increased (linear; $P < 0.02$) premiums and decreased (linear; $P < 0.01$) weight discounts. Total value and net revenue received were similar ($P > 0.32$) between treatments as HCW decreased in fasted pigs, but feed intake per pig also decreased (quadratic; $P < 0.001$), resulting in feed savings of up to $0.78/pig. Withholding feed for 24 h resulted in a numeric increase in net revenue of $0.89/pig compared to 7 h.

In Exp. 2, the 48-h treatment was removed and replaced with a 12-h treatment in order to more accurately determine the proper time to implement feed withdrawal. The incidence of runny bung and leaking ingesta were also recorded to determine whether a relationship existed between feed withdrawal and the incidence of these processing concerns. A total of 843 pigs (BW = 273.0 lb, 16 to 26 pigs per pen) were assigned to 1 of 4 treatments: withholding feed for 7, 12, 24, or 36 h before harvest. Pigs were fed a common corn-soybean meal-based diet containing 20% DDGS. As a result of misidentification of pigs by plant personnel, data were analyzed from only 25 of the original 40 pens. Withholding feed tended to decrease (linear; $P < 0.09$) live weight. Unlike Exp. 1, there were no differences ($P > 0.22$) in HCW, percentage lean, or backfat depth across treatments. However, as in Exp.1, percentage yield (linear; $P < 0.001$) increased with increasing withdrawal time. Although withholding feed had no effect ($P > 0.31$) on the incidence of runny bung, it did increase (linear; $P < 0.001$) the incidence of

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

[2] Special thanks to JBS Swift and Co. (Greeley, CO) for use of facilities (Worthington, MN) and technical assistance in data collection.

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leaking ingesta. For economics, as in Exp. 1, withholding feed increased (linear; $P < 0.002$) live price. Additionally, pigs that were fasted had increased (quadratic; $P < 0.05$) carcass price. Although premiums were similar ($P > 0.32$) across treatments, withholding feed decreased (quadratic; $P < 0.04$) weight discounts. Total value and net revenue received per pig were similar ($P > 0.88$) across treatments, but withholding feed decreased (linear; $P < 0.001$) feed intake, resulting in feed savings of up to $0.46/pig. Overall, withholding feed can be used to avoid weight discounts in heavyweight pigs without negatively impacting carcass composition and maintaining overall revenue per pig. However, these advantages come with a potential reduction in carcass weight and increased incidence of leaking ingesta, which can result in condemned heads at inspection and losses of $3 to 4 per carcass.

Key words: carcass, fasting, feed withdrawal

Introduction

Pigs experience a period of feed withdrawal prior to slaughter for multiple reasons. First, all pigs are subjected to a period of restricted feed access during transport to and lairage time within the harvesting facility. In the early 1980s, a survey of five slaughter plants (Warriss and Bevis, 1986[5]) found that lairage times could range from less than 1 h to more than 20 h. Additionally, withdrawing feed before slaughter reduces the risk of lacerating the gastrointestinal tract during evisceration and decreases the overall drop weight of the tract, thus increasing warm carcass yield. Several studies have also demonstrated that fasting before slaughter reduces the incidence of PSE pork (Murray & Jones, 1994[6]). Fasting pigs for up to 24 h before slaughter results in significant feed savings with minimal effects on carcass weight and pork quality (Kephart and Mills 2005[7]). Feed withdrawal can also be implemented as a means of reducing average pig weight per truckload in order to avoid penalties for heavyweight loads at the slaughter plant, as was the case in these experiments (JBS Worthington, MN; penalty incurred when mean live BW > 280 lb). However, fasting for 24 h or longer reduces hot carcass weight and thus reduces overall carcass value (Kephart and Mills, 2005[5]). Industry reports have also raised concern regarding an association between feed withdrawal and the incidence of runny bung (leaking of fecal matter onto the carcass) or leaking ingesta (stomach contents leaking out of the mouth after shackling). The incidence of these events causes increased food safety risk from carcass contamination and leads to loss in carcass value. For example, leaking ingesta leads to an increased occurrence of condemned heads, which have an approximate value of $3 to 4 per carcass. It is hypothesized that these events occur in greater frequency with fasted pigs because they are more likely to drink a large volume of water in lairage, thus changing the stomach contents to a more liquid form. However, more data are necessary to determine whether a true relationship exists between fasted pigs and the prevalence of runny bung and leaking ingesta.

[5] Warriss, P. D. and E. A. Bevis. 1986. Transport and lairage times in British slaughter pigs. British Veterinary Journal.142:124-130.

[6] Murray, A. C., and S. D. Jones. 1994. The effect of mixing, feed restriction and genotype with respect to stress susceptibility on pork carcass and meat quality. Can. J. Anim. Sci. 74:587-594.

[7] Kephart, K. B. and E. W. Mills. 2005. Effect of withholding feed from swine before slaughter on carcass and viscera weights and meat quality. J. Anim. Sci. 83: 715-721.

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Therefore the objective of these studies was to examine the effects of feed withdrawal before slaughter on carcass composition, feed savings, and overall revenue.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. Both experiments were conducted in a commercial research-finishing barn in southwestern Minnesota.

The barns were naturally ventilated and double-curtain sided. Pens had completely slatted flooring and deep pits for manure storage. Each pen was equipped with a 5-hole stainless steel dry self-feeder and a cup waterer for ad libitum access to feed and water. Daily feed additions to each pen were accomplished through a robotic feeding system (FeedPro; Feedlogic Corp., Willmar, MN) capable of providing and measuring feed amounts by pen.

Exp. 1

A total of 728 pigs (PIC 337 × 1050 and initially 286.4 ± 2.7 lb BW) were used with 10 to 19 pigs per pen and 12 replicate pens per treatment in a randomized design. Pens were ranked by mean pig weight and then allotted to each of 48 pens, with pigs per pen and location within the barn balanced across treatment. Pens were mixed gender and had ad libitum access to water throughout the experiment. A common complete diet containing 4.5 g/ton ractopamine HCl (RAC; Paylean, Elanco Animal Health, Greenfield, IN) was fed throughout the experiment. The corn-soybean meal-based diet contained dried distillers grains with solubles (DDGS) and bakery co-products. Before allotment, the heaviest pigs and underweight or cull pigs were removed from each pen according to the farm's normal marketing procedure.

Experimental treatments were designed to reflect the amount of time that pigs had feed removed prior to exsanguination. The four treatments were: (1) feed access up until point of loading on the day of slaughter (7 h), (2) 24-h feed withdrawal, (3) 36-h feed withdrawal, and (4) 48-h feed withdrawal. Pigs were initially weighed by pen at 52 h before exsanguination to allow time for allotment before the application of the 48-h treatment. At this time, feed amounts in each feeder were recorded. The FeedPro system recorded any additional feed delivered to each pen during the experiment. When treatments were applied, feeders were shut off, cleaned, and remaining feed recorded for calculation of feed intake during the test period. Pigs were weighed by pen immediately before loading.

To eliminate transportation effects, the 3 trucks were loaded so each truck included a balanced number of pens. Duration from the beginning of load-out, which started at 0900, until the first pig was exsanguinated was approximately 7 h. This included approximately 3 h for load-out and transit and approximately 4 h of lairage (exact times were not recorded). Upon arrival at the slaughter plant, pigs were again weighed by pen, and transport shrink was calculated. During lairage, pigs had access to water but not feed.

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Exp. 2

A total of 843 pigs (PIC 337 × 1050, initially 273.0 lb BW) were used, with 16 to 26 pigs per pen (mixed gender) and 10 replicate pens per treatment in a randomized design. Pens were ranked by mean pig weight and pigs were allotted to each of 40 pens, with pigs per pen and location within the barn balanced across treatment. Before allotment, the heaviest pigs and underweight or cull pigs were removed from each pen. A common complete diet containing 4.5 g/ton ractopamine HCl (RAC; Paylean, Elanco Animal Health, Greenfield, IN) was fed throughout the experiment. The corn-soybean meal-based diet contained 20% dried distillers grains with solubles (DDGS). Ad libitum access to water was provided.

Based on results from Exp. 1, the 48-h treatment was removed due to negative effects on hot carcass weight. That treatment was replaced with feed removed for 12 h before slaughter to more accurately assess the effects of shorter-term feed withdrawal. Additionally, the prevalence of runny bung and leaking ingesta also were recorded.

Four experimental treatments were used: (1) control (7 h), (2) 12-h feed withdrawal, (3) 24-h feed withdrawal, and (4) 36-h feed withdrawal. Pigs were initially weighed by pen 42 h before exsanguination to allow time for allotment before the application of the 36-h treatment. Feed intake was measured as described in Exp. 1.

To eliminate transportation effects, the 4 trucks were loaded so each truck included a balanced number of pens. Load-out began at 0300 and concluded at approximately 0500, with all trucks arriving at the plant before 0800. Actual time when the first pig was exsanguinated was 1205. Mean time between load-out and slaughter was 7 h across treatments. Upon arrival at the slaughter plant, pigs were again weighed by pen. During lairage, pigs had access to water but not feed.

In both experiments, optical probe data (Fat-O-Meater, SFK Technology, Inc., Cedar Rapids, IA), HCW, and payment values including premiums and discounts were recorded on a per-pen basis. Net revenue per pig was calculated based on total value per carcass minus the cost of feed consumed from allotment until slaughter. In Exp. 2, the incidence of runny bung and leaking ingesta was recorded by JBS personnel at the inspection station on a per-pig basis, and then calculated and recorded as overall percentage prevalence per pen.

In both experiments, data were analyzed as a completely randomized design using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Hot carcass weight was used as a covariate for fat depth, loin depth, and lean percentage. Means were evaluated using linear and quadratic CONTRAST statements in SAS. The coefficients for the unequally spaced linear and quadratic contrasts were derived using the PROC IML procedure in SAS. Least square means were calculated for each independent variable. Results were considered to be significant if P-values were ≤ 0.05 and considered to be a trend if P-values were ≤ 0.10.

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Results and Discussion

Exp. 1

As expected, pigs subjected to longer withdrawal times had decreased live weight at load-out (linear; $P < 0.001$) and at the abattoir (linear; $P < 0.001$, Table 1). In terms of carcass characteristics, pigs that had fasted for longer periods had lighter (linear; $P < 0.02$) HCW than pigs treated with normal transit and lairage times. Increased withdrawal time also increased (quadratic; $P < 0.01$) dressing yield. These results agree with studies by Beattie et al. (2002[8]), reporting an increase in dressing yield (from 75.4% to 77.3%) with longer fasting intervals (from 0 to 20 h) resulting from decreased gut fill and offal weight. Longer withdrawal periods also increased percentage lean (linear; $P < 0.01$), decreased (linear; $P < 0.03$) backfat depth, and had no effect ($P > 0.35$) on loin depth.

Withholding feed increased live (quadratic, $P < 0.01$) price up to $2.34/cwt. Carcass price also increased (linear; $P < 0.001$) in fasted pigs, resulting in up to $1.27/cwt greater returns compared to pigs with feed access until load-out. Pigs withheld from feed also received more premiums (linear; $P < 0.02$) and less sort loss discounts (linear; $P < 0.01$) at JBS Swift and Company (Worthington, MN). However, there was no effect ($P > 0.32$) on total value received per pig because of the reduction in live and HCW in pigs fasted longer than 24 h. Withholding feed decreased (quadratic; $P < 0.001$) feed intake per pig marketed, resulting in savings of up to $0.78 per pig. However, these feed savings did not translate into an effect ($P > 0.55$) on net revenue received per pig. Withholding feed for 24 h resulted in a numeric increase in net revenue of $0.89/pig, and pigs fasted for 36 h received only $0.04 less per pig than those with feed access up until loading. These results imply that withholding feed before slaughter can be implemented in order to successfully avoid sort loss discounts and improve premiums received on the rail. However, fasting for 48 h before harvest resulted in a loss of $0.75/pig compared to pigs with full access to feed until load-out, which suggests that the ideal fasting time rests somewhere between 7 and 36 h before slaughter.

Exp. 2

In order to more accurately determine the optimal time to implement feed withdrawal, a 12-h treatment was added to Exp. 2 (Table 2). Due to the significant decrease in HCW and numerically lower economic returns seen in the 48-h treatment during Exp. 1, this treatment was not included in Exp. 2.

Although 843 pigs and 10 replicate pens per treatment were initially allotted to this experiment, data were recovered from only 25 pens (543 pigs, initially 276.0 ± 3.3 lb BW) as a result of pig misidentification by plant personnel. Of the original 10 replicates per treatment, we were able to utilize 7 pens from the 7-h control group, 7 pens from the 12-h treatment, 6 pens from the 24-h group, and 5 pens from the 36-h treatment. Therefore, the on-farm live weight and feed intake data are reported for the 25 pens where carcass data were obtained.

[8] Beattie, V. E., Burrows, M. S., Moss, B. W., and Weatherup, R. N.(2002). The effect of food deprivation prior to slaughter on performance, behavior and meat quality. Meat Science, 62, 413-418.

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There were no differences ($P > 0.34$) in live weight across treatment for the remaining pens at allotment, although the 7-h control pigs averaged 5.0 lb lighter than pigs with the 24-h feed withdrawal treatment. As in Exp. 1, increased duration of feed withdrawal tended to decrease (linear; $P < 0.09$) live weights at load-out and upon arrival at the abattoir. However, in contrast to results seen in Exp. 1, there were no differences ($P > 0.44$) in HCW, percentage lean, or backfat depth with longer periods of feed withdrawal. Withholding feed increased (linear; $P < 0.001$) percentage yield over time. As in Exp. 1, there were no differences ($P > 0.34$) in loin depth with feed withdrawal.

The prevalence of runny bung within each pen was similar ($P > 0.31$) across all treatments. However, the prevalence of leaking ingesta within each pen increased (linear; $P < 0.001$) with longer periods of feed withdrawal. This was most evident in the 36-h treatment, where 19.5% of pigs within each pen exhibited leaking ingesta. This rate is a concern, because visible leaking ingesta is a major criterion for head condemnation and results in a loss of approximately $3 to 4 per carcass.

In terms of economics, longer periods of feed withdrawal increased (linear, $P < 0.002$) live price. Carcass price also increased (quadratic; $P < 0.05$) when pigs were fasted. Unlike Exp. 1, the amount of premium received was similar ($P > 0.32$) across treatments. However, there was a decrease (quadratic; $P < 0.04$) in sort loss discounts with longer fasting periods. As expected, feed intake per pig marketed decreased (linear; $P < 0.001$) with longer periods of feed withdrawal, resulting in feed savings of up to $0.46/pig. Nonetheless, there were no differences ($P > 0.88$) in net revenue received per pig across treatments. However, withholding feed between 12 and 36 h before slaughter numerically improved net revenue between $0.69 and $0.83/pig.

After the recovered data were analyzed in Exp 2, there were greater differences in initial BW than desired. Because the control group had a lighter initial BW, they most likely avoided a portion of the sort loss discounts that the control group had received in Exp. 1. This would explain the quadratic response seen in carcass price and sort loss discounts where there had been a strong linear response in both variables in Exp. 1.

In conclusion, both experiments demonstrated that feed withdrawal can be utilized as an effective means of managing heavyweight market hogs in order to avoid sort loss discounts at the abattoir without negatively affecting carcass composition. Additionally, withholding feed may be a useful tool to improve live and carcass price and recover more value, depending on the pricing matrix used at the plant. However, the increased prevalence of leaking ingesta in fasted pigs may offset the processing advantages associated with feed withdrawal and limit packer acceptance.

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Table 1. Effects of feed withdrawal on finishing pig performance and carcass traits in a commercial environment (Exp. 1)[1]

	Treatment, h[2]					Probability, *P* <	
Item	7	24	36	48	SEM	Linear	Quadratic
BW, lb							
d 0 (48 hr before marketing)	286.3	285.8	286.8	286.2	2.727	0.94	0.92
d 2 (Wt on farm, lb)	288.9	283.6	276.5	274.2	2.473	0.001	0.19
d 2 (Wt at plant, lb)	283.8	276.8	270.7	268.7	2.448	0.001	0.11
HCW, lb	211.3	210.6	206.7	205.3	1.966	0.02	0.73
Yield, %	74.43	76.09	76.35	76.40	0.231	0.001	0.01
Lean, %[3]	50.63	50.85	51.03	51.09	0.110	0.01	0.26
Fat depth, in[3]	0.67	0.65	0.64	0.63	0.009	0.03	0.26
Loin depth, in[3]	2.49	2.51	2.51	2.53	0.023	0.35	0.96
Economics[4]							
Live price, $	51.43	52.94	53.66	53.77	0.282	0.001	0.01
HCW price, $	69.10	69.58	70.29	70.37	0.281	0.001	0.19
Premiums, $	2.74	3.02	3.18	3.26	0.151	0.02	0.36
Sort loss, $	-1.45	-1.25	-0.71	-0.70	0.206	0.01	0.27
Total value/pig, $	145.99	146.48	145.29	144.47	1.401	0.32	0.83
Feed intake/pig marketed, lb	13.79	8.11	4.14	2.69	0.431	0.001	0.001
Feed cost/pig, $	0.97	0.57	0.29	0.19	0.030	0.001	0.001
Net revenue/pig, $[5]	145.03	145.92	144.99	144.28	1.406	0.55	0.72

[1] A total of 728 pigs (initially 286.4 ± 2.7 lb BW) were used with 12 replicate pens/treatment and averaging 15 pigs/pen.
[2] Treatments reflect actual time feed was withheld before slaughter. 7-hr treatment served as control.
[3] Adjusted with HCW as a covariate.
[4] Reflect actual values received at JBS Swift (Worthington, MN). Live and HCW price based off of base prices of $50.18/cwt and $67.81/cwt, respectively.
[5] Net revenue = (HCW x HCW price) - (Feed intake/pig marketed x $0.07/lb)

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Table 2. Effects of feed withdrawal on finishing pig performance and carcass traits in a commercial environment (Exp. 2)[1]

	Treatment, h[2]					Probability, *P* <	
Item	7	12	24	36	SEM	Linear	Quadratic
BW, lb							
d 0 (48 hr prior to marketing)	274.1	277.9	279.1	275.7	3.455	0.84	0.34
d 2 (Wt on farm, lb)	274.5	277.7	274.6	266.9	3.379	0.09	0.26
d 2 (Wt at plant, lb)	268.2	271.1	267.6	260.9	3.135	0.07	0.30
Weight change, lb	-5.9	-6.8	-11.5	-14.9	0.760	0.001	0.001
HCW, lb	202.0	204.7	203.8	200.8	2.899	0.65	0.44
Yield, %	75.21	75.47	76.04	77.00	0.298	0.001	0.55
Lean, %[3]	53.28	53.25	53.18	53.83	0.280	0.22	0.30
Fat depth, in[3]	0.80	0.78	0.80	0.77	0.015	0.51	0.49
Loin depth, in[3]	2.24	2.24	2.21	2.29	0.038	0.47	0.34
Runny bung, % prevalence/pen	3.34	1.24	6.06	5.12	2.196	0.31	0.78
Leaking ingesta, % prevalence/pen	3.34	4.62	9.52	19.52	2.689	0.001	0.36
Economics[4]							
Live price, $/cwt	53.36	53.09	53.66	55.00	0.351	0.002	0.13
Carcass price, $/cwt	70.89	70.31	70.46	71.47	0.303	0.12	0.05
Premiums, $/cwt	0.77	0.73	0.62	1.08	0.229	0.41	0.32
Sort loss, $cwt	-0.69	-1.23	-0.97	-0.42	0.190	0.14	0.04
Total value/pig, $	143.20	143.97	143.61	143.49	2.296	0.99	0.90
Feed Intake/pig marketed, lb	7.80	6.93	3.93	1.28	0.247	0.001	0.93
Feed cost/pig, $	0.55	0.49	0.28	0.09	0.017	0.001	0.001
Net revenue/pig, $[5]	142.7	143.48	143.34	143.40	2.297	0.88	0.90

[1] Of the 40 pens (843 pigs) initially allotted to this experiment, only 25 pens (543 pigs initially 276.0 ± 3.3 lb BW) were utilized as a result of data lost at the plant. Number of observations: 7 h (7 pens); 12 h (7 pens); 24 h (6 pens); 36 h (5 pens).

[2] Treatments reflect actual time feed was withheld before slaughter. 7-h treatment served as control.

[3] Adjusted with HCW as a covariate.

[4] Reflect actual values received at JBS Swift (Worthington, MN). Live and HCW price based off of base prices of $52.40/cwt and $70.81/cwt, respectively.

[5] Net revenue = (HCW x HCW price) - (Feed intake/pig marketed x $0.07/lb)

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The Importance of Defining the Method in Particle Size Analysis by Sieving

A. C. Fahrenholz, L. J. McKinney, C. E. Wurth, and K. C. Behnke

Summary

The American Society of Agricultural and Biological Engineers (ASABE) publishes a standard for identifying particle size by sieving (ASABE S319.4). However, this standard includes a number of options that allow the test to be conducted differently, and different laboratories may analyze a single sample with different results. Options include the type of sieve shaker used, the use of sieve agitators, the use of a dispersion agent, and the sieving time. A small study was conducted to examine the effect of varying these methods on the calculated geometric mean diameter by weight (d_{gw}) and geometric standard deviation by weight (s_{gw}). Results indicated that large differences existed depending on the methods used, with d_{gw} varying by as much as 100 microns, and s_{gw} varying by as much as 0.42 simply by altering one option. When compounding the differences in methods, the variations can be even larger. These discrepancies demonstrate that, for particle size analysis by sieving to be used as an effective tool, the same methodology must be used to compare samples. Additionally, the data demonstrate that unless the methods in the current standard are better defined, d_{gw} and s_{gw} should be used only as relative values for comparison.

Key words: particle size, sieving, standard

Introduction

Recently, there have been a growing number of questions about defining the exact particle size of ground cereal grains incorporated into animal diets. Additionally, the uniformity of particle size distributions has been suggested as having an important role in animal nutrition. Although measuring particle size and distribution remains an important aspect in quality control, a lack of communication between academia and industry, along with nonuniform interpretation of the standard published by the American Society of Biological and Agricultural Engineers (ASABE S319.4), have led to a divergence in methodologies.

The first step to understanding particle size analysis is to understand the meanings of the resultant values. The geometric mean of particle diameter by weight, or d_{gw}, is also the median particle size. It is important to note that this value is not the same as the arithmetic mean, or what is commonly referred to as the average, though d_{gw} has taken on this misnomer. The geometric standard deviation of particle diameter by weight, or s_{gw}, is similarly different from the arithmetic standard deviation. The geometric standard deviation is a factor, rather than a specific value, and has no unit. It can be used to make observations on the particles that fall within a given range.

The ASABE standard allows considerable latitude in accepted test equipment and sieving methods. The following are the specific sections of the standard reviewed for the purpose of this article: *1.) Section 4.2 - A sieve shaker, such as a Tyler Ro-Tap, Retsch, or equivalent unit, is required; 2.) Section 4.4 - Sieve agitators such as plastic or leather rings,*

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or small rubber balls may be required to break up agglomerates on finer sieves, usually those smaller than 300mm in opening (ISO 3310-1) or US sieve No. 50; 3.) Section 4.5 - A dispersion agent can be used to facilitate sieving of high-fat or other material prone to agglomeration; and 4.) Section 5.2 - Place the charge on one sieve or the top sieve of the nest of test sieves and shake until the mass of material on any on sieve reaches end point. End point is decided by determining the mass on each sieve at 1-minute intervals after an initial sieving time of 10 minutes. If the mass on the smallest sieve containing any material changes by 0.1% or less of the charge mass during a 1-minute period, the sieving is considered complete. For industrial applications, the end-point determination process can be omitted, and the end-point is set to be the sieving time of 15 minutes.

Procedures

A single sample of freshly ground corn was obtained from the Feed Processing and Research Center in the Department of Grain Science and Industry at Kansas State University. This sample was mixed and split using a Boerner divider before each particle size analysis. Analyses were conducted to determine the effects of using a Tyler Ro-Tap vs. a Retsch sieve shaker, using vs. not using sieving agitators, using vs. not using a dispersion agent, and sieving for 10 vs. 15 minutes. In order to reduce the number of trials, the different methods were mixed in an incomplete factorial design; however, because interactions were not of concern and because of the obviously large differences between the methods, it was determined that statistical analysis was not warranted.

Results

The Tyler Ro-Tap sieve shaker is the most commonly used in the feed industry. However, as the ASABE standard states, a Retsch sieve shaker can also be used. Though both sieve shakers facilitate feed particle passage through the sieve stack, one could argue that particle motion within the sieve stack is different when comparing the two. This difference can be seen in the results shown in Table 1. The use of the Ro-Tap yielded a d_{gw} 93 microns greater than that from the use of the Retsch. The s_{gw} varied by 0.42, with the Retsch yielding the greater value.

It would be uncommon not to use sieve agitators of some kind; however, as the standard neither requires nor provides for a precise method for their use (i.e., specific agitator and sieve designations), it was decided to consider a scenario in which they were not used at all. It would be expected that an intermediate level of use would provide for intermediate results. Not using the agitators led to a 101-micron increase in d_{gw} and a 0.40 decrease in s_{gw}. Concerning the sieving time, it is likely that some labs sieve for a total of 10 minutes, and do not measure the mass on each sieve at 1-minute intervals after 10 minutes to determine an end point, as suggested in the standard. Some others may follow this guideline or use the 15-minute period "for industrial applications." Therefore, a minimum time of 10 minutes and a maximum of 15 minutes were used, with the shorter period generating a d_{gw} of 523 and an s_{gw} of 2.40 vs. 481 and 2.56 respectively for the 15-minute period.

Use of a dispersion agent has become more common in the feed industry over the last few years. A previous study published in this publication[1] showed that the use of a dispersion agent reduces the d_{gw} by approximately 80 microns and produces a greater

[1] Goodband et al., Swine Day 2006, SRP966, p. 163

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value for s_{gw}, and this was consistent across the range of particle sizes evaluated. The data from this study appear to confirm these findings, with a reduction in d_{gw} of 74 microns, and an increase in s_{gw} of 0.36.

Discussion

While it is difficult to recommend a procedure as the one correct method for measuring particle size and distribution, it is clear that differences in methodology can lead to large differences in results. In general, it is assumed that lower d_{gw} and higher s_{gw} values are representative of better sifting, as the particles have more likely reached their ideal place in the sieve stack. When the options are compounded in best vs worst sifting scenarios, the range of results can be very large. Figures 1 and 2 show the range of d_{gw} and s_{gw} values from the 25 observations made during this study, using the same sample. In addition to the data shown here, some preliminary data suggest that variations such as sieve age, the way in which the sieve shaker is mounted on the table, and the individual running the analysis can also substantially affect the results.

Feed mills that are being pressured to produce ground grain with a specific d_{gw} and s_{gw} may face challenges if the in-house quality control laboratory is following different procedures compared with an outside lab. Because such large variations can exist, it is important that the methodology be standardized when comparisons are being made, whether for quality control, nutritional analysis, or contractual conditions.

Table 1: Average geometric means (dgw) and standard deviations (s_{gw}) for differing methods

	Geometric mean (d_{gw})	Geometric standard deviation (s_{gw})
Sieve shaker		
Tyler Ro-Tap	589	2.11
Retsch	497	2.53
Sieve agitators		
With	523	2.40
Without	624	2.00
Dispersion agent		
With	486	2.46
Without	560	2.10
Sieving time		
10 minutes	523	2.40
15 minutes	481	2.56

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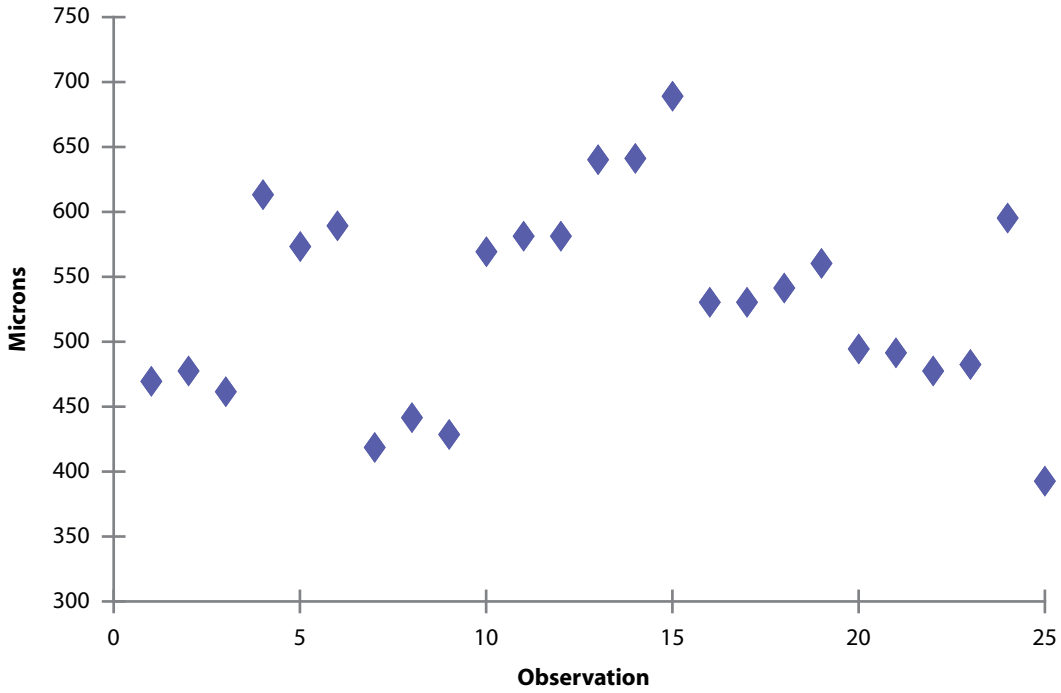

Figure 1: Geometric means (dgw) from 25 observations of a single sample

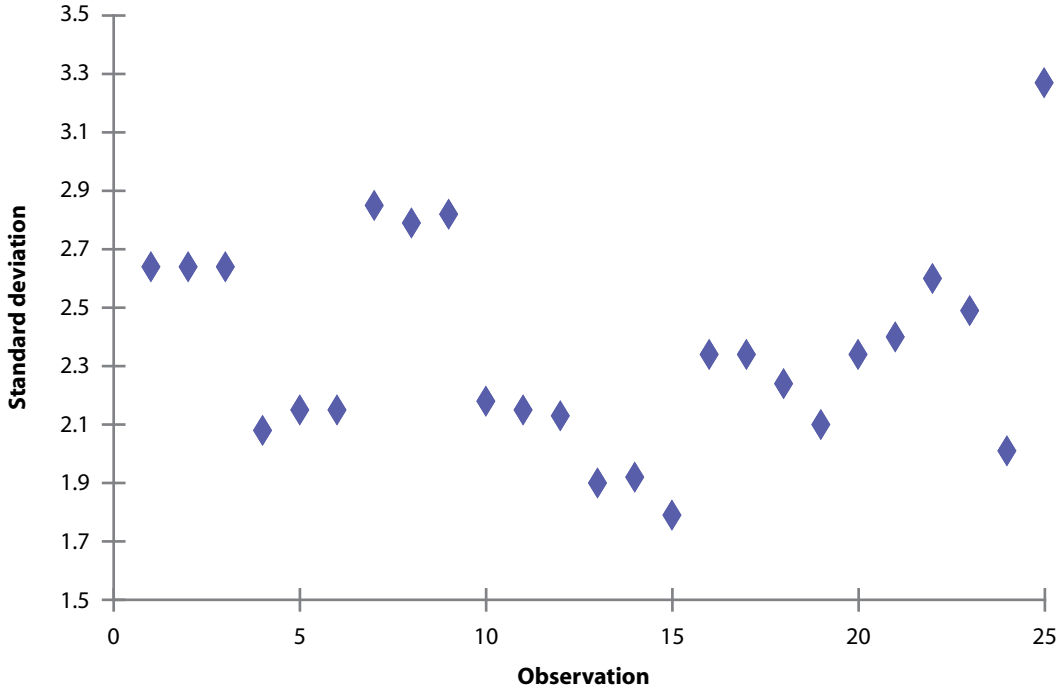

Figure 2: Geometric standard deviations (sgw) from 25 observations of a single sample

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Nutrient Analysis of Sorghum Dried Distillers Grains with Solubles from Ethanol Plants Located in the Western Plains Region[1]

K. M. Sotak, R. D. Goodband, M. D. Tokach, J. M. DeRouchey, S. S. Dritz[2], and J.L. Nelssen

Summary

Samples of sorghum dried distillers grains with solubles (DDGS) were collected and analyzed to establish a nutrient database and evaluate the quality and consistency between and within samples taken from 5 ethanol plants in the Western Plains region. Four plants were located in Kansas and 1 in Texas. A total of 21 samples were collected, with 4 plants contributing 4 samples each and 1 plant contributing 5 samples from different manufacturing lots of DDGS. Each sample was analyzed for amino acids, DM, CP, crude fiber, crude fat, ash, NDF, ADF, Ca, P, trace minerals, GE, and starch. In addition, DE, ME, and NE were calculated from the nutrient analysis. Of the 5 plants, 3 produced pure sorghum DDGS samples while 2 produced mixed sorghum and corn DDGS samples, with sorghum representing 60 or 70% of the DDGS. For the pure sorghum DDGS, the overall sample average means for each nutrient on a DM basis were: DM (89.5%), CP (34.2%), crude fat (10.5%), ash (4.4%), NFE (40.3%), crude fiber (10.6%), ADF (26.4%), NDF (35.1%), starch (4.3%), calculated DE (1,560 kcal/lb), calculated ME (1,454 kcal/lb), calculated NE (919 kcal/lb), Ile (1.37%), Leu (3.84%), Lys (0.88%), Met (0.55%), Thr (1.04%), Trp (0.26%), Val (1.67%), Ca (0.01%), and P (0.72%). The mixed DDGS samples' means were generally similar to the pure sorghum DDGS nutrient analysis values. Results of these analyses can be used by nutritionists to better utilize sorghum DDGS in swine diets.

Key words: dried distillers grains with solubles, nutrient analysis, sorghum

Introduction

Dried distillers grains with solubles (DDGS) are usable by-products of ethanol production. Dried distillers grains with solubles are commonly added to swine diets to lower feed costs. However, concern about consistency and quality variation among ethanol plants presents challenges to swine nutritionists in using DDGS in diet formulation. Dried distillers grains with solubles also tend to have low lysine and tryptophan concentrations, limiting the inclusion rate. Quality depends upon crop selection, fermentation type, and drying temperature and duration (Spiehs et al, 2002[3]). While most of the information gathered to date has focused on corn DDGS, little information exists regarding sorghum DDGS from the Great Plains region. Therefore, the objective of this study was to determine the nutrient content of Great Plains sorghum DDGS.

[1] The authors wish to thank the United Sorghum Checkoff Program for partial financial support for this project and the ethanol plants participating in this survey.

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

[3] Spiehs, M.J., M.H. Whitney, and G.C. Shurson. 2002. Nutrient database for distiller's dried grains with solubles produced from new ethanol plants in Minnesota and South Dakota. J. Anim. Sci. 80:2639-2645.

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Procedures

A total of 21 samples of sorghum DDGS were collected from 5 plants in the Western Plains Region (KS=4, TX=1) between May and June 2010. Four of the plants contributed 4 individual samples, while 1 plant contributed 5 individual samples. Of the 5 ethanol plants, 3 produced pure sorghum DDGS while 2 produced a DDGS mixture of either 60 or 70% sorghum with 40 or 30% corn. The 21 samples were then divided into subsamples for proximate and mineral composition analyses (Ward Laboratories, Kearney, NE), amino acid analysis (University of Missouri, Experiment Station Laboratory, Columbia, MO), and particle size analysis and bomb calorimeter (Kansas State University). Digestible, metabolizable, and net energy values on a DM basis were calculated using the following equations:

- DE kcal/kg = -174 + (0.848 × GE) + {2 × [100 - (CP + EE + Ash + NDF)]} - (16 × ADF); Ewan (1989[4])
- ME kcal/kg = (1 × DE) - (0.68 × CP); Noblet and Perez (1993[5])
- NE kcal/kg = (0.726 × ME) + (13.3 × EE) + (3.9 × starch) - (6.7 × CP) - (8.7 × ADF); Noblet et al. (1994[6])

Descriptive statistics (Microsoft Excel 2007; Microsoft Corp., Redmond, WA) were used to calculate the mean for each plant as well as the combined samples within each DDGS type. Also, descriptive statistics were used to calculate the standard deviation from samples within each plant, within all samples of each DDGS type, and across plants.

Results and Discussion

All nutrient values are presented on a 100% DM basis (Tables 1, 2, 3 and 4).

For the pure sorghum samples, the average DM was 89.5% with a standard deviation of 0.96% (Table 1). The average CP was 34.2% with a standard deviation of 3.78 %. The CP in DDGS from Kansas ethanol plants was consistently between 31 and 33%, with CP from the Texas plant being considerably higher at 39.13%. This could be due to the lower percentage of solubles present in the Texas DDGS sample. This is also suggested because the Texas sample had a much lower particle size, again suggesting fewer solubles added back to the DDGS. In comparison, values from Feoli (2008[7]) showed the average value for DM sorghum DDGS was 88.30% and the DM value for CP at 34.14% (Feoli, 2008). The NRC (1998[8]) reported the CP (converted to DM at 89%) to be 10.34% for sorghum grain. The CP of DDGS is generally 3 times higher than the CP of the grain

[4] Ewan, R. C. 1989. Predicting the energy utilization of diets and feed ingredients in pigs. pp. 271-274 in Energy metabolism, European Association of Animal production Bulletin No. 43, Y. van der Honing and W. H. Close, eds. Pudoc Wageningen, Netherlands.

[5] Noblet, J., and J. M. Perez. 1993. Prediction of digestibility of nutrients and energy values of pig diets from chemical analysis. J. Anim. Sci. 71(12): 3389-3398.

[6] Noblet, J., H. Fortune, X. S. Shi, and S. Dubois. 1994. Prediction of net energy value of feeds for growing pigs. J. Anim. Sci. 72(2): 344-354.

[7] Feoli, C. Use of corn and sorghum-based distillers dried grains with solubles in diets for nursery and finishing pigs. Dissertation Abstract. Retrieved September 17, 2010 from K-State Electronic Theses, Dissertations, and Reports: 2004 – Present.

[8] NRC, 1998, Nutrient Requirements of Swine, 10th ed.. Natl. Acad. Press, Washington, D.C.

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from which it originated, thus values for the DDGS sampled in this study are generally close to that correlation.

The average crude fat content of pure sorghum DDGS was 10.49% with a standard deviation of 1.10%. The mixed DDGS samples were slightly higher in crude fat, which might be a result of the corn blended with the sorghum before fermentation. According to Feoli (2008), the average value for crude fat in sorghum DDGS was 8.61%, lower than the reported values in the present study.

The average ADF was 26.43% (4.96) and the average NDF was 35.07% (5.34) for the pure sorghum DDGS samples. The mixed DDGS samples had average ADF and NDF values of 22.07% (2.28) and 36.73% (1.46), respectively. Because NDF is more digestible than ADF, the mixed samples might be considered to have slightly greater digestibility than the pure sorghum DDGS samples. Stein (2007[9]) reported the ADF and NDF of corn DDGS to be 13.48% and 44.94%, respectively. The average values for the sorghum grain (NRC, 1998) were lower for both ADF (9.33%) and NDF (20.22%) compared to the DDGS in the present study, which was expected, due to ADF and NDF being concentrated in DDGS compared to the grain from which it originated.

For amino acids, the average lysine content in the pure sorghum DDGS was 0.88%, while the mixed DDGS samples had a value of 0.87%. Feoli (2008) reported pure sorghum DDGS had 0.97% lysine, while Stein (2007[9]) reported corn DDGS had 0.88% lysine. For sorghum grain, the NRC (1998) published a lysine value of 0.25%.

The average tryptophan and threonine values for the pure sorghum DDGS were 0.26% and 1.04%, respectively. Tryptophan was higher than Feoli's (2008) value of 0.17%, and Stein's (2007) corn DDGS value of 0.24%. In DDGS, regardless of cereal grain source, tryptophan is considered limiting and generally restricts the amount of crystalline lysine that can be added to the diet.

Average methionine content was 0.55% for the pure sorghum DDGS and mixed DDGS samples. The samples' values were slightly lower than Feoli's (2008) sorghum DDGS value of 0.59% and Stein's (2007) corn DDGS value of 0.62%.

For pure sorghum DDGS, arginine (1.17%), histidine (0.67%), and phenylalanine (1.48%) average values were lower than Feoli's (2008) reference values (1.35%, 0.85%, and 1.90%, respectively) for the sorghum DDGS sand Stein's (2007) corn DDGS references values (1.30%, 0.81%, and 1.51%, respectively). Amino acids are essential components of pigs' growth and performance. Due to their importance, nutritionists should be aware of the variability within the ingredients and ethanol plants when determining a diet source.

Phosphorus is important because of its cost as well as its role in land base requirements for manure application. Both corn and sorghum DDGS contain relatively high concentrations of P, which are highly available to the pig, resulting in a lower requirement level

[9] Stein, H. 2007. Dried distillers grains with solubles (DDGS) in diets fed to swine. In: Swine Focus-#001. pp. 1-8.

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of dietary inorganic phosphorus. The average phosphorus content of the pure sorghum DDGS was 0.72%, while the content of the mixed DDGS samples was 0.74%.

The average ash concentration in the pure sorghum DDGS samples was 4.42%, with the Kansas region ethanol plants (5.02% and 4.93%) being higher than the Texas ethanol plant (3.32%) in this study. The composite means and standard deviations for Ca, K, Mg, S, Na, Zn, Mn, Cu, and Fe were all profiled to determine the amounts present in each sample.

The gross energy (GE) for the pure sorghum DDGS samples was 2,142 kcal/lb with a standard deviation of 42.7, while the GE for the mixed DDGS samples was 2,187 kcal/lb with a standard deviation of 28.2. The GE values for the mixed DDGS samples were higher than those of the pure DDGS samples, which was expected because corn has a higher energy content than sorghum grain. In comparison, Feoli (2008) reported a GE value of 2,232 kcal/lb for the sorghum DDGS while Stein (2007) reported 2,465 kcal/lb for the corn DDGS. The digestible energy (DE), metabolizable energy (ME), and the net energy (NE) for the pure sorghum DDGS samples were 1,560 kcal/lb (54.6), 1,454 kcal/lb (62.9), and 919 kcal/lb (79.3), respectively. While the NRC (1998) sorghum grain values were DE at 1,723 kcal/lb, ME at 1,702 kcal/lb, and NE at 1,149 kcal/lb. The difference in energy content between sorghum grain and sorghum DDGS is wider than we would have expected. Research has shown that corn and corn DDGS have similar energy values. The DE, ME, and NE for the mixed DDGS samples were 1,629 kcal/lb (17.1), 1,528 kcal/lb (19.5), and 1,005 kcal/lb (32.2) respectively (Table 4). The mixed samples contained a higher amount of energy than the pure sorghum samples as expected, but still lower than the sorghum grain (NRC, 1998). Also, the energy value standard deviations of the pure DDGS samples were approximately double those of the mixed DDGS samples, meaning there was a larger variation in energy content within samples for the pure DDGS compared to the mixed DDGS samples.

Particle size of the pure sorghum DDGS samples varied from 447 to 843 microns, with an average of 670 microns. There was considerable range in average particle size between plants, which may have been influenced by the amount of solubles added back to the mash during drying. The average of the mixed DDGS samples was 632 microns. Particle size and DM are generally considered the two biggest contributors to the flow ability of both corn and sorghum DDGS, in which a higher DM and lower particle negatively affect flow ability.

The nutrient and calculated energy values established from this study of pure sorghum DDGS and sorghum-corn DDGS mixtures can now be used by swine nutritionists to more accurately formulate diets. Routine analysis of sorghum DDGS is essential to update nutrient specifications, as variability among geographic regions, crop-growing conditions, and plant manufacturing processes will influence DDGS composition.

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Table 1. Proximate analysis of sorghum dried distillers grains with solubles (DDGS) from ethanol plants located in the Western Plains region (DM basis)

		Nutrient, %								
Sample Origin	No of samples	DM	CP	Fat	Ash	NFE	Crude Fiber	ADF	NDF	Starch
Pure Samples										
1	4	88.64 (0.75)[6]	31.23 (0.84)	10.55 (0.26)	5.02 (0.16)	43.93 (0.84)	9.28 (0.57)	22.45 (1.29)	30.43 (0.78)	4.58 (0.44)
2	4	89.35 (0.35)	32.28 (0.66)	11.73 (0.21)	4.93 (0.07)	40.95 (0.75)	10.10 (0.22)	23.90 (1.49)	33.18 (1.44)	4.75 (0.61)
3	4	90.49 (0.60)	39.13 (1.43)	9.20 (0.24)	3.32 (0.28)	36.00 (0.42)	12.35 (0.93)	32.95 (0.31)	41.60 (3.41)	3.58 (0.49)
Average	12	89.49 (0.96)	34.21 (3.78)	10.49 (1.10)	4.42 (0.83)	40.29 (3.47)	10.58 (1.48)	26.43 (4.96)	35.07 (5.34)	4.30 (0.72)
SD among plants	3	0.93	4.29	1.26	0.96	4.00	1.59	5.69	5.82	0.63
Mixed Samples										
1[1]	5	90.26 (0.27)	32.00 (1.08)	11.10 (0.26)	3.64 (0.07)	41.62 (1.62)	11.64 (0.66)	20.38 (1.32)	36.38 (1.66)	3.42 (0.38)
2[2]	4	90.29 (0.38)	33.55 (1.20)	11.60 (0.34)	4.58 (0.15)	39.40 (1.29)	10.88 (0.46)	24.18 (0.90)	37.18 (1.25)	3.55 (0.17)
Average	9	90.27 (0.30)	32.69 (1.34)	11.3 (0.4)	4.06 (0.51)	40.63 (1.82)	11.30 (0.68)	22.07 (2.28)	36.73 (1.46)	3.48 (0.29)
SD among plants	2	0.03	1.10	0.35	0.67	1.57	0.54	2.68	0.56	0.09
Feoli, 2008[3] sorghum DDGS		88.30	34.14	8.61	4.08	45.07	8.10	---	---	---
Stein, 2007[4] corn DDGS		89.00[7]	30.90	10.11		---	---	13.48	44.94	8.20
NRC, 1998[5] sorghum grain		89.00	10.34	3.26		---	---	9.33	20.22	---

[1] Mixed sample contained 60% sorghum and 40% corn.
[2] Mixed sample contained 70% sorghum and 30% corn.
[3] Feoli, C. Use of corn and sorghum-based distillers dried grains with solubles in diets for nursery and finishing pigs. Dissertation Abstract. Retrieved September 17, 2010, from K-State Electronic Theses, Dissertations, and Reports: 2004 – Present.
[4] Stein, H. 2007. Dried distillers grains with solubles (DDGS) in diets fed to swine. In: Swine Focus-#001. Pp. 1-8.
[5] NRC, 1998. Nutrient Requirements of Swine, 10th ed. Natl. Acad. Press, Washington, D.C.
[6] () Values in parenthesis represent the standard deviation of the mean.
[7] Assumed DM for nutrient calculations.

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Table 2. Essential amino acid concentrations for sorghum dried distillers grains with solubles (DDGS) from ethanol plants located in the Western Plains region (DM basis)

		Amino acid, %[7]									
Sample origin	No. of samples	Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val
Pure DDGS Samples											
1	4	1.15 (0.05)	0.62 (0.03)	1.28 (0.08)	3.31 (0.21)	0.88 (0.04)	0.47 (0.03)	1.30 (0.08)	0.98 (0.06)	0.25 (0.01)	1.56 (0.09)
2	4	1.18 (0.04)	0.67 (0.02)	1.32 (0.02)	3.61 (0.08)	0.93 (0.03)	0.62 (0.21)	1.41 (0.03)	1.02 (0.03)	0.25 (0.01)	1.63 (0.03)
3	4	1.18 (0.08)	0.73 (0.06)	1.52 (0.14)	4.60 (0.44)	0.83 (0.06)	0.57 (0.04)	1.74 (0.16)	1.14 (0.09)	0.28 (0.02)	1.83 (0.16)
Average	12	1.17 (0.06)	0.67 (0.06)	1.37 (0.14)	3.84 (0.63)	0.88 (0.06)	0.55 (0.13)	1.48 (0.22)	1.04 (0.09)	0.26 (0.02)	1.67 (0.15)
SD among plants	3	0.02	0.05	0.13	0.67	0.05	0.08	0.23	0.08	0.01	0.14
Mixed DDGS Samples											
1[1]	5	1.23 (0.03)	0.74 (0.02)	1.25 (0.03)	3.69 (0.10)	0.89 (0.01)	0.55 (0.01)	1.44 (0.03)	1.04 (0.02)	0.25 (0.01)	1.56 (0.03)
2[2]	4	1.20 (0.04)	0.72 (0.03)	1.37 (0.07)	3.91 (0.25)	0.85 (0.02)	0.77 (0.17)	1.50 (0.09)	1.05 (0.05)	0.24 (0.01)	1.69 (0.09)
Average	9	1.22 (0.04)	0.73 (0.03)	1.30 (0.08)	3.79 (0.20)	0.87 (0.03)	0.55 (0.16)	1.47 (0.07)	1.05 (0.04)	0.24 (0.01)	1.62 (0.09)
SD among plants	2	0.02	0.02	0.08	0.16	0.03	0.16	0.04	0.01	0.002	0.09
Feoli, 2008[3] sorghum DDGS		1.35	0.85	1.58	4.56	0.97	0.59	1.90	1.18	0.17	1.91
Stein, 2007[4,5] corn DDGS		1.30	0.81	1.13	3.56	0.88	0.62	1.51	1.20	0.24	1.52
NRC, 1998[6] sorghum grain		0.43	0.26	0.42	1.38	0.25	0.19	0.56	0.35	0.11	0.52

[1] Mixed sample contained 60% sorghum and 40% corn.
[2] Mixed sample contained 70% sorghum and 30% corn.
[3] Feoli, C. Use of corn and sorghum-based distillers dried grains with solubles in diets for nursery and finishing pigs. *Dissertation Abstract*. Retrieved September 17, 2010 from K-State Electronic Theses, Dissertations, and Reports: 2004 – Present.
[4] Stein, H. Dried distillers grains with solubles (DDGS) in diets fed to swine. 2007. In: Swine Focus-#001. pp. 1-8.
[5] Assumed DM of 89.0% for nutrient calculations.
[6] NRC, 1998 Nutrient Requirements of Swine, 10th ed. Natl. Acad. Press, Washington, D.C.
[7] () Values in parenthesis represent the standard deviation of the mean.

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Table 3. Mineral composition of dried distillers grains with solubles (DDGS) from ethanol plants located in the Western Plains region (DM basis)

		Mineral[4]									
Sample origin	No. of samples	Ca, %	P, %	K, %	Mg, %	S, %	Na, %	Zn, ppm	Mn, ppm	Cu, ppm	Fe, ppm
Pure Samples											
1	4	0.11	0.84	1.15	0.39	0.77	0.14	37.95	44.25	7.83	119.25
		(0.01)	(0.02)	(0.04)	(0.01)	(0.02)	(0.01)	(1.24)	(0.96)	(0.25)	(11.87)
2	4	0.07	0.87	1.17	0.42	0.54	0.12	45.58	42.75	6.53	117.00
		(0.01)	(0.02)	(0.01)	(0.01)	(0.05)	(0.01)	(0.79)	(1.89)	(0.19)	(10.23)
3	4	0.07	0.45	0.54	0.23	0.42	0.18	42.55	35.75	7.00	136.50
		(0.01)	(0.04)	(0.03)	(0.03)	(0.09)	(0.05)	(9.20)	(12.87)	(0.42)	(18.70)
Average	12	0.08	0.72	0.95	0.35	0.57	0.15	42.03	40.92	7.12	124.25
		(0.02)	(0.20)	(0.31)	(0.09)	(0.16)	(0.04)	(5.86)	(7.83)	(0.62)	(15.66)
SD among plants	3	0.02	0.24	0.36	0.10	0.18	0.03	3.84	4.54	0.66	10.67
Mixed Samples											
1[1]	5	0.05	0.68	0.81	0.28	0.57	0.04	41.00	21.60	4.82	92.60
		(0.03)	(0.02)	(0.01)	(0.01)	(0.04)	(0.01)	(0.78)	(1.52)	(0.52)	(6.91)
2[2]	4	0.06	0.82	1.07	0.37	0.47	0.11	57.88	43.50	7.05	12.25
		(0.01)	(0.02)	(0.03)	(0.01)	(0.01)	(0.01)	(1.58)	(2.52)	(0.44)	(14.86)
Average	9	0.06	0.74	0.93	0.32	0.53	0.07	48.50	31.33	5.81	106.22
		(0.02)	(0.07)	(0.14)	(0.05)	(0.06)	(0.04)	(8.96)	(11.69)	(1.26)	(19.18)
SD among plants	2	0.01	0.09	0.18	0.07	0.07	0.05	11.93	15.49	1.58	21.67
NRC, 1998[3] sorghum grain		0.03	0.33	0.39	0.17	0.09	0.01	16.85	17.05	5.68	51.14

[1] Mixed sample contained 60%sorghum and 40% corn.
[2] Mixed sample contained 70% sorghum and 30% corn.
[3] NRC, 1998 Nutrient Requirements of Swine, 10th ed. Natl. Acad. Press, Washington, D.C.
[4] () Values in parenthesis represent the standard deviation of the mean.

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Table 4. Proximate analysis of sorghum dried distillers grains with solubles (DDGS) from ethanol plants located in the Western Plains region (DM basis)

		Energy, kcal/lb[9]				Particle size[9]	
Sample Origin	No of samples	GE	DE[1]	ME[2]	NE[3]	Mean,	Std deviation
Pure Samples							
1	4	2,123 (34.6)	1,579 (29.7)	1,483 (27.7)	965 (20.4)	843 (111.6)	1.78 (0.01)
2	4	2,161 (18.3)	1,597 (24.9)	1,497 (26.6)	974 (27.1)	721 (23.6)	1.73 (0.03)
3	4	2,142 (64.6)	1,504 (54.9)	1,384 (53.6)	817 (36.9)	447 (65.9)	2.06 (0.05)
Average	12	2,142 (42.7)	1,560 (54.6)	1,454 (62.9)	919 (79.3)	670 (186.0)	1.86 (0.16)
SD among plants	3	19.2	49.0	61.8	87.7	202.7	0.18
Mixed Samples							
1[4]	5	2,174 (24.0)	1,632 (15.6)	1,533 (17.3)	1,022 (31.0)	662 (44.0)	1.82 (0.03)
2[5]	4	2,204 (26.2)	1,626 (20.8)	1,523 (23.2)	984 (20.7)	594 (91.9)	1.78 (0.07)
Average	9	2,187 (28.2)	1,629 (17.1)	1,528 (19.5)	1,005 (32.2)	632 (73.8)	1.80 (0.05)
SD among plants	2	21.1	4.0	7.4	26.7	48.5	0.03
Feoli, 2008[6] sorghum DDGS		2,232	1,572	---	---	---	---
Stein, 2007[7] corn DDGS		2,465	1,878	1,768	---	---	---
NRC, 1998[8] sorghum grain		---	1,723	1,702	1,149	---	---

[1] DE = -174 + (0.848 × GE) + {2 × [100 - (CP + EE + Ash + NDF)]} - (16 × ADF).
[2] ME = (1 × DE) - (0.68 × CP).
[3] NE = (0.726 × ME) + (13.3 × EE) + (3.9 × starch) - (6.7 × CP) - (8.7 × ADF).
[4] Mixed sample contained 60% sorghum and 40% corn.
[5] Mixed sample contained 70% sorghum and 30% corn.
[6] Feoli, C. Use of corn and sorghum-based distillers dried grains with solubles in diets for nursery and finishing pigs. *Dissertation Abstract*. Retrieved September 17, 2010 from K-State Electronic Theses, Dissertations, and Reports: 2004 – Present.
[7] Stein, H. 2007. Dried distiller's grains with solubles (DDGS) in diets fed to swine. In: Swine Focus-#001. pp. 1-8.
[8] NRC, 1998 Nutrient Requirements of Swine, 10th ed. Natl. Acad. Press, Washington, D.C.
[9] () Values in parenthesis represent the standard deviation of the mean from all individual samples.

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Factors Affecting Storage Stability of Various Commercial Phytase Sources[1]

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Summary

A 360-d study was performed to evaluate the effects of environmental conditions on storage stability of exogenous phytases. Coated and uncoated products from 3 phytase sources (Ronozyme P, OptiPhos, and Phyzyme) were stored as pure forms, in a vitamin premix, or in a vitamin and trace mineral (VTM) premix. Pure products were stored at 0, 41, 73, and 99°F (75% humidity). Premixes were stored at 73 and 99°F. Sampling was performed on d 0, 30, 60, 90, 120, 180, 270, and 360. Sampling of the pure products stored at 0 and 41°F was discontinued after d 120 due to mold growth in the 41°F samples. Stability was measured as the residual phytase activity (% of initial) at each sampling point. For the stability of the pure forms, all interactive and main effects of phytase product, coating, time, and temperature of storage were significant ($P < 0.01$), except for time × coating interaction. When stored at 73°F or less, pure phytases retained at least 91, 85, 78, and 71% of initial phytase activity at 30, 60, 90, and 120 d of storage, respectively. However, storing pure products at 99°F reduced ($P < 0.01$) phytase stability, with OptiPhos retaining the most ($P < 0.01$) activity. Coating mitigated ($P < 0.01$) the negative effects of high storage temperature for Ronozyme and OptiPhos (from d 90 onward) but not for Phyzyme. For the stability of phytase in different forms of storage, all interactive and main effects of phytase product, form, coating, time, and temperature of storage were significant ($P < 0.01$). When stored at room temperature (73°F), retained phytase activities for a majority of the phytase sources were more than 85, 73, and 60% of initial activity up to 180 d when stored as pure products, vitamin premixes, or VTM premixes, respectively. When stored at 99°F, pure phytase products had greater ($P < 0.01$) retention of initial phytase activity than when phytases were mixed with the vitamin or VTM premixes. Coated phytases stored in any form had greater ($P < 0.01$) activity retention than the uncoated phytases at all sampling periods. In conclusion, storage stability of commercially available phytases is affected by duration of storage, temperature, product form, coating, and phytase source. Pure products held at 73°F or less were the most stable. In premixes, longer storage time and higher temperature reduced phytase activity, but coating mitigated some of these negative effects.

Key words: enzyme, phytase, stability, storage

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

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

[4] Enzyvia, LLC, Sheridan, IN.

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Introduction

Phytases are routinely used in swine and poultry diets as an economical P source to increase the availability of phytate phosphorus in the diet. The rapid increase in phytase use has led to the introduction of several commercial phytases produced from various microbial sources. The ultimate value of any phytase product depends on its efficacy and stability. As with any catalytic proteins, phytases lose significant amount of activity when subjected to feed processing treatments. Research has focused on optimizing thermostability of exogenous phytases in industrial settings. Nutritionists most often consider minimum guaranteed levels of phytase after feed processing in their diet formulations; however, the stability of phytases during storage receives little attention. Currently, there has been no independent study evaluating the effects of various factors such as coating, time, or temperature of storage on the stability of commercial phytases. In addition, the use of phytase-fortified vitamin and vitamin-trace mineral premixes is becoming more popular in the industry. There also may be potential interactions between phytase and some components of the premixes that may affect phytase activity.

Therefore, the objective of this study was to determine the effects of coating, storage form, storage temperature, and duration of storage on the stability of six commercially available phytases.

Procedures

This study was conducted at the Animal Nutrition Laboratory and at the Bioprocessing and Industrial Value Added Program (BIVAP) Building at Kansas State University.

Phytase sources

Six commercially available phytases were used in this experiment: OptiPhos 2000-M (uncoated, declared potency of 2,000,000 phytase units [FTU]/kg); OptiPhos 2000-PF (coated, declared potency of 2,000,000 FTU/kg); Phyzyme XP 5000 G (uncoated, declared potency of 5,000,000 FTU/kg); Phyzyme XP 10,000 TPT (coated, declared potency of 10,000,000 FTU/kg); Ronozyme P-M (uncoated, declared potency of 50,000,000 phytase units [FYT]/kg); and Ronozyme P-CT (coated, declared potency of 10,000,000 FYT/kg). One phytase unit (FTU or FYT) was defined as the amount of enzyme that catalyzes the release 1 μmol of iP per minute from 5.1 mM sodium phytate in pH 5.5 buffer at 37°C. Pure cornstarch was used as a negative control due to the low inherent phytase activity. The coated and uncoated phytases were obtained from a third-party distributor. The manufacturing dates of all products were obtained from the original supplier to ensure that the products were within 6 mo of manufacture and were not expired.

Pure products

On d 0, 3 lb of each of the pure phytase products and cornstarch were individually placed into 12 open, single-lined paper bags. Three bags of each product were stored in a freezer (0°F), in a refrigerator (41°F), at room temperature (73°F), and in a controlled environment chamber set at 99°F and 75% humidity. A blind sample from each bag was taken at d 30, 60, 90, 120, 180, 270, and 360, and sent to Technical Marketing Analytical Services of DSM Nutritional Products, Inc. (Belvidere, NJ) for phytase analysis using a slight modification of the AOAC official method (AOAC, 2000). A second sample from each bag of the cornstarch control, OptiPhos 2000-M, and Opti-

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Phos 2000-PF was blinded and sent to Phytex, LLC (Portland, ME) for phytase analysis using the Phytex method. However, sampling of the pure products stored at 0 and 41°F was discontinued after d 120 due to mold growth in the retained 41°F samples. Thus, only pure products stored at 73 and 99°F were sampled for all time points.

Premixes

Each phytase product and the cornstarch control were added and mixed with either the K-State vitamin premix or the vitamin and trace mineral premix (VTM). The amount added for each phytase product was determined such that including 0.30% premix in the diet would provide the levels of phytase recommended by its respective manufacturer (250 FTU/kg, OptiPhos 2000-M and OptiPhos 2000-PF; 500 FTU/kg, Phyzyme XP 5000 G and Phyzyme XP 10,000 TPT; 1,850 FYT/kg, Ronozyme P-M and Ronozyme P-CT).

A total of 5.4, 5.4, 3.0, 1.5, 5.6 and 1.1 lb of pure OptiPhos 2000-M, OptiPhos 2000-PF, Phyzyme XP 5000-G, Phyzyme XP 10000 TPT, Ronozyme P-M, and Ronozyme P-CT, respectively, were weighed. Cornstarch was added to the pure phytase products to create 21.7-(OptiPhos) or 15.0-(Phyzyme XP and Ronozyme P) lb batches, which were mixed with a paddle mixer for 5 min. A total of 108 (OptiPhos) or 75 (Phyzyme XP and Ronozyme P) lb of vitamin or VTM premix was added to each batch and mixed with a paddle mixer for an additional 12 min to create premix batches of 130 (OptiPhos) or 90 (Phyzyme XP and Ronozyme P) lb. Additionally, 130 lb of cornstarch made up the control batch. The vitamin premix was that recommended by K-State. The VTM contained equal quantities of K-State-recommended vitamin and trace mineral premixes.

The 7 batches were each equally divided into 6 open, single-lined paper bags. Three bags of each batch were stored either at room temperature (approximately 73°F) or in the environmentally-controlled chamber set at 99°F and 75% humidity. A sample from each bag was taken every 30 d until d 180, except for the last 2 samplings (taken at d 270 and 360). Each blind sample was sent for phytase analysis to Technical Marketing Analytical Services of DSM Nutritional Products, Inc., using a slight modification of the AOAC official method. A second sample from each bag containing the control, OptiPhos 2000-M, and OptiPhos 2000-PF premixes, was blinded and sent to Phytex, LLC for phytase analysis using the Phytex method.

Statistical analyses

Data were analyzed using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) to determine the interactive and main effects of coating, storage form, storage temperature, and time on stability of six commercially available phytases. Because the vitamin and VTM premixes were only stored at room temperature and in the environmentally controlled heat chamber, 2 analyses were performed. The first was with the pure forms only, and the second was for pure forms, vitamin, and VTM premixes at 73°F and 99°F. Least square means were calculated for each independent variable. When treatment effect was a significant source of variation, differences were determined by using the preplanned, pairwise comparisons (PDIFF option of SAS). Statistical significance and tendencies were set at $P \leq 0.05$ and $P < 0.10$ for all statistical tests.

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Results

Initial phytase activity

The calculated and analyzed initial (d 0) phytase activity of the samples is shown in Table 1. Using the AOAC assay, the control samples for the pure product, the vitamin premix, and the VTM premix contained 4,967 to 10,500 phytase units/kg. However, the phytase activity of the control samples analyzed using the Phytex assay was much higher than the analyses using the AOAC assay. For all three forms, the AOAC-analyzed phytase levels of OptiPhos, Phyzyme XP, and Ronozyme P were 196 to 295, 97 to 157, and 103 to 142% higher than their calculated phytase levels. Using the Phytex assay, samples of the pure OptiPhos 2000-M and OptiPhos 2000-PF had similar (101 to 102%) phytase activity compared to their calculated levels. In contrast, phytase activity of both OptiPhos products added to the vitamin and the VTM premix were lower, ranging from 30 to 68% of their calculated levels.

Pure products

All interactive and main effects of phytase product, coating, time, and temperature of storage were significant ($P < 0.01$; Table 2), except for time × coating interaction.

When stored at 73°F or less, the retained activity of phytases stored in pure form decreased ($P < 0.01$) as storage duration increased, regardless of phytase source or coating (Figures 1 to 3). At d 30, 60, and 90, pure phytases retained at least 91, 85, and 78% of initial phytase activity, respectively. Until d 120, the pure forms retained 71 to 102% of initial phytase activity, except for Ronozyme M, which retained 59% at 41°F. However, storing pure products at 99°F had greater ($P < 0.01$) effects on phytase stability. At d 30, both OptiPhos products stored in pure form retained 91 to 93% of initial activity when stored at 99°F, whereas the Phyzyme phytases retained 69 to 74%. Ronozyme CT retained 69% of initial phytase activity at d 30, but Ronozyme M only retained 36%. Afterward, phytases stored in pure forms retained at least 44, 39, and 33% of initial phytase activity at d 60, 90, and 120, respectively, except for Ronozyme M. Ronozyme M retained only 5% of initial phytase activity at d 120. At d 180, 270, and 360, phytases stored in pure forms at 99°F had retained phytase activities ranging from 1 to 53%, compared with 50 to 109% when stored at 73°F.

The coated OptiPhos had similar retention rates compared with the uncoated OptiPhos at d 30 and 60 when stored at 99°F, but coating improved ($P < 0.01$) its retention rates from d 90 onward. Coating also improved ($P < 0.01$) the retained phytase activities of Ronozyme phytase throughout the study; however, the coated Phyzyme had lower ($P < 0.01$) phytase activities than the uncoated Phyzyme until d 360. Among the coated phytases, the retention rates of Ronozyme-CT were lower ($P < 0.01$) than OptiPhos 2000-PF until d 120, while it was similar with Phyzyme 10,000 TPT until d 90. Among the uncoated phytases, OptiPhos 2000-M had greater ($P < 0.01$) phytase activities than both Phyzyme 5,000 G and Ronozyme M at d 30, but Phyzyme 5,000 G retained more ($P < 0.01$) than the other 2 uncoated phytases from d 90 onward.

Premixes

All interactive and main effects of phytase product, form, coating, time, and temperature of storage were significant ($P < 0.01$; Table 3), except for time × form × coating and coating × temp interactions ($P < 0.08$).

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When stored at 73°F, pure forms retained more ($P < 0.01$) phytase activity with increasing duration of storage than phytase-supplemented vitamin or VTM premixes (Figures 4 to 6). Pure phytase products retained at least 85 and 72% of initial phytase activity until d 180 and d 360, respectively; except for Ronozyme M (50%). In contrast, phytase-supplemented vitamin premixes retained at least 73% until d 180, except for Phyzyme 5,000 G (67%). At d 270 and d 360, both Phyzyme 5,000 G and Ronozyme M retained 56 to 59% of initial phytase activity, while the rest of the phytases retained at least 68%. Among all the phytases, OptiPhos 2000 PF retained the most activity (> 92%; $P < 0.01$) until d 360 when mixed with the vitamin premixes. In comparison, Ronozyme CT retained at least 83% of its initial phytase activity, whereas Phyzyme 10,000 TPT retained at least 73% until d 360. For the phytase-supplemented VTM premixes, retained phytase activities were at least 60% until d 180, except for OptiPhos 2000 M (43%). At d 270 and d 360, OptiPhos 2000 M only had 28% of its initial phytase activity, compared with at least 52% for the rest of phytases when mixed into the VTM premixes. As with the vitamin premixes, OptiPhos 2000 PF retained the most activity ($P < 0.01$) among all the phytases when mixed into the VTM premixes; however, its retention rates were lower ($P < 0.01$) than the rates obtained in the vitamin premixes. At d 360, OptiPhos 2000 PF, Ronozyme CT, and Phyzyme 10,000 TPT retained at least 83, 75, and 63% of initial phytase activity, respectively.

When stored at 99°F, retained phytase activities were much lower ($P < 0.01$) than the retention rates observed in samples stored at 73°F, regardless of the phytase source, coating, or form of storage. Pure phytase products also had greater ($P < 0.01$) retained phytase activities than the phytase-supplemented vitamin or VTM premixes. For the phytase-supplemented vitamin and VTM premixes, retained phytase activities after only 30 d of storage was 59 and 62% on average, which is lower ($P < 0.01$) than 72% for the pure phytase products. Ronozyme M was the least stable when mixed into vitamin premixes, retaining only 31% of its initial phytase activity at d 30. For the VTM premixes, OptiPhos 2000 M was the most affected, retaining only 20% of its initial phytase activity after a month of storage. At d 180, the phytase treatments had 3 to 53% of initial phytase activity. At the end of study (d 360), all the phytases had less than 28% of initial phytase activity.

The coated phytases stored in pure form or phytase-supplemented vitamin or VTM premixes had greater ($P < 0.01$) phytase activity than the uncoated phytases at all sampling periods. However, the differences in phytase activity between the coated and uncoated phytases were smaller ($P < 0.01$) when they were stored in pure forms than in the vitamin and VTM premixes. At d 30, 60, and 90, the differences in retained phytase activity between the coated and uncoated phytases ranged from 4.2 to 4.5, 11.5 to 28.6, and 33.4 to 44 percentage units when the phytases were in pure forms, vitamin premixes, and the VTM premixes. At d 30, coated phytases had similar phytase activities between the 3 forms when stored at 99°F; however, uncoated phytases stored in pure form had greater ($P < 0.01$) phytase activity than those mixed with the vitamin and VTM premixes. Likewise, uncoated phytases in vitamin premixes retained greater ($P < 0.01$) phytase activity than those in VTM premixes. When uncoated phytases were used and stored at 99°F, the pure forms had greater ($P < 0.01$) phytase activities than those in vitamin premixes, while both had greater ($P < 0.01$) phytase activities than the VTM premixes at all sampling periods.

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Discussion

Phytase assays

Previous research at Kansas State University (Jones, et al. 2009[5]) demonstrated that the level of accuracy of the analysis for phytase activity depended on the phytase product and assay method used. Using the AOAC method, the initial phytase activity of OptiPhos was 2 to 3 times greater than levels calculated by the manufacturer, which is similar (2.5 times) to the difference observed in earlier research. The analyzed initial phytase activities for Phyzyme and Ronozyme were closer (1 to 1.6 times greater) to their calculated levels, which is expected, as the AOAC assay is the recommended method of analysis for these products. For Optiphos, the analyzed initial phytase activity was similar to the manufacturer's calculated levels when their recommended Phytex assay was used.

Phytases in pure forms

Phytase manufacturers often provide overages as much as 10 to 30% in phytase activity to account for potential losses during feed processing treatments and storage. However, data are limited on the storage stability (defined as % of initial phytase activity) of commercial phytases, except for those reported by manufacturers in product registrations (European Food Safety Authority, 2006[6]; 2008[7]; 2009[8]). Though temperatures and conditions from manufacture, transport, and storage of phytases may not approximate conditions during feed processing, enough variation exists in storage conditions and time among phytase users to expect further losses in phytase activity. Most nutritionists do not measure phytase activity at the time of use, thus, it is important to understand the stability of the different commercial phytases during storage as affected by temperature and time.

The results of this study demonstrated that when phytase is stored at room temperature (73°F) or less, the pure product retained most (~85%) of its activity up to 60 d of storage, regardless of the phytase source or coating. However, phytase source influenced stability when storing the product for more than 60 d at 73°F or less, with Optiphos and Phyzyme retaining more activity than Ronozyme. In the current study, Phyzyme XP 5000G and Phyzyme XP 10000 TPT retained 90.9 and 86.3% of initial activity, respectively, when stored at 73°F and 180 d, which is similar to the retention rates reported to the European Food Safety Authority (2006, 2008). In these reports, the product had 87 and 80% of initial activity after 365 d of storage at 68°F. However, the current results did not confirm the retention rates reported for Ronozyme M (European Food Safety Authority, 2009). After 180 d, it was reported that Ronozyme M retained 99 and 90% of initial phytase activity when stored at 50 and 77°F, respectively, which is greater than our observations (58.7% for 120 d at 41°F and 60.6% after 180 d at 73°F).

Storing phytase in ambient temperatures greater than 99°F and 75% relative humidity was detrimental to the stability of the pure product. More importantly, phytase source affected retention rates with increasing time of storage, with the highest rates recov-

[5] Jones et al., Swine Day 2009, Report of Progress 1020, pp. 106-121.
[6] European Food Safety Authority. 2006 The EFSA Journal 404:1-20.
[7] European Food Safety Authority. 2008. The EFSA Journal 915:1-10.
[8] European Food Safety Authority. 2009. The EFSA Journal 1097:1-20.

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ered from OptiPhos, followed by Phyzyme, and finally, by Ronozyme. This ranking among the three phytase sources was the same throughout the study. The difference in retained phytase activities between OptiPhos and Ronozyme was large (91.5 vs 52.6% after 30 d, 45.8 vs 8.9% after 180 d). In the European Food Safety Authority report (2009), Ronozyme M kept at 104°F and 60% relative humidity retained only 50% of its initial phytase activity after 30 d, which is similar to the rate retained in the current study. The stability limit of *Escherichia coli* phytases, such as OptiPhos and Phyzyme, has been reported to be 140°F, whereas the stability limit for *Peniophora lycii* phytases has been reported at 176°F. Both temperatures are greater than the heat treatment used in this study; however, one major difference is that these thermal stability rates were determined by incubating the enzyme at low pH for a short duration of time (~30 min) whereas the enzyme was subjected to lower but sustained heat for a longer duration (up to 180 d) in this study. Another factor may be the high humidity (75%) in the chambers in our study. Others have evaluated the effects of increasing ambient humidity (from 53 to 90%) on the stability of commercial phytases stored at high ambient temperatures (104°F) for 70 d, and observed that phytase activity decreased significantly with increasing ambient humidity. This suggests that regardless of the phytase source, the environmental conditions set in the current study were sufficient to denature the enzyme and reduce activity. These conditions do not attempt to mimic real conditions during transport of the product or storage where temperatures and humidity may be more variable, but it clearly demonstrates the importance of maintaining better conditions (e.g., 73°F or less and lower ambient humidity) during storage to achieve greater stability from phytase products

Overall, coated pure products had greater phytase activity than uncoated pure products when exposed to 99°F and increasing storage time, but this differed between phytase sources. Coating was beneficial for Ronozyme and OptiPhos (only from d 90 onward) but not for Phyzyme, wherein the uncoated product retained more activity than the coated product throughout the study. This suggests that the type of coating may differ between phytase manufacturers, and that some coated phytase products may provide better protection during storage than others.

Phytases in premixes

For most of the commercial phytase sources tested, retained phytase activities were more than 85, 73, and 60% of initial activity up to 180 d when stored as pure products, vitamin premixes, or VTM premixes, respectively, and when storage temperatures were at 73°F. The exceptions were Ronozyme M for the pure phytase products, Phyzyme 5000 G for the vitamin premixes, and OptiPhos 2000 M for the VTM premixes, which are all uncoated phytases. In general, greater retention was observed with increasing storage time when phytases were stored as pure products than when mixed into either of the premixes. This suggests that storing phytase in pure forms may have advantages in retaining its original phytase activity compared with including it in premixes, when stored at room (73°F) or lower temperatures.

When phytase was mixed into vitamin or VTM premixes and exposed to heat treatment (99°F), coated phytases retained greater activities than uncoated phytases, especially when stored for more than 90 d. However, there were some differences between phytase sources, where coating had the greatest benefits for OptiPhos. Results also showed that uncoated phytases have very poor stability when mixed into the premixes

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and stored for even as few as 30 d. The loss of phytase activity was greater when phytase was mixed with VTM premixes than with vitamin premixes. These results suggest that high heat and humidity, as well as potential interactions with some components of the premixes, increased the rate of denaturation of phytases. Previous work has shown that mixing inorganic trace minerals with vitamins leads to significant losses in vitamin activity, which is thought to be due to the presence of ionic charges in mineral salts that can act as oxidizing agents. It is not the objective of the study to identify specific vitamins or trace minerals that may have contributed to greater losses in phytase activity, but the results clearly indicate that coated phytases should be used in premixes. This also demonstrates the differences in the ability of coating technologies to protect phytases not only from environmental degradation, but also against the negative effects of certain components in vitamin and VTM premixes.

In conclusion, stability of commercially available phytases during storage is affected by numerous factors, such as storage time, temperature, product form, coating, and source. Pure phytase products stored at 73°F or less were the most stable. In premixes, longer storage time and higher temperature reduced phytase activity, but coating mitigated some of these negative effects.

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Table 1. Calculated and analyzed phytase composition of samples at d 0[1]

	Phytase composition				
Item	Calculated, PU/kg[2]	AOAC analysis, PU/kg	AOAC ratio[3]	Phytex analysis, PU/kg	Phytex ratio[4]
Pure product					
Control[5]	0	10,500	---	3,343,000	---
OptiPhos 2000-M[6]	2,000,000	3,932,000	1.96	2,046,000	1.02
OptiPhos 2000-PF[6,9]	2,000,000	5,179,000	2.58	2,022,000	1.01
Phyzyme 5000 G[7]	5,000,000	5,144,000	1.03	---	---
Phyzyme 10000 TPT[7,9]	10,000,000	10,587,000	1.06	---	---
Ronozyme P-M[8]	50,000,000	52,148,500	1.04	---	---
Ronozyme P-CT[8,9]	10,000,000	12,057,500	1.20	---	---
Vitamin premix					
Control[5]	0	4,967	---	37,000	---
OptiPhos 2000-M[6]	83,333	214,425	2.51	41,000	0.49
OptiPhos 2000-PF[6,9]	83,333	250,853	2.95	57,000	0.68
Phyzyme 5000 G[7]	166,666	266,339	1.57	---	---
Phyzyme 10000 TPT[7,9]	166,666	266,116	1.57	---	---
Ronozyme P-M[8]	616,666	738,388	1.19	---	---
Ronozyme P-CT[8,9]	616,666	637,467	1.42	---	---
Vitamin and trace mineral premix					
Control[5]	0	4,948	---	77,000	---
OptiPhos 2000-M[6]	83,333	209,424	2.45	25,000	0.30
OptiPhos 2000-PF[6,9]	83,333	244,067	2.87	55,000	0.66
Phyzyme 5000 G[7]	166,666	209,437	1.23	---	---
Phyzyme 10000 TPT[7,9]	166,666	166,239	0.97	---	---
Ronozyme P-M[8]	616,666	699,542	1.13	---	---
Ronozyme P-CT[8,9]	616,666	877,884	1.03	---	---

[1] Values represent means of 3 replicates sampled in duplicate. AOAC analysis was performed at DSM Nutritional Products laboratory (Belvidere, NJ) while the Phytex analysis was performed at Phytex LLC (Sheridan, IN).
[2] PU = phytase units
[3] Ratio of average AOAC analyzed values to calculated values.
[4] Ratio of Phytex analyzed values to calculated values.
[5] Cornstarch used as the negative control.
[6] Phytex LLC, Sheridan, IN.
[7] Danisco Animal Nutrition, Marlborough, UK.
[8] DSM Nutritional Products, Basel, Switzerland.
[9] Coated phytase.

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Table 2. Probabilities of interactive and main effects of storage time, temperature, coating, and phytase product on stability (as defined by % of initial phytase activity) of commercially available phytase sources in pure forms.

Item	*P*-value
Interactive effects	
Time × Temp × Coating × Product	<0.0001
Time × Temp × Product	<0.0001
Time × Temp × Coating	<0.0001
Time × Coating × Product	<0.0001
Temp × Coating × Product	<0.0001
Temp × Coating	<0.0001
Temp × Product	<0.0001
Time × Temp	<0.0001
Time × Coating	0.428
Time × Product	<0.0001
Coating × Product	<0.0001
Main effects	
Time	<0.0001
Temp	<0.0001
Coating	<0.0001
Product	<0.0001

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Table 3. Probabilities of interactive and main effects of storage time, form, temperature, coating, and phytase product on stability (as defined by % of initial phytase activity) of commercially available phytase sources.

Item	*P*-value
Interactive effects	
Time × Form × Coating × Product × Temp	< 0.0001
Time × Form × Coating × Product	< 0.0001
Time × Form × Coating × Temp	< 0.0001
Time × Form × Product × Temp	< 0.0001
Time × Coating × Product × Temp	< 0.0001
Form × Coating × Product × Temp	< 0.0001
Time × Form × Coating	< 0.0721
Time × Form × Product	< 0.0001
Time × Form × Temp	< 0.0001
Time × Coating × Product	< 0.0001
Time × Coating × Temp	< 0.0001
Time × Product × Temp	< 0.0003
Form × Coating × Product	< 0.0001
Form × Coating × Temp	< 0.0004
Form × Product × Temp	< 0.0001
Coating × Product × Temp	< 0.0001
Time × Form	< 0.0001
Time × Coating	< 0.0028
Time × Product	< 0.0001
Time × Temp	< 0.0001
Form × Coating	< 0.0001
Form × Product	< 0.0001
Form × Temp	< 0.0001
Coating × Product	< 0.0001
Coating × Temp	< 0.0829
Product × Temp	< 0.0001
Main effects	
Time	< 0.0001
Form	< 0.0001
Coating	< 0.0001
Product	< 0.0001
Temp	< 0.0001

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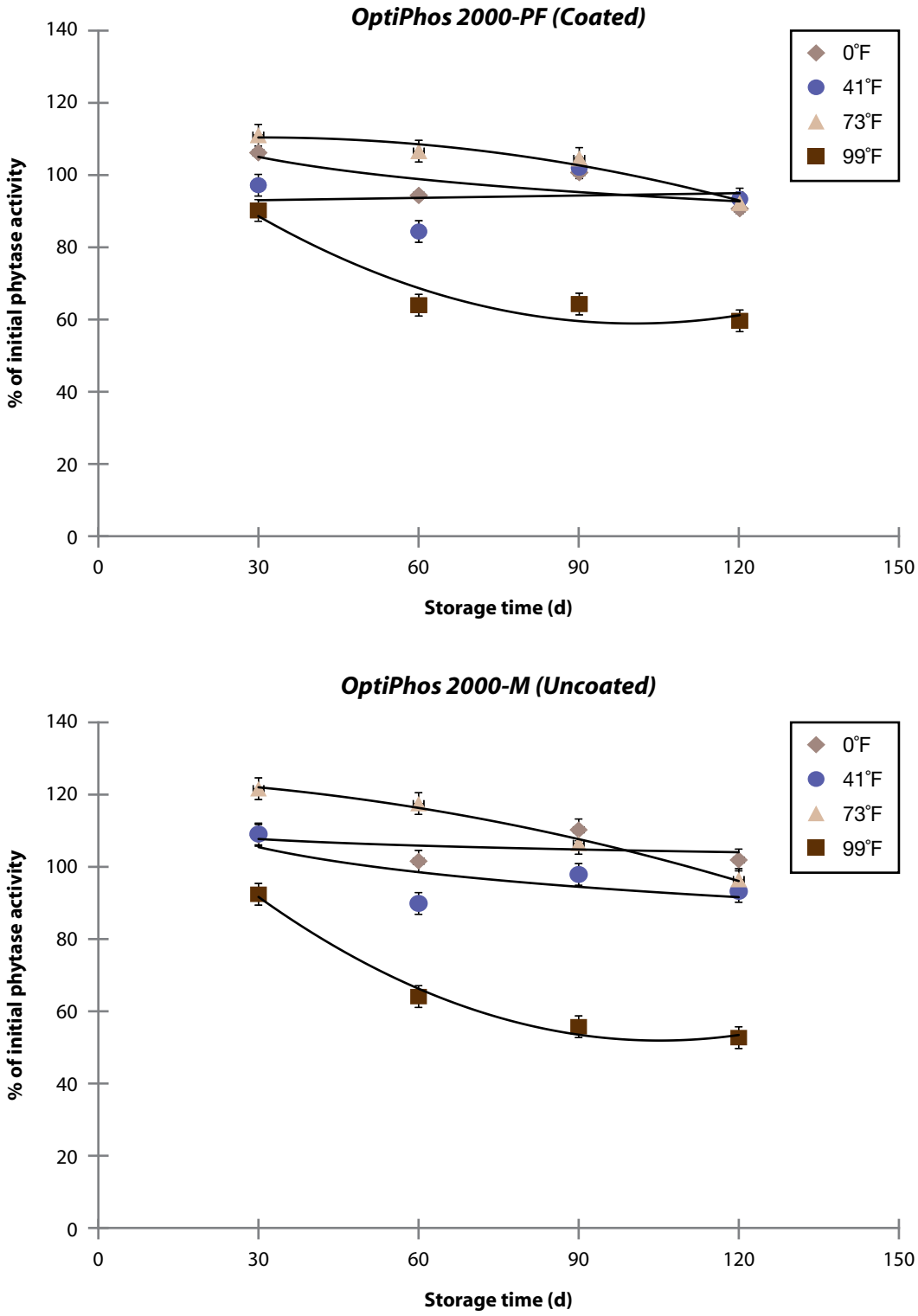

Figure 1. Residual phytase activity (% of initial) for OptiPhos 2000-PF (coated) and OptiPhos 2000-M (uncoated) as affected by storage temperature (freezer [0°F], refrigerator [41°F], at room temperature [73°F], and in a controlled environment chamber [99°F and 75% humidity]) and time (30 to 120 d). Each data point (least square mean ± 2.32) is the mean of 3 observations.

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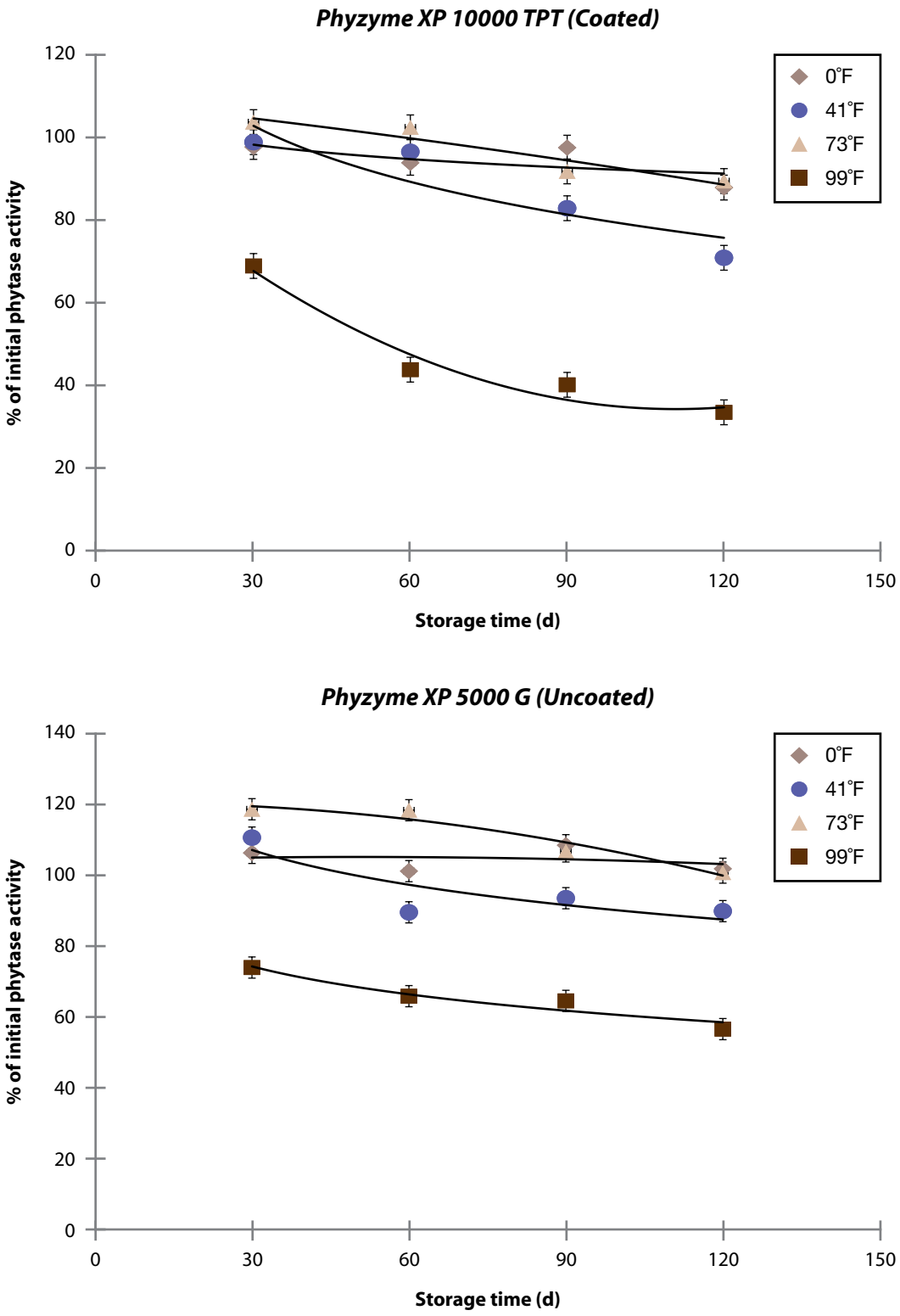

Figure 2. Residual phytase activity (% of initial) for Phyzyme 10000 TPT (coated) and Phyzyme 5000G (uncoated) as affected by storage temperature (freezer [0°F], refrigerator [41°F], at room temperature [73°F], and in a controlled environment chamber [99°F and 75% humidity]) and time (30 to 120 d). Each data point (least square mean ± 2.32) is the mean of 3 observations.

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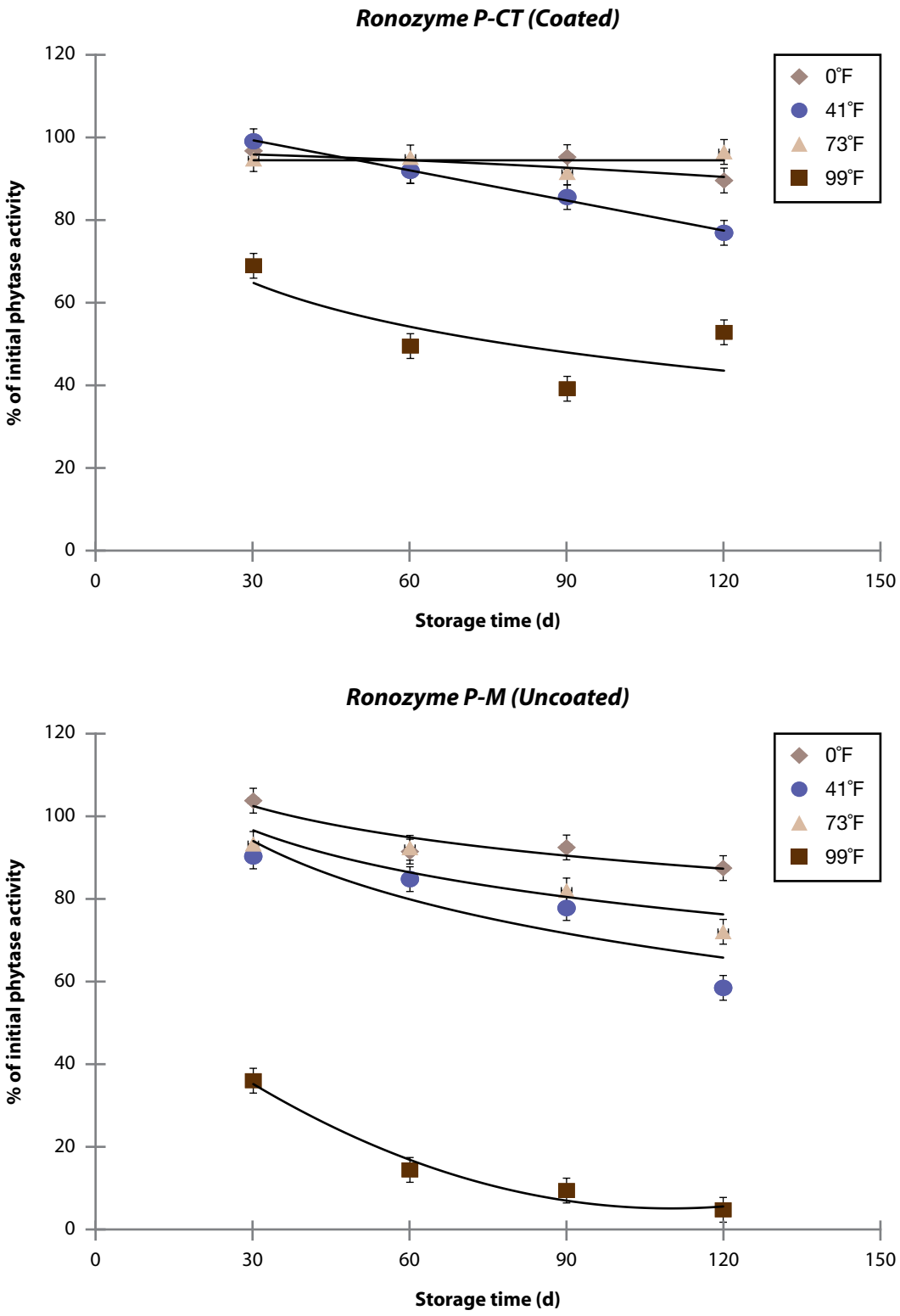

Figure 3. Residual phytase activity (% of initial) for Ronozyme CT (coated) and Ronozyme M (uncoated) as affected by storage temperature (freezer [0°F], refrigerator [41°F], room temperature [73°F], and in a controlled environment chamber [99°F and 75% humidity]) and time (30 to 120 d). Each data point (least square mean ± 2.32) is the mean of 3 observations.

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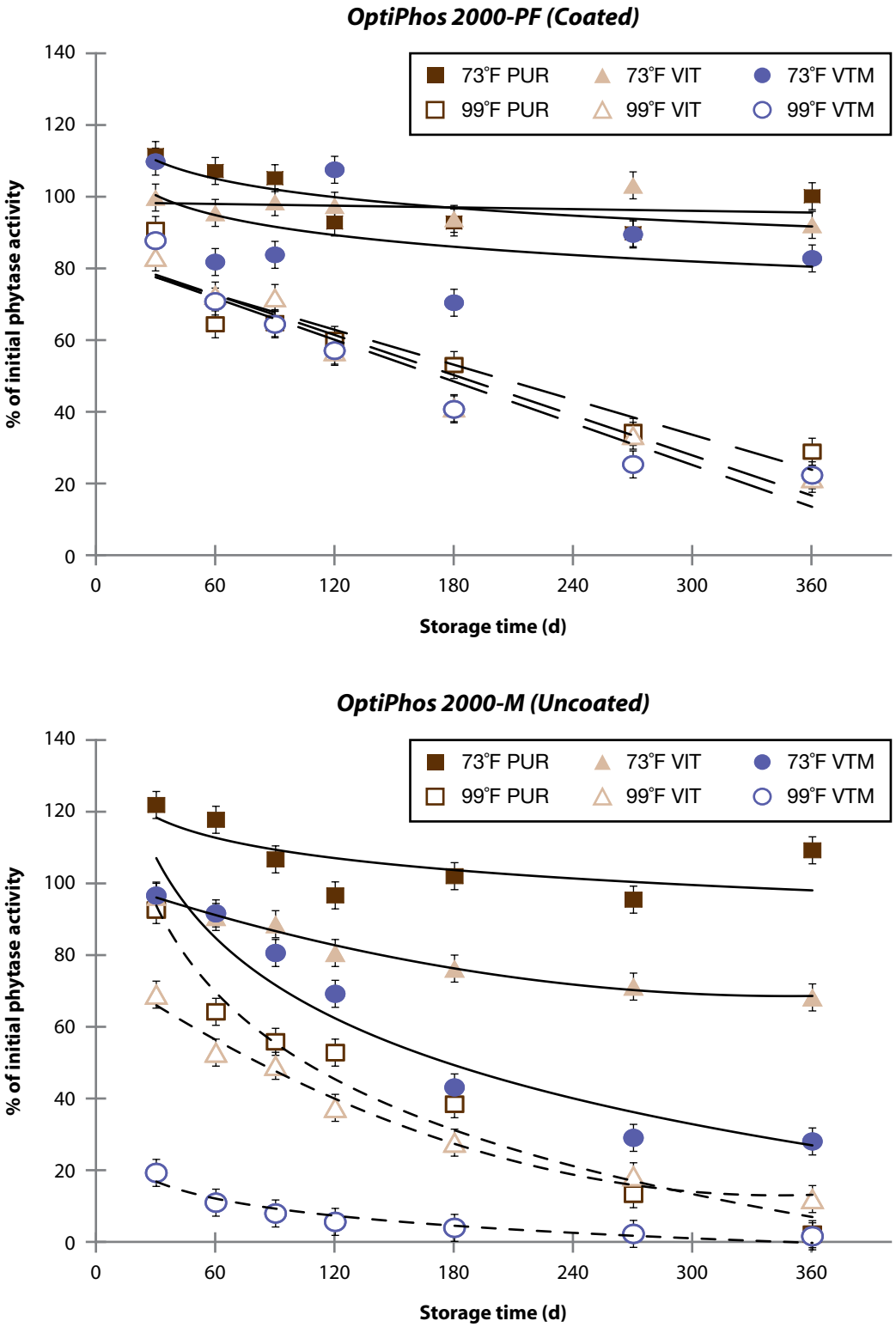

Figure 4. Residual phytase activity (% of initial) for OptiPhos 2000-PF (coated) and OptiPhos 2000-M (uncoated) as affected by form of storage (as pure product [PUR], in a vitamin premix [VIT], or in a vitamin-trace mineral premix [VTM]), storage temperature (room temperature [71°F], and in a controlled environment chamber [99°F and 75% humidity]) and time (30 to 360 d). Each data point (least square mean ± 3.75) is the mean of 3 observations.

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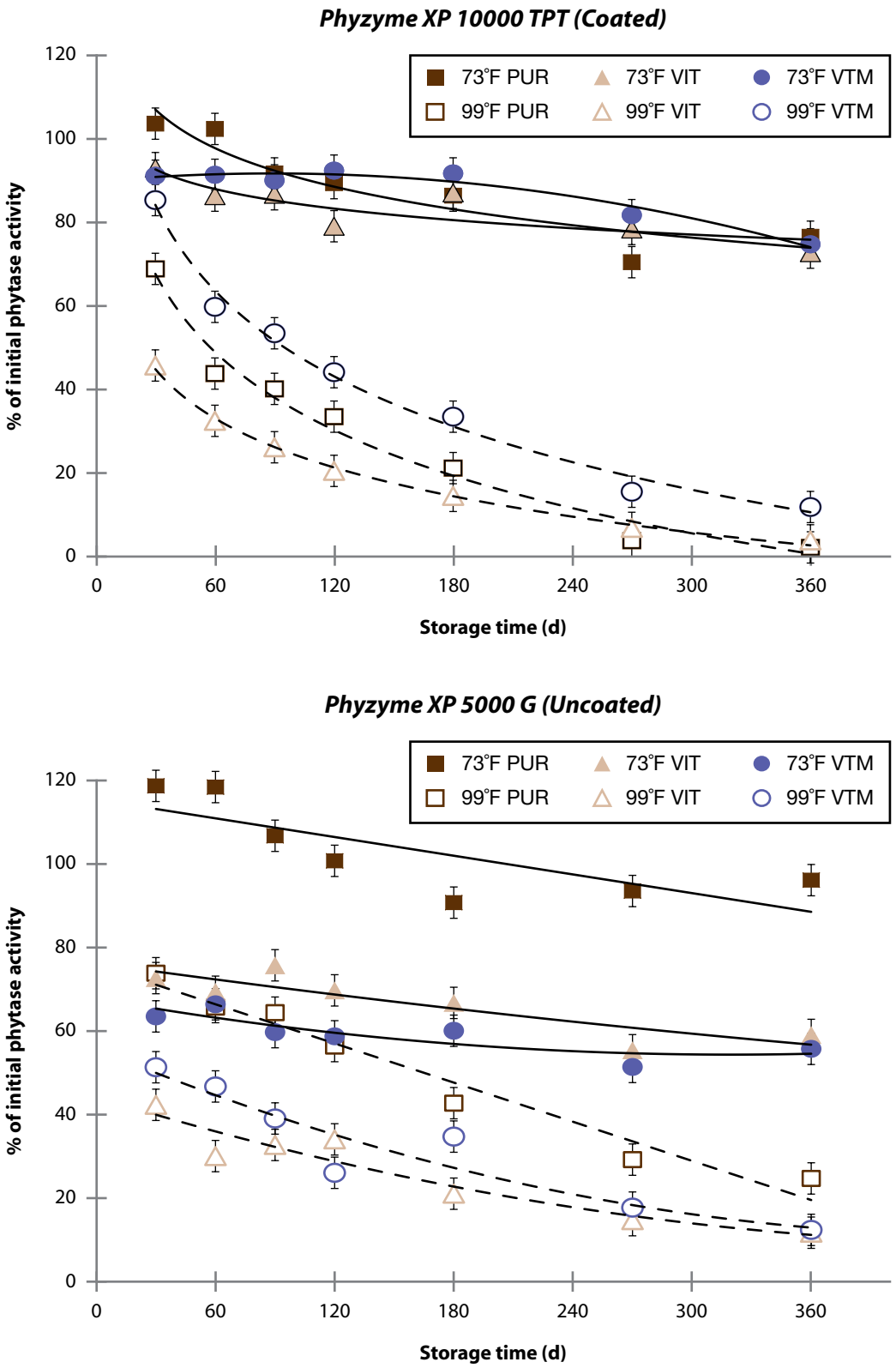

Figure 5. Residual phytase activity (% of initial) for Phyzyme 10000 TPT (coated) and Phyzyme 5000G (uncoated) as affected by form of storage (as pure product [PUR], in a vitamin premix [VIT], or in a vitamin-trace mineral premix [VTM]), storage temperature (room temperature [73°F], and in a controlled environment chamber [99°F and 75% humidity]) and time (30 to 360 d). Each data point (least square mean ± 3.75) is the mean of 3 observations.

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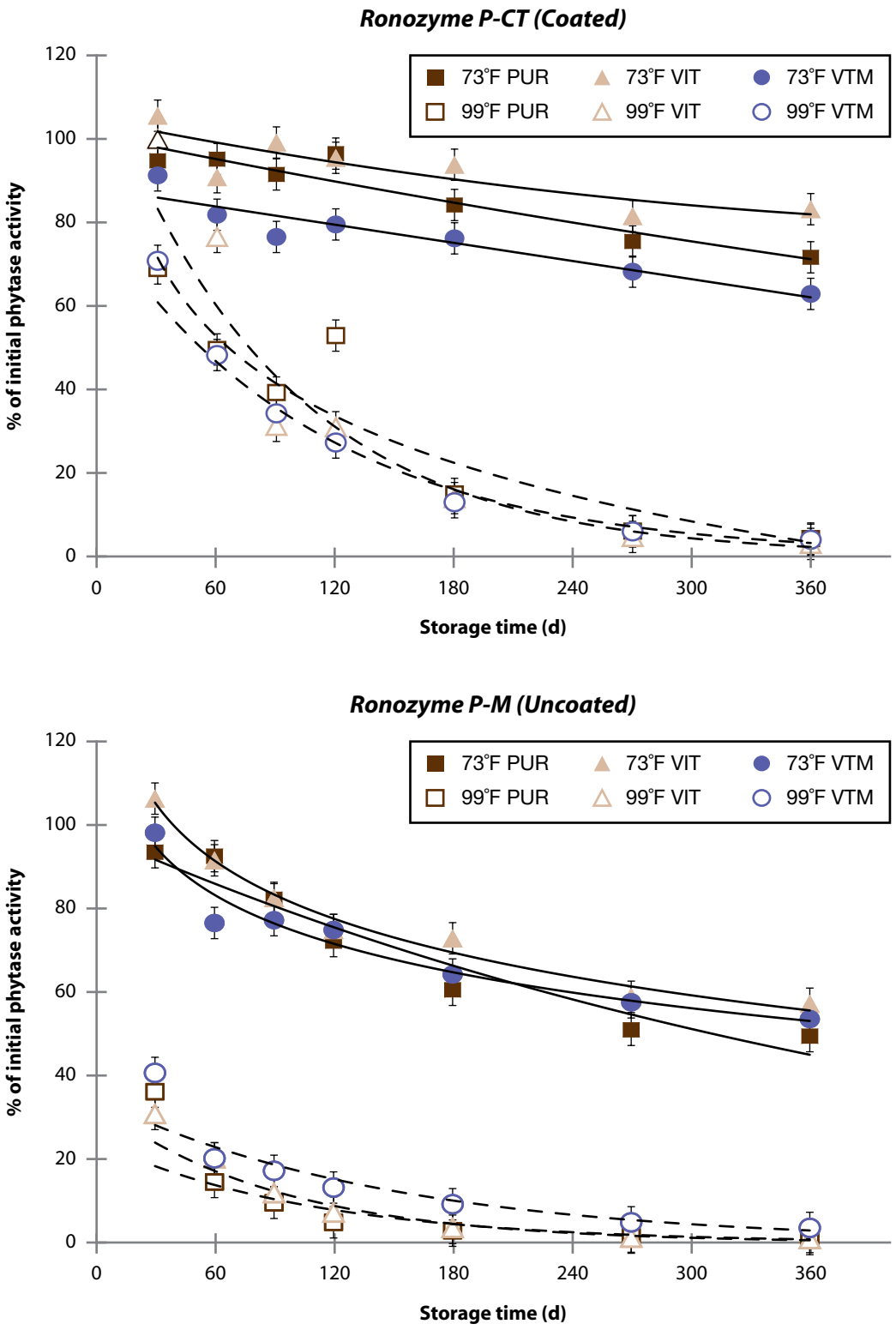

Figure 6. Residual phytase activity (% of initial) for Ronozyme CT (coated) and Ronozyme M (uncoated) as affected by form of storage (as pure product [PUR], in a vitamin premix [VIT], or in a vitamin-trace mineral premix [VTM]), storage temperature (room temperature [73°F], and in a controlled environment chamber [99°F and 75% humidity]) and time (30 to 360 d). Each data point (least square mean ± 3.75) is the mean of 3 observations.

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