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2008 Nebraska Swine Report

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NEBRASKA SWINE REPORT

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Prepared by the staff in Animal Science and cooperating Departments for use in Extension, Teaching, and Research programs.

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Agricultural Research Division
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Nebraska Swine Report Acknowledgments for 2008

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2008 Nebraska Swine Report

Editor: Marcia Oetjen
Typesetting & Design: Anne Moore

Pork Central's Al Prosch Retires

Al Prosch retired from his position as Pork Central Coordinator in June 2007 after 11 years at the University of Nebraska.

Pork Central was a Nebraska Pork Producers Association (NPPA) and University of Nebraska–Lincoln Extension sponsored information clearinghouse with a mission to assist Nebraskans in the profitable production of quality pork. Al was Pork Central's sole coordinator. He enthusiastically and competently responded to producers' expressed needs for more information and education relating to business management and marketing.

Through Al's leadership, Pork Central offered producers a variety of methods to obtain information and advice critical for their business. Al created and maintained UNL's only pork-specific Web site. Al created and answered UNL's first and only pork-specific 800 phone line. His direct communication with producers provided the UNL Swine Group valuable feedback on producers' educational needs, which led to the development of numerous programs. He led a team of 11 specialists and educators to develop and deliver the Pork Central Management Review. Under Al's leadership, Pork Central, after operating only two years, was proven to be a valuable asset to producers, according to a survey conducted of Pork Central users.

Al partnered with NPPA to conduct a survey of over 2,700 Nebraska pork producers to determine educational needs. Acting on the results of that survey, Al organized UNL colleagues and out-of-state speakers to deliver "Improving Your Ability to Compete in the Pork Industry," a series of five meetings delivered by satellite.

Al's direct teaching mostly involved marketing, business management, and helping producers to create new opportunities for themselves. In addition to the weekly market updates Al posted on Pork Central's Web site, he presented marketing information on Market Journal about 60 times. He had a major teaching role

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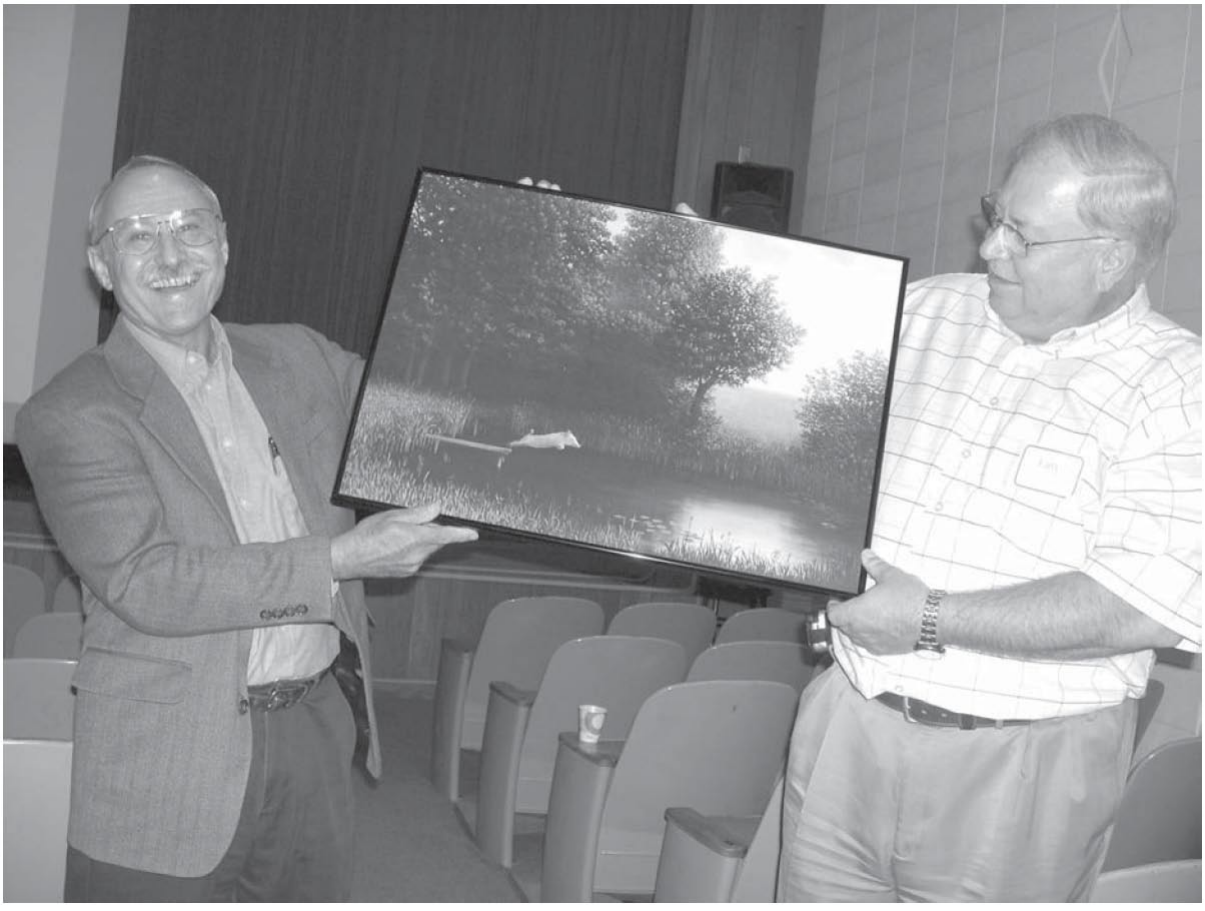

Figure 1. Larry Stizman (right), Nebraska Pork Producers Association executive director, presents Al Prosch a gilt to acknowledge his efforts as Pork Central coordinator at the University of Nebraska.

in "Marketing in Turbulent Times," a program that attracted 102 participants and influenced over $9 million worth of annual pork production. Working with colleagues in the Department of Agricultural Economics, USDA, Nebraska Cattlemen, NPPA, and Farm Bureau, Al conducted 18 meetings, teaching producers and insurance agents about livestock risk protection (LRP). Al combined his knowledge of LRP and Web design to work with a development team to create an LRP Web site.

Establishing the "Business Planning Workshops for Pork Producers" in cooperation with NPPA was a major, four-year team programming effort that Al led. Seventy-five individuals representing 47 pork producing operations were impacted. Other programs that Al developed and assumed a significant teaching role in involved niche pork production and marketing.

Al provided considerable leadership for the development of the "Nebraska Model," a blueprint for reestablishing pork production throughout Nebraska. He developed the economic backbone of the model which received the endorsement of Nebraska pork producers and allied industry. His efforts have contributed to the recent increase in Nebraska's pig inventory.

Al's vision, insights, and strong background in business management made Pork Central a strong and very visible educational program in Nebraska. He was very successful in helping producers establish a model for the success of their businesses. He didn't stop there. He provided the educational programs and analytical tools to successfully carry out their plan.

The Effect of Corn Distillers Dried Grain with Solubles (DDGS) on Growth Performance of Growing-Finishing Pigs

Growth performance of growing-finishing pigs was reduced as dietary DDGS inclusion increased from 0 to 15%. These results appear to be affected by the fiber content of the DDGS source used in this study.

Roman Moreno
Phillip S. Miller
Thomas E. Burkey
Matthew W. Anderson
Laura R. Albrecht
Jeffrey M. Perkins
Donald R. McClure
Thomas E. McGargill[1]

Summary

Two-hundred forty growing-finishing pigs were used to evaluate the feeding value of distillers dried grains with solubles (DDGS). Treatments consisted of 0, 5, 10 and 15% dietary DDGS inclusion. Treatments did not affect average daily gain (ADG), average daily feed intake (ADFI) or gain: feed (G:F) during the grower 1 period ($P > 0.05$). During the grower 2 period, ADG and ADFI linearly decreased as DDGS increased ($P < 0.05$). No differences among treatments were detected throughout the feeding phase finisher 1 for ADG, ADFI, and G:F ($P > 0.05$). During the finisher 2 feeding phase, there was a linear reduction in ADG and ADFI in response to dietary DDGS inclusion ($P = 0.01$). Overall, linear reductions in ADG, ADFI, and G:F were recorded as dietary DDGS increased ($P < 0.05$). Backfat and loingissimus muscle area decreased as dietary DDGS concentration increased ($P < 0.05$). Overall, growth performance was reduced as dietary DDGS inclusion increased from 0 to 15%. The reduction in performance may have been partially explained or exacerbated by the elevated fiber concentration detected in the source of DDGS used in this study.

Introduction

The maximum amount of DDGS that can be included in the diet of growing-finishing pigs is debated. Conflicting results can be found in the literature. Some authors recommend dietary DDGS inclusion up to 30%, while others recommend no more than 15%. In general, DDGS contains elevated concentrations of fat, crude protein (CP), and lysine (lys); however, variability exist among DDGS sources. The inclusion of DDGS in diets of finishing pigs may require the addition of crystalline amino acids (AA) in order to maintain the lys to essential AA ratios recommended for maximum growth performance. The following experiment was designed to evaluate DDGS inclusion rates of 0, 5, 10, and 15% in growing-finishing diets formulated on a total lys basis.

Procedures

Animals and facilities

This experimental protocol was reviewed and approved by the Institutional Animal Care and Use of the University of Nebraska–Lincoln. Two hundred forty barrows and gilts [(Danbred × NE white line) × Danbred] were used in a 16-week study. The initial average weight was 49.2 lb. Five barrows and five gilts were housed in each of 24 pens, and there were six replicates for each of the four dietary treatments.

Pigs were housed in a 24-pen building equipped with automatic environmental control. Pens dimensions were 4.95 × 15.84 ft and each pen was equipped with automatic feeder and waterer. The flooring was one-half solid concrete and one-half concrete slats. Pigs had ad libitum access to feed and water throughout the experimental period.

Dietary treatments

Pigs received a four phase dietary growing-finishing regime (Tables 1 and 2). The diets included 0, 5, 10 or 15% DDGS. Crystalline lys was incorporated into diets containing DDGS in order to maintain a constant total lys concentration among diets. Other nutrient concentrations were formulated to meet or exceed allowances identified in the Nebraska–South Dakota Swine Nutrition Guide.

Data and sample collection

Pigs and feeders were weighed at 0800 at the beginning of the experiment and biweekly thereafter. Feed disappearance was estimated by the difference between feed offered and feed remaining on the feeder at the end of each biweekly period. Body weight gain was estimated by the difference between the weight at the beginning and at the end of each biweekly period. Average daily gain (ADG), average daily feed intake (ADFI), and ADG: ADFI (G:F) were estimated based on the individual biweekly body weight gain and feed disappearance. At the beginning of the experiment and every eight weeks thereafter, ultrasound was used to measure backfat thickness (BF) and longissimus muscle area (LMA) at the 10th rib.

(Continued on next page)

Table 1. Ingredient, calculated and analyzed composition of growing pig diets, as-fed basis.

	Grower 1 (45-80 lb)				Grower 2 (80-130 lb)			
	DDGS[c], %							
Item, %	0	5	10	15	0	5	10	15
Corn	69.39	67.00	64.54	62.05	74.00	71.68	69.42	66.97
Soybean meal, 46.5% CP	25.40	22.80	20.25	17.75	21.70	19.00	16.25	13.70
Tallow	2.50	2.50	2.50	2.50	2.00	2.00	2.00	2.00
Dicalcium phosphate	1.15	1.05	1.00	0.90	0.85	0.75	0.70	0.60
Limestone	0.90	0.95	0.97	1.02	0.82	0.90	0.92	0.97
Salt	0.22	0.20	0.17	0.15	0.22	0.20	0.17	0.15
Vitamin premix[a]	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Trace mineral mix[b]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
L-Lysine•HCl	0.13	0.20	0.26	0.32	0.10	0.16	0.23	0.30
DDGS[c]	0.00	5.00	10.00	15.00	0.00	5.00	10.00	15.00
Analyzed Composition								
CP[d], %	17.24	17.10	17.45	17.41	15.82	16.15	16.07	16.10
GE[e], Mcal[f]/lb	1.80	1.83	1.86	1.88	1.80	1.83	1.85	1.88
NDF[f], %	10.77	13.14	17.37	17.11	12.17	14.10	12.59	14.26
EE[g], %	4.87	5.42	5.62	6.00	4.41	4.84	5.26	5.63
Calculated Composition								
Lysine, %	1.00	1.00	1.00	1.00	0.88	0.88	0.88	0.88
CP[d], %	18.00	18.00	18.00	18.00	16.50	16.50	16.50	16.50
ME[e], Mcal[f]/lb	1.55	1.53	1.52	1.51	1.55	1.53	1.52	1.51

[a]Supplied per kilogram of diet at 0.2% inclusion: vitamin A supplied as retinyl acetate, 4,400 IU; cholecalciferol, 440 IU; a-tocopherol acetate, 24 IU; menadione sodium bisulfite, 3.5 mg; riboflavin, 8.8 mg; d-pantothenic acid, 17.6 mg; niacin, 26.4 mg; vitamin B_{12}, 26.4 mg.
[b]Supplied per kilogram of diet at 0.1% of inclusion: Zn (as ZnS_4O), 85 mg; Fe (as $FeSO_4•H_2O$), 85 mg; Mn (as MnO), 20 mg; Cu (as $CuSO_4•5\ H_2O$), 7 mg; I (as $Ca(IO_3)•H_2O$), 0.17 mg; Se (as Na_2SeO_3), 0.17 mg.
[c]DDGS = Corn distillers dried grain with solubles.
[d]CP = Crude protein.
[e]ME = Metabolizable energy.
[f]NDF = Neutral detergent fiber.
[g]EE = Ether extract.

Table 2. Ingredient, calculated and analyzed composition of finishing pig diets, as-fed basis.

	Finisher 1 (130-190 lb)				Finisher 2 (190-250 lb)			
	DDGS[c], %							
Item	0	5	10	15	0	5	10	15
Corn	80.27	77.65	75.31	72.95	85.1	82.6	80.27	77.79
Soybean meal, 46.5% CP	15.60	13.25	10.60	8.00	11.00	8.50	5.85	3.35
Tallow	2.00	2.00	2.00	2.0	2.00	2.00	2.00	2.00
Dicalcium phosphate	0.75	0.67	0.60	0.50	0.60	0.55	0.47	0.40
Limestone	0.80	0.85	0.90	0.95	0.80	0.83	0.87	0.90
Salt	0.22	0.20	0.17	0.15	0.22	0.20	0.18	0.17
Vitamin premix	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Trace mineral mix	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
L-Lysine•HCl	0.10	0.12	0.16	0.20	0.02	0.06	0.10	0.13
DDGS[c]	0.00	5.00	10.00	15.00	0.00	5.00	10.00	15.00
Analyzed Composition								
CP[d], %	13.53	13.67	13.93	14.33	12.04	11.94	12.11	12.16
GE[e], Mcal/lb	1.80	1.84	1.86	1.88	1.82	1.84	1.85	1.88
NDF[f], %	8.80	10.24	11.67	14.27	9.59	12.92	13.17	15.35
EE[g], %	4.80	5.34	5.78	6.18	5.12	5.47	5.76	6.13
Calculated Composition								
Lysine, %	0.72	0.72	0.72	0.72	0.55	0.55	0.55	0.55
CP[d], %	14.20	14.20	14.20	14.20	12.30	12.30	12.30	12.30
ME[e], Mcal/lb	1.55	1.54	1.52	1.51	1.55	1.54	1.52	1.51

[a]Supplied per kilogram of diet at 0.15% inclusion: vitamin A supplied as retinyl acetate, 3,300 IU; cholecalciferol, 330 IU; a-tocopherol acetate, 18 IU; menadione sodium bisulfite, 2.64 mg; riboflavin, 6.60 mg; d-pantothenic acid, 13.23 mg; niacin, 19.80 mg; vitamin B_{12}, 19.80 mg.
[b]Supplied per kilogram of diet at 0.1% of inclusion: Zn (as ZnS_4O), 85 mg; Fe (as $FeSO_4•H_2O$), 85 mg; Mn (as MnO), 20 mg; Cu (as $CuSO_4•5\ H_2O$), 7 mg; I (as $Ca(IO_3)•H_2O$), 0.17 mg; Se (as Na_2SeO_3), 0.17 mg.
[c]DDGS = Corn distillers dried grain with solubles.
[d]CP = Crude protein.
[e]ME = Metabolizable energy.
[f]NDF = Neutral detergent fiber.
[g]EE = Ether extract.

Table 3. Response and effect of dietary DDGS[a] inclusion on growth performance of growth finishing pigs.

	DDGS[a], %					*P*-value		
Item	0	5	10	15	SEM[b]	Treatment	Linear	Quadratic
No. of pigs	60	60	60	60				
No. of pens	6	6	6	6				
Initial weight, lb	49.44	49.42	48.85	49.27	0.32	0.57	0.47	0.51
Final weight, lb	260.65	252.96	249.96	240.84	4.56	0.02	0.02	0.54
Grower 1 (week 1 to 4)								
ADG[c], lb	1.66	1.61	1.53	1.56	0.04	0.24	0.08	0.43
ADFI[d], lb	3.49	3.43	3.34	3.43	0.05	0.32	0.30	0.18
G:F[e]	0.47	0.47	0.45	0.45	0.01	0.39	0.10	0.89
Grower 2 (week 5 to 8)								
ADG[c], lb	1.82	1.60	1.72	1.60	0.05	0.02	0.03	0.38
ADFI[d], lb	4.83	4.40	4.58	4.50	0.08	0.01	0.04	0.05
G:F[e]	0.37	0.36	0.37	0.35	0.01	0.25	0.17	0.61
Finisher 1 (week 9 to 12)								
ADG[c], lb	1.93	1.94	1.85	1.80	0.06	0.83	0.11	0.65
ADFI[d], lb	6.29	5.85	5.91	5.84	0.17	0.23	0.11	0.28
G:F[e]	0.30	0.33	0.31	0.30	0.01	0.29	0.77	0.16
Finisher 2 (week 13 to 16)								
ADG[c], lb	2.05	1.92	1.83	1.79	0.67	0.06	0.01	0.51
ADFI[d], lb	7.04	7.09	6.86	6.73	0.17	0.44	0.14	0.60
G:F[e]	0.29	0.27	0.26	0.26	0.01	0.04	0.01	0.13
Overall (week 1 to 16)								
ADG[c], lb	1.86	1.76	1.73	1.68	0.03	0.01	0.01	0.39
ADFI[d], lb	5.40	5.14	5.13	5.11	0.09	0.11	0.04	0.20
G:F[e]	0.34	0.34	0.33	0.33	0.01	0.01	0.01	0.43

[a]DDGS = Corn distillers dried grain with solubles.
[b]SEM=Standard error of the mean.
[c]ADG = Average daily gain.
[d]ADFI = Average daily feed intake.
[e]G:F = Gain to feed ratio.

Table 4. Response and effect of dietary DDGS[a] inclusion on BF[b] and LMA[c] of growing-finishing pigs.

	DDGS[a], %					*P*-value		
Item	0	5	10	15	SEM[d]	Treatment	Linear	Quadratic
No. of pigs	60	60	60	60				
No. of pens	6	6	6	6				
Initial weight , lb	49.44	49.42	48.85	49.27	0.32	0.57	0.47	0.51
Final weight, lb	260.65	252.96	246.96	240.84	4.56	0.02	0.01	0.54
Initial (day 0)								
BF[b], in	0.27	0.29	0.28	0.28	0.01	0.19	0.38	0.21
LMA[c], in^2	1.45	1.48	1.45	1.49	0.12	0.33	0.22	0.84
Day 56								
BF[b], in	0.47	0.44	0.48	0.43	0.01	0.08	0.31	0.43
LMA[c], in^2	3.46	3.29	3.31	3.24	0.07	0.21	0.06	0.52
Final (d 112)								
BF[b], in	0.81	0.76	0.79	0.71	0.03	0.05	0.03	0.52
LMA[c], in^2	5.62	5.53	5.45	5.28	5.16	0.13	0.02	0.93

[a]DDGS=Corn distillers dried grain with solubles.
[b]BF=Back fat at 10th rib.
[c]LMA=Longissimus muscle area at 10th rib.
[d]SEM=Standard error of the mean.

Statistical analysis

The MIXED procedure (SAS Inst. Inc., Cary, N.C.) was used to analyze the data. Contrasts were designed to evaluate linear and quadratic responses to addition of DDGS to dietary treatments. Pen was considered the experimental unit and the model was a completely randomized design. Pen was considered a random effect.

Results and Discussion

The growth performance responses of growing-finishing pigs to varying dietary concentrations of DDGS are provided in Table 3. Final weight decreased linearly as DDGS increased ($P = 0.02$). During the grower 1 period, treatments did not affect ADG, ADFI, or G:F ($P > 0.05$). Treatment did affect ADG during the grower 2 period ($P = 0.02$). A linear ($P = 0.03$) response of ADG to dietary DDGS concentration indicated that ADG decreased as dietary DDGS inclusion increased. Also during grower 2, treatment effected ADFI ($P = 0.01$). We observed a linear reduction in ADFI as dietary DDGS concentration increased ($P = 0.04$). Feed efficiency was not affected by dietary treatment ($P = 0.25$). No differences among treatments were detected throughout the feeding phase finisher 1 for ADG, ADFI, and G:F ($P > 0.05$). During the finisher 2 period, despite the lack of treatment effect ($P = 0.06$), we observed a linear reduction in ADG and G:F in response to dietary DDGS inclusion ($P = 0.01$). For the overall period, ADG and G:F differed among treatments ($P = 0.01$), and a linear reduction in ADG and G:F was recorded as dietary DDGS increased ($P = 0.01$). Although not significant ($P = 0.11$), increased dietary DDGS concentration resulted in a linear reduction in ADFI ($P = 0.04$).

Backfat and LMA results are provided in Table 4. No difference among treatments was detected for BF or LMA at day 0, 56 or 112 ($P > 0.05$); however, at day 112, BF and LMA were reduced as dietary DDGS increased ($P < 0.05$). A number of studies have shown no reduction in growth performance on DDGS inclusion up to 20% of the diet. Our results contradict previous findings.

We initially screened DDGS samples for CP and lysine content. After the completion of the trial, analysis indicated the neutral detergent fiber (NDF) concentrations in the DDGS used were approximately 45 to 50% (See Table 1 for diet com-

(Continued on next page)

position). Normally, DDGS contains approximately 30 to 40% NDF. The additional concentration of cell wall content found in the DDGS used could explain the reduction in performance associated with increased DDGS inclusion observed in our study. This observation highlights the importance of screening DDGS samples for all nutrient components (including, CP, lysine, fat, and fiber).

Conclusions

Overall, growth performance decreased as dietary DDGS inclusion increased from 0 to 15%. This reduction in performance may have been partially explained or exacerbated by the elevated fiber concentration detected in the source of DDGS used in this study.

[1]Roman Moreno is a graduate student and research technologist; Phillip S. Miller is a professor; and Thomas E. Burkey is an assistant professor in the Animal Science Department. Matthew W. Anderson is manager of the UNL Swine Research Farm. Jeffrey M. Perkins, Thomas E. McGargill, and Donald R. McClure are research technicians at the UNL Swine Research Farm.

The Effect of Corn Distillers Dried Grain with Solubles (DDGS) on Carcass Characteristics and Pork Quality

Dietary distillers dried grains with solubles (DDGS) inclusion decreased saturated fatty acid and increased unsaturated fatty acid concentrations in fat samples from growing-finishing pigs. Pork color, chemical composition, or sensory characteristics were not affected by DDGS.

Roman Moreno
Phillip S. Miller
Thomas E. Burkey
Steven J. Jones
Susan L. Cuppett
Timothy P. Carr
Tommi F. Jones
Ruth M. Diedrichsen[1]

Summary

A study was conducted to evaluate the effect of feeding 0, 5, 10 or 15% distillers dried grains with solubles (DDGS) on carcass quality, color stability, and sensory characteristics of the longissimus muscle (LM) of finishing pigs. Live weight and hot carcass weight decreased as dietary DDGS increased ($P < 0.05$). Dressing percentage did not differ among treatments ($P = 0.72$). After 10 days of retail display, no differences were observed among treatments for color or color change ($P > 0.05$). No differences in shear force were observed ($P = 0.34$). Total unsaturated fatty acids increased and total saturated fatty acids decreased ($P < 0.05$) as dietary DDGS increased. Treatments did not affect sensory characteristics ($P > 0.05$). The results of this investigation suggest that dietary DDGS inclusion altered fatty acid profile of the backfat of pigs by reducing total saturated fatty acid and increasing total unsaturated fatty acid concentration. Increasing the concentration of dietary DDGS did not affect color, chemical composition, or sensory characteristics of the LM.

Introduction

The increased availability of corn distillers dried grain with solubles (DDGS) has resulted from the increase in ethanol production from corn. Research indicates that pork quality is influenced by the dietary ingredients used in growing-finishing pig diets, and there is evidence to suggest that DDGS affects carcass quality by reducing carcass weight and dressing percentage. Additionally, some investigators report that feeding DDGS results in softer carcasses due to increased unsaturated and decreased saturated fatty acid concentration in fat. From the consumer's point of view, pork color and absence of off-flavors are important traits; therefore, it is essential to evaluate the nutritional value of DDGS as well as its effect on sensory characteristics of pork. This report is a companion article to the previous article that reports the feeding value of diets for growing-finishing pigs with varying DDGS concentration. The objective of this study was to evaluate the effects of feeding varying concentrations of DDGS on carcass and sensory characteristics of pork.

Materials and Methods

Carcass data collection

Two hundred forty pigs weighing an average of 49.2 lb were assigned to one of four dietary treatments. Each treatment consisted of a standard diet in which a portion of dietary corn and soybean meal were replaced to include 0, 5, 10 or 15% of DDGS. Details of the growth study are described in a companion article. At the end of the feeding phase all pigs were transported to a commercial pork packing facility located approximately 30 miles from the University of Nebraska Swine Research

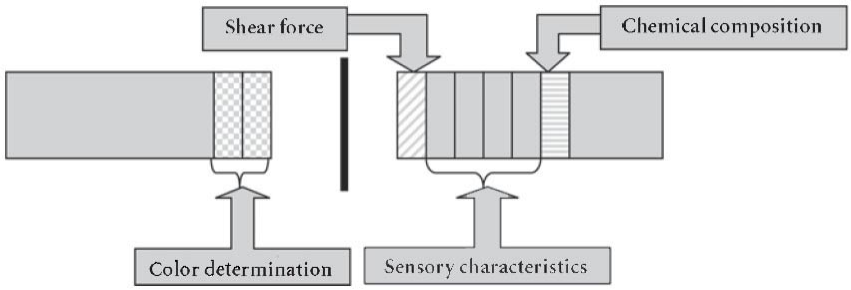

Figure 1. Longissimus muscle sections of the loins used for shear force, color determination, sensory characteristics, and chemical analysis

Table 1. Attribute, magnitude, and description and scale of sensory characteristics.

	Magnitude		
Attribute	0 mm	150 mm	Comments
Appearance	Very non-uniform	Very uniform	Color of interior meat
Toughness	Very tough	Very tender	During the first bite
Chewiness	Very hard to breakdown	Very easy to breakdown	During chewing
Juiciness	Very dry	Very moist	
Pork flavor	Lacking	Intense	
Off-flavor	Lacking	Intense	
Aftertaste pork flavor	Lacking	Intense	
Aftertaste off flavor	Lacking	Intense	
Overall acceptability	Very undesirable	Very desirable	

Unit. Pigs were weighed before entering (live weight; LW) and before leaving the harvesting floor (hot carcass weight; HCW). Dressing percentage (DP) was calculated using the following formula DP = ((LW / HCW)×100). Carcasses were subjected to a standard spray-chilling procedure for 24 hours. Before entering the fabrication floor, a cut was made on the right side of the carcasses between the 10th and 11th rib and the longissimus muscle (LM) was traced on acetate paper and area (LMA) was measured. Tenth-rib backfat depth (TRBF) and last-rib backfat depth (LRBF) were measured. A backfat sample was obtained perpendicular to the 10th rib, submerged in liquid nitrogen and maintained at -112°F until analyzed for fatty acid profile. Two pigs from each pen were randomly selected prior to harvesting, carcasses were identified on the chilling floor, marked in the vertebrae, and the loin (410 pork loin; NAMP, 1997) from the right side of the carcass was collected. The collected loins were individually vacuum-packed and transported to the Meat Science Laboratory at the University of Nebraska. Seven days post mortem, the loins were boned and a section of LM (412B pork loin, boneless, center-cut, eight ribs; NAMP, 1997) was removed and divided in two sections (Figure 1). A total of nine 1-inch sections were obtained for color determination, shear force estimation, sensory characteristics evaluation, and chemical composition.

Color determination

The two sections of the LM used for color determination were packed in Styrofoam trays, wrapped with PVC film, and maintained at 34°F under fluorescent light illumination for 10 days. Color spectrometry measurements L*, a*, and b* (representing lightness, redness, and yellowness respectively) were obtained through the packing film on five sites on each section at the beginning (day 0) of the 10 day-color trial and daily thereafter using a Hunter Lab® Mini Scan XE plus (Model 45/0-L, Reston, Va.) handheld colorimeter. The calibration of the colorimeter was performed daily using black and white tiles. The change in total color (E) was calculated as [((L* at d 10 – L* at d 0)^2 + (a* at d 10 – a* at d 0)^2 + (b* at d 10 – b* at d 0)^2)^{½}; Minolta, 1998]. This formula was developed in order to better describe the changes in color that would occur during periods of retail display.

Warner-Bratzler shear force analysis.

The loin sections used for Warner-Bratzel shear force (WBSF; AMSA, 1995) were vacuum-packed and maintained at -4°F until analysis. Before the analysis chops were allowed to thaw, cooked to an internal temperature of 158°F on a Hamilton Beach Grill (Washington, N.C.), and cooled for 4 hours at 35.6°F. During the cooking process, temperature was monitored using thermocouples. Three cores of 0.5 in^2 from each section were removed parallel to the arrangement of the muscle fiber. Cores were sheared parallel to the muscle fiber using an Intron Universal Testing Machine (Model 55R1123, Canton, Mass.) equipped with a Warner-Bratzler shear attachment. The speed for the test was 250 mm/minute.

Fatty acid profile

Fat samples were extracted in hexane and methyl esters were formed. The mass ratio of fatty acids were quantified using a gas chromatograph (Heweltt-Packard, Model 5890, Farmington Hills, Mich.).

Sensory evaluation

Chops were cooked and sensory evaluation was conducted using 40 consumer panelists recruited from the Animal Science Department and the Department of Food Science and Technology at the University of Nebraska–Lincoln. The chops were cooked using an electric grill to an internal temperature of 158°F. Once cooked, chops were trimmed of excess fat. Samples of 1 in^2 were obtained and maintained warm until served to the panelists. A descriptive scale was used to determine the effect of DDGS inclusion on pork quality and flavor. Panelists used an unstructured line-scale to evaluate the attributes provided in Table 1.

(Continued on next page)

Table 2. Response and significance of dietary DDGS[a] inclusion on final weight and carcass characteristics of growing-finishing pigs.

	DDGS[a], %					*P*-value		
Item	0	5	10	15	SEM[b]	Treatment	Linear	Quadratic
No. of pigs	13	11	12	11				
Live weight, lb	273.25	266.60	257.64	250.07	5.12	0.02	0.02	0.92
Hot carcass weight, lb	203.95	197.49	190.72	184.39	3.93	0.01	0.01	0.98
Dressing, %	74.64	74.10	74.02	73.72	0.57	0.72	0.28	0.83
Last rib BF[c], in	1.04	0.99	0.98	0.94	0.28	0.14	0.02	0.94
10th rib BF, in	0.94	0.76	0.85	0.85	0.10	0.68	0.69	0.40
LMA[d], in^2	7.82	8.02	7.59	7.25	0.20	0.07	0.02	0.19

[a]DDGS = Corn distillers dried grain with solubles.
[b]SEM = Standard error of the mean
[c]BF = Backfat.
[d]LMA = Longissimus muscle area

Table 3. Response and significance of dietary [a]DDGS inclusion on the composition, shear force and color of the longissumus muscle of growing-finishing pigs.

	DDGS[a], %					*P*-value		
Item	0	5	10	15	SEM[b]	Treatment	Linear	Quadratic
Composition, %								
Crude protein	22.50	22.69	22.59	22.55	0.21	0.89	0.94	0.55
Moisture	71.90	71.31	70.73	72.23	0.50	0.17	0.84	0.04
Ash	1.12	1.14	1.18	1.16	0.02	0.32	0.11	0.41
Fat	3.87	4.12	4.86	3.04	0.49	0.08	0.38	0.03
Shear force, lb	6.7	7.03	6.37	6.92	0.28	0.34	0.99	0.66
Color (d 0)								
a*, (redness)	20.84	20.84	20.41	20.57	0.42	0.71	0.50	0.85
b*, (yellowness)	17.68	17.67	17.52	17.30	0.34	0.89	0.43	0.77
L*, (lightness)	54.31	54.07	54.72	54.49	0.43	0.84	0.75	0.99
Color (d 10)								
a*, (redness)	17.16	18.34	17.66	17.10	0.62	0.71	0.68	0.13
b*, (yellowness)	16.31	17.02	16.96	16.41	0.46	0.89	0.91	0.17
L*, (lightness)	54.08	55.14	55.91	56.07	0.72	0.84	0.22	0.97
E[c]	4.17	2.81	3.03	4.07	0.64	0.32	0.97	0.70

[a]DDGS = Corn distillers dried grain with solubles.
[b]SEM = Standard error of the mean.
[c]E = Change in color.

Statistical analysis

Carcass characteristics, chemical composition, fatty acid profile and sensory characteristics were analyzed as a complete randomized design using the MIXED procedure (SAS Inst. Inc., Cary, N.C.). Each pig was considered an experimental unit and pen was considered a random effect. Color data were analyzed as repeated measures in time using the MIXED procedure of SAS. Pig was considered the experimental unit and tray was considered a random effect.

Results and Discussion

Carcass traits are shown in Table 2. A negative linear response to DDGS concentration was recorded for LW and HCW ($P < 0.05$), which indicates that LW and HCW decreased as dietary DDGS increased. Dressing percentage was not affected ($P = 0.72$) by dietary DDGS. These results differ from those reported in other studies that showed reductions in DP as DDGS concentration increased. Treatments did not affect LMA, LRBF, and TRBF ($P > 0.05$).

The results of the chemical analysis and color of LM are provided in Table 3. Protein, moisture, fat, and ash were not affected by dietary DDGS inclusion ($P > 0.05$). Shear force did not differ among treatments ($P = 0.34$). At day 0 and 10 there was no difference among treatments ($P > 0.05$) for redness (a*), yellowness (b*), lightness (L*), and color change (E). These results indicate that during the 10-day experimental period, pigs receiving increasing dietary concentration of DDGS showed a pattern in change of color (E) similar to the control diet (0 % DDGS).

Table 4 shows the fatty acid profile of backfat samples. Mysistic, palmitoleic, stearic, oleic, vaccenic, and α-linolenic were not affected by dietary DDGS concentration ($P > 0.05$). Treatments affected palmitic acid concentration ($P = 0.03$) and exhibited a linear reduction in mass % as dietary DDGS inclusion increased ($P = 0.01$). Linoleic acid concentration was affected by treatment ($P = 0.01$); increasing dietary DDGS increased mass % of this fatty acid in backfat ($P = 0.01$). Despite the lack of significant treatment effect ($P = 0.06$), increasing the concentration

Table 4. Response and significance of dietary DDGS[a] inclusion on fatty acid profile of finishing pigs.

	DDGS[a], %					*P*-value		
Item	0	5	10	15	SEM[b]	Treatment	Linear	Quadratic
Fatty acid, mass %								
Myristic, (14:0)	1.47	1.37	1.38	1.36	0.37	0.18	0.07	0.31
Palmitic, (16:0)	25.16	24.32	24.57	23.36	0.41	0.03	0.01	0.66
Palmitoleic, (16:1)	2.23	2.30	2.24	2.25	0.10	0.95	0.99	0.75
Stearic, (18:0)	13.55	12.44	12.64	12.00	0.54	0.24	0.07	0.66
Oleic, (18:1)	38.86	40.15	39.62	39.68	0.46	0.25	0.35	0.19
Vaccenic, (18:1)	4.20	4.29	4.24	4.20	0.11	0.92	0.91	0.55
Linolenic, (18:2)	10.03	10.69	10.93	12.49	0.47	0.01	0.01	0.34
α-linolenic, (18:3)	0.40	0.39	0.37	0.40	0.01	0.68	0.99	0.31
Others	4.07	4.00	3.97	4.21	0.18	0.81	0.64	0.42
Total saturated fatty acids	40.18	38.13	38.60	36.7	40.88	0.06	0.01	0.91
Total mono-unsaturated fatty acids	45.30	46.76	46.10	46.13	0.60	0.41	0.49	0.24
Total poly-unsaturated fatty acids	10.43	11.09	11.30	12.90	0.49	0.01	0.01	0.34

[a]DDGS = Corn distillers dried grain with solubles.
[b]SEM = Standard error of the mean.

Table 5. Response and effect of dietary [a]DDGS inclusion on sensory characteristics of longissumus muscle of growing-finishing pigs.

	DDGS[a], %					*P*-value		
Item	0	5	10	15	SEM[b]	Treatment	Linear	Quadratic
Attribute[c], mm								
General appearance	97.35	88.97	88.03	94.85	5.34	0.58	0.69	0.18
Toughness	71.97	65.95	67.19	79.50	5.61	0.33	0.36	0.11
Chewiness	79.74	75.60	76.78	81.18	5.51	0.87	0.88	0.43
Juiciness	73.23	78.90	82.05	75.73	4.88	0.60	0.62	0.22
Pork flavor	83.00	82.95	80.11	79.86	4.57	0.93	0.54	0.98
Off-flavor	43.13	43.79	43.85	58.62	5.87	0.17	0.07	0.22
Aftertaste pork flavor	80.58	81.45	72.90	69.18	4.80	0.19	0.04	0.62
Aftertaste off-flavor	45.53	40.03	40.32	61.86	5.61	0.01	0.05	0.01
Overall acceptability	83.00	75.87	80.51	74.92	5.01	0.54	0.31	0.80

[a]DDGS = Corn distillers dried grain with solubles.
[b]SEM = Standard error of the mean.
[c]Attribute description provided in Table 1.

of DDGS in the diet of finishing pigs resulted in a linear reduction in the concentration of total saturated fatty acids (TSFA; $P = 0.01$). Increasing the concentration of DDGS resulted in increased relative TUFA concentration in backfat samples ($P = 0.01$). Reports in the literature indicate that a reduction in the content of saturated fatty acids in adipose tissue occurs when sources of unsaturated fatty acids are included in the diet of pigs. This alteration in the saturation of backfat observed in the present study may be the consequence of increased concentration of unsaturated fatty acids in the diets as dietary DDGS concentration increased.

The effects of DDGS inclusion on taste characteristics of the longissimus muscle of finishing barrows are provided in Table 5. The inclusion of increasing concentration of DDGS in the diets did not affect general appearance, texture, chewiness, juiciness, pork flavor, off-flavor, aftertaste, and overall acceptability of longissimus muscle ($P > 0.05$). A significant effect of treatment was detected for aftertaste off-flavor ($P = 0.01$). Off flavor was more pronounced as dietary DDGS increased ($P = 0.01$). In general, increasing dietary DDGS had minimal effects on pork sensory characteristics.

Conclusions

These results suggest that the inclusion of increasing levels of DDGS in diets of finishing pigs from the University of Nebraska–Lincoln nutrition line did not affect carcass characteristics; however, as DDGS inclusion increased HCW was reduced.

Dressing percentage, chemical composition, color, and sensory characteristics of the LM was not affected by dietary DDGS up to 15%.

The results of this investigation suggest dietary inclusion of DDGS may result in an increase in total unsaturated fatty acid and a decrease in total saturated fatty acid concentrations.

[1]Roman Moreno is a graduate student and research technologist; Phillip S. Miller, and Steven J. Jones are professors; and Thomas E. Burkey is an assistant professor in the Animal Science Department. Susan L. Cuppett is a professor in the Department of Food Science and Technology. Timothy P. Carr is a professor in the Department of Nutrition and Health Sciences. Tommi F. Jones is research supervisor in the Animal Science Department. Ruth M. Diedrichsen is the Nonruminant Laboratory supervisor in the Animal Science Department.

Effects of Increasing Concentrations of Distillers Dried Grains with Solubles (DDGS) on Growth Performance of Weanling Pigs

Feeding low concentrations of DDGS early in the nursery period does not help to maintain growth performance when high concentrations of DDGS are incorporated in the diets during the late nursery period.

Thomas E. Burkey
Phillip S. Miller
Swapna S. Shepherd
Roman Moreno
Erin E. Carney[1]

Summary

The objective of this experiment was to evaluate growth performance of weanling pigs introduced to low concentrations (5%) of DDGS during phase 2 of the nursery period followed by high concentrations (30%) during phase 3 of the nursery period. Overall (day 0 to 42), pigs fed 5 or 30% DDGS in phase 2 (and 30% DDGS in phase 3) had decreased ($P < 0.05$) average daily gain (ADG) compared to control pigs. In addition, pigs fed 30% DDGS (during phase 2 and 3) had decreased ($P < 0.05$) body weight (BW) compared to control pigs and pigs that only received DDGS during phase 3. However, pigs fed 0% DDGS during phase 2 (followed by 30% DDGS in phase 3) had similar BW, ADG and average daily feed intake compared to pigs fed the control diet. This research indicates that the inclusion of DDGS during phase 2 of the nursery may negatively affect growth performance, particularly when followed by inclusion of high concentrations of DDGS during phase 3 of the nursery period. However, growth performance may be maintained when high concentrations of DDGS are included in the diets of pigs (with no previous exposure to DDGS) late in the nursery period.

Introduction

Distillers dried grains with solubles (DDGS) is the primary co-product of ethanol production that is used in the swine industry. Incorporation of DDGS in swine diets is expected to grow rapidly because of its improved quality and increased availability. To date, much of the research documenting the effects of DDGS is focused on growing-finishing pig performance. Little emphasis has been placed on the effects of DDGS on nursery pig performance. Currently, some nutritionists recommend that DDGS should not be fed at concentrations greater than 5% of the diet during the nursery phase. However, because little emphasis has been placed on research documenting the growth performance of nursery pigs fed DDGS (particularly high quality DDGS from new generation ethanol plants), DDGS may be underutilized in nursery-pig diets. The objective this research was to evaluate growth performance of weanling pigs introduced to low concentrations (5%) of DDGS during phase 2 of the nursery period followed by high concentrations (30%) during phase 3 of the nursery period.

Materials and Methods

Experimental design

Ninety-six weaned (17 to 19 days post-farrowing) pigs were sorted by weight and sex and randomly allotted to dietary treatment in a 42-day experiment (4 treatments; 6 pigs/pen; 4 replicates/treatment) that was conducted at the University of Nebraska–Lincoln. Average initial body weight was 12.3 lb. During phase 1 (days 1 to 7) all pigs were fed a common transition diet, during phase 2 (days 8 to 21) and 3 (days 22 to 42) the 4 dietary treatments (Table 1) were arranged as follows: 1) basal diet (CTL; 0% DDGS in phase 2 and 3); 2) 0% DDGS (0% DDGS in phase 2, 30% DDGS in phase 3); 3) 5% DDGS (5% DDGS in phase 2, 30% DDGS in phase 3); and 4) 30% DDGS (30% DDGS in phase 2 and 3). All diets were fed in meal form and formulated to meet or exceed NRC requirements for growth without growth-promoting antibiotics, zinc oxide, or copper sulfate. All pigs were housed in a temperature-controlled room with constant lighting. Each pen contained a single nipple waterer and a single self-feeder to facilitate ad libitum access to water and feed. Pig weights and feed disappearance measurements were obtained on day 7, 21, and 42. Pig body weight (BW) and feed disappearance were measured weekly and used to calculate average daily gain (ADG), average daily feed intake (ADFI), and feed efficiency (G:F).

Statistical analyses

Growth data were analyzed as a completely randomized design using the MIXED procedure of SAS. The main effect of the statistical models was dietary treatment. Pen was considered as the experimental unit for analyses.

Results and Discussion

Pig BW and growth performance results are summarized in Table 2. At the end of phase 1 (day 7; during which all pigs were fed a transition diet) pig BW averaged 14.2 lb. As expected, BW and growth performance during phase 1 (days 0 to 7) were not affected by dietary treatment. At the end of phase 2 (day 21), pig BW was similar among treatments and averaged 23.7, 23.6, 22.7, and 21.2 lb for pigs fed the control, 0% DDGS, 5% DDGS, and 30% DDGS diets, respectively. During phase 2, no differences in growth performance were observed between pigs fed 5% DDGS compared to pigs fed the control diet. However,

Table 1. Composition of phase 2 (P2)[a,b] and phase 3 (P3)[a,c] diets (as-fed basis) %.

	Control		0% DDGS		5% DDGS		30% DDGS	
Ingredient, %	P2	P3	P2	P3	P2	P3	P2	P3
Corn	43.90	58.96	43.90	37.51	41.00	37.51	22.80	37.51
Soybean meal, 47.5 % CP	32.00	35.00	32.00	26.75	29.98	26.75	23.43	26.75
Spray dried whey	15.00	0.00	15.00	0.00	15.00	0.00	15.00	0.00
Select menhaden fish meal	4.00	0.00	4.00	0.00	4.00	0.00	4.00	0.00
Corn oil	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Dicalcium phosphate, 21% P	1.00	1.65	1.00	0.75	0.90	0.75	0.25	0.75
Limestone	0.35	0.63	0.35	1.23	0.40	1.23	0.80	1.23
Salt	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
UNL mineral mix[d]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
UNL vitamin mix[e]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Lysine•HCl	0.00	0.04	0.00	0.04	0.00	0.04	0.00	0.04
DL-methionine	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
DDGS[f]	0.00	0.00	0.00	30.00	5.00	30.00	30.00	30.00
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[a]Control = 0% DDGS in phase 2 and 3; 0% DDGS = 0% DDGS in phase 2 and 30% DDGS in phase 3; 5% DDGS = 5% DDGS in phase 2 and 30% DDGS in phase 3; 30% DDGS = 30% DDGS in phase 2 and 3.
[b]Phase 2 diets were formulated to contain: lysine, 1.4% ; Ca, 0.85% ; P, 0.7% ; available P, 0.47%.
[c]Phase 3 diets were formulated to contain: lysine, 1.24% ; Ca, 0.81% ; P, 0.71% ; available P, 0.36%.
[d]Supplied per kg of diet: Zn (as ZnO), 128 mg; Fe (as $FeSO_4 \cdot H_2O$), 128 mg; Mn (as MnO), 30 mg; Cu (as $CuSO_4 \cdot 5H_2O$), 11 mg; I (as $Ca(IO_3) \cdot H_2O$), 0.26 mg; Se (as Na_2SeO_3), 0.3 mg.
[e]Supplied per kg of diet: vitamin A (as retinyl acetate, 5,500 IU; vitamin D (as cholecalciferol), 550 IU; vitamin E (as α-tocopheryl acetate), 30 IU; vitamin K (as menadione dimethylpyrimidinol bisulfate), 4.4 mg; riboflavin, 11.0 mg; d-pantothenic acid, 22.05 mg; niacin, 33.0 mg; vitamin B_{12} (as cyanocobalamin), 33.0 mg.
[f]Distillers dried grains with solubles.

Table 2. Body weights (BW), average daily gain (ADG), average daily feed intake (ADFI) and feed efficiency (G:F) of nursery pigs fed various dietary concentrations of distillers dried grains with solubles (DDGS).[a]

	Dietary Treatments[b]					*P*-values
	Control	0% DDGS	5% DDGS	30% DDGS	SEM[c]	treatment
BW, lb						
day 0	12.1	12.4	12.5	12.3	0.46	0.8
day 7	14.4	14.3	14	14	0.27	0.3
day 21	23.7	23.6	22.7	21.2	0.43	0.3
day 42	55.2[d]	52.8[d]	51.6[de]	48.7[e]	1.08	0.003
Phase 1 (day 0 to 7)						
ADG, lb	0.33	0.28	0.21	0.23	0.06	0.6
ADFI, lb	0.4	0.41	0.33	0.37	0.02	0.16
G:F, lb/lb	0.81	0.7	0.61	0.61	0.18	0.8
Phase 2 (day 8 to 21)						
ADG, lb	0.67[d]	0.66[d]	0.63[d]	0.52[e]	0.02	0.001
ADFI, lb	1.00[d]	1.05[d]	0.97[d]	0.8[e]	0.05	0.03
G:F, lb/lb	0.68	0.64	0.64	0.63	0.03	0.7
Phase 3 (day 22 to 42)						
ADG, lb	1.50[d]	1.39[de]	1.38[e]	1.31[e]	0.05	0.03
ADFI, lb	2.28[d]	2.13[d]	2.09[d]	1.79[e]	0.09	0.01
G:F, lb/lb	0.66[d]	0.66[d]	0.66[d]	0.73[e]	0.02	0.01
Overall (day 0 to 42)						
ADG, lb	1.03[d]	0.96[de]	0.93[ef]	0.86[f]	0.03	0.003
ADFI, lb	1.54[d]	1.48[d]	1.43[d]	1.23[e]	0.05	0.005
G:F, lb/lb	0.67	0.65	0.65	0.71	0.02	0.1

[a]A total of 96 pigs (initially 12.3 ± 0.2 lb and 18 ± 1 d of age at weaning) with six pigs per pen and four pens per treatment.
[b]Control = 0% DDGS in phase 2 and 3; 0% DDGS = 0% DDGS in phase 2 and 30% DDGS in phase 3; 5% DDGS = 5% DDGS in phase 2 and 30% DDGS in phase 3; 30% DDGS = 30% DDGS in phase 2 and 3.
[c]Standard error of the mean.
[d-f]Means in the same row with different superscripts differ ($P < 0.05$).

pigs fed 30% DDGS had decreased ADG and ADFI compared to all other treatments ($P < 0.05$). At the end of phase 3 (day 42), pig BW was similar among treatments averaging 23.7, 23.6, 22.7 and 21.2 lb, respectively for pigs fed the control, 0% (0% in phase 2 and 30% in phase 3), 5% (5% in phase 2 and 30% in phase 3), and 30% (30% in phase 2 and 3) diets. During phase 3, pigs that received the control diet had greater ADG ($P < 0.05$) compared to pigs that received DDGS (including both the 5 and 30% DDGS treatments) during phase 2 of the experiment. In addition, pigs that received 30% DDGS (in both phase 2 and 3) had decreased ($P < 0.05$) ADFI and increased ($P < 0.05$) G:F compared to pigs fed the control diet.

Overall (day 0 to 42), pigs fed 30% DDGS (during both phase 2 and 3) had decreased ADG and ADFI compared to pigs fed the control diet ($P < 0.05$). In addition, BW (averaging 55.2, 52.8, 51.6, and 48.7 lb, respectively for pigs fed the control, 0, 5, or 30% DDGS treatment diets) for pigs fed 30% DDGS was decreased compared to all other treatments ($P < 0.05$). However, pigs that were introduced to 30% DDGS late in the nursery (received 30% DDGS during phase 3 only) had similar BW and growth performance compared to control pigs.

Conclusions

This research indicates that the inclusion of DDGS at low concentrations during phase 2 did not help to maintain growth performance when high concentrations of DDGS were included during phase 3 and that inclusion of high levels (30%) of DDGS throughout the nursery period has a negative effect on growth performance. However, growth performance may be maintained when high levels of DDGS (30%) are included during the late nursery period (phase 3).

[1]Thomas E. Burkey is an assistant professor; Phillip S. Miller is a professor, Swapna S. Shepherd is a research technician; and Roman Moreno and Erin E. Carney are graduate students in the Animal Science Department.

Dietary Fiber in Sow Gestation Diets — An Updated Review

Opportunities exist for pork producers to maintain or improve sow reproductive performance by using fibrous feedstuffs during gestation.

Duane E. Reese
Allen Prosch
Daryl A. Travnicek
Kent M. Eskridge[1]

Summary

Twenty-four published reports dating from 1975 to 2007 were examined to determine the overall effects of feeding gestation sows additional fiber. Sow and litter traits among trials were weighted by the number of litters for each treatment within each trial. Overall, sows can successfully consume high-fiber diets during gestation with few deleterious effects. Positive effects from feeding high-fiber diets were evident in litter size (0.2 to 0.6 pigs/litter) and sow lactation feed intake (0.5 to 0.8 lb/day), but they are not largely evident until the second reproductive cycle following exposure to the diet. It's possible that to ensure sow and litter performance improvements from feeding fiber, fiber must be included in the diet before mating.

Introduction

Gestating sows are excellent candidates for high-fiber diets. They can consume more of a concentrate diet than necessary to meet their energy requirement during gestation. This excess feed intake capacity can be exploited by offering sows less energy-dense diets. Also, in contrast to growing pigs allowed ad libitum access to feed, gestation sows derive more energy from fibrous feedstuffs.

The recent increase in corn price has prompted pork producers to consider alternative, high-fiber feedstuffs in swine diets. According to literature reviews published in the *1997 Nebraska Swine Report* and in Lewis and Southern, 2000 (Swine Nutrition, 2nd ed.), the number of pigs born alive and weaned was improved by 0.4 and 0.5 pigs/litter respectively, by feeding sows additional fiber during gestation. A slight improvement in sow longevity was also observed in fiber-fed sows.

Additional research results from four reports where sows were fed high-fiber diets during gestation have appeared since those earlier reviews. In addition, fiber intake was characterized as neutral detergent fiber (NDF) earlier. Currently there's recognition that perhaps more appropriate measures of fiber are soluble fiber (SF) and insoluble fiber (IF). The objective of this paper is to summarize sow fiber feeding results in order that the role of fibrous ingredients in sow gestation diets can be further elucidated.

Materials and Methods

Twenty-four published reports dating from 1975 to 2007 were examined. Results from each comparison between control and treatment sows were evaluated to determine the number of comparisons where a decrease, no change, or an increase in response was observed from feeding high-fiber diets. Then the hypothesis of a 0.5 probability of an increase due to additional fiber was tested using the sign test (Sprent and Smeeton, 2007). Average response to dietary fiber was calculated for each sow and litter trait among trials weighted by the number of litters for each treatment within each trial. The mean difference between control and fiber of each variable and the interaction between fiber and reproductive cycle category was tested for significance using weighted analyses of variance where weights were based on the number of litters in each treatment for each trial. Computations were conducted using the NPAR1WAY and GLM procedures (SAS Inst. Inc., Cary, N.C.). Reported metabolizable energy (ME), NDF, SF and ISF intakes were recorded; otherwise, intakes were estimated from reported sow feed intakes and published composition values for the feedstuffs (Table 1).

Overall effects on reproductive performance

None of the mean responses to feeding sows additional fiber in gestation were significant ($P > 0.10$; Table 2). However, for some response variables, we determined that the likelihood sow performance changed as a result of feeding fiber rather than by chance was greater than 95 in 100. These results indicate that sows fed high-fiber diets during gestation consumed less ME/day during gestation and more feed during lactation, completed the experiments at a higher rate and farrowed more live-born pigs per litter that weighed less ($P < 0.05$; Table 2).

Despite attempts by many researchers to equalize energy intake during gestation, the net effect of feeding high-fiber diets resulted in slightly decreased sow ME intake. Errors associated with assigning an energy value to the treatment diet were often cited as contributing to the decreased energy intake. Research results from feeding sows less ME derived from a corn/soybean meal diet during gestation show a similar relationship between gestation ME intake and sow lactation feed intake as that reported in Table 2.

Table 1. Composition of corn, soybean meal, and other fibrous feedstuffs (as-fed basis).[a]

Ingredient	ME, kcal/lb	NDF, %	SF,%	ISF, %
Corn	1555	9.6	1.7	4.7
Soybean meal, 44% CP	1445	13.3	1.6	31.5
Soybean meal, 46.5% CP	1536	8.9	1.4	26.2
Alfalfa meal and hay	900	45	4.2	52.4
Alfalfa haylage (90% dry matter)	900	32.8	3.1	38.3
DDGS[b]	1559	44	0.7	42.2
Wheat shorts		35	3.3	37.7
Perennial peanut hay		40.2		
Oat hulls		71.8		
Sunflower hulls		70.6		
Corn gluten feed	1184	36.8		
Soybean hulls	950	67	8.4	75.5
Oats	1232	31.4		
Wheat straw		85	0.5	71.0
Beet pulp	1134	54	11.7	53.9
Oat bran		19.2	7.5	8.3

[a]ME = metabolizable energy NDF = neutral detergent fiber; SF = soluble fiber; ISF = insoluble fiber.
[b]Dried distillers grains with solubles.

Table 2. Summary of responses to additional fiber in sow gestation diets.[a]

	No. of comparisons exhibiting…				No. litters	
Item	Increase	No change	Decrease	Response[b]	Control	Fiber
ME intake, Mcal/d[c]	11	3	19[f]	-0.2	1,936	2,415
Gestation weight gain, lb	19	1	16	-7.7	1,970	2,458
Lactation weight loss, lb	17	1	18	-1.4	1,500	1,992
Lactation feed intake, lb/day	20	2	8[f]	0.5	1,943	2,416
Completion rate, %[d]	10	0	2[f]	10.0	773	1,080
Live pigs born/litter	29	0	11[e]	0.2	2,024	2,524
Pigs weaned/litter	19	3	12	0.3	1,520	1,988
Piglet birth weight, lb	12	7	22[e]	0.0	2,048	2,548
Piglet weaning weight, lb	16	4	18	-0.1	2,042	2,530

[a]Data from 24 reports representing 19 fiber sources; maximum number of comparisons between control and fiber diets = 41.
[b]Mean response among trials weighted by numbers of litters for each treatment within each trial.
[c]ME = metabolizable energy.
[d](Number of females that completed the study/number of females assigned to each treatment) x 100; percentage units.
[e] $P < 0.01$ (Number increase vs. number no change + number decrease).
[f] $P < 0.05$ (Number increase vs. number no change + number decrease).

The litter size responses at birth and weaning are 0.2 pigs/litter less than previously reported. Of the four research reports that were not available for the previous literature reviews, litter size response was positive in two and only slightly positive to negative in two.

One vs. multiple reproductive cycle evaluation

Consideration regarding timing of fiber-feeding is warranted when evaluating litter size information, because it's well established that nutritional interventions intended to affect litter size must be employed before mating. In gestation studies that are limited to one reproductive cycle, sows are seldom introduced to the treatment diets before mating. However, in gestation studies that extend beyond one reproductive cycle, sows can be reintroduced treatment diets at weaning. Therefore, in an attempt to better understand the role of fiber in the gestation diet, research results from Table 2 were partitioned according to whether they were obtained from sows that were fed treatment diets for one or more than one reproductive cycle.

Sows fed additional fiber during gestation in the multiple-cycle studies produced 0.5 more pigs at weaning than those fed the control diet; however, in studies that involved one reproductive cycle, fiber-fed sows produced 0.2 fewer pigs at weaning, respectively than sows fed the control diet ($P = 0.08$; Table 3). No other significant reproductive cycle category x diet interactions were observed. However, it seems that additional fiber improved the number of live-born pigs/litter and lactation feed intake more in the multiple vs. single reproductive cycle studies (0.4 vs. -0.1 pigs/litter and 0.8 vs. -0.2 lb/day, respectively).

The different response observed in litter size to feeding additional fiber between sows involved in multiple vs. single reproductive cycle studies warrants further investigation. If it is important to feed additional fiber to sows before mating to observe a litter size response, it is reasonable to expect that within the multiple cycle studies, the litter size response would be greater in the later cycles of a study than in the first. Therefore, the number of live born pigs by reproductive cycle from sows fed the control and treatment diets in each multiple-cycle study was summarized. Changes in litter size by reproductive cycle were calculated and compared to the litter size response obtained from feeding fiber to sows that were involved in one reproductive cycle (Figure 1). As expected, the average litter size response observed during the first reproductive cycle in studies that involved multiple cycles was smaller compared to that observed for the second and third cycle (0.1 vs. 0.9 and 0.5 pigs/litter, $P = 0.0008$). Moreover, the responses for the first reproductive cycle in studies that involved multiple cycles is similar to that derived for studies involving a single reproductive cycle (0.1 vs. -0.1 pigs/litter, $P = 0.49$).

These results suggest that summarizing sow fiber feeding data according to reproductive cycle number further elucidates the role of fiber in sow diets. Therefore, subsequent analyses will be limited to data from sows involved in multiple reproductive cycles. Also, it seems the results from studies where sows were fed treatment diets for more than one reproductive cycle show greater benefits from feeding high-fiber diets during gestation.

The extent that daily fiber intake

(Continued on next page)

Table 3. Summary of the effects of additional fiber in sow gestation diets when evaluated during one vs. multiple reproductive cycles.[a,b]

	No. reproductive cycles							
	1			>1			No. litters	
Item	Control	Fiber	Response	Control	Fiber	Response	1 cycle	>1 cycle
Daily intake								
ME, Mcal[c]	6.2	6.3	0.1	6.8	6.4	-0.4	1,322	3,029
NDF, g[d]	181	574	393	380	792	412	1,346	3,029
SF, g[e]	16	44	28	150	327	177	1,113	2,671
ISF g[f]	185	421	236	178	541	363	1,113	1,737
Gestation weight gain, lb	60.0	63.1	3.1	110.5	99.0	-11.5	1,297	3,131
Lactation weight loss, lb	-15.9	-19.0	3.1	-9.1	-5.2	-3.9	1,297	2,207
Lactation feed intake, lb/day	13.0	12.8	-0.2	11.6	12.4	0.8	1,287	3,073
Live pigs born/litter	10.3	10.2	-0.1	10.4	10.8	0.4	1,321	3,227
Pigs weaned/litter[g]	9.6	9.4	-0.2	8.4	8.9	0.5	1,215	2,293
Piglet birth weight, lb	3.2	3.2	0.0	3.3	3.3	0.0	1,369	3,227
Piglet weaning weight, lb	12.5	12.8	0.3	14.7	14.5	-0.2	1,345	3,227

[a]Data from 24 reports representing 19 fiber sources.
[b]Mean response among trials weighted by numbers of litters for each treatment within each trial.
[c]ME = metabolizable energy.
[d]Neutral detergent fiber.
[e]Soluble fiber.
[f]Insoluble fiber.
[g]P = 0.08 for diet x reproductive cycle category.

was improved by feeding fibrous feedstuffs may depend on the basis for characterizing fiber and on the number of reproductive cycles utilized. The inclusion of fibrous feedstuffs in the diet seemed to increase daily NDF intake to a similar extent in sows involved in multiple- vs. single-cycle studies (412 vs. 393 g/day; Table 3). In contrast, the inclusion of fibrous feedstuffs in the diet increased daily SF intake by 532% (177 vs. 28 g) in sows involved in multiple-cycle studies compared with those in single-cycle studies. Daily ISF intake was increased by 54% (363 vs. 236 g) by incorporating fibrous feedstuffs in the diet of treatment sows involved in multiple vs. single cycle studies. These results suggest that characterizing fiber as SF and ISF may be more descriptive than NDF is for feeding sows.

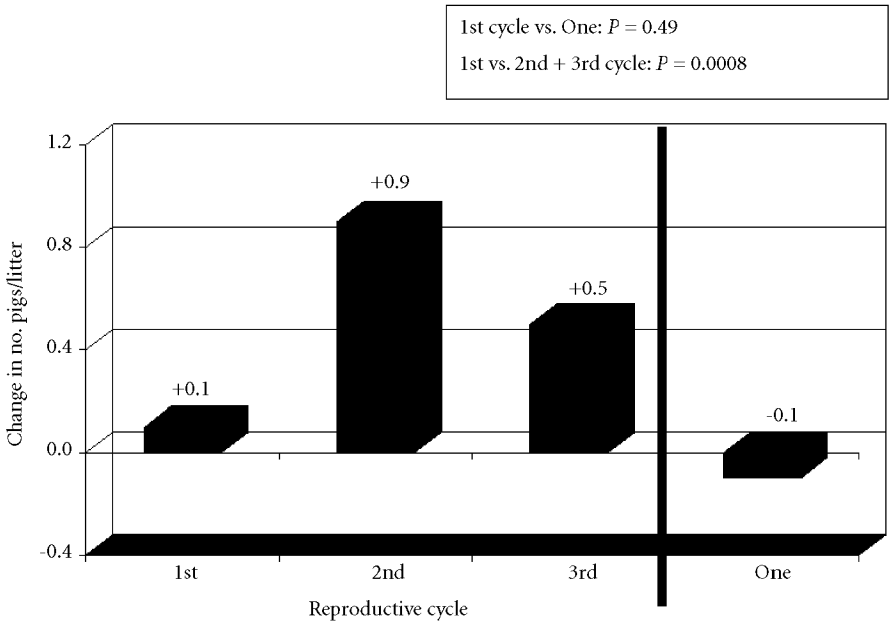

Figure 1. Change in number of live births per litter from feeding sows high-fiber diets during gestation according to reproductive cycle. Data for reproductive cycles 1 to 3 are from studies where sows were fed high-fiber diets over more than one reproductive cycle; data for One reproductive cycle are from studies where sows were fed high-fiber diets for one reproductive cycle only. Summary from 22 published reports; 14, 14, 11 and 24 control and fiber diet comparisons made for 1st, 2nd, 3rd, and One reproductive cycle category, respectively.

Evaluation of fiber additions to corn/soybean meal-based diets

In the United States, sows are typically fed corn/soybean meal-based diets. Therefore, they would normally consume about 180, 30, and 120 g of NDF, SF and ISF per day, respectively. Sows involved in the multiple cycle studies that consumed the control diet averaged 380, 150 and 178 g of NDF, SF and ISF per day, respectively (Table 3). Assuming there is a threshold at which additional fiber in the diet does not further improve reproductive performance and given that fibrous feedstuffs would be incorporated into corn/soybean meal-based diets in the USA, it's pertinent to limit an evaluation to results from studies that utilized corn/soybean meal-based diets in control and treatment sows.

The removal of results from two studies from the data set where diets other than those based on corn/soybean meal were provided to control

Table 4. Summary of the effects of additional fiber in corn/soybean meal-based (corn-soy) sow gestation diets when evaluated over multiple reproductive cycles.[a,b]

Item	Diet		Response	SEM[c]	*P*- value	No. litters	
	Corn-soy	Corn-soy + fiber				Corn-soy	Corn-soy + fiber
Daily intake							
ME, Mcal[d]	6.2	6.1	-0.1	0.1	0.56	773	987
NDF, g[e]	183	563	380	46	<0.0001	773	987
SF, g[f]	30	46	16	5	0.04	664	738
ISF g[g]	160	483	323	51	0.0005	664	738
Gestation weight gain, lb	80.9	73.2	-7.7	6.2	0.37	825	1,037
Lactation weight loss, lb	-8.0	-2.5	-5.5	3.0	0.19	830	1,042
Lactation feed intake, lb/day	11.8	12.5	0.7	0.3	0.18	791	1,013
Live pigs born/litter	10.0	10.4	0.4	0.2	0.13	873	1,085
Pigs weaned/litter	8.3	8.9	0.6	0.2	0.03	873	1,085
Piglet birth weight, lb	3.3	3.3	0.0	0.1	0.72	873	1,085
Piglet weaning weight, lb	13.3	12.8	-0.5	0.9	0.69	873	1,085

[a]Data from 11 reports representing 11 fiber sources.
[b]Mean response among trials weighted by numbers of litters for each treatment within each trial.
[c]Standard error of the mean.
[d]ME = metabolizable energy.
[e]Neutral detergent fiber.
[f]Soluble fiber.
[g]Insoluble fiber.

Table 5. Average change in litter size according to source of dietary fiber fed to the sow during gestation.[a]

Fiber source	Dietary level, %	Daily intake of treatment sows, g[b]			Live pigs born	Pigs weaned	No. litters	No. references
		NDF	SF	ISF				
Alfalfa meal	5.0	210	33	161	-1.3	-1.1	87	1
Alfalfa hay	50.0	620	66	681	0.9	0.7	375	2
Alfalfa haylage	53.0	515	54	506	0.8	1.0	110	1
Alfalfa-orchardgrass hay	45.8	934			0.1	0.9	86	1
Corn gluten feed	93.0	830			0.9	0.6	193	1
DDGS[c]	50.0				0.8	0.3	140	1
Perennial peanut hay	79.6				-0.2	-0.4	58	1
Soybean hulls	19.1	471	67	476	-0.8	-0.7	35	1
Sunflower hulls	22.2	568			0.5	0.2	153	1
Wheat straw	14.2	429	30	368	0.5	0.7	699	1
Wheat shorts	97.5	682	65	734	0.6	1.2	96	1

[a]Control sows fed corn/soybean meal-based diets; control and treatments diets provided for >1 reproductive cycle.
[b]NDF = neutral detergent fiber; SF = soluble fiber; ISF = insoluble fiber.
[c]Dried distillers grains with solubles.

and treatment sows resulted in similar responses due to feeding additional fiber for all response variables except for SF intake (responses in Table 3 vs. Table 4). The response in daily SF intake decreased from 177 to 16 g.

The large reduction in the amount of SF provided to sows is explained by the large amount of SF sows in the two studies that were removed from the analysis consumed during gestation (457 and 806 g/day). Considering that the response in litter size did not diminish at the removal of the two studies where sows consumed a large quantity of SF, it's possible that sows do not need to consume more than about 46 g of SF per day to elicit a litter size response as long as the fiber-feeding occurs over more than one reproductive cycle.

As expected, adding fibrous ingredients to corn/soybean meal-based diets resulted in greater intakes of NDF ($P < 0.0001$), SF ($P = 0.04$) and ISF ($P = 0.0005$; Table 4). Feeding additional fiber during gestation improved litter size at weaning by 0.6 pigs/litter ($P = 0.03$). Sows fed fiber appeared to lose 5.5 lb less weight during lactation, consume 0.7 lb more feed during lactation and farrow 0.4 more pigs/litter. Overall, this analysis indicates that the addition of fiber from various sources to corn/soybean meal-based gestation diets is not likely to reduce reproductive performance; some improvement may be observed for some traits.

Effect of fiber source on litter size

The information in Table 4 may be the best available to show the effect of including fibrous feedstuffs in corn/soybean meal-based gestation diets. However, there are 11 different fiber sources represented in that summary. Does one fiber source affect sow performance more than another?

Results of a summary examining change in litter size according to source of dietary fiber when fed for

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more than one reproductive cycle are presented in Table 5. Of the 11 fiber sources shown, providing three (alfalfa meal, perennial peanut hay and soybean hulls) to gestation sows appeared to reduce litter size. Litter size improvements ranged from 0.1 to 1.2 pig per litter for the remaining sources.

Soybean hulls and alfalfa meal are generally widely available and excellent candidates for inclusion in sow gestation diets. Given the relatively few number of litters that have been produced from alfalfa meal feeding research (87) and the positive results observed from feeding high-quality alfalfa hay and haylage and alfalfa-orchard grass, producers feeding alfalfa meal to sows are not likely to observe any reduction in litter size. However, results from feeding soybean hulls to gestation sows are mixed and difficult to predict. Two, single-cycle studies, involving a total of 493 litters that were included in the overall summary (Table 1), reported changes in number of pigs born alive and weaned ranging from -0.9 to 0.1 and 0.0 to 0.2 pigs per litter, respectively due to feeding soybean hulls during gestation.

Conclusion

Despite research results that span decades, questions remain about feeding high-fiber diets to gestating sows. However, the body of data summarized for this review indicates that sows can successfully consume high-fiber diets during gestation with few deleterious effects. Positive results in litter size and lactation feed intake were observed, but they are not largely evident until the second reproductive cycle. It's possible that to ensure sow and litter performance improvements from feeding fiber, that fiber-feeding must be initiated before mating.

Based on the results of this analysis, additional research directed at feeding high-fiber diets to gestating sows could 1) entail an evaluation of the fiber source(s) for more than one reproductive cycle, 2) exam the optimum time to introduce high-fiber diets to elicit a litter size response, 3) determine the amount of additional fiber necessary to elicit a litter size response and 4) reexamine the value of soybean hulls in gestation diets.

[1]Duane E. Reese is extension swine specialist and Allen Prosch was Pork Central coordinator at the University of Nebraska; Daryl A. Travnicek is an SAS programmer and Kent M. Eskridge is statistics professor at the University of Nebraska. References available upon request at dreese1@unl.edu.

Effects of Nutrition During Gilt Development on Lifetime Productivity of Sows of Two Profile Maternal Lines: Summary of Growth Characteristics and Sow Productivity — 2008

Differences in litter performance between genetic lines do not appear to be due to gilt management. Dietary energy restriction during the gilt development period positively affects litter weaning weight.

Phillip S. Miller
Rodger K. Johnson
Roman Moreno
Matthew W. Anderson
Jeffery M. Perkins
Donald R. McClure
Thomas McGargill[1]

Summary

An experiment was conducted to determine the effects of energy restriction during the gilt development period on lifetime sow reproductive performance of two maternal lines. There were essentially no interactions among line, dietary treatment, and parity. The Large White x Landrace gilts were heavier before and after dietary treatments, matured later, and had greater longissimus muscle area compared to Nebraska Line gilts. Restricting energy intake during the developmental period increased litter weaning weight but had no affect on litter size. Nutritional management of prolific sow lines during the gilt development period does affect sow and litter performance. However, these results do not suggest that the sow populations studied should be fed differently during the gilt development period.

Introduction

A study to investigate the effects of nutrition during the developmental period on gilt growth and sow reproductive performance of two prolific maternal lines was initiated in 2005. Updates and reports have been provided in the 2006 and 2007 Nebraska Swine Report. Currently, data are being collected for the fourth parity of the three replications of the

Table 1. Number of gilts at the beginning (day 123) and end (day 226) of the developmental period and number of litters at each parity.

	Developmental period			Litters at each parity			
Item	Day 123	Day 226	AP[a]	1	2	3	4
Line							
LW × LR	260	256	217	147	91	68	35
L45	211	206	197	149	85	65	31
Dietary treatment							
AL[b]	235	232	218	156	83	62	35
R[c]	236	230	196	140	937	131	
Total	471	462	414	296	176	133	66

[a]Age at puberty measurement.
[b]Ad libitum group.
[c]Restricted to 75% of the AL group.

Table 2. Body weight (BW), age at puberty (AP), backfat (BF), and longissimus muscle area (LMA) of LW × LR and L45 gilts with ad libitum (AL) access or restricted (R) to 75% of the AL group energy intake.

	LW × LR		L45			*P* value		
Item	AL	R	AL	R	SEM[a]	Line	AL vs. R	L × T
Day 123 BW, lb	158.5	157.1	144.4	145.7	2.03	< 0.001	0.94	0.44
Day 226 BW, lb[b]	310.9	266.6	295.9	248.6	2.95	< 0.001	< 0.001	0.59
AP, day	175.4	174.4	169.0	169.1	3.02	0.054	0.88	0.85
BF, in	1.16	0.79	1.19	0.78	0.03	0.37	< 0.001	0.056
LMA, in^2	6.65	5.97	6.39	5.60	0.09	0.005	< 0.001	0.43

[a]Standard error of the mean.
[b]End of the feeding period.

designed study. To our knowledge, this study represents the sole effort to examine effects of nutrition (dietary energy restriction) during the gilt developmental period on reproductive performance of two prolific sow lines studied over four parities.

Previous reports have highlighted the issues regarding the challenges facing swine and seedstock producers in developing gilts for inclusion into the sow herd. Although a multitude of factors affecting optimization of gilts face the swine industry, two factors (genetic background and energy intake) have been isolated in the study described herein. The reader is encouraged to review the companion article to this report (Johnson et al., 2008) for elaboration of gilt populations, dietary regimens, gilt management, and measurements.

Materials and Methods

Gilt populations

Two populations of gilts were used. One population was the progeny of UNL swine nutrition females and an industry maternal line (L_M) boar and will be denoted as LW × LR. The other group was progeny of the L_M boars described above and females from the Nebraska Index Line selected for increased litter size and also selected for improved carcass characteristics and growth performance during the last six generations (denoted L45).

Gilt management and dietary treatments

Gilts from both populations were similarly managed in the nursery until approximately 60 days of age (45 lb). Gilts were penned in groups (n = 10) and received identical diets (corn-soybean meal-based) and management until 123 days of age (3-phase growing-finishing period). At this time, gilt pens were assigned to receive one of two dietary regimens; ad libitum treatment (**AL**) that was a corn-soybean meal diet (0.70% lysine, 0.70% Ca, 0.60% P) provided until gilts were moved into the breeding barn, or a restricted treatment (**R**). The R group received a corn-soybean diet at approximately 75% of the energy intake of the AL group until moved into the breeding barn. The diet provided to the R groups contained 0.93% lysine, 1.0% Ca, and 0.80% P. The R treatment was designed to only restrict energy intake and maintain the intake of all other nutrients. An elaboration of procedures used to allocate feed to the R gilts is described in the *2007 Nebraska Swine Report,* pp. 10-13 and companion report (Johnson et al., *2008 Nebraska Swine Report*, pp. 21-26).

Measured traits

Beginning at approximately 123 days of age, pigs were weighed every 14 days and ultrasound measurements of 10^{th}-rib longissimus muscle area (LMA) and backfat (BF) depth were recorded. Feeders were weighed for the determination of average daily feed intake (AL groups only). The feeding regimens were continued until pigs were moved into the breeding barn (approximately day 226).

Prior to breeding and during gestation, all gilts were fed 4 lb/day of a standard corn-soybean meal based diet (13.8% protein, 0.66% lysine) until 90 days of gestation when feed intake was increased to 5.0 lb daily. Gilts were housed in pens until inseminated and then moved into gestation stalls.

At approximately 110 days of gestation, females were placed in farrowing crates and fed 6 lb/day of a corn-soybean meal based lactation diet (18.5% protein, 1.0% lysine) until farrowing; thereafter, feed intake was increased daily for three days and then ad libitum access to feed was provided

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Table 3. Sow and litter performance of LW x LR and L45 gilts provided ad libitum (AL) or 75% of AL intake (R) among four parities.

	LW × LR		L45		Parity					*P* value			
Item	AL	R	AL	R	1	2	3	4	SEM[a]	Line	AL vs. R	L × T	Parity
Total born	12.50	12.41	12.74	12.88	12.75	12.18	12.81	12.78	0.27	0.32	0.94	0.71	0.20
No. born alive	11.52	11.42	11.85	11.51	11.40	11.27	11.93	11.70	0.25	0.54	0.53	0.70	0.27
No. weaned	9.55	9.97	9.41	9.58	9.64	9.99	9.63	9.25	0.14	0.15	0.073	0.38	0.010
Litter weaning wt., lb	114.9	122.6	108.9	113.6	106.3	123.7	117.7	112.5	2.23	0.007	0.028	0.54	< 0.001

[a]Standard error of the mean.

until weaning. Litters were weighed and weaned at an average age of approximately 17 days postfarrowing. After weaning, sows were moved to the breeding area, remated and evaluated until their fourth parity.

Statistical analyses

Body weight and composition data were analyzed with a model that included line, gilt development regimen and their interaction. Replication and pen were considered random effects and pen was considered the experimental unit. Total pigs born and number of pigs born alive were analyzed with replication, line, dietary treatment, parity, and random effect of sow fitted to the model. Some crossfostering occurred, so in addition to the aforementioned effects, number of pigs weaned and litter weaning weight were adjusted for the number of pigs nursed and litter weaning age. See Johnson et al., 2008 Nebraska Swine Report, pp. 21-26 for additional details regarding statistical analyses.

Results and Discussion

It should be noted that the analysis presented herein presents means pooled among treatments. These traits are interpreted as if all sows were given an opportunity to raise the same number of pigs for the same length of time. As noted in the companion paper and identified in this report, the number of gilts/sows varied among population/dietary treatment/parity. Also, the results of the companion paper suggest that lifetime productivity may differ according to genetic line, dietary treatment and/or parity without necessarily affecting pooled mean responses at any parity (presented herein). The number of gilts at the beginning and end of the developmental period, and the number of litters at each parity are presented in Table 1.

Body weight (BW) , BF, LMA, and age at puberty results are presented in Table 2. The LW × LR gilts were heavier ($P < 0.001$) than L45 gilts at day 123 (157.8 vs. 145.1 lb) and at the end of the feeding period (288.8 vs. 272.3 lb). Dietary energy restriction compared to the AL treatment resulted in 46 lb reduction ($P < 0.001$) in day 226 BW. At the end of the feeding period there was no difference in BF between genetic lines (0.98 in); however, BF was reduced ($P < 0.001$) 33% in R vs. AL gilts. Longissimus muscle area was greater ($P = 0.005$) in LW × LR compared to L45 gilts (6.31 vs. 6.00 in^2) at the end of the feeding period. Energy restriction during the developmental period (R vs. AL gilts) decreased ($P < 0.001$) LMA (6.59 vs. 5.79 in^2).

Total pigs born and number born alive were not affected by genetic line, dietary treatment, or parity (Table 3). There was a trend ($P = 0.073$) for sows that received a restricted energy intake during the developmental period to wean more pigs (9.78 vs. 9.56). Parity affected ($P = 0.010$) number of pigs weaned (9.64, 9.99, 9.63, and 9.25 for Parity 1, 2, 3, and 4, respectively). The LW × LR sows weaned heavier ($P = 0.007$) litters compared to the L45 gilts (118.8 lb vs. 111.3 lb). Energy restriction during the developmental period resulted in sows that had heavier litters at weaning (AL = 111.9 lb, R = 118.1 lb). Parity affected ($P < 0.001$) litter weaning weight. Litter weaning weight was greatest at Parity 2 and least at Parity 1.

There were essentially no interactions among line, dietary treatment, and parity. The LW × LR gilts were heavier before and after the initiation of dietary treatments, matured later, and had greater LMA compared to L45 gilts. Restricting energy intake during the developmental period increased litter weaning weight.

Because sow weight and body condition (backfat) at farrowing and weaning were similar between genetic lines and dietary treatments (data presented in the companion article), the differences observed in litter weaning weight do not appear to be related to these traits. We did not measure feed intake during lactation, but changes in lactational feed intake could affect litter performance. Although the L45 sows were derived from the Nebraska line selected for increased litter size, total number of pigs born per litter was not different between lines. Likewise, milk production appears to be decreased in the L45 vs. LW × LR sows, but again, the physiological and/or nutritional basis for the difference is currently unknown . It should be noted that the maternal lines were not directly evaluated and were crossed with an unrelated industry maternal-line boar to produce the two populations of females used in this study.

[1]Phillip S. Miller and Rodger K. Johnson are professors in the Animal Science Department; Roman Moreno is graduate student and research technologist in the Animal Science Department; Matthew W. Anderson is manager of the UNL Swine Research Farm; Jeffrey M. Perkins, Donald R. McClure and Thomas E. McGargill are research technicians at the UNL Swine Research Farm.

Effects of Nutrition During Gilt Development and Genetic Line on Farrowing Rates Through Parity 3, Causes of Culling, Sow Weights and Backfats through Parity 4, and Factors Affecting Farrowing Rates

Restricting feed intake during the gilt development period may reduce the number available for breeding in some genetic lines, but thereafter has little effect on sow longevity or productivity.

Rodger K. Johnson
Phillip S. Miller
Matthew W. Anderson
Jeffrey M. Perkins
Kelsey A. Rhynalds
Trevor J. Glidden
Donald R. McClure
Thomas E. McGargill
Darryl J. Barnhill
Roman Moreno[1]

Summary

Gilts of two genetic lines were developed with either ad libitum access to feed or energy restriction (75% of ad libitum) to determine effects on subsequent sow performance and longevity. Gilts can be developed with regimens in which energy is restricted during the growing period, but the proportion that express pubertal estrus may be reduced in leaner, faster growing lines. Effects on subsequent farrowing rates are small. Sow weight and backfat at farrowing and weaning of Parity 1 litters affect the likelihood of producing a Parity 2 litter, but these effects are dependent on lean growth rate of the line and on the gilt development regimen. Weight was important in the slower growing, fatter line developed with the restricted feeding regimen; backfat was important in the leaner, faster growing line, but the effect was twice as great in females developed with restricted feeding than for those developed with ad libitum access to feed.

Introduction

Many variables contribute to variation in sow mortality and lifetime production, including housing systems, management during gilt development, sow management practices, and use of different genetic lines. At the University of Nebraska–Lincoln (UNL), we are focusing on whether nutritional regimens during gilt development affect longevity and whether the effect differs between two prolific lines that differ in rate of lean growth.

It is generally recommended that gilts be managed to achieve weights of 300 lb or more at breeding and that gilts have adequate backfat; however, the amount of backfat that is adequate is generally not specified. Producers accomplish these targets with various management practices. Gilts may be developed with ad libitum access to feed until weights of 230 to 250 lb, then feed intake is limited until breeding, with a flush just prior to breeding. Other producers maintain gilts with ad libitum access to feed right up to breeding to ensure target weights are achieved. In most cases, breeders attempt to mate gilts at their second or third post-pubertal estrus and mate sows for subsequent litters within five to 10 days of weaning after a 15 to 23-d lactation period.

Optimum gilt development regimens, however, may depend on the prolificacy of the genetic line and on its rate of lean growth. We initiated an experiment to address the effects of two nutritional regimens during gilt development on sow reproduction and longevity. These regimens were 1) providing ad libitum access to feed during the entire growing period until one week before breeding commenced, and 2) providing ad libitum access to feed until 123 days of age; thereafter, until one week before breeding commenced, feed was restricted to 75% of that consumed by gilts on Regimen 1. Nutrients in the diet of Regimen 2 were increased so that gilts consumed the same amounts of protein, vitamins, and minerals per unit of body weight as those on Regimen 1. Mothers of the gilts were 1) an industry Large White x Landrace cross (LW x LR) or 2) sows of the Nebraska Index Line (L45) that has been selected mainly for increased litter size with some selection for lean growth. Sows of these two lines were inseminated with semen from boars of an industry maternal line; the same boars were used across sow lines. Thus, the experimental gilts were paternal half sibs, with 50% of their genes coming from either industry LW x LR or L45, which differ in rate of lean growth. The experiment was designed to determine whether gilt nutritional development strategies affect longevity and lifetime productivity differently for these two kinds of crossbred females.

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The project is being conducted in three replicates in which approximately 160 gilts per replicate started the experiment at 123 days of age. The experiment is nearing its completion. Females in Replications 1 and 2 have completed four parities and females in Replication 3 have completed three parities. The *2007 Nebraska Swine Report* contained feed intake data and weight, backfat, and longissimus muscle area growth curves for all gilts. With ad libitum access to feed, LW x LR cross gilts had greater rates of body weight gain and lean gain than L45 cross gilts. Restricting energy intake caused approximately equal proportional reductions in rate of growth, backfat thickness, and longissimus muscle area of gilts of both lines, but muscle area per unit of body weight was similar to that of gilts allowed ad libitum access to feed.

Summary data and effects of line and diet on final growth traits and on sow production traits are in the preceding report. This report presents results of analyses to determine whether gilt development regimen and genetic line affected the likelihood that females designated for breeding produced litters at Parities 1, 2, and 3, lifetime production per female through Parity 3, and associations of traits related to sow culling through Parity 3.

Materials and Methods

The LW x LR cross gilts were the progeny of UNL swine nutrition females and industry maternal line (L_M) boars and are designated as LW x LR cross. The L45 cross gilts were the progeny of same L_M boars mated with females of the Nebraska Index line (Line 45) and are designated as L45 X. L45 has been selected mainly for large litter size with some selection for lean growth rate.

Gilt management and dietary treatments

All gilts were managed alike in the nursery until approximately 60 days of age (46 lb). They were then moved to the grow-finish facility where they were penned (10/pen) by line-treatment designation. They all were allowed ad libitum access to a corn-soybean meal based diet and were managed alike until 123 days of age. A three-phase growing-finishing diet was used: phase 1; 1.15% lysine (60 d to 80 lb); phase 2, 1.0% lysine (80 to 130 lb); and phase 3, 0.90% lysine (130 lb to 123 days). At 123 days, pens of gilts on treatment 1 (AL) were allowed ad libitum access to a corn-soybean meal based diet (0.70% lysine, 0.70% Ca, 0.60% P) until they were moved into the breeding barn. Gilts on the restricted intake diet (R) received a corn-soybean meal based diet at approximately 75% of the energy intake as AL-fed gilts until moved into the breeding barn. Energy restriction was achieved by predicting intake with a quadratic equation of average daily feed intake on body weight of AL-fed gilts. The predicted ad libitum intake (based on the projected body weight for the upcoming two-week period) was multiplied by 0.75 to determine the daily feed intake for R gilts. The diet contained 0.93% lysine, 1.0% Ca, and 0.80% P. All vitamins and minerals, except selenium, were increased so that daily intake of these nutrients per unit of body weight was expected to be equal for gilts on both diets. Additional details of the diets and management are in two articles in the *2007 Nebraska Swine Report* (Johnson et al., pp. 10-14 and Miller et al., pp. 14-17).

During the growing period, gilts were weighed and backfat and longissimus muscle area were recorded every 14 days. Beginning at approximately 140 days of age, gilts were moved by pen to an adjacent building where boar exposure and estrus detection occurred. Date of first observed estrus and each additional estrus were recorded. Only gilts that could be mated at their third or later estrus were moved to the breeding barn. Gilts were checked twice daily for estrus and were inseminated each day that they were observed in estrus. Insemination was with semen from commercial terminal sire line boars.

Breeding and lactation management

A restricted breeding period of 25 days (Rep 1), 24 days (Rep 2), and 26 days (Rep 3) was used to match the unit's production schedule. Gilts that did not express estrus, those that were mated but diagnosed open with an ultrasound pregnancy test 50 days post-breeding, and those that were diagnosed pregnant but did not farrow a litter were culled. In addition, lame gilts and those in poor health were culled.

Before breeding and during gestation, all gilts were fed a standard corn-soybean meal based diet (13.8% protein, 0.66% lysine) at the rate of 4.0 lb daily until 90 days of gestation when feed intake was increased to 5.0 lb daily. Gilts were in pens of approximately eight per pen until inseminated and then were moved to gestation stalls.

At approximately 110 days of gestation, females were weighed and backfat thickness was recorded ultrasonically. They were placed in farrowing crates in rooms of 12 crates per room and fed 6 lb per day of a corn-soybean meal based lactation diet (18.5% protein, 1.0% lysine). Sows were provided only a small amount of feed on the day they farrowed, 6 lb on the second day, 10 lb the third day, and then were given ad libitum access to feed.

Litters were weaned at an average age of approximately 17 days of age. Each sow was weighed and ultrasonic backfat was recorded at weaning. Sows were then moved to the breeding area and placed in groups of approximately eight sows per pen. Feeding, estrus detection, insemination, and management during gestation and subsequent lactations were as described above for gilts. The breeding period for sows within replications and parities ranged from 24 to 32 days. Breeding continued until 10 days after the last sow in the replication was weaned. Thus, every sow had at least 10 days to express post-weaning estrus, and most had 15 to 20 days. Sows that did not express estrus, those that were detected to be open by an ultrasonic pregnancy test, and those diagnosed pregnant but

Table 1. Number of gilts that finished the performance test (NF), number that expressed puberty (PUB), number moved to breeding (B), and numbers that did not express estrus during the breeding period (NE), died or culled due to lameness or unhealthy status (D), number mated but not pregnant (NP) from movement to breeding to Parity 1 (P0 to P1), Parity 1 to Parity 2 (P1 to P2) and Parity 2 to Parity 3 (P2 to P3), and number that farrowed at each parity (F).

					P0 to P1				P1 to P2				P2 to P3			
Line[a]	Trt[b]	NF	PUB	B	NE	D	NP	F	NE	D	NP	F	NE	D	NP	F
LW/LR	AL	129	118	105	8	1	19	77	17	10	7	43	2	0	8	33
LW/LR	R	127	99	93	4	3	16	70	13	1	8	48	2	2	9	35
L45 X	AL	103	100	94	1	2	12	79	3	2	14	40	3	2	6	29
L45 X	R	103	97	87	3	4	10	70	11	6	8	45	3	1	5	36
LW/LR		256	217	198	12	4	35	147	30	11	15	91	4	2	17	68
L45 X		206	197	181	4	6	22	149	14	8	22	85	6	3	11	65
	AL	232	218	199	9	3	31	156	20	12	21	83	5	2	14	62
	R	230	196	180	7	7	26	140	24	7	16	93	5	3	12	71
Total		462	414	379	16	10	57	296	44	19	37	176	10	5	26	133

[a]LW/LR = females were progeny of LW x LR sows, L45 X are progeny of Nebraska selection line sows.
[b]AL = gilts developed with ad libitum feeding, R = gilts developed with energy restriction.

that did not farrow a litter were culled. In addition, lame and unhealthy sows were culled.

Traits and data analysis

Based on females designated for breeding, each female was scored as 1 if she farrowed a litter at Parity 1, Parity 2, and Parity 3 and 0 if not. These scores, which are measures of success/failure to reproduce, were fitted with general linear models designed for binomial data to determine the importance of line, gilt treatment, and interaction of line with treatment. Performance variables were fitted as covariates to estimate their effect on whether sows reproduced. Variables fitted for Parity 1 scores were gilt final test weight, backfat, longissimus muscle area, and age at puberty. Variables fitted to Parity 2 scores were the sow's Parity 1 total litter size born, total weight of litter weaned, prefarrowing sow weight and backfat, sow weight and backfat at weaning, and weight and backfat loss from farrowing to weaning. These same variables recorded in Parity 2 sows were fitted in models analyzing success/failure to produce a Parity 3 litter. Solutions for each variable were obtained and are presented as the change in probability of producing a litter per unit change in the co-variable.

Total number of pigs produced per female through Parity 3 was calculated for each sow based first on all females that entered the breeding herd (those females that did not produce a Parity 1 litter were credited with a 0), and second based only on those sows that produced Parity 1 litter. These two measures of lifetime production, designated LNBA1 and LNBA2, were fitted to models to estimate line, treatment, and interaction effects.

Results and Discussion

Table 1 contains numbers of gilts at each stage of production and the numbers that were culled for failure to express estrus, died or were unhealthy, or that were mated, but open. The percentage of gilts that expressed pubertal estrus was affected by both genetic line ($P < 0.001$) and developmental diet ($P < 0.005$). More L45 X gilts attained puberty (96%) than LW/LR gilts (85%) and more gilts developed with ad libitum access to feed attained puberty than those developed with energy restriction (95% vs. 85%). Thus, as a percentage of those gilts that finished the performance test, a higher percentage of L45 X gilts than LW/LR gilts (88% vs. 77%) and a higher percentage of gilts on treatment AL than R (86 % vs. 78%) were moved into the breeding barn. However, there was a line x treatment interaction ($P < 0.01$) on the proportion of gilts that attained puberty. Of the LW/LR gilts developed on treatment AL, 118 of 129 (91.4%) attained puberty, whereas 99 of 127 (78.0%) of those developed on treatment R attained puberty. Gilt development diet did not affect whether a L45 X gilt attained puberty (AL = 97.1%, R = 94.2%).

The most common cause of culling from breeding to P1 litters was mated gilts that were not pregnant (57), which was not affected by either genetic line or gilt development diet. Failure to express estrus during the breeding period and mated gilts that were not pregnant were approximately equal causes of culling from P1 to P2 and P2 to P3. Again, these causes were not related to either genetic line or to diet during gilt development. Overall, 34 females (9.0 % of those designated for breeding) died or were culled due to poor health before farrowing a Parity 3 litter.

Table 2 contains mean proportions of gilts designated for breeding that farrowed litters and lifetime number of live pigs per female through Parity 3. A greater proportion of L45 X than LW/LR gilts designated for breeding produced litters at each parity, but the difference was significant only at parity 1 (L45 X = 69%, LW/LR = 56%, $P < .01$). Treatment and interaction were not significant for any trait. Thus, gilt development diet did not significantly affect the likelihood

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that a female would produce litters up through Parity 3.

Based on females designated for breeding, Line 45 X gilts produced 2.85 $\pm$ 1.57 ($P = 0.07$) more live pigs through Parity 3 than LW x LR females. This difference was due entirely to more L45 X females than LW x LR females producing a Parity 1 litter as there was no difference in lifetime number of live pigs per sow that farrowed a Parity 1 litter. Gilt development diet did not affect lifetime number of live pigs per female based on those females that entered the breeding herd. However, when based on those females that produced a Parity 1 litter, females developed with R intake produced 2.91 $\pm$ 1.61 ($P = 0.07$) more live pigs than those developed with AL intake. Because there was little difference in number born alive at each parity due to gilt development diet (see the preceding report), this cumulative difference came about because of slightly greater success rate from P1 to P2 and P2 to P3 for females developed with the R diet.

Table 3 contains mean sow weights and backfats at farrowing and when litters were weaned by line, treatment, and parity. Probability values for effects in the model are shown in each column under that effect. Parity significantly affected all traits. Sows increased in weight and declined in backfat from Parity 1 to 3, but means were similar for Parity 3 and 4 sows. Both weight loss and backfat loss were greatest at Parity 1. Line by treatment interaction existed ($P < 0.05$) for sow weight at farrowing and for farrowing to weaning weight loss. LW x LR females developed with the AL treatment had greater farrowing weights and greater weight loss than those developed on the R treatment, but that did not occur for L45 X females. Interaction between gilt development diet and parity existed for sow backfat at farrowing and at weaning and for backfat loss from farrowing to weaning. Females developed on the AL diet had more backfat at Parity 1 than those developed on the R diet and they lost more backfat from farrowing to

Table 2. Mean proportion, estimated with general linear models, of females of each line and treatment that were retained as breeders that produced Parity 1, 2 and 3 litters, lifetime number of live pigs produced per female, and probabilities associated with tests of significance for line, treatment, and interaction.

						Lifetime No. Live pigs per female	
Line[a]	Trt[b]	No Breeders	Parity1	Parity2	Parity3	LNBA1[c]	LNBA2[c]
LW/LR	AL	105	.58	.39	0.25	12.99	22.24
	R	93	.54	.33	0.27	13.38	24.81
L45	XAL	94	.73	.37	0.26	15.77	21.97
	R	87	.65	.36	0.33	16.30	25.22
LW/LR		198	.56	.35	0.26	13.19	23.53
L45 X		181	.69	.39	.30	16.04	23.59
	AL	199	.65	.34	.26	14.38	22.11
	R	180	.59	.39	.30	14.84	25.01
		Probability for effects in model					
Line			0.004	0.42	0.40	0.07	0.97
Trt			0.17	0.28	0.28	0.75	0.07
Line x Trt			0.73	0.97	0.60	0.97	0.83

[a]LW/LR = females were progeny of LW x LR sows, L45 X are progeny of Nebraska selection line sows.
[b]AL = gilts developed with ad libitum feeding, R = gilts developed with energy restriction.
[c]Based on gilts entering the breeding herd.
[d]Based on females that farrowed Parity 1 litter.

Table 3. Mean sow weight and backfat at farrowing and at weaning, and weight and backfat loss from farrowing to weaning, by line, treatment and parity.

Line, treatment, and parity			Farrowing		Weaning			
Line	Trt	Parity	Wt, lb	BF, in	Wt, lb	BF, in	Wt loss	BF loss
LW/LR			479.4	0.80	417.4	0.72	62.1	0.08
L45 X			469.7	0.79	408.1	0.72	59.3	0.07
			0.07[a]	***0.70***[a]	***0.16***[a]	***0.94***[a]	***0.55***[a]	***0.26***[a]
	AL		476.7	0.81	411.2	0.73	62.0	0.08
	R		472.5	0.79	414.3	0.71	59.4	0.08
			0.38[a]	***0.46***[a]	***0.59***[a]	***0.31***[a]	***0.57***	***0.69***
		1	453.6	0.97	354.8	0.83	99.0[a]	0.15[a]
		2	462.8	0.79	403.7	0.72	58.3	0.07
		3	484.0	0.71	438.8	0.66	43.2	0.05
		4	497.9	0.72	454.0	0.67	42.4	0.05
			<0.01[a]	***<0.01***[a]	***<0.01***[a]	***<0.01***[a]	***<0.01***[a]	***<0.01***[a]
LW/LR	AL		485.8	0.82	413.9	0.73	67.9	0.09
LW/LR	R		473.0	0.79	421.2	0.71	56.4	0.08
L45 X	AL		467.7	0.79	408.8	0.73	56.2	0.06
L45 X	R		471.9	0.79	407.7	0.71	62.3	0.08
			0.04[a]	***0.53***[a]	***0.43***[a]	***0.76***[a]	***0.03***[a]	***0.06***[a]
LW/LR		1	459.5	0.97	361.6	0.84	98.8	0.15
LW/LR		2	471.2	0.80	410.6	0.73	63.2	0.07
LW/LR		3	486.9	0.71	442.5	0.65	43.3	0.06
LW/LR		4	500.1	0.72	455.1	0.65	43.3	0.06
L45 X		1	447.4	0.96	347.9	0.82	99.1	0.14
L45 X		2	454.2	0.77	396.9	0.70	53.4	0.07
L45 X		3	481.1	0.71	435.0	0.67	43.1	0.04
L45 X		4	495.9	0.73	452.9	0.69	41.4	0.03
			0.58[a]	***0.82***[a]	***0.50***[a]	***0.13***[a]	***0.59***[a]	***0.68***[a]
	AL	1	458.2	1.03	352.8	0.87	105.7	0.17
	AL	2	463.9	0.79	401.5	0.72	57.1	0.07
	AL	3	488.0	0.71	441.0	0.67	43.1	0.04
	AL	4	496.1	0.69	450.0	0.66	42.2	0.02
	R	1	448.7	0.90	356.8	0.79	92.3	0.12
	R	2	461.5	0.78	405.9	0.72	59.5	0.07
	R	3	480.0	0.72	436.6	0.65	43.3	0.06
	R	4	480.9	0.85	415.9	0.72	42.5	0.07
			0.61[a]	***<0.0***[a]	***10.45***[a]	***<0.01***[a]	***0.16***[a]	***0.02***[a]

[a]Bold values in italics within each trait are significance probabilities for effects above them; e.g., the probability that farrowing weight is equal for LW/LR and L45 cross sows is 0.07 (significant at $P < 0.10$), whereas the probability that backfats for the lines are equal is 0.70 (nonsignificant).

Table 4. Changes in probability (effect and standard error, SE) of farrowing Parity 1 litter per deviation of 10 lb weight or 0.10 in backfat from line x treatment mean off-test weight and backfat (interaction of effects with line x treatment were significant, $P < 0.05$).

		Off-test Means		Wt-dev			BF-dev		
Line	Trt	Wt, lb	BF, in	Effect	SE	Pr[a]	Effect	SE	Pr[a]
LW/LR	AL	311.3	1.16	.0039	0.014	0.79	0.033	0.016	0.03
LW/LR	R	266.1	0.79	-.0219	0.016	0.16	0.078	0.024	0.001
L45	AL	295.2	1.24	.0162	0.016	0.34	-0.019	0.018	0.27
L45	R	248.7	0.79	.031	0.014	0.04	0.040	0.029	0.17

[a]Pr = probability for test of whether effect equals 0.

Table 5. Change in probability of farrowing a Parity 2 (P1) litter per 10 lb deviation from average sow weight at farrowing and weaning of Parity 1 (P1) litter and loss in weight from farrowing to weaning of Parity1 litter.

Trait	Overall Mean	Change per 10 lb	SE	Pr[a]
P1 sow farrow wt	453.4	-0.018	0.010	.07
P1 sow weaning wt	361.6	0.019	0.007	0.005
Wt loss	91.8	-0.018	0.007	0.005

[a]Pr = probability for test of whether effect equals 0.

weaning, but differences between AL and R females were relatively small at Parities 2 to 4.

The only traits that significantly affected whether gilts produced a Parity 1 litter were off-test weight and backfat. Because treatment affected these traits, each female's record was expressed as a deviation from the respective line x treatment mean. These deviations were then fitted in general linear models to test whether they were related to the likelihood that a female produced a litter. Similar analyses were performed with off-test longissimus muscle area and with age at puberty, but these traits had no effect ($P > 0.25$) on whether a female produced a Parity 1 litter.

Results for weight and backfat deviations are in Table 4. Weight deviation from line means significantly affected the likelihood that L45 X gilts developed on the R diet farrowed a Parity 1 litter, but did not significantly affect the outcome for L45 X gilts developed with the AL diet or LW x LR gilts developed with either diet. For each increase of 10 lb from the mean of 248.7 lb, L45 x gilts developed with the R diet had an increase of .031 $\pm$ 0.014 ($P < 0.05$) in the likelihood they would produce a litter; a deviation of -10 lb caused an average decrease of 0.031 in this likelihood.

Off-test backfat, however, did not affect the likelihood that a L45 X gilt produced a Parity 1 litter, regardless of which diet gilts were fed. However, backfat significantly affected the likelihood that LW x LR cross gilts produced a Parity 1 litter and the effect was more than twice as large for gilts developed on the R than AL diet. For LW x LR gilts developed on the AL diet, a change of 0.10 in backfat from the mean off-test backfat of 1.16 in was associated with a change in likelihood of producing a Parity 1 litter of 0.033 $\pm$ 0.016; the change was 0.078 $\pm$ 0.024 per 0.10 change in backfat for LW x LR gilts developed on the R diet.

Parity 1 sow weight, but not backfat, litter size, or litter weaning weight, affected whether a sow produced a Parity 2 litter. Effects of 10 lb changes from the mean weight at farrowing, weaning and weight loss from farrowing to weaning on likelihood of producing a Parity 2 litter are in Table 5. These effects did not interact with line or treatment, so only the overall effect is presented. Greater pre-farrowing sow weights at Parity 1 decreased the likelihood that sows produced a Parity 2 litter, but greater sow weights at weaning increased the likelihood. The magnitude of these effects was approximately equal (-0.018 $\pm$ 0.010 change per 10 lb increase in farrowing weight, 0.019 $\pm$ 0.007 change per increase of 10 lb in sow weight at weaning). The most useful measure of the effect of weight on subsequent reproduction is weight loss. The average sow lost 91.8 lb from farrowing to weaning of her Parity 1 litter, including the weight of the litter produced. Whether a sow produced another litter was not related to the number or weight of the pigs she produced, but was related to her weight loss. For each deviation of 10 lb from the mean weight loss, the likelihood of producing a Parity 2 litter changed by 0.018 $\pm$ 0.007 (increased deviation caused a decline in likelihood of producing a Parity 2 litter, and decreased deviation caused an increase in likelihood).

The likelihood of producing a Parity 3 litter was not affected ($P > 0.25$) by any trait measured in Parity 2 sows. Therefore, neither litter size or weight, or sow weights and backfats had a bearing on whether Parity 2 sows produced a Parity 3 litter.

Conclusions

Restricting feed intake to 75% of that of gilts allowed ad libitum access to feed from 123 days of age to breeding decreased the proportion of gilts that expressed pubertal estrus. However, the effect was line dependent, causing a greater reduction in the leaner, faster growing LW x LR (91.4% vs. 78%) gilts than in the L45 X gilts (97.1% vs. 94.2%). Once designated for breeding, the most frequent causes of female culling through Parity 3 were those that were mated but not pregnant and those that did not express estrus during the breeding period.

More L45 X gilts than LW x LR gilts produced a Parity 1 litter, but lines did not differ in the likelihood of producing Parity 2 and 3 litters. Thus, L45 X females produced 2.85 $\pm$ 1.57 more live pigs per female entering the breeding herd than LW x LR cross females. Gilt development diet did not significantly affect the likelihood of females producing a litter at any parity; however, because those developed with restricted feed intake had somewhat greater success at Parities 2 and 3, those developed with restricted

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feed intake produced 2.91 ± 1.61 more live pigs from Parity 1 to 3 than those developed with ad libitum access to feed.

Gilt weight and backfat at 135 days of age affected the likelihood that gilts farrowed a Parity 1 litter. The effect depended on genetic line and development regimen. Each 10 lb increase/decrease in weight from the mean weight of 248.7 lb was associated with an increase/decrease of .031 ± 0.014 in the likelihood a L45 X gilt developed with restricted feed intake farrowed a P1 litter. Weight had no effect on the likelihood of producing a Parity 1 litter for L45 X gilts developed with ad libitum access to feed or LW x LR cross gilts developed with either feeding regimen. Backfat at 135 days affected the likelihood that a LW x LR gilt produced a Parity 1 litter, but did not affect L45 X gilts. The effect was more than twice as large for LW x LR gilts developed on the restricted feeding regimen (increase/decrease of 0.078 ± 0.024 increase/decrease of 0.10 in deviation in backfat from the mean backfat of 0.79 in) than those developed with ad libitum access to feed (increase/decrease of 0.033 ± 0.016 per increase/decrease of 0.10 change from the mean backfat of 1.16 in)

Parity 1 sow weight, but not backfat, litter size, or litter weaning weight, affected whether a sow produced a Parity 2 litter. The average sow lost 91.8 lb from farrowing to weaning of her Parity 1 litter. Each increase/decrease of 10 lb from the mean weight loss was associated with a decrease/increase of 0.018 ± 0.007 in the likelihood of producing a Parity 2. The likelihood of producing a Parity 3 litter was not affected by any trait measured in Parity 2 sows.

[1]Rodger K. Johnson and Phillip S. Miller are professors in the Animal Science Department. Matthew W. Anderson is manager of the Swine Research Farm; Jeffrey M. Perkins, Kelsey A. Rhynalds, Trevor J. Glidden, Donald R. McClure, Thomas E. McGargill, and Darryl J. Barnhill are technicians at the Swine Research Farm. Roman Moreno is a graduate student and research technician in the Animal Science Department.

Estimation of the Lysine Requirements for High-Lean Growth Pigs

The lysine requirements (total basis) for high-lean growth potential barrows and gilts raised to maximize growth performance was 1.14, 1.04, 0.94, and 0.86% lysine, for Grower-1, 44 to 79 lb; Grower-2, 79 to 132 lb; Finisher-1, 132 to 189 lb; and Finisher-2, 189 to 260 lb, respectively.

Phillip S. Miller
Roman Moreno
Thomas E. Burkey
Rodger K. Johnson[1]

Summary

An experiment was conducted to determine the lysine regime required to maximize growth performance for high-lean-growth potential barrows and gilts beginning at 45 lb and concluding at approximately 260 lb. There were four growing-finishing phases and four lys treatments within phase (Grower-1, 44 lb to 79 lb; Grower-2, 79 lb to 132 lb; Finisher-1, 132 lb to 189 lb; and Finisher-2, 189lb to 260 lb). Dietary treatments were corn-soybean meal based supplemented with 0.15% crystalline lysine. The formulation of 2 dietary treatments was aimed to provide lysine below the requirement, while the other 2 dietary treatments provided lys above the requirement. The lysine regimen (requirement) to maximize growth performance of barrows and gilts appears to be approximated by 1.14%, 1.04%, 0.94%, and 0.86% total lysine, respectively, but greater dietary lysine concentrations (similar to the greatest lysine regimen) may be warranted to maximize carcass leanness. However, it should be noted that the highest lysine regimen (1.30, 1.20, 1.10, and 1.00%, respectively) may reduce feed intake and daily gain.

Introduction

Many studies have been conducted to investigate the amino acids requirements for growing-finishing pigs. Typically, these studies have focused on one specific phase of the growing-finishing period (i.e., 45 to 90 lb, 90 to 120 lb, etc). Often, information from a variety of these studies is collectively summarized to provide amino acid requirements for pigs throughout the growing-finishing period. An array of environmental and genetic factors have been documented to affect amino acid requirements for growing-finishing pigs and necessitate the periodic review and reassessment of amino acids requirements as management systems change and genetic selection for increased lean growth occurs. Therefore, the objective of this study was to define the lysine (lys) regimen (for the entire growing-finishing period) required for high lean-growth barrows and gilts.

Materials and Methods

Location and facilities

The experiment was conducted from December to April at the

Table 1. Ingredients and calculated composition of the experimental diets, as-fed basis

	Phase 1				Phase2				Phase 3				Phase 4			
Ingredient (%)	T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4
Corn	77.17	70.77	63.99	57.71	81.60	74.85	68.07	61.80	85.87	79.12	72.59	66.07	89.80	84.80	75.80	70.26
SBM, 47.5 % CP	17.35	23.75	30.50	36.75	13.45	20.00	26.75	33.00	9.25	16.00	22.50	29.00	5.50	10.50	19.50	25.00
Tallow	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
Dicalcium phosphate	1.30	1.30	1.30	1.30	1.05	1.05	1.05	1.05	0.90	0.90	0.90	0.90	0.75	0.75	0.75	0.75
Limestone	0.88	0.88	0.88	0.88	0.80	0.80	0.80	0.80	0.78	0.78	0.78	0.78	0.75	0.75	0.75	0.75
Salt	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
DL-Methionine	0.00	0.00	0.03	0.06	0.00	0.00	0.03	0.05	0.00	0.00	0.03	0.05	0.00	0.00	0.00	0.04
L-Lysine · HCL	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Vitamin premix[a]	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Trace mineral mix[b]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Calculated composition																
lysine, %	0.80	0.97	1.14	1.30	0.70	0.87	1.04	1.20	0.60	0.77	0.94	1.10	0.50	0.63	0.86	1.00
CP, %	14.80	17.30	19.90	22.00	13.20	15.90	18.50	20.90	11.70	14.30	16.90	19.40	10.20	12.20	15.70	17.90
ME,[c] Mcal/lb	1.55	1.55	1.55	1.55	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56
Calcium, %	0.70	0.72	0.74	0.76	0.60	0.63	0.65	0.67	0.55	0.57	0.59	0.61	0.50	0.51	0.54	0.56
Phosphorus, %	0.58	0.60	0.63	0.66	0.51	0.54	0.55	0.60	0.50	0.50	0.53	0.55	0.43	0.45	0.49	0.51
Lys:ME, g/Mcal	2.34	2.84	3.34	3.81	2.04	2.53	3.03	3.50	1.74	2.24	2.73	3.20	1.45	1.82	2.49	2.91
Met + Cys, %	0.52	0.59	0.66	0.79	0.48	0.55	0.65	0.74	0.44	0.51	0.60	0.70	0.40	0.45	0.55	0.64
Threonine, %	0.54	0.64	0.75	0.85	0.48	0.59	0.69	0.79	0.42	0.53	0.63	0.73	0.36	0.44	0.58	0.67
Tryptophan, %	0.16	0.20	0.24	0.27	0.14	0.17	0.21	0.25	0.11	0.15	0.19	0.23	0.09	0.12	0.17	0.20
Met+Cys:lys	0.65	0.60	0.60	0.60	0.68	0.63	0.62	0.61	0.73	0.66	0.63	0.63	0.80	0.71	0.64	0.64
Thr:lys	0.68	0.66	0.65	0.65	0.68	0.67	0.66	0.65	0.70	0.68	0.67	0.66	0.72	0.69	0.67	0.67
Trp:lys	0.20	0.20	0.21	0.20	0.20	0.19	0.20	0.20	0.18	0.19	0.20	0.20	0.18	0.19	0.19	0.20

[a]Supplied per kilogram of diet at 0.2% inclusion: 4,400 IU vitamin A as retinyl acetate; 440 IU vitamin D_3 as cholecalciferol; 24 IU vitamin E as α-tocopherol acetate; menadione sodium bisulfite, 3.5 mg; riboflavin, 8.8 mg; d-pantothenic acid, 17.6 mg; niacin, 26.4 mg; vitamin B_{12}, 26.4 mg.
[b]Supplied per kilogram of diet at 0.15% inclusion: Zn (as ZnS_4O), 128 mg; Fe (as $FeSO_4 \cdot H_2O$),128 mg; Mn (as MnO), 30 mg; Cu (as $CuSO_4 \cdot 5\ H_2O$), 11 mg; I (as $Ca(IO_3) \cdot H_2O$), 0.26 mg; Se (as Na_2SeO_3), 0.3 mg.
[c]ME = Metabolizable energy.

University of Nebraska Swine Research Unit located in Mead, NE. Pigs were housed in a 24-pen modified-open-front building equipped with automated environmental controls. Pens were 4 × 15 ft and flooring was half concrete half slotted. Each pen was equipped with one automatic feeder and one nipple waterer.

Animals

One hundred twenty barrows and gilts (NE index × Landrace) × Pietran were used in a 16-wk experiment. The average initial body weight (BW) was 44.5 lb and final BW was 260.8 lb. Three barrows and three gilts were placed in each of 20 pens, and there were five replicates for each of the four dietary treatments. All management and experimental procedures were approved by the Institutional Animal Care and Use Committee of the University of Nebraska–Lincoln.

Experimental diets

Pens were randomly assigned to one of four dietary treatments designed as follows: Four experimental diets were formulated to contain a complete lysine regimen fed during the entire growing-finishing period. There were four growing-finishing phases and four lys treatments within phase [Grower-1 (G1), 44 to 79 lb; Grower-2 (G2), 79 to 132; Finisher-1 (F1), 132 to 189 lb; and Finisher-2 (F2), 189 to 260 lb)]. Dietary treatments were corn-soybean meal based supplemented with 0.15% crystalline lysine. The formulation of 2 dietary treatments was aimed to provide lys below the estimated requirement, while the other two dietary treatments provided lys above the requirement. Other nutrient concentrations were formulated to meet or exceed allowances identified in the Nebraska-South Dakota Swine Nutrition Guide. The composition of dietary treatments is described in Table 1.

Data and sample collection

Pigs and feeders were weighed at the beginning of the experiment and bi-weekly thereafter. Pigs and feeders were also weighed at dietary phase changes. Feed disappearance was estimated by the difference between feed offered and feed remaining in the feeder. Average daily gain (ADG), average daily feed intake (ADFI) and ADG:ADFI (G:F) were estimated based on the individual biweekly BW and feed disappearance. Additionally, ultrasound measurements of 10^{th} -rib backfat (BF), and longissimus muscle area (LMA) were conducted every 28 days.

Statistical analysis

Each pen was considered an experimental unit. The model was a completely randomized design and data were analyzed using a single-factor analysis of variance using the MIXED procedure (SAS Inst. Inc., Cary, N.C.). Pen effect was considered

(Continued on next page)

Table 2. Effect of lysine concentration on average daily gain (ADG), average daily feed intake (ADFI) and feed efficiency (G:F) of (NE index × Landrace) × Pietran pigs.

		Treatment					*P*-value		
Item		1	2	3	4	SEM[a]	Treatment	Linear	Quadratic
No. of pigs		30	30	30	30				
No. of pens		5	5	5	5				
Initial BW, lb		43.84	44.70	44.56	44.98	0.441	0.33	0.11	0.62
Final BW, lb		235.62	272.32	270.86	264.34	3.528	< 0.0001	< 0.0001	< 0.0001
Grower 1, week 0 to 3									
	ADG, lb	1.504	1.738	1.813	1.801	0.035	< 0.0001	< 0.0001	0.0032
	ADFI, lb	3.724	3.804	3.753	3.715	0.053	0.6344	0.7357	0.2794
	G:F, lb/lb	0.891	1.008	1.065	1.069	0.020	< 0.0001	< 0.0001	0.0098
Grower 2, week 4 to 6									
	ADG, lb	1.715	1.790	1.993	1.766	0.093	0.2076	0.4091	0.1252
	ADFI, lb	4.606	4.481	4.767	4.271	0.123	0.0682	0.2089	0.1544
	G:F, lb/lb	0.820	0.880	0.924	0.911	0.035	0.1833	0.0539	0.3151
Finisher 1, week 7 to 11									
	ADG, lb	1.599	1.956	2.185	1.956	0.115	0.0194	0.0228	0.0219
	ADFI, lb	5.852	6.125	6.258	5.513	0.161	0.0229	0.2353	0.0060
	G:F, lb/lb	0.602	0.708	0.770	0.781	0.044	0.0436	0.0083	0.3010
Finisher 2, week 12 to 16									
	ADG, lb	1.786	2.245	1.998	2.143	0.154	0.2141	0.2482	0.3248
	ADFI, lb	5.945	6.886	6.774	6.668	0.172	0.0056	0.0165	0.0076
	G:F, lb/lb	0.662	0.719	0.650	0.703	0.042	0.6142	0.7392	0.9721
Overall									
	ADG, lb	1.658	1.965	2.020	1.945	0.040	< 0.0001	< 0.0001	0.0002
	ADFI, lb	5.173	5.548	5.669	5.285	0.064	0.0001	0.1258	< 0.0001
	G:F, lb/lb	0.706	0.781	0.785	0.811	0.011	< 0.0001	< 0.0001	0.0533

[a]Standard error of the mean.

Table 3. Effect of lysine concentration on back fat (BF) and longissimus muscle area (LMA) of (NE index × Landrace) × Pietran pigs.

		Treatment					*P*-value		
Item		1	2	3	4	SEM[a]	Treatment	Linear	Quadratic
No. of pigs		30	30	30	30				
No. of pens		5	5	5	5				
Initial wt, lb		43.835	44.695	44.563	44.982	0.441	0.33	0.11	0.62
Final weight, lb		235.626	272.318	270.862	264.335	3.528	<0.0001	<0.0001	<0.0001
Initial, day 0									
	BF, in	0.260	0.252	0.248	0.260	0.004	0.6719	0.8268	0.4194
	LMA, in^2	1.113	1.170	1.096	1.149	0.026	0.2298	0.7856	0.9591
Final, day 112									
	BF, in	0.925	1.004	0.929	0.760	0.012	0.0038	0.0058	0.0061
	LMA, in^2	5.270	6.459	6.479	6.369	0.121	< 0.0001	< 0.0001	< 0.0001
Week 0 to 8									
	BF change, in	0.236	0.232	0.220	0.142	0.012	0.0004	0.0002	0.0157
	LMA change, in^2	2.113	2.641	2.843	2.571	0.099	0.0007	0.0026	0.0010
Week 9 to 16									
	BF change, in	0.425	0.508	0.457	0.354	0.031	0.0355	0.1078	0.0133
	LMA change, in^2	2.043	2.646	2.540	2.647	0.155	0.0417	0.0257	0.1303
Overall									
	BF change, in	0.661	0.744	0.681	0.496	0.035	0.0023	0.0047	0.0033
	LMA change, in^2	4.156	5.289	5.383	5.219	0.119	< 0.0001	<0.0001	< 0.0001

[a]Standard error of the mean.

random, and treatment was considered a fixed effect. In addition, orthogonal contrasts examining the linear and quadratic effect of lysine-feeding regime were evaluated.

Results and Discussion

The responses of ADG, ADFI, and G:F to lys regimen is shown in Table 2. Significance of treatment as well as linear and quadratic effects are also shown in Table 2. The response of BF and LMA change to lys regimens and the significance of treatment, linear and quadratic effect are shown in Table 3.

No treatment, linear, or quadratic effects were observed for initial BW (IBW; $P = 0.33$, $P = 0.11$, $P = 0.62$ respectively); however, lys regimen affected final weight (FW). The lightest FW was recorded for T1 while the

greatest weight corresponded to pigs receiving T2. There was a slight reduction in the FW of T4 (264.3 lb) compared to T2 and T3 (272.3 and 270.9 lb, respectively).

Average daily gain was affected by lys regimen during G1 ($P < 0.0001$), and F1 phases ($P = 0.0194$); however, no differences among treatments were detected for phases G2 ($P = 0.2076$) and F2 ($P = 0.2141$). For the overall period, ADG was affected by lys regimen ($P < 0.0001$). Average daily gain responded linearly ($P < 0.0001$), and quadratically ($P = 0.0002$) to lysine regimen. For the overall period, the quadratic effect indicated that increased lys concentration resulted in an increase in ADG; however, ADG was maximized at dietary lys concentrations corresponding to T3 (2.02 lb) and a further increase in lys concentration resulted in a reduction in ADG for T4 (1.95 lb).

No treatment effect was recorded for ADFI during G1 ($P = 0.6344$) or G2 ($P = 0.0682$); however, there was an effect of lys regimen on ADFI during F1 ($P = 0.0229$) and F2 ($P = 0.0056$). The linear effect of lys regimen on ADFI was not significant for any of the feeding phases except for F2 ($P = 0.0165$). A quadratic effect of lysine regimen on ADFI for F1 and F2 ($P = 0.0060$, $P = 0.0076$ respectively) was observed. With respect to the overall experimental period lys regimen affected ADFI ($P = 0.0001$). A quadratic effect was detected ($P < 0.0001$) which was consistent with the reduction in ADFI resulting from feeding pigs diets with a lys concentration above those used in the T3 regimen.

Lysine regimen affected G:F. A quadratic effect of lys concentration on G:F for G1 ($P < 0.0001$) was observed; however, G:F was not affected by increasing concentrations of lys during feeding phases G2 and F2 ($P = 0.1833$, $P = 0.6142$ respectively). During F1, the increase in lys concentration resulted in a linear increase in G:F ($P = 0.0083$). For the overall period, G:F was linearly affected by increased lys concentration ($P < 0.0001$).

At the beginning of the experimental period, no difference among treatments was recorded for BF ($P = 0.8268$) or LMA ($P = 0.2298$; Table 3). Feeding different lys regimens affected both final BF ($P = 0.0038$) and LMA ($P < 0.0001$). For BF, the results were consistent with previous lysine-titration studies which showed that the lowest BF changes for the T4 treatment occurred during the first, and second halves of the experimental period and overall (0.14, 0.35, and 0.50 in, respectively). The same treatment (T4) also recorded the lowest final BF (0.76 in). The increments in BF change for T1 were the second lowest for the weeks 9 to 16 and for the overall experimental period (0.43 and 0.66 in respectively); however, during the first half of the experimental period, T1 showed the greatest increase in BF among all treatments (0.24 in) which was likely the result of deficient amounts of lys consumed by pigs receiving this treatment (Table 1). Backfat change during the second half of the experimental period ($P = 0.2076$) and during the overall period ($P = 0.0033$), responded quadratically to dietary lysine regimen. For the overall experimental period, the lowest BF change was for T4 and the greatest change was for T2 (0.50 and 0.74 in respectively). The response of BF to lys regimen suggests that the lys concentration required for minimum BF deposition is between T3 and T4 lys regimens. It appears that when the lys requirements are met for growth performance, further increase in dietary lysine result in decreased BF deposition. This agrees with the results from previous lysine-titration studies.

There was no difference in LMA among treatments at the beginning of the experiment ($P = 0.2298$). A significant effect of lys regimen on LMA change was recorded during both periods of the experiment and overall, ($P = 0.0007$, $P = 0.0417$, and $P < 0.0001$ respectively). The lowest change in LMA was observed for T1 during the 0 to 8 and 9 to 16 week periods as well as overall period (2.11, 2.04, and 4.16 in^2 respectively). The greatest change in LMA during the first half of the experiment corresponded to T3 (2.84 in^2); however, during the second half of the experimental period, the maximum increase in LMA was associated with the T4 treatment (2.65 in^2). The lowest LMA was observed for the T1 treatment at the end of the experimental period (5.27 in^2), while the greatest LMA was recorded for T3 (6.48 in^2). During the first half of the experimental period, as well as the overall period, lys concentration fed to growing finishing pigs had a quadratic effect on LMA change ($P = 0.0010$, and $P < 0.0001$ respectively). Again, in the latter part of the finishing period, dietary lysine concentrations needed to maximize muscle (protein) deposition may be greater than concentrations needed to maximize overall growth.

Conclusions

The lys regimen (requirement) to maximize growth performance of barrows and gilts (NE index × Landrace) × Pietran] appear to be approximated by T3 (1.14, 1.04, 0.94, and 0.86% total lysine, respectively for grower 1, 2, Finisher 1, and 2), but greater dietary lysine concentrations (similar to the greatest lysine regimen (T4)) may be warranted to maximize carcass leanness. However, it should be noted that the T4 regimen may reduce ADFI and ADG.

[1] Phillip S. Miller is a professor, Roman Moreno is a graduate student and research technologist; Thomas E. Burkey is an assistant professor, and Rodger K. Johnson is a professor in the Animal Science Department. The authors would like to acknowledge the financial support of Monsanto Co.

Effect of Increasing Lysine:net Energy Ratio on Growth Performance and Plasma Urea Nitrogen Concentration of Late-Finishing Barrows Fed Low-Protein Amino Acid-Supplemented Diets and Ractopamine

Low-crude protein, amino acid-supplemented diets containing ractopamine balanced to contain 4.57 to 5.2 g of lysine/Mcal of net energy can adequately supply amino acids for growth in late finishing pigs.

Roman Moreno
Phillip S. Miller
Thomas E. Burkey[1]

Summary

An experiment was conducted to determine the optimum lysine (lys):Net energy (NE) ratio of low-crude protein (CP) amino acid (AA)-supplemented diets needed in conjunction with ractopamine (RAC) to improve growth performance of late-finishing barrows from the University of Nebraska–Lincoln (UNL) herd. Treatments consisted of five low CP, AA-supplemented diets with addition of ractopamine (16% CP; 4.5 g/ton), formulated to contain 3.35, 3.95, 4.57, 5.2 and 5.83 g of lys/Mcal of NE. A corn-soybean meal diet with no RAC supplementation served as negative control (20% CP; 5.24 g of Lys/Mcal of NE). Treatment did not affect growth performance ($P > 0.05$). Despite the lack of treatment effect ($P = 0.09$), increasing dietary lys/NE concentration resulted in a linear decrease in final backfat ($P = 0.01$). Treatments did not affect final longissimus muscle area ($P = 0.69$). Results indicate that the optimum lys/NE for late-finishing pigs from the UNL herd fed low-CP AA-supplemented diets containing 4.5 g of RAC is between 4.57, and 5.2 g of lys/Mcal of NE.

Introduction

Ractopamine (RAC) is a beta-adrenergic compound which has been used in late-finishing pigs to increase protein and to reduce fat deposition by redirecting a portion of the energy that the pig would use for fat synthesis to protein accretion. There is evidence that these changes in energy distribution result in increments in average daily gain (ADG), and gain:feed (G:F) as well as reduction in average daily feed intake (ADFI). Pigs fed diets supplemented with RAC require increased amounts of limiting amino acids (AA) especially lysine (lys), in order to respond to RAC inclusion. Increasing crude protein (CP) concentration in the diets of pigs may result in an excess of dietary non-essential AA concentration. The nitrogen (N) generated by the degradation processes of the excess of amino acids, eliminated by the pigs in feces and urine, has the potential to contaminate soil and water. The use of low-CP AA-supplemented diets appears to be effective to provide essential AA to pigs in the adequate amounts while avoiding feeding excessive CP concentration which in turn will help to reduce N excretion into the environment.

The objective of the present investigation was to determine the optimum lys:Net energy (NE) ratio of low-CP AA-supplemented diets needed in conjunction with RAC to improve growth performance of late-finishing barrows from the UNL herd. The present experiment was designed based on the results obtained in two previous experiments performed to define adequate CP and lys:NE dietary contents to maximize response to RAC of late-finishing from the UNL herd.

Procedures

Animals and treatments

Twenty-four crossbred [(Nebraska XL line × Danbred) × Pietrain] late-finishing barrows were used in a 28-day experiment. The average initial body weight (BW) was 184 lb and the final average BW was 254 lb. Pigs were individually penned in fully-slotted pens, maintained at 72°F, and had ad libitum access to feed and water. All management and experimental procedures were approved by the UNL Institutional Animal Care and Use Committee.

Experimental diets

The pigs were randomly assigned to one of six dietary treatments. To create the dietary treatments six diets were balanced for lys:NE. The control diet contained 5.2 g/Mcal NE and 20% CP. The five low-CP AA-supplemented counterparts contained 16% CP and varying lys:NE concentration ranging from 3.4 to 5.8 g of lys/Mcal of NE and 4.5 g RAC/ton (Table 1). Two of these diets had lys:NE less than adequate (3.35 and 3.95 g of lys/Mcal of NE), one of them was adequate (4.57 g of lys/Mcal of NE) and two had excessive lys:NE (5.2 and 5.83 g of lys/Mcal of NE) compared to NRC recommendations. All diets meet or exceed the lys to limiting AA ratios (Met + Cys, Trp,

Table 1. Ingredient and calculated nutrient composition of the experimental diets, as-fed basis.

	Treatment					
CP, %[a]	20	16	16	16	16	16
Lys:NE, g/Mcal[b]	5.24	3.35	3.95	4.57	5.2	5.83
RAC, g/ton[c]	0	4.5	4.5	4.5	4.5	4.5
Item, %						
Corn	65.91	75.58	75.99	76.08	76.04	75.93
Soybean meal, 46.5% CP	30.20	20.5	20	19.5	19.1	18.8
Tallow	2	2	2	2	2	2
Dicalcium phosphate	0.25	0.5	0.5	0.5	0.5	0.51
Limestone	0.75	0.70	0.7	0.7	0.7	0.7
Salt	0.3	0.3	0.3	0.3	0.3	0.3
Vitamin mix[d]	0.15	0.15	0.15	0.15	0.15	0.2
Mineral mix[e]	0.1	0.1	0.1	0.1	0.1	0.1
L-Lysine·HCl	0.23	0.01	0.21	0.4	0.6	0.79
L-Tryptophan	0	0	0	0.04	0.08	0.1
L-Threonine	0.05	0	0.03	0.12	0.23	0.34
DL-Methionine	0.06	0	0	0.09	0.18	0.26
Paylean® (ractopamine•HCl; 9 g/lb)	0	0.02	0.02	0.02	0.02	0.02
Total	100	100	100	100	100	100
Calculated composition						
ME, Mcal/lb[f]	1.55	1.56	1.56	1.55	1.55	1.53
CP, %	20.00	16.00	16.00	16.00	16.00	16.00
Total Lysine, %	1.2	0.78	0.92	1.06	1.2	1.34
Calcium, %	0.51	0.51	0.51	0.51	0.51	0.51
Available phosphorus, %	0.44	0.44	0.44	0.44	0.44	0.44

[a]CP = Crude protein.
[b]Lys:NE = Lysine: Net energy.
[c]RAC = Ractopamine.
[d]Supplied per kilogram of diet: Vitamin A (as retinyl acetate), 4,400 IU; vitamin D (as cholecalciferol), 440 IU; Vitamin E (as α-tocopheryl acetate), 24 IU; vitamin K (as menadione dimithyl pyrimidinol bisulfite), 3.5 mg; riboflavin, 8.8 mg; d-pantothenic acid, 17.6 mg; niacin, 26.4 mg; vitamin B_{12}, 26.4 mg.
[e]Supplied per kilogram of diet: Zn (as ZnO), 128 mg; Fe (as $FeSO_4 \cdot H_2O$),128 mg; Mn (as MnO), 30 mg; Cu (as $CuSO_4 \cdot 5H_2O$), 11 mg; I (as $Ca(IO_3) \cdot H_2O$), 0.26 mg; Se (as Na_2SeO_3), 0.3 mg.
[f]ME = Metabolizable energy.

and Thr) proposed by the Nebraska-South Dakota Swine Nutrition Guide for late-finishing pigs fed RAC. All other nutrients met or exceeded the NRC (1998) requirements.

Data and sample collection

Average daily gain (ADG) average daily feed intake (ADFI) and feed efficiency (G:F) were estimated based on pig weight and feed disappearance. Blood samples for the PUN determinations were taken by venipuncture of the vena cava region at the beginning of the experiment and weekly thereafter. The samples were centrifuged at 2,000 × *g* for 20 min. Plasma was maintained at -4°F until analysis for urea nitrogen concentration (PUN).

Statistical analyses

Each pig was considered an experimental unit and data were analyzed for treatment, linear and quadratic effects using the MIXED procedure (SAS Inst., Inc., Cary, N.C.). Pen was considered a random effect.

Results and Discussion

Growth performance

Table 2 shows the growth response of pigs to RAC inclusion and increasing dietary lys/NE. There was no difference among treatments, linear or quadratic response to lys/NE on final weight (FW), ADG, ADFI or G:F ($P > 0.05$).

Ultrasound measurements

Despite the lack of treatment effect ($P = 0.09$), increasing dietary lys/NE concentration resulted in a linear decrease in final BF ($P = 0.01$). This reduction in BF as lys/NE increased may be partially explained by the numeric reduction in ADFI as lys/NE increased. The later could be an indication that feeding diets containing less than adequate lys/NE concentrations may affect the ability of the pigs to use energy for protein deposition; therefore, the energy that otherwise would be use for protein accretion may be used for fat deposition. Treatments did not affect LMA ($P = 0.69$).

Plasma Urea Nitrogen

There was a significant treatment effect for PUN on d 21 and 28 ($P = 0.01$, and 0.03 respectively; Table 3); however, there were no linear or quadratic effects of lys/NE ($P > 0.05$). The PUN concentration recorded for the control treatment was the greatest for all sampling days except for day 14. These differences may be the consequence of a greater protein concentration of the control diet compared to the low-CP AA-supplemented diets plus RAC treatments (20 vs. 16% CP). The later is supported by findings reported in the literature that showed increased PUN as dietary CP concentration increased. This increase in PUN in pigs receiving the control diet may be the consequence of an excess of AA supplied by the diet. The low-CP AA-supplemented and RAC dietary treatments, demonstrated decreased PUN which may be an indication that the concentration of AA supplied was closer to the adequate concentration of AA in the diet.

Conclusions

The outcome of this experiment indicates that the optimum lys/NE for late-finishing pigs from the UNL herd fed low-CP AA-supplemented diets

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Table 2. Response of ADG[a], ADFI[b], G:F[c] backfat and LMA[d] to treatment and significance of linear and quadratic responses to lys/NE.

	Treatment									
CP, %[e]	20	16	16	16	16	16				
Lys/NE, g/Mcalf[f]	5.24	3.35	3.95	4.57	5.2	5.83				
RAC, g/ton[g]	0	4.5	4.5	4.5	4.5	4.5				
								P-value		
Item							SEM[h]	Treatment	Linear	Quadratic
No. of pigs	4	4	4	4	4	4				
Initial wt, lb	183.01	185.22	185.33	184.56	184.72	183.29	4.39	0.99	0.75	0.89
Final weight, lb	247.95	258.26	256.61	260.47	257.71	251.87	5.23	0.62	0.51	0.47
Growth performance										
ADG, lb	2.32	2.61	2.54	2.71	2.61	2.44	0.15	0.51	0.59	0.41
ADFI, lb	5.82	6.43	6.01	6.74	6.05	5.78	0.33	0.33	0.22	0.36
G:F	0.40	0.40	0.42	0.40	0.43	0.42	0.01	0.55	0.36	0.95
Ultrasound measurements										
Backfat, in										
Initial	0.57	0.64	0.55	0.54	0.51	0.52	0.07	0.79	0.21	0.49
Final	0.79	0.89	0.75	0.72	0.65	0.67	0.06	0.09	0.01	0.25
Change	0.23	0.26	0.20	0.18	0.14	0.15	0.06	0.70	0.14	0.69
LMA, in^2										
Initial	4.89	5.37	5.31	5.17	5.84	5.38	0.23	0.19	0.48	0.97
Final	6.81	7.44	7.33	7.41	7.85	7.63	0.44	0.69	0.53	0.92
Change	1.91	2.06	2.01	2.23	2.01	2.24	0.43	0.99	0.79	0.93

[a]ADG = Average daily gain.
[b]ADFI = Average daily feed intake.
[c]G:F = Average daily gain/average daily feed intake.
[d]LMA = Longissimus muscle area.
[e]CP = Crude protein.
[f]Lys:NE = Lysine:Net energy ratio g/Mcal NE.
[g]RAC = Ractopamine.
[h]SEM = Standard error of the mean.

Table 3. Response of PUN[a] to treatment and significance of linear and quadratic responses to lys/NE[b].

	Treatment									
CP, %[c]	20	16	16	16	16	16				
Lys:NE, g/Mcal[b]	5.24	3.35	3.95	4.57	5.2	5.83				
RAC, g/ton[d]	0	4.5	4.5	4.5	4.5	4.5				
								P-value		
Day				PUN[a], mg/100 mL			SEM[e]	Treatment	Linear	Quadratic
0	8.94	12.76	10.38	11.72	11.70	10.23	1.19	0.30	0.33	0.91
7	16.34	13.95	11.78	13.90	10.89	12.35	1.29	0.09	0.33	0.66
14	13.55	13.71	11.19	12.97	10.00	12.17	1.72	0.62	0.44	0.48
21	19.07	13.90	11.77	15.13	12.85	12.80	1.24	0.01	0.77	0.75
28	19.70	13.88	12.06	16.79	12.58	13.74	1.64	0.03	0.96	0.63

[a]PUN = Plasma urea nitrogen.
[b]Lys:NE = Lysine:Net energy.
[c]CP = Crude protein.
[d]RAC = Ractopamine.
[e]SEM = Standard error of the mean.

added with 4.5 g RAC is between 4.57 and 5.2 g of lys/Mcal of NE. Increments above 5.8 g lys/ Mcal of NE may negatively affect growth performance.

Barrows from the UNL herd showed a reduction in BF in response to increasing lys/NE fed low-CP AA-supplemented diets and with 4.5 g of RAC/ton.

The results of this experiment also suggest that pigs receiving RAC and low-CP AA-supplemented diets received more adequate AA concentration compared to the standard diet.

[1]Roman Moreno is a graduate student and research technologist; Phillip S. Miller is a professor and Thomas E. Burkey is an assistant professor in the Animal Science Department.

Does Dam Parity Affect Progeny Health Status?

Preliminary data indicate that progeny health status may improve with increasing parity.

Thomas E. Burkey
Phillip S. Miller
Rodger K. Johnson
Duane E. Reese
Roman Moreno[1]

Summary

A preliminary experiment was conducted to investigate the health status of progeny derived from different parities; health status was characterized by evaluating the ability of P1 and P3 dams to produce and passively transfer immunoglobulins (IgA and IgG) to their progeny. At parturition, circulating concentrations of IgA and IgG were greater ($P < 0.01$) in P3 dams compared to P1 dams. As expected, during lactation, concentrations of IgA and IgG were greater ($P < 0.002$) in colostrum compared to milk (mid- and late-lactation). No parity differences were observed in immunoglobulin concentrations in colostrum or milk obtained from P1 and P3 dams. However, when immunoglobulins were quantified in the progeny of P1 and P3 dams a parity × time interaction was observed for circulating IgG ($P < 0.03$) and a trend for a parity × time interaction was observed for IgA ($P = 0.06$). Within a time point (d), serum IgG was greater ($P < 0.001$) in P3 progeny compared to P1 progeny for each time point measured. These results suggest that health status, as indicated by circulating immunoglobulin concentration, in neonatal pigs, may be affected by dam parity.

Introduction

Modern production systems have driven the need for novel techniques designed to optimize reproductive and growth performance. Segregated, all-in all-out and multisite production systems have been implemented in order to maximize the benefit of passive immunity to: decrease disease agent transmission, allow for specialized labor in each phase of production, simplify the logistics of production, maximize reproductive performance and, ultimately, optimize pig (pork) production. Anecdotal data (summarized in Table 1) suggest that P1 progeny experience reduced weaning weights, decreased nursery and finishing average daily gain (ADG) and greater mortality in the nursery and in finishing. It is generally accepted that differences observed among parities are a direct result of P1 progeny having a reduced health status compared with progeny from mature sows. Health status and differences in health status among parity are affected by complex biological factors. For example, health status may be affected by, but not limited to, exposure and susceptibility to pathogens, animal stress, and passive transfer of immunity from the dam to the neonate. However, the idea that differences exist in health status among progeny from different dam parities is not fully elucidated. Peer-reviewed, hypothesis-driven research has not been conducted to support or refute this idea. Therefore, the objective of this experiment was to begin to provide baseline information that will contribute to a greater understanding of parity health differences by evaluating the production and passive transfer of immunoglobulins (IgA and IgG) from dams of increasing parity to their progeny.

Materials and Methods

Experimental design

The experimental protocol was reviewed and approved by the Institutional Animal Care and Use Committee of the University of Nebraska–Lincoln (UNL). Dams (Large White × Landrace) included in this study were part of an ongoing sow longevity experiment currently being conducted at the UNL Swine Unit. Sows (Parity 3, P3; n = 5) included in this experiment farrowed on Sept. 26, 2006, and gilts (Parity 1, P1; n = 4) selected for inclusion in this experiment farrowed on Oct. 30, 2006. Following parturition, four to five piglets from each dam (n = 20 total progeny from each parity, P3 and P1) were randomly selected for inclusion in the analyses described below.

Laboratory analyses

To begin to ascertain the health status of progeny derived from different parities, three parameters were evaluated: 1) Circulating concentrations of IgA and IgG in P1 and P3 dams; 2) Concentrations of IgA and IgG during lactation in colostrum and mid- and late-lactation milk; and 3) Circulating concentrations of IgA and IgG in P1 and P3 progeny. Whole blood was collected via jugular venipuncture from each dam 24 hours pre-farrowing and from dam progeny at 0, 8, 15, 20 (weaning), 29, and 37 days post-farrowing. Serum was harvested by centrifugation (20 min at 1,500 × *g*), diluted (1:100,000) and used to quantify concentrations of IgA and IgG via swine-specific enzyme-linked immunosorbent assays (ELISA; Bethyl Labs Inc., Montogomery Tex.). Colostrum (obtained within 12 hours of parturition), mid-lactation (7 days post-farrowing), and late-lactation (20 days post-farrowing) milk was expressed from each functional teat in sterile flasks and frozen (-20°C) for subsequent analyses. For mid- and late-lactation milk collection, oxytocin

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(40 USP i.m.) was administered to facilitate milk collection. Colostrum and milk samples were diluted (1:50,000) and quantified by ELISA as described above. Results reported for each ELISA included values adjusted according to the dilution factors used for each respective sample.

Statistical analyses

The MIXED procedure of SAS was used to analyze the progeny serum and lactation data as completely random designs with repeated measures over time on each experimental unit. The model included terms for the fixed effects of parity and time and their interaction. Comparisons between parity and time were made only when a significant ($P < 0.05$ unless noted otherwise) F-test for the main effect or interaction was detected using the least significant difference procedure. All means presented are least squares means.

Results and Discussion

The concentration of IgA and IgG in serum obtained from P1 and P3 females 24 hours prior to parturition are depicted in Figure 1. The values obtained for both IgA and IgG are within normal ranges (0.5 to 5.0 and 17.0 to 29.0 mg/mL for IgA and IgG, respectively). However, P3 females had greater concentrations of both IgA and IgG compared to P1 females ($P < 0.01$ and $P < 0.004$, respectively for IgA and IgG). One explanation for this phenomena may be that P1 gilts have greater levels of stress near the time of parturition. It has been documented that gilts have a greater stress load (evidenced by increased concentrations of cortisol) during parturition and it is known that cortisol is immunosuppressive and may act to dampen the immune response (and possibly decrease the production of immunoglobulins during and shortly after parturition).

Even though clear differences exist in circulating concentrations of immunoglobulins between P1 and P3 females at the time of parturition, this trend did not continue when IgA and IgG concentrations were evaluated in colostrum and milk samples obtained from the same females (Figure 2). All immunoglobulin concentrations for colostrum (9.5 to 10.0 and 30.0 to 70.0 mg/mL for IgA and IgG, respectively) and milk (3.0 to 7.0 and 1.0 to 3.0 mg/mL for IgA and IgG, respectively) were within normal ranges. As expected, IgA and IgG concentrations observed in colostrum samples obtained within 12 hours of parturition were greater ($P < 0.0002$) than IgA and IgG concentrations observed in milk samples

Table 1. Comparison of Parity 1 (P1) and Parity 2 (P2) progeny in commercial nursery and finishing barns.

	System 1[a]		System 2[b]	
Parameter	P1 Progeny	P2 Progeny	P1 Progeny	P2 Progeny
Nursery				
Weaning wt, lb	12.1	13.0	11.7	12.6
ADG, lb	0.92	0.95	0.91	0.96
Mortality, %	3.2	2.6	3.2	2.6
Finishing				
ADG, lb	1.99	2.01	1.62	1.69
Mortality, %	4.8	4.8	4.3	3.0

[a]Averages calculated from 242,406 and 677,661 P1 and P2 progeny, respectively.
[b]Total number of progeny were not included.

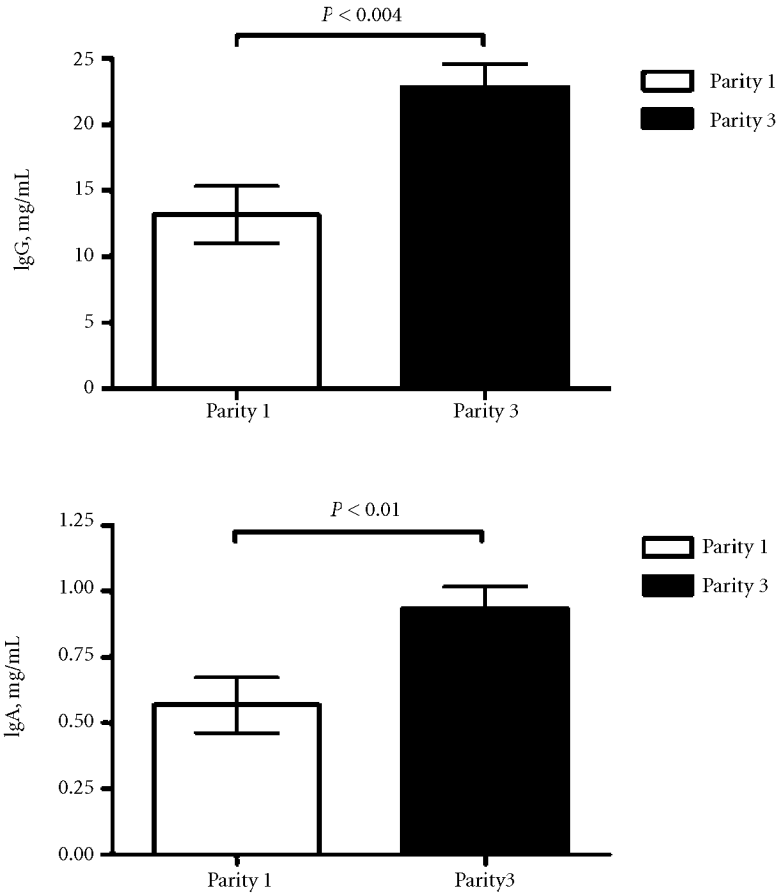

Figure 1. Circulating concentrations of IgG (top panel) and IgA (bottom panel) in gilts (Parity1) and sows (Parity 3). Immunoglobulin concentrations were evaluated in serum obtained within 24 hours pre-farrowing. Each bar represents the least squares mean (± SEM) of 5 observations.

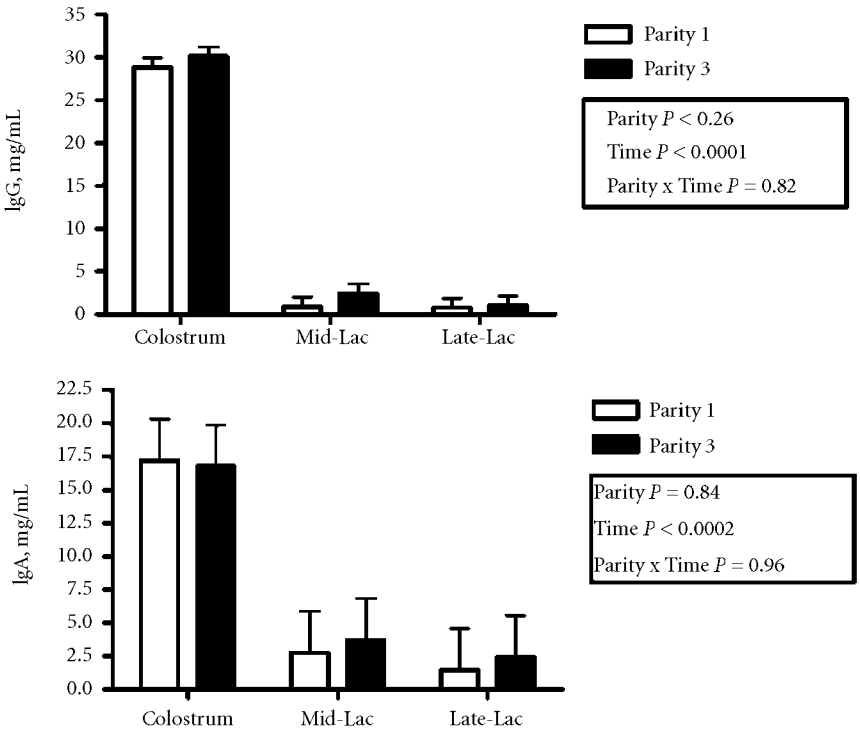

Figure 2. The concentration of IgG (top panel) and IgA (bottom panel) in colostrum and milk (mid- and late-lactation) obtained from gilts (Parity1) and sows (Parity 3) following parturition. Each bar represents the least squares mean (± SEM) of 5 observations.

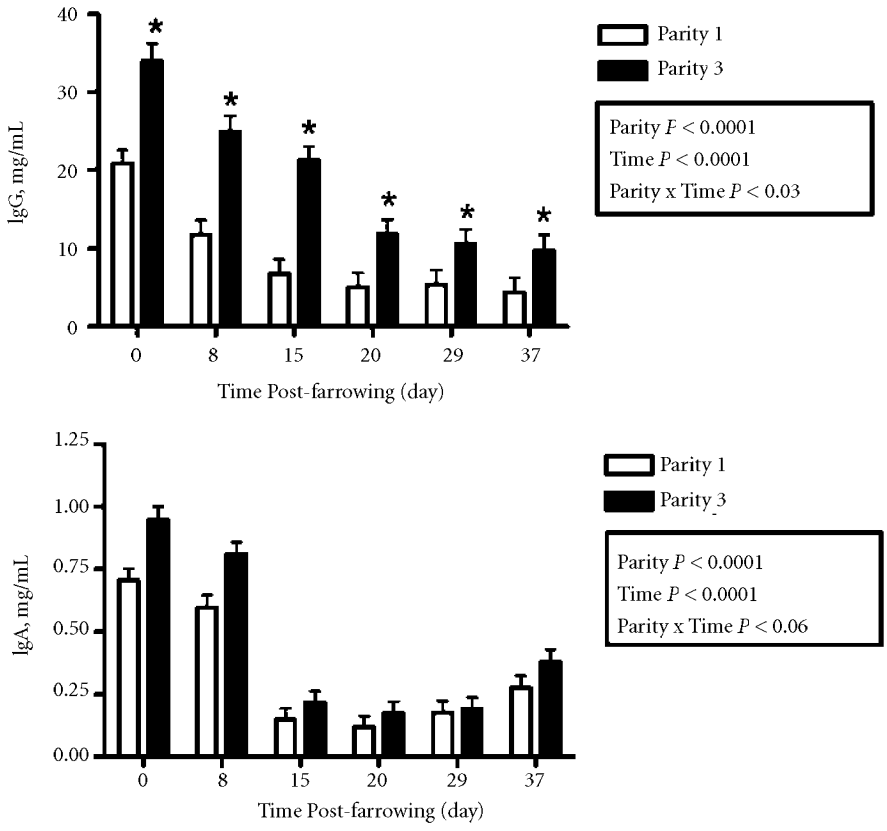

Figure 3. Circulating concentrations of IgG (top panel) and IgA (bottom panel) in serum obtained from the progeny of gilts (Parity1) and sows (Parity 3). Immunoglobulin concentrations were evaluated in serum obtained at 0, 8, 15, 20, 29 and 37 days post-farrowing. Each bar represents the least squares mean (± SEM) of 20 observations. Within a timepoint, (*) denote differences between parities ($P < 0.05$).

obtained at mid- or late-lactation. Although differences exist in immunoglobulin concentrations in the serum of these same females, it was somewhat surprising that no differences in colostrum or milk immunoglobulin concentrations were observed during lactation.

Figure 3 depicts circulating IgA and IgG concentrations in P1 and P3 progeny at several timepoints following parturition. A parity × time interaction was observed for IgG ($P < 0.03$) and there was a trend for a parity × time interaction for IgA ($P = 0.06$). The progeny of P3 females had greater ($P < 0.05$) concentrations of IgG compared to the progeny of P1 females at every timepoint evaluated and, although not statistically significant, a similar numerical trend was observed for IgA. Progeny immunoglobulin concentrations from birth to about 2 weeks of age are almost solely attributed to passive transfer from the dam.

In the current experiment, immunoglobulin concentrations were evaluated to begin to assess the effects of dam parity on progeny health status. The passive transfer of immunity via immunoglobulins is of utmost importance in young pigs because there is no transplacental transfer of immunoglobulins in utero. Therefore, neonatal pigs rely on passive transfer of immunoglobulins via colostrums and milk until they can synthesize their own immunoglobulins beginning from 2 to 5 weeks of age. Clearly, it would be advantageous for P3 progeny to have greater concentrations of circulating immunoglobulins (as observed in the current study, Figure 3) compared to lower concentrations observed in P1 progeny. This advantage may improve the overall health status of the animal by increasing immune protection against environmental antigens.

The health status of an organism is related to complex physiological, biological and environmental interactions. According to our observations, the parity differences in circulating immunoglobulins between P1 and P3 progeny may not be attributed to

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a similar trend in immunoglobulin concentrations in colostrum/milk via passive transfer. It is unclear why P3 progeny have greater concentrations of circulating immunoglobulins. One explanation is that P3 sows may simply provide a greater volume of colostrum/milk to their offspring carrying a greater volume of immunoglobulins. Another explanation is that P3 progeny may have greater expression of immunoglobulin receptors on intestinal epithelial cells allowing greater immunoglobulin absorption.

Conclusions

This preliminary experiment suggests that dam parity may influence progeny health status. Additional research in this area will help elucidate the effects of dam parity on progeny health status and may also provide insight towards developing new strategies to improve production efficiency.

[1]Thomas E. Burkey is an assistant professor, Phillip S. Miller and Rodger K. Johnson are professors, Duane Reese is an extension swine specialist, and Roman Moreno is a graduate student and research technologist in the Animal Science Department. The authors would also like to thank Matthew W. Anderson, Daryl J. Barnhill, Kelsey A. Rhynalds and Brenda B. Williams. References available upon request from tburkey2@unl.edu

Key Points From the 48th Annual George A. Young Swine Health and Management Conference, August 16, 2007

Bruce W. Brodersen[1]

Summary

The conference focused on biosecurity with particular attention to porcine reproductive and respiratory syndrome virus (PRRSV) and porcine circovirus type 2 (PCV2). Speakers included faculty from the University of Minnesota, Iowa State University, and Kansas State University and veterinary practitioners from Iowa and Minnesota. Many of the topics focused on details relating to on-farm and off-farm biosecurity measures. Economic impacts of PRRSV and PCV2 infections were discussed in terms of specific case reports.

Dr. Tom Gillespe — PCVAD: When immunology goes wrong, life on the farm becomes very expensive

Dr. Gillespie spoke about porcine circovirus associated disease (PCVAD). Porcine circovirus type 2 (PCV2) is necessary for PCVAD but is not the only risk factor. Clinical expression in a herd often lasts up to two years. Circovirus may have been around since 1991 and there is serologic evidence that suggests PCV2 has existed since 1969. Clinically, disease due to PCV2 was first recognized in Canada. What has allowed this virus to be a major pathogen in such a short time is not really known. Porcine reproductive and respiratory syndrome (PRRS) virus exacerbates PCV2 infection. Some serotypes appear to be more virulent than others.

Clinically, there is respiratory disease without much coughing and porcine dermatitis nephropathy syndrome. Occasional diarrhea, mummies with myocarditis, and doubled mortality rate are all part of case definition. Vaccination appears to reduce reproductive losses.

Costs of PCV2 infection

In one case, mortality increased three standard deviations above normal (from 1.6 to 4.85%) in 11 – 16 week-old pigs infected with PCV2. Pigs exhibited classic lesions and clinical signs of PCVAD and increased culling rate. Feed efficiency and average daily gain decreased. Total cost per pig was about $6.60 plus lost opportunity costs and increased fixed costs.

Transmission

PCVAD is transmitted from fecal to oral even in non-clinical pigs. There can be more than one strain present at the same time. Maternal antibody provides variable protection. Pigs can be congenitally infected. Semen transmission does not appear to be a high risk.

Vaccination

If there is a vaccine, what is the value? Anecdotally, vaccinated finisher pigs are heavier pigs and "look" better. Mortality dropped from 8.78 to 2.4%, average daily gain, feed efficiency and carcass leanness improved in one trial. Vaccinated groups perform more uniformly in terms of growth performance and carcass merit. The role of sow vaccination is uncertain.

Dr. Derald Holtkamp — The PRRS Risk Assessment Tool for the Breeding Herd: Practical Applications and Lessons Learned

In 2002, development began on a tool for the sow herd by Boehringer Ingelheim™ who then offered it to American Association of Swine Veterinarians (AASV) in 2005. Later AASV and Iowa State University agreed to establish a disease risk assessment tool and databases of completed PRRS risk assessments held by AASV.

A database was built and associations to production situations were made. Hazards defined by the tool included: Distance to other farms, aerosolized virus, and passing trucks possibly leading to an adverse outcome.

Consequences of PRRS infec-

tion included costs in gilt supply and genetics; cost of the PRRSV elimination project; diagnostic testing, early culling, lost breeding herd productivity, wean to finish productivity loss; transportation and logistical costs; increased medication; and vaccination.

The value of risk assessment was increased communication between veterinarians and producers and their personnel. The tool provides a framework for critical review including an analysis of gaps in biosecurity, risk comparison among farms, and demonstrated improvement in biosecurity and in decision making.

How the tool has been used

Ninety-five veterinarians have been trained to use the tool. Over 700 assessments are in the database. A Web version is being developed. Among available reports, there are site reports, benchmarking reports, and risk factors organized for internal risk and external risk.

Studies conducted

Four studies have been conducted. They include 1) quantifying risk factors relative to PRRS-negative status, 2) an industry education program for understanding risk factors to breaks in herds naïve to PRRSV, 3) a cross-sectional study of positive herds to evaluate the association between risk factors and a case definition, and 4) developing PRRS control strategies.

Future plans

Plans are to improve the tool for use in the breeding herd and expand it to grow finish pigs and other diseases.

Dr. Robert Morrison — Regional Eradication of PRRS: A Pilot Project

The objective was to determine the prevalence of PRRS, assess distribution of the virus and determine if veterinarians and producers would test their herds. The project was conducted in the east half of Rice County and Stevens County in Minnesota. In Rice County, all expenses were paid, while in Stevens County producers funded the program.

In Rice County, 90% of the herds were tested at least once. There has been limited spread of the virus since. In Stevens County, numerous swine herds have left the industry; several herds have eliminated PRRS since 2004.

Challenges

Challenges to the eradication project included: 1) identifying local opinion leaders to determine if they support the program, 2) some producers respect the opinion of leaders, 3) overcoming suspicion, 4) determining if 90% participation is sufficient, 5) getting participants to attend quarterly meetings, 6) unwillingness of some producers to invest to eliminate PRRS, 7) positive or variable PRRS status in a region initially, and 8) show pigs bringing virus back to farm.

Outcome of this project

From this project, it was learned that three important factors need to be considered before starting an elimination project : 1) Choose a region where there is limited pig movement into a region, 2) Begin with the end in mind and 3) Set some goals regarding: PRRS control, stability of infection in sow herds, and if a long term goal is to be PRRS-free.

The rewards of this project included breaking down barriers in communication among producers. The producers shared data and were collectively smarter. There was movement toward PRRS-free status. Thirteen of 15 farms produced more pigs per year after PRRS was eradicated. There was decreased cost of production with reduced antibiotic usage, improved pig welfare, and increased worker morale.

For future PRRS elimination projects, the question remains who should pay for testing, sequencing virus, correspondence, and any other expenses that are incurred.

Summary

1) Adequate knowledge exists to eliminate PRRS, 2) selection of correct geographic area is critical, 3) the region must have a low risk of re-infection, 4) more success stories with low eradication expenses are needed, and 5) meetings and education are important.

Dr. Andy Holtcamp — Filtration for Disease Prevention

There are numerous reports of indirect transmission of diseases in the literature, suggesting aerosol transmission. Some of these organisms are *Actinobacillus pleuropneumoniae, Mycoplasma hyopneumoniae,* pseudorabies virus, swine influenza virus (SIV), PRRS virus, and foot and mouth disease virus.

Due to the history of three prior PRRS breaks in four years at a boar stud, a decision was made to install a positive pressure ventilation system in the stud. The events that lead to each break could usually be tracked. Along with installation of a positive pressure ventilation system, general biosecurity measures needed to be enforced. These included perimeter fences, limited entries, no pigs within 5 miles, personnel wear removable boots from the car to the office, supplies disinfected, removed from box and 48-hour down time, 72-hour down time for personnel, and eight week isolation period on boars.

When selecting an engineer, it was discovered some engineering firms are just trying to keep their construction crews busy and university personnel are often too busy to commit to a project. It is important to find a firm who has your interest in mind.

There are three stages to a high efficiency particulate air (HEPA) system: prefilter, intermediate filter, and the actual HEPA filter. HEPA filters remove 99.97% of particles 0.3 microns in diameter. It was determined it would be too costly to cool the building by conventional air conditioning. Prefilters need to be changed yearly in order to protect the HEPA filters. Intermediate filters are connected directly to HEPA filters. To date, the HEPA filters still look brand new after three years. Fans need to be designed to ensure there are no back drafts due to high winds. When loading pigs out of the

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building, outlets need to be closed so all exhaust air exits via the chute.

It cost $52,000 to convert a barn to this system. There needed to be four times the number of inlets over what had been in the previous ventilation system. There exist filters which are 95% as effective as HEPA filters and cost half of HEPA filters. Some operations may want to consider this, but it was decided not to use the less effective filters. Another consideration is operation (electricity) costs, which were estimated to be about three times that of no filtration.

Previously, there had been three different strains of PRRS enter the boar stud in four years. After filters installed, there have been no breaks in PRRS but two breaks of SIV.

Summary

We still need to still pay attention to biosecurity. The cost of depopulation of a boar stud was estimated to be $320,000, so utilization of the HEPA system was cheap compared to depopulation of a boar stud after a PRRS outbreak.

Dr. Dick Hesse — Research Considerations for Biosecurity

Discussion centered on containment of porcine circovirus during an experimental infection in order to prevent noninfected control pigs from becoming infected. A demonstration on fomites as a means of transmission of infectious agents was given using the Glo-germ™ system.

Porcine circovirus is very stable and can withstand heating at 133°F for an hour. Therefore, it is very difficult to contain in an experimental situation where there are infected and non-infected pigs in close proximity. In order to completely contain the virus, complete shower in and out practices between all rooms were utilized. Hoses with foamers containing Virkon™ disinfectant were placed in hallways. Rooms were arranged so negative animals were farthest away from the positive animals. When leaving the hallway, disinfectant was sprayed to cover the workers' trail. Footbaths were always kept filled with fresh disinfectant (5% solution Clorox™). It was discovered that it was necessary to maintain door seals so there was no spray under the door during room cleaning. Pens were arranged inside the rooms so they can be washed with spray directed away from the door. There needs to be sinks in all rooms to clean and disinfect equipment. When leaving a room, equipment is double-bagged and disinfected.

Decontamination of a room between experiments includes using a Hotsy™ with a detergent to remove any organic matter. This is followed by disinfection with Clorox and then Virkon™. Let the room dry and then rinse before animals are placed in a room.

Demonstration of spread of infectious agents utilizing Glo-Germ™

A demonstration focused on the spreading of the virus. Means of spread included aerosol, tracking, splashing, and a simple handshake. During registration, a pen was "contaminated" to show how fomites would be a source of infection. Other demonstrations included spread by needles and hog snares. Simple rinsing of needles, syringes, and snares was shown to be ineffective. Splatter from spraying floors was shown as a means of virus spread. Towels and other cleaning material can also serve as a source of infection. Door knobs, handshake, and foot traffic were also shown to be a means of spreading virus. One may use Rit™ dye instead of Glo-Germ™; however, Rit™ dye doesn't go into solution as well.

Dr. Joel Nerem — Practical Approaches to Biosecurity from a Practitioner's Perspective

Why biosecurity?

PRRS cost to the swine industry has been estimated to be $560,000,000 per year. It is estimated to cost $300-500K to eradicate PRRS from a 3,000-sow unit. Benefits of biosecurity also include improved animal welfare, public perception, and worker morale. Every farm is at risk. Biosecurity can be divided into two areas of interest: off-farm biosecurity and on-farm biosecurity.

Off-farm practices of biosecurity

Practices that can aid off-farm biosecurity include: 1) strict monitoring of incoming gilts and semen, 2) thoroughly washing and disinfecting trailers, 3) having trailers dedicated for each sow farm, 4) strict adherence to protocol, 5) controling farm access using a "Biosecurity Update" (A Biosecurity Update categorizes each farm's health status so people know the order of farms to visit.) and 6) mortality disposal may consist of composting, incineration, or rendering. If using a rendering pick-up, there needs to be an on-farm side and an off-farm side so there is no crossover of traffic between off- and on-farm personnel or vehicles.

On farm practices of biosecurity

Clean side — dirty side concept — how do you get things from the dirty to clean side? Initially, the clean and dirty transition points need to be defined. It is important to document what needs to be done to prevent disease transfer, and to train the staff accordingly.

There are four transition points where there is entry into facilities. A sign-in sheet is used to document who, what, and when regarding entries.

1. Personnel — supply showers and locked doors (key pads).
2. Materials and equipment — when bringing materials and equipment on site, identify a period of time for decontamination and for down time.
3. Incoming genetic material — test semen on every collection day (random semen samples) and hold it until negative results are obtained.
4. Replacement gilts — quarantine and test (bleed on arrival and three to four weeks later).

Other points to consider: Wash and disinfect live haul transport chutes; use barn lime in winter since it is not practical to wash and disinfect in extremely cold weather; haul dead stock and garbage out at end of day when personnel go home. Concerning

manure removal, follow biosecurity guidelines, including cleaning equipment before arrival on farm. Regarding pest control, prevent spilled feed, keep weeds mowed, utilize rodent bait boxes (rotate rodenticides), and eliminate trash.

Successful biosecurity is based on communication, commitment, consistency, and accountability. A biosecurity checklist audit can be used to help ensure biosecurity.

To move forward, utilization of new technology such as vaccine, air-filtration, industry investment, and communication to share ideas needs to occur. For continued success, there needs to be producer leadership.

Speaker Information

Dr. Thomas G. Gillespie
Rensselaer Swine Services, P.C.
Rensselaer, Ind.

Dr. Derald Holtkamp
Iowa State University
College of Veterinary Medicine
Ames, Iowa

Dr. Robert Morrison
University of Minnesota
College of Veterinary Medicine
St. Paul, Minn.

Dr. Andy Holtcamp
Iowa Select Farms, LP
Iowa Falls, Iowa

Dr. Richard A. Hesse
Kansas State University
College of Veterinary Medicine
Diagnostic Medicine/Pathobiology
Manhattan, Kan.

Dr. Joel Nerem
Pipestone Veterinary Clinic/Pipestone Systems
Pipestone, Minn.

[1]Bruce W. Brodersen is a research associate professor in the Department of Veterinary and Biomedical Sciences.

Validating the Odor Footprint Tool Using Field Data

This study supports using the Odor Footprint Tool as a planning and screening tool for assessing odor impact from livestock facilities and estimating minimum separation distances to meet annoyance-free targets.

Richard R. Stowell
Kara R. Niemeir
Dennis D. Schulte[1]

Summary

Trained participants monitored odors around a 4,800-head finishing site in eastern Nebraska during 2005 and 2006. "Mobile odor assessors" monitored odors within the downwind odor plume and reported that odors at off-site locations (at least 200 feet away) were consequentially annoying in 20 out of 192 assessments. On-site odor levels were considered annoying in 33 of 39 instances. For the same off-site locations and times, modeling predicted 18 annoying events, resulting in a 90% prediction rate (18 vs. 20) of annoyance frequency. Five residents regularly monitored for odors outside their residences and made 1,007 assessments. On 42 occasions, or 4.2% of the total, residents reported that annoying odor levels were present, equating to a 95.8% odor annoyance-free status. Predicted odor annoyance-free frequencies using the Odor Footprint Tool ranged from 90 to 99% for the five residences, given the locations of the residences and the livestock production facilities in the area.

Background

Rural residents are concerned about the potential impacts of nearby animal feeding operations on the local environment, having fears that air quality will be degraded and that they will have to frequently endure annoying odors. The Odor Footprint Tool is a science-based setback-estimation tool that has been developed at the University of Nebraska. It uses historical weather information and research on odor emissions and dispersion to determine minimum separation distances in differing directions from a site. The Odor Footprint Tool can help people visualize the projected impact of odors on the area surrounding a livestock facility and the reduction in odor impact achievable by implementing a proven odor control technology.

The primary objective of this project was to evaluate the Odor Footprint Tool's performance within a rural setting. Ground-truthing the tool with a pork production operation, neighboring residents, and impartial outside participants in an odor-monitoring study should encourage acceptance and subsequent adoption of the tool.

Methodology

For the odor-monitoring study, 16 people were trained to assess odors using state-of-the-art field methods. Participants were trained to assess odor intensity, concentration, offensiveness, and character. Participants also provided a rating of the odor's "annoyance potential" by specifying whether the odor was "not annoying" or either "slightly," "moderately," "highly" or "extremely annoying." This subjective rating was to encompass how the state of odor would affect their behavior (i.e. any change in activity) and how long the event would be remembered (e.g. hours vs. months). This information was collected to help qualify prediction of odor annoyance and to obtain a more direct linkage between odor levels and likely

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consequences of odor events. Moderately, highly, and extremely annoying states of odor were collectively referred to as "consequentially annoying," since a behavioral response was involved.

Participants monitored odors around a 4,800-head finishing site in eastern Nebraska during 2005 and 2006. For six consecutive Tuesday evenings during the summer of 2005, five to seven participants from Lincoln traveled to the area to monitor odor levels at locations downwind of the selected site, both before and after dark. During late spring and summer of 2006, two participants from another rural community in the local county monitored odor levels at downwind locations two to five times a week. Both of these groups were referred to as "mobile odor assessors." During that same time period, seven people who owned residences within 1.5 miles of the selected site also monitored odors. Five of these individuals monitored for odors three times a day — once each during daylight, twilight and nighttime conditions – just outside their residence.

Dispersion modeling was then performed for the times and locations corresponding to the field odor assessments to compare model predictions with field observations. Additional sources of livestock odor were limited mainly to two other swine facilities that were at least ¾ of a mile away. Odor sources were determined based upon wind direction, assuming no background odor.

Results and Discussion

Based upon data reported by the mobile odor assessors, the state of odor at off-site locations (at least 200 feet away) was reported to be consequentially annoying in 20 out of 192 in-plume assessments. On-site odor levels (within 100 feet of the facility) were quite likely to be considered annoying (33 of 39 instances). When on-site data was included, the rate rose to 53 consequentially annoying ratings out of 231 total in-plume assessments. Modeling of each these assessment periods predicted 18 annoying odor events at the corresponding off-site locations. The 90% prediction rate (18 predicted vs. 20 reported) for annoyance frequency was considered very promising given the nature of what is involved (odor, weather phenomena, and human assessments). Some steps for fine tuning the predictive capabilities are being investigated to address the slight under-prediction of annoying odor levels and to minimize error rates.

Five residents regularly monitored for odors outside their residences and made a total of 1,007 assessments. This large number of observations covering a broad spectrum of weather conditions was desired to test the general accuracy of the Odor Footprint Tool's prediction of "odor annoyance-free frequency." "Swine-related odor" was detected during 92 of the observations or 9.1% of the total, with a range of 0-14.0% among residents. On 42 of these odor events, or 4.2% of the total assessments, residents indicated that the states of odor were annoying. Since annoyance typically was not qualified as to whether it was "consequential" or not, the annoyance potential numbers for the residents indicate any degree of perceived annoyance. An annoyance frequency of 4.2% equates to a 95.8% odor annoyance-free status overall. Given the locations of the residences with respect to the three swine production facilities in the area, predicted individual odor annoyance-free frequencies using the Odor Footprint Tool ranged from 90 to 99%. Annoyance frequencies for individual residents ranged from 0 to 11.4% and showed considerable variation due to individual biases (some residents were for and some against having the swine facilities in the area), senses of smell, data collection times, etc. On the whole, though, the composite annoyance-free frequency based upon information supplied by area residents was comfortably within the predicted range.

Evening measurement times were selected for the mobile odor assessors to increase likelihood of having stable atmospheric conditions. When unstable conditions existed, it was much more challenging to locate the odor plume as odors were quickly dispersed and diluted at off-site locations to levels not normally considered to be consequential. During relatively calm or otherwise stable atmospheric conditions, though, exhausted odorous air stayed near the ground, and odor concentrations diminished much more slowly. Under these stable conditions, odor was detected a mile or more downwind. The residents, on the other hand, were asked to make numerous measurements at differing times of day to better represent prevailing atmospheric conditions and limit selective timing of measurements.

Summary and Conclusions

A field odor monitoring study was conducted to help validate use of the Odor Footprint Tool for assessing odor impact in rural communities and estimating minimum separation distances needed to maintain odor annoyance-free criteria. The study employed and trained local residents as well as mobile odor assessors from outside the area to document odor conditions in the vicinity of a 4,800-head swine finishing facility. The two main results of this study were that:

1) The dispersion model's prediction rate for the frequency of consequential annoyance was 90% when compared to observations made by trained mobile odor assessors at off-site locations; and
2) The overall frequency of annoying states of odor, as documented by area residents, was 4.2%, which corresponded well with the predicted range (90 to 99% odor annoyance-free) for the residences using the Odor Footprint Tool.

Predicted frequencies of odor annoyance compared favorably with actual observations, so the conclusion was made that there is good support for using the Odor Footprint Tool as a planning and screening tool, especially with animal housing facilities.

Implications

The data from this field study confirm our understanding that, most of the time, odors are quickly dispersed and diluted to off-site levels that would not normally be considered consequential. Producers need to recognize, though, that when stable atmospheric conditions keep odorous air near the ground, odor concentrations diminish much more slowly, and the potential for negative, consequential odor effects extends greater distances downwind. The composite annoyance-free frequency based upon information supplied by area residents was comfortably within the predicted range using the Odor Footprint Tool. The predicted frequency of consequential odor events also matched up reasonably well with information provided by trained mobile odor assessors. The information from this study supports using the Odor Footprint Tool as a planning and screening tool for assessing odor impact from livestock facilities and estimating minimum separation distances to meet annoyance-free targets.

[1]Richard R. Stowell is an extension specialist in animal environment; Kara R. Niemeir is graduate research assistant and Dennis D. Schulte is a professor in the Department of Biological Systems Engineernig.

Acknowledgements

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Association of Odor Measures with Annoyance: Results of an Odor-Monitoring Field Study

Linkages between odor measurements and consequential odor annoyance were found, which raises the prospects that objective measures may be used to predict when odors will be construed as being annoying.

Richard R. Stowell
Christopher G. Henry
Richard K. Koelsch
Dennis D. Schulte[1]

Summary

Multiple assessments of ambient odor were made by trained individuals around a swine finishing operation in eastern Nebraska. Assessor responses were analyzed to determine relationships between field odor measurements/ratings and ratings of annoyance potential, and to identify candidate measurement threshold values for causing annoyance. The likelihood of annoyance increased as odors became more offensive, intense, and concentrated, with r^2 values of 0.89, 0.81, and 0.64, respectively. Candidate thresholds were sought to delineate both "any degree of stated annoyance" and "consequential annoyance," defined as likely causing a change in behavior or activity level and instilling some memory of the odor event. Candidate thresholds for any stated annoyance and consequential annoyance, respectively, were: 1 and 2 for intensity (on a 0-5 scale); 2 and 7 dilutions to threshold for odor concentration (as measured using a mask scentometer); and -1 and -2 for Hedonic tone (on a +4 to -4 scale).

Background

Odor concerns are a primary barrier at the local level to the growth of livestock operations. Dispersion modeling may help producers evaluate the expected extent of odor impact from their operations on neighbors, and control strategies are being developed to mitigate odor emissions. Credible field odor measurement techniques are needed, though, to help demonstrate the benefits that improved site selection and odor control may offer to rural residents.

While progress is being made in measuring ambient odors using electronic devices, using humans to make field measurements of ambient odor remains the most widely accepted approach. People with a normal range/sense of smell can be trained to provide fairly consistent, calibrated responses for odor intensity and odor concentration. People can also provide subjective ratings of odor offensiveness (via Hedonic tone), odor character, and the potential for annoyance, the latter of which is necessary to evaluate cause-and-effect relationships.

More cause-and-effect information on measurable odor parameters and the potential for odor to be annoying is needed. Odor having an intensity of 2 or greater (on a 0-5 scale) has been assigned as a threshold for annoyance, but has not been verified with supporting data. Odor concentration is often used in odor regulation, with 7 dilutions to threshold (D/T) being a common regulatory threshold for states that consider ambient odor levels[2]. Odor offensiveness and annoyance are often used interchangeably, even though the meanings of each differ.

To help validate use of the Odor Footprint Tool as an odor impact/

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setback-estimation tool, the University of Nebraska–Lincoln conducted a field study of ambient odor levels in the vicinity of a livestock facility during 2005-06. The design of the field study was adapted from a study conducted to help validate use of the OFFSET setback-estimation tool developed by the University of Minnesota. As a secondary objective of this project, the field measurement data were analyzed to determine individual relationships of odor intensity, concentration, and hedonic tone with perceived annoyance potential. This report provides results of this analysis and discusses candidate thresholds for predicting annoyance.

Methodology

Study participants

Graduate students from the University of Nebraska were trained in field olfactometry methods and employed to make objective assessments of odor in the vicinity of a swine finishing operation in eastern Nebraska. The students had a mix of farm and nonfarm backgrounds. During July and August of 2005, they made weekly visits to measure and rate ambient odors downwind of the primary (4,800-head) facility and at three set locations around the facility. These "mobile odor assessors" traveled as a group under the guidance of a scout and a team leader. Assessments were made by five to seven people every Tuesday for six weeks, with one assessment period occurring during the early evening (before dusk) and another taking place later in the evening (after sunset).

Measured parameters and scales

Odor intensity: Odor intensity measures the strength of an odor. Field odor intensity was measured on a 0-to-5 scale. The method used was adapted by the University of Minnesota from an ASTM Standard.

Odor concentration: Odor concentration was measured using a special mask fitted to conduct field olfactometry (Figure 1). Readings were taken by turning a dial on the mask through a series of notches that corresponded to decreasing dilution ratios. With each turn of the dial, more ambient, potentially odorous air was allowed to be drawn into the mask. When the dilution setting first reached the point at which the person wearing the mask detected the odor, the mask setting was recorded. The mask settings corresponded to dilution ratios as follows:

A = 170 D/T (dilutions-to-threshold)	D = 7 D/T
B = 31 D/T	E = 2 D/T
C = 15 D/T	Non-detect ➔ 1 D/T

For reference, 170 dilutions-to-threshold is conceptually the same as an odor concentration of 170 odor units (OU).

Hedonic tone: Hedonic tone ratings were made to assess the degree of unpleasantness or pleasantness of odor using a -4 to +4 scale.

Odor character: Assessors filled in the blank to the phrase "This odor smells like _____."

Annoyance potential: Participants rated the degree of annoyance that they would likely experience if the given state of odor existed outside their respective residences. The rating scale was designed to incorporate two response parameters that appeared to be generally associated with nuisance events: the prospective nuisance i) affects behavior and ii) invokes remembrance of the event. Odor assessors used the following scale and symbols:

Rating:	*Symbol*	*Likely behavioral response, memory effect:*
Not annoying	O	No response or effect
Slightly annoying	S	Make no changes in activities or routine; short-term recall only
Moderately annoying	M	Alter routine/activities to reduce exposure; recollection fades
Highly annoying	H	Postpone activities or stop sooner than planned; lasting effect
Extremely annoying	X	Stop activities to find relief / leave area; engrained into memory

To help establish a common basis for making these ratings, participants were to picture themselves having

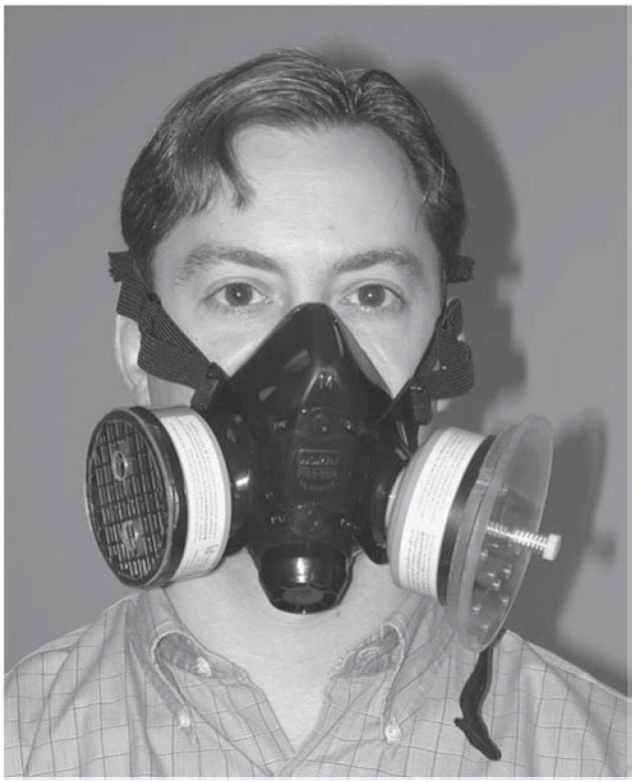

Figure 1. Mask scentometer for performing field olfactometry.

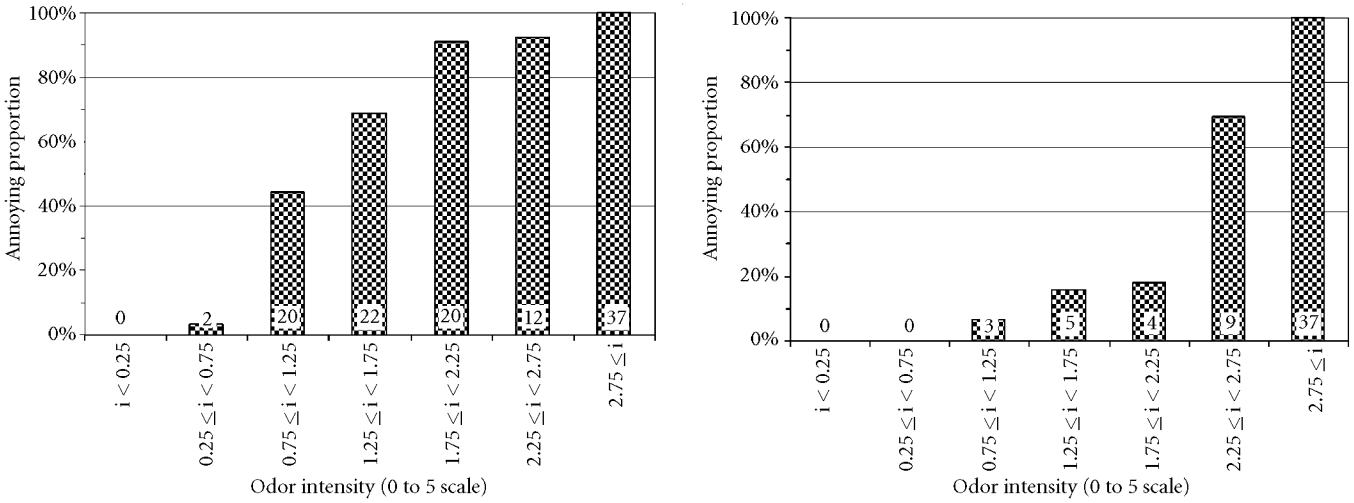

Figure 2. Likelihoods that odors assessed by mobile odor assessors were perceived as annoying (left) and consequentially annoying (right) based upon odor intensity. The number at the bottom of each bar is the number of responses indicating annoyance within the given range.

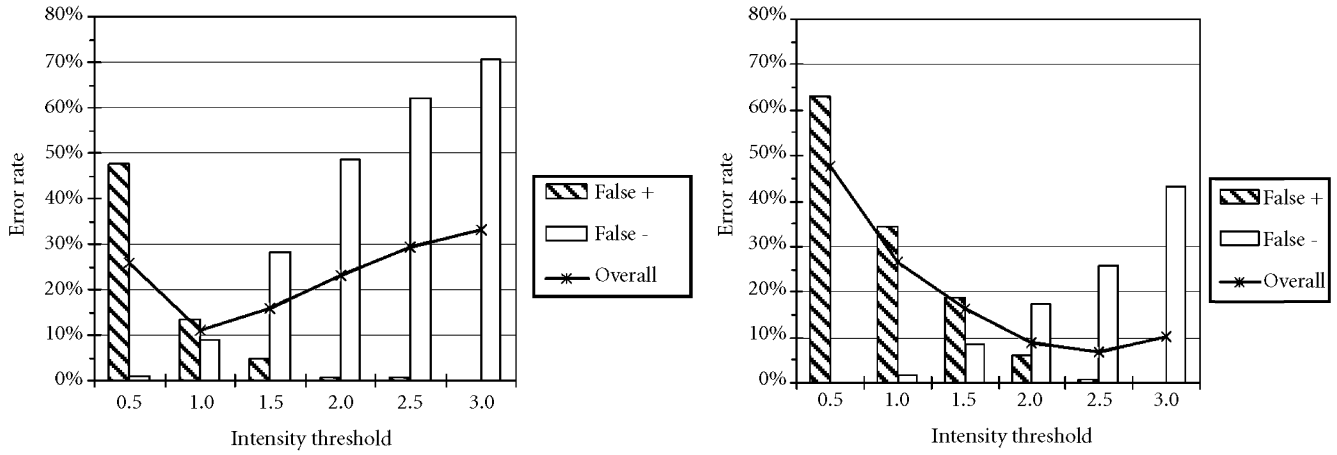

Figure 3. Error rates when using odor intensity to predict odor annoyance (left) and consequential annoyance (right), shown as functions of the threshold odor intensity.

invited friends/family over for an informal outdoor gathering. Beyond establishing the rating scale and common basis for making ratings, no attempt was made to calibrate participant responses.

Measurement data collection

When assessing detectable odor, the assessors made twelve sets of mask and intensity readings. When all 12 sets of readings were made, each assessor assigned a Hedonic tone rating, an odor descriptor, and an annoyance potential rating to represent the general state of odor during the measurement period (typically 8-10 minutes).

Data analysis

Each round of readings made by an individual assessor for a given time and location was evaluated as a single assessment. The 12 mask and intensity readings for each individual assessment were averaged and subsequently analyzed as means.

Linear regressions were performed to determine relationships between odor intensity, concentration, and Hedonic tone (independent variables) and annoyance potential (dependent variable). Thresholds were delineated as causing either any degree of annoyance (slightly annoying and greater) or consequential annoyance (moderately annoying and greater). Prospective thresholds were then evaluated based upon annoyance frequency and rates of false positives and negatives.

Results and Discussion

Odor was detected in 241 of the individual assessments (312 total) made by mobile odor assessors in 2005. Of these 241 assessments, the state of odor was considered to be at least slightly annoying in 113 (47%) of them and consequentially annoying — implying that the state of odor would likely influence assessor behavior — in 58 (24%) odor assessments.

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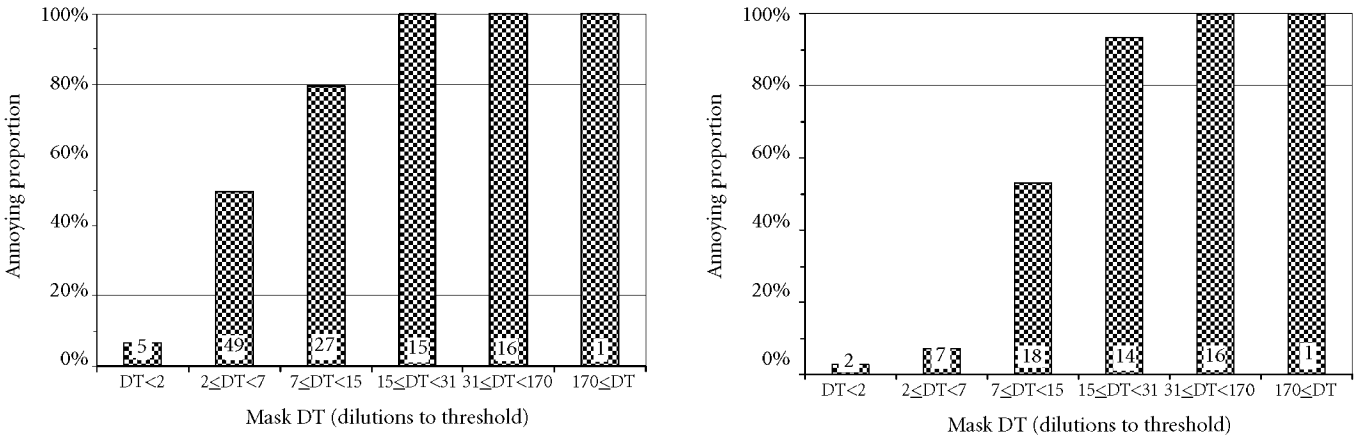

Figure 4. Likelihoods that odors assessed by mobile odor assessors were perceived as annoying (left) and consequentially annoying (right) based upon odor concentration. The number at the bottom of each bar is the number of responses indicating annoyance within the given range.

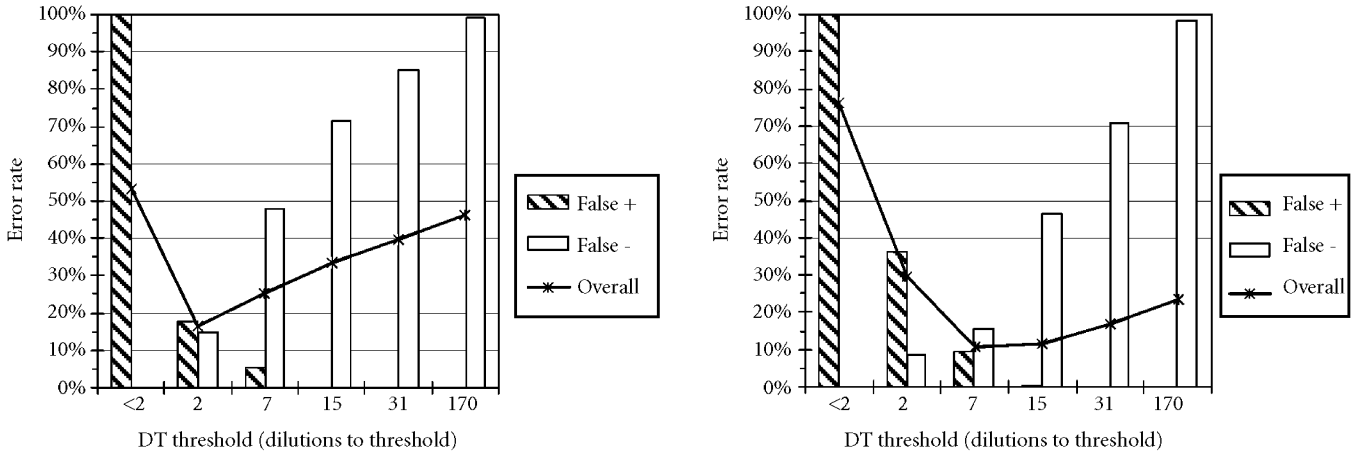

Figure 5. Error rates when using odor concentration to predict odor annoyance (left) and consequential annoyance (right), as a function of the threshold concentration (via mask scentometer).

Odor intensity

The perceived potential for odor annoyance increased with measured odor intensity and correlated reasonably well with intensity ($r^2 = 0.81$). A histogram can show where a sudden increase in the frequency of reported annoyance potential occurs. According to Figure 2, the thresholds for any annoyance and for consequential annoyance occurred for odor intensities of 1 and 2.5, respectively.

Another way to evaluate thresholds is to consider prediction error rates. Figure 3 shows the trends in prediction errors when the threshold for annoyance is set incrementally at intensities of 0.5 up to 3, for any annoyance and for consequential annoyance, respectively. A "false +" error refers to a situation where an intensity exceeded the assigned threshold, but the receptor did not rate the state of odor as being annoying, and a "false -" error refers to a situation where an intensity did not exceed the threshold value, but the receptor rated the state of odor as annoying.

The false-positive error rate for predicting any annoyance ranged from about 48% (61/128) at a 0.5 intensity threshold to below 1% for $i \geq 2$ (Figure 3, left graph). The false-negative error rate ranged from below 1% for a 0.5 threshold to over 70% (80/113) at $i = 3$. The data illustrate the challenge involved in trying to catch all objectively reported annoying odor conditions, in that a high false-positive rate would need to be endured, or visa versa. The minimum number of errors overall occurred for an intensity threshold of $i = 1.0$. The false-positive error rate for identifying consequential annoyance ranged from about 63% at a 0.5 intensity threshold to below 1% for $i \geq 2.5$ (Figure 3, right graph). The false-negative error rate ranged from 0% at an intensity threshold of 0.5 to about 43% at $i = 3$. The minimum number of errors overall occur for an intensity threshold of $i = 2.5$, but a lower threshold probably is needed to avoid not catching a sizeable percentage of objectively reported, consequentially annoying odor conditions.

Odor concentration

The perceived potential for annoyance also increased with measured odor concentration. Annoyance was moderately correlated with concentration ($r^2 = 0.64$).

When the odor concentration measured using a mask scentometer was reported to exceed 15 D/T, over 90% of the assessor responses indicated that potential for consequential odor annoyance existed (Figure 4). Given that the definition of odor annoyance would likely be defined at a lower frequency (i.e. 67%, 50% or lower), the threshold for any degree of annoyance appears to be between 2 and 15 D/T (Figure 4, left graph). Similarly, the threshold for consequential annoyance appears to be between 7 and 31 D/T (Figure 4, right graph).

The false-positive error rate ranged from 100% for odors that were not detectable at a 2:1 dilution ratio (128/128, by default) to 0% for a concentration threshold of 15 D/T (Figure 5, left graph). The false-negative error rate started at 15% and was over 99% for 170 D/T. The minimum number of errors overall occurred for a concentration threshold of 2 D/T. The false-positive error rate in identifying odor states that were likely to lead to consequential annoyance ranged from 100% for odors that were not detectable at 2:1 dilution to below 1% for an odor concentration threshold of 15 D/T (Figure 5, right graph). The false-negative error rate started at about 9% and was over 98% for 170 D/T. The minimum number of errors overall occurred for a concentration threshold of 7 D/T.

Hedonic tone

No positive/pleasant Hedonic tone ratings were provided by the assessors, so the ratings fit within the context of an offensiveness rating. A fairly strong correlation ($r^2 = 0.89$) existed between the perceived potential for odor annoyance and odor offensiveness, and a nearly 1-to-1 association existed between the two ratings (slope = 0.97). The assessors in this study clearly associated the offensiveness of odor with the potential for the odor to cause an annoying odor event. This occurred even though the two parameters were assigned differing non-numeric scales and had different bases for the ratings.

Measurement of hedonic tone is much more subjective than is measurement of odor intensity or concentration, however, and one could question the merits of comparing two ratings, which involve perceptions about odor. Unfortunately, hedonic tone ratings do not lend themselves to use in prediction of odor events using dispersion modeling either.

Odor character

The descriptive information collected by assessors was examined, but was not used in subsequent analysis, due to challenges in assigning quantitative values to descriptive terms and the limited variety of resulting responses. The terms used most often to describe the odor being assessed were "manure" / "pig manure"; "pigs" / "animals"; and less frequently, "earthy."

Summary and Conclusions

Field data were analyzed to compare assessor measurements of odor intensity, concentration, and hedonic tone (offensiveness) against assessor ratings of perceived odor annoyance potential. The following conclusions were made about the strength of associations between these measures and annoyance, and about candidate thresholds for defining annoying states of odor:

1) Positive correlations with annoyance potential exist for the 3 assessed odor measures, with the ranked order of correlations being offensiveness ($r^2 = 0.89$), intensity ($r^2 = 0.81$), and concentration ($r^2 = 0.64$).
2) Selection of threshold values for defining odor annoyance depends on whether the intent is to describe any degree of perceived odor annoyance or only consequential annoyance. Candidate thresholds for the three field measures at each of the two levels of annoyance are:

	Any Annoyance	Consequential Annoyance
Intensity (0-5 scale)	1	2
Concentration	2 D/T	7 D/T
Hedonic tone	-1	-2

Data is needed from more operations, including other types of swine facilities and production phases, to confidently establish thresholds for predicting potential for odor annoyance. Further inquiry into what constitutes annoyance and guidance on acceptable error rates is also needed.

Implications

This information provides baseline data for objectively defining states of odor that impact people. If objective measures of odor can be shown to be associated with annoying odor events, then rural residents will become more trusting of objective, science-based means of predicting when such odor events exist. Some pork producers might be a little uncomfortable with the notion that field measurements could be used to document that odors exceeded a prescribed threshold for annoyance. On the other hand, many find the current landscape, which relies primarily on complaints and arbitrary standards to define annoyance as far less desirable.

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[1]Richard R. Stowell is an extension specialist in animal environment; Christopher G. Henry is an extension engineer; Richard K. Koelsch is an extension livestock bioenvironmental engineer; and Dennis D. Schulte is a professor in the Department of Biological Systems Engineering.

[2]Iowa DNR. 2006. Results of the Iowa DNR Animal Feeding Operations Odor Study. Iowa DNR, Ambient Air Monitoring Group, *http://www.iowadnr.com/air/afo/afo.html.*

Acknowledgements

The field study from which this data was obtained was supported by a grant from the Nebraska Pork Producers Association.

Effects of Organic Acid Salts on the Quality Characteristics of Whole Muscle Hams

Using organic acid salts in hams at increased formulation use levels will reduce product yields, flavor and texture desirability, and overall ham acceptability.

Karaline A. Poovey
Dennis E. Burson
Susan L. Cuppett
Roger W. Mandigo
Harshavardhan Thippareddi[1]

Summary

The use of organic acid salts in the meat industry enhances product shelf life and safety. Minimal research is available evaluating the effects of high levels of organic acid salts on quality and sensory attributes of ready-to-eat products. Whole muscle hams were cured with brine solutions containing one of the following organic acid salt additions: 0% Control; 2.5 or 3.5% L-sodium lactate and sodium diacetate; 1.3, 2.5, or 3.5% buffered sodium citrate; 1.3, 2.5, or 3.5% buffered sodium citrate and sodium diacetate. The increased use of organic acid salts decreased product moisture and cooking yield ($P < 0.05$). Sensory panelists perceived decreased overall acceptability, with increased sourness/acidity and bitterness. Moderate levels of organic acid salts provided more acceptable products while maintaining many sensory attributes. Meat processors choosing to use organic acid salts in ready-to-eat products should be cautious as product yield losses and flavor changes may outweigh benefits at certain levels.

Introduction

Organic acid salts, often used as "antimicrobial agents" in the meat industry, offer processors enhanced product shelf life and improved product safety for consumers without losing quality attributes. These ingredients are commonly used to control the growth of *Listeria monocytogenes*, a pathogen of concern in ready-to-eat meat products. In addition, USDA Food Safety and Inspection Service (FSIS) regulations for *Listeria monocytogenes* control encourage the use of these antimicrobial ingredients. Common organic acid salts include buffered sodium citrate, sodium lactate, potassium lactate, and sodium diacetate.

FSIS currently limits the inclusion of buffered sodium citrate to 1.3% of the formulation, yet higher levels may be needed for effective control of *Listeria monocytogenes*. Research on the effects of higher levels of organic acid salts on sensory and quality traits of ready-to-eat meat products such as ham is lacking. Research in this area is essential for improving product quality and safety as well as providing information to FSIS for evaluating regulatory limits.

The purpose of this experiment was to evaluate the effects of various levels of organic acid salts on sensory and quality characteristics of whole muscle hams.

Procedures

Ham production

Boneless inside hams (IMPS 402F) were purchased from a commercial processor and delivered to the University of Nebraska–Lincoln's (UNL) Loeffel Meat Laboratory. Ham muscles were trimmed of external fat and macerated to increase surface area for tumbling and curing. The hams were cured with one of nine different brine solutions. The base brine included water, salt, sugar, organic acid salt (level and type depended on treatment), sodium nitrite and sodium erythorbate. The treatments included the following organic acid salt additions: 0% Control; 2.5 or 3.5% L-sodium lactate and sodium diacetate (SL+SDA) (Optiform SD4, Purac, Lincolnshire, Ill.); 1.3, 2.5 or 3.5% buffered sodium citrate (SC) (Ional, WTI, Jefferson, Ga.); and 1.3, 2.5 or 3.5% buffered sodium citrate and sodium diacetate (SC+SDA) (Ional LC, WTI, Jefferson, GA). Treatments were replicated on three separate production days.

Each of nine brines were individually mixed and added to 20 lb of ham muscle in a bag for tumbling to achieve a final weight of 112% of green weight. The bags were clipped and treatments were tumbled at 39°F without vacuum for three hours. All treatments were held at 39°F overnight, tumbled for 1.5 hours, stuffed into fibrous casings, and cooked to an internal temperature of 158°F.

After cooking, hams were chilled in a 36°F cooler. Final cooked ham size measured approximately 3.5 in deep, 5.5 in wide, and at least 11.8 in long. Hams were weighed again to achieve a final cooked (chill) weight and smokehouse yield was calculated (Smokehouse Yield (%) = [1- (pre-cook weight – final cook weight)/ pre-cook weight] x 100).

Slicing and packaging

Five hams from each treatment were sliced into one half inch thick slices and the slices were vacuum packaged. Slices from each ham were randomly assigned to the following analyses: color, purge, consumer taste

panel, and focus taste panel. The slices were placed in dark storage in a 37°F cooler (day 0 of storage) and held in dark storage until analysis on the designated day of storage.

Qualitative analyses

Proximate analysis (moisture, ash, and fat) and pH were analyzed on day 0. Protein was calculated by difference. The percentage of purge lost from slices in the vacuum-packaged bags was determined from slices held in dark storage at 37°F on day 28. Hunter L* (lightness), a* (redness), b* (yellowness) were determined on the ham slices on day 28.

Sensory analysis was conducted using both a consumer panel and a focus panel. Consumer panels occurred at day 29 and focus panel evaluations were conducted at day 35. The consumer panel survey scale was composed of 6 in horizontal lines for the attributes measured and panelists marked their preference point with a vertical mark on the scale whereas lacking was 0 and intense was 15. Attributes included: appearance, flavor (saltiness, sweetness, sourness/acidity, bitterness, and overall ham flavor), juiciness, texture, ham aftertaste, and overall ham acceptability. The focus panel participants tasted and evaluated ham samples as training for sample analysis. Panelists chose major attributes during trainings to be used in the sample survey. The focus panel survey evaluated the following: odor (smoke, sour, sweet, off-odor), texture (first bite, chew, juiciness), flavor (saltiness, sweetness, sourness/acidity, smoke, metallic, overall ham flavor), and ham aftertaste (metallic, sour).

Statistical analysis

Data were analyzed as a completely randomized design by analysis of variance (ANOVA) using the SAS 9.1 GLIMMIX procedure with a predetermined significance level of $P \leq 0.05$. Proximate composition data, purge, yield, pH, were analyzed as a completely randomized design. Colorspace values were analyzed as a repeated measures design, and sensory evaluation data were analyzed as a partial balanced incomplete block design. When significance was indicated by ANOVA, means separations were performed using the LSMEANS and DIFF function of SAS.

Table 1. Least square (LS) means of proximate composition, purge, cooking yield, and pH of boneless ham slices by treatment.

Treatment	Moisture (%)	Fat (%)	Ash (%)	Protein (%)	Purge (d28)	Yield (%)	pH (d0)
Control	72.94[a]	1.95	3.73	21.38[f]	1.73	87.70[a]	6.15
2.50% SL+SDA[g]	70.50[b]	2.36	4.02	23.13[e]	1.81	88.06[a]	6.21
3.50% SL+SDA	68.79[bcd]	3.07	4.25	23.90[de]	1.86	88.15[a]	6.14
1.30% SC[h]	70.11[bc]	2.70	3.69	23.50[e]	1.74	81.66[b]	6.02
2.50% SC	67.06[ef]	2.94	3.66	26.33[ab]	1.57	75.63[de]	6.03
3.50% SC	66.44[f]	2.74	3.64	27.18[a]	1.73	74.09[e]	5.96
1.30% SC+SDA[i]	70.32[b]	2.24	3.37	24.07[cde]	1.92	82.88[b]	6.11
2.50% SC+SDA	68.49[cde]	2.31	3.73	25.46[bc]	1.52	78.99[c]	6.03
3.50% SC+SDA	67.76[def]	2.87	4.02	25.36[bcd]	1.96	77.59[cd]	6.08
SEM[j]	0.593	0.429	0.22	0.556	0.252	1.453	0.104
P-Value	< 0.0001	0.601	0.204	< 0.0001	0.11	< 0.0001	0.794

[abcdef]Means within the same column and within a main effect without a common superscript differ ($P < 0.05$).
[g]SL+SDA = Sodium lactate + sodium diacetate
[h]SC = Sodium citrate
[i]SC+SDA = Sodium citrate + sodium diacetate
[j]SEM = Standard error of the mean

Table 2. LSMeans for day 28 HunterLab L*, a*, and b* for ham slices from different treatments.

Treatment	L*	a*	b*
Control	66.39	13.58	9.22[d]
2.50% SL+SDA[e]	65.31	14.05	9.50[cd]
3.50% SL+SDA	65.23	14.00	9.68[bcd]
1.30% SC[f]	70.01	12.36	10.25[ab]
2.50% SC	67.29	13.47	10.39[a]
3.50% SC	67.07	13.34	10.46[a]
1.30% SC+SDA[g]	67.27	13.52	10.42[a]
2.50% SC+SDA	67.20	13.51	10.10[abc]
3.50% SC+SDA	67.05	13.61	10.31[a]
SEM[h]	1.414	0.536	0.211
P-Value	0.420	0.532	0.003

[abcd]Means within the same column and within a main effect without a common superscript differ ($P < 0.05$).
[e]SL+SDA = Sodium lactate + sodium diacetate.
[f]SC = Sodium citrate.
[g]SC+SDA = Sodium citrate + sodium diacetate.
[h]SEM = Standard error of the mean.

Results and Discussion

The addition of organic acid salts had a significant effect on the percentage of moisture and protein in cured hams ($P < 0.0001$); however, no differences were noted among treatments for percent fat or ash ($P > 0.05$; Table 1). Hams that had no organic acid salt added (Control treatments) had the greatest percentage of moisture ($P < 0.0001$) and the percentage of moisture decreased as the percentage of organic acid salt increased ($P < 0.05$). The decrease in moisture was mostly explained by differences in cooking yields for the different treatments. The cooking yield percentage decreased as percentage of buffered sodium citrate increased. However, hams with SL+SDA increased in cooking yield as the percentage of organic acid salt increased ($P < 0.0001$). A reduction in percentage moisture and cooking yield may impact the sensory qualities of the ham.

No differences were found among treatments when measuring percentages of purge lost at day 28 post-packaging ($P = 0.11$). While purge indicates mois-

(Continued on next page)

Table 3. LSMeans for flavor of ham by treatment as evaluated by consumer panels.

	Flavor				
Treatment	Saltiness[i]	Sweetness[i]	Sourness/ acidity[i]	Bitterness[i]	Ham aftertaste[j]
Control	6.67^{bc}	6.26^{b}	6.13^{c}	5.50^{d}	7.76^{a}
2.5% SL+SDA[e]	7.43^{b}	5.51^{b}	6.78^{abc}	6.11^{bcd}	7.92^{a}
3.5% SL+SDA	8.56^{a}	6.35^{b}	7.52^{a}	6.48^{abc}	7.76^{a}
1.3% SC[f]	7.14^{bc}	6.10^{b}	6.51^{bc}	5.65^{cd}	8.28^{a}
2.5% SC	7.06^{bc}	5.51^{b}	7.40^{a}	6.77^{ab}	7.64^{a}
3.5% SC	7.41^{b}	5.72^{b}	7.30^{ab}	6.39^{abcd}	7.80^{a}
1.3% SC+SDA[g]	6.48^{c}	6.45^{b}	6.09^{c}	5.62^{cd}	8.26^{a}
2.5% SC+SDA	6.85^{bc}	6.46^{b}	6.91^{abc}	6.11^{bcd}	8.05^{a}
3.5% SC+SDA	6.84^{bc}	7.64^{a}	7.51^{a}	7.15^{a}	6.56^{b}
SEM[h]	0.32	0.40	0.32	0.32	0.36
P-Value	0.0003	0.027	0.0005	0.001	0.032

[abcd]Means within the same column and within a main effect without a common superscript differ ($P < 0.05$).
[e]SL+SDA = Sodium lactate + sodium diacetate.
[f]SC = Sodium citrate.
[g]SC+SDA = Sodium citrate + sodium diacetate.
[h]SEM = Standard error of the mean.
[i]Flavor attributes were evaluated individually on a 15 point scale where 1 = lacking and 15 = intense.
[j]Ham aftertaste was evaluated on a 15 point scale where 1 = undesirable and 15 = highly desirable.

Table 4. LSMeans of juiciness, texture, appearance, and acceptability of ham by treatment as evaluated by consumer panels.

Treatment	Juiciness[i]	Texture[j]	Appearance[k]	Overall ham acceptability[l]
Control	7.77^{abc}	8.71^{a}	7.68	7.97^{ab}
2.5% SL+SDA[e]	8.69^{a}	8.24^{ab}	8.82	8.28^{ab}
3.5% SL+SDA	7.89^{ab}	7.47^{bc}	8.45	8.19^{ab}
1.3% SC[f]	6.32^{cd}	7.99^{ab}	8.09	8.41^{a}
2.5% SC	5.90^{d}	6.34^{d}	8.06	7.18^{bc}
3.5% SC	5.76^{d}	6.79^{cd}	8.96	7.68^{abc}
1.3% SC+SDA[g]	7.00^{bcd}	8.14^{ab}	7.96	8.33^{a}
2.5% SC+SDA	6.37^{cd}	7.36^{bc}	7.94	7.72^{abc}
3.5% SC+SDA	5.77^{d}	6.59^{cd}	8.21	6.69^{c}
SEM[h]	0.53	0.33	0.36	0.39
P-Value	0.0002	< .0001	0.149	0.016

[abcd]Means within the same column and within a main effect without a common superscript differ ($P < 0.05$).
[e]SL+SDA Sodium lactate + sodium diacetate
[f]SC = Sodium citrate
[g]SC+SDA = Sodium citrate + sodium diacetate
[h]SEM = Standard error of the mean
[i]Juiciness was evaluated on a 15 point scale where 1 = very dry and 15 = very juicy.
[j]Texture was evaluated on a 15 point scale where 1 = tough/hard/coarse and 15 = tender/soft/smooth.
[k]Appearance was evaluated on a 15 point scale where 1 = very undesirable and 15 = very desirable.
[l]Overall ham acceptability was evaluated on a 15 point scale where 1 = extremely dislike and 15 = extremely like.

ture loss over time, smokehouse yields provide insight on potential moisture loss of the product during thermal processing (Table 1). There were no statistical differences found for HunterLab L* or a* ($P > 0.05$); however, treatments with SC tended to have higher, or more yellow, HunterLab b* values ($P = 0.003$) (Table 2).

Sensory analysis

Sensory characteristics were measured using both consumer and focus panels. Consumer panelists identified traits by preferences, while the focus panels more precisely identified descriptive differences in sensory characteristics.

Basing their decisions on a 0.4 in^3 ham sample, consumers were not able to distinguish differences in appearance ($P = 0.149$) or overall ham flavor ($P = 0.158$; Tables 3, 4). Significant differences ($P < 0.03$) were found in traits like saltiness, sweetness, sourness/acidity, and bitterness. In addition to flavor attributes, consumers also determined significant distinctions in levels of juiciness, texture, and overall ham acceptability ($P < 0.02$).

Treatments with 3.5% SL+SDA were rated highly by consumer panels for saltiness, sourness/acidity, bitterness, ham aftertaste, juiciness, and overall ham acceptability (Tables 3, 4). The 2.5% SL+SDA treatments ranked high among attributes such as sourness/acidity, ham aftertaste, juiciness, texture, and overall ham acceptability. It appears that lower levels of SL+SDA have more desirable sensory traits, and that the addition of SL at either level boosts acceptable flavor traits while reducing negative traits like bitterness or sourness.

Although hams including 3.5% SC+SDA provided consumers a sweeter ham, they also increased more undesirable characteristics: sourness/acidity, bitterness, undesirable aftertaste, decreases in juiciness, and lower overall acceptability (Tables 3, 4). If lower levels of SC+SDA are used (1.3%), these traits are significantly reduced and comparable to Control ($P < 0.05$). Without the inclusion of SDA, product overall acceptability was similar to Control; however, sourness and bitterness traits at 2.5% and 3.5% were still less desirable.

While the focus panel also based their sensory decisions on a 0.4 in^3 ham piece, additionally they evaluated whole ham slices for appearance. The focus panelists found no differences among samples when examining for smoke odor, off-odor, smoke flavor, overall ham flavor, sour aftertaste, or iridescent sheen ($P > 0.05$) (Tables 5, 6).

Focus panelists reported a more tender first bite, smoother chewing capabilities, increased juiciness, and increased slice integrity while increasing the saltiness for hams containing

Table 5. LSMeans of odor, texture, and appearance of ham by treatment as evaluated by focus panels.

	Odor[i]		Texture			Appearance	
Treatment	Sour	Sweet	First bite[j]	Chew[k]	Juiciness[k]	Cured color intensity[l]	Slice integrity[m]
Control	5.14^{abc}	2.93	8.76^{a}	7.86^{abcd}	7.82^{ab}	6.76^{cd}	6.91^{a}
2.5% SL+SDA[e]	5.84^{ab}	4.32	8.59^{ab}	8.23^{abc}	8.01^{ab}	7.57^{b}	7.14^{a}
3.5% SL+SDA	3.91^{c}	3.32	8.78^{a}	8.72^{a}	7.06^{abc}	8.61^{a}	6.98^{a}
1.3% SC[f]	4.86^{bc}	2.97	7.80^{abc}	8.29^{ab}	6.67^{bc}	6.51^{d}	6.63^{a}
2.5% SC	5.05^{abc}	3.33	5.36^{d}	6.08^{d}	5.05^{d}	7.27^{bc}	5.63^{bc}
3.5% SC	4.68^{bc}	2.83	6.74^{abcd}	6.09^{cd}	4.48^{d}	6.67^{cd}	5.17^{c}
1.3% SC+SDA[g]	6.50^{a}	3.99	8.6^{ab}	8.65^{a}	8.42^{a}	6.6^{cd}	6.65^{a}
2.5% SC+SDA	5.17^{abc}	3.40	6.61^{bcd}	6.47^{bcd}	4.92^{d}	6.71^{cd}	6.57^{ab}
3.5% SC+SDA	6.05^{ab}	3.92	6.34^{cd}	6.59^{abcd}	5.75^{cd}	7.18^{bcd}	6.46^{ab}
SEM[h]	0.55	0.40	0.74	0.78	0.56	0.28	0.35
P-Value	0.049	0.08	0.003	0.036	< .0001	< .0001	0.001

[abcd]Means within the same column and within a main effect without a common superscript differ ($P < 0.05$).
[e]SL+SDA = Sodium lactate + sodium diacetate.
[f]SC = Sodium citrate.
[g]SC+SDA = Sodium citrate + sodium diacetate.
[h]SEM = Standard error of the mean.
[i]Odor attributes were evaluated individually on a 15 point scale where 1 = lacking and 15 = intense.
[j]First Bite was evaluated on a 15 point scale where 1 = tough and 15 = tender.
[k]Chew was evaluated on a 15 point scale where 1 = fibrous and 15 = smooth.
[l]Cured color intensity was evaluated on a 15 point scale where 1 = pale pink and 15 = dark pink.
[m]Slice integrity was evaluated on a 15 point scale where 1 = lacking bind and 15 = bound.

Table 6. LSMeans for flavors of ham by treatments as evaluated by focus panels.

	Flavor[j]				
Treatment	Saltiness	Sweetness	Sourness/ acidity	Metallic	Metallic aftertaste
Control	6.35^{c}	4.28^{c}	5.66	1.53^{de}	2.35^{c}
2.5% SL+SDA[f]	8.31^{ab}	4.99^{bc}	6.78	1.39^{e}	2.04^{c}
3.5% SL+SDA	8.99^{a}	4.36^{c}	6.66	1.84^{cde}	2.9^{bc}
1.3% SC[g]	7.19^{bc}	4.89^{bc}	5.38	2.83^{abc}	3.22^{bc}
2.5% SC	8.28^{ab}	4.61^{c}	6.31	3.26^{a}	4.9^{a}
3.5% SC	8.33^{ab}	4.92^{bc}	7.18	2.06^{bcde}	3.91^{ab}
1.3% SC+SDA[h]	6.79^{c}	5.09^{bc}	6.25	2.58^{abcd}	4.18^{ab}
2.5% SC+SDA	7.41^{bc}	5.75^{ab}	5.73	2.53^{abcd}	3.87^{ab}
3.5% SC+SDA	7.56^{bc}	6.28^{a}	10.64	3.10^{ab}	5.13^{a}
SEM[i]	0.43	0.39	1.16	0.39	0.52
P-Value	0.0003	0.086	0.067	0.003	< .0001

[abcde]Means within the same column and within a main effect without a common superscript differ ($P < 0.05$).
[f]SL+SDA = Sodium lactate + sodium diacetate.
[g]SC = Sodium citrate.
[h]SC+SDA = Sodium citrate + sodium diacetate.
[i]SEM = Standard error of the mean.
[j]Flavor attributes were evaluated individually on a 15 point scale where 1 = lacking and 15 = intense.

3.5% SL+SDA ($P < 0.05$). Reducing the concentration of SL+SDA (2.5%) resulted in reduced ham saltiness and metallic flavors ($P < 0.05$) without compromising juiciness and sweetness intensities.

Hams with 3.5% SC+SDA were more sour/acidic, less juicy, and more intense in metallic flavor and metallic aftertaste while also testing more sweet. Hams from 1.3% SC+SDA were more tender during the first bite, and more smooth and juicy during chewing when compared to hams of 3.5% SC+SDA. The lowest level treatment (1.3%) with SC alone provided hams with a more tender first bite, smooth chewing capabilities, moderate juiciness and highly bound slice integrity. In both SC and SC+SDA samples, cured color intensity greatly declined. As well, panelists noticed modest saltiness, metallic flavor, and metallic aftertastes.

Conclusion

Though the utilization of organic acid salts (SL+SDA, SC, and SC+SDA) may increase product shelf life and safety, this research revealed that their incorporation affects quality and sensory attributes of ham. As the concentration of organic acid salt treatments increased product yields while product moisture decreased. Decreases in moisture led to sensory panelists finding decreased levels of juiciness, slice integrity, and overall acceptability. As well, consumers perceived increased levels of saltiness, sourness/acidity, and bitterness with increasing concentration of the organic acid salts, while total ham aftertaste decreased.

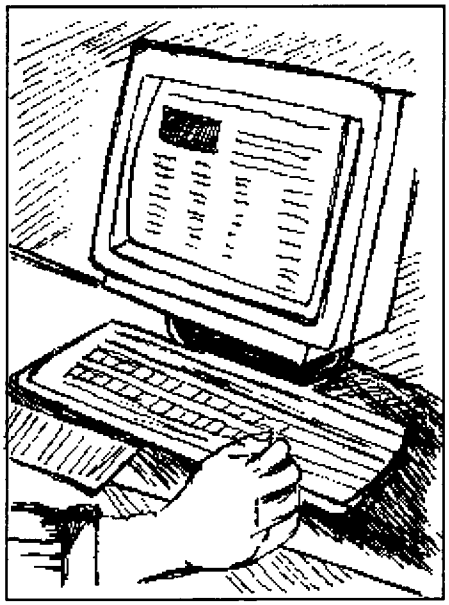
Formulations of ham with lower levels of organic acid salts are capable of providing processors a product with minimal impact on processing quality, as well as sensory and quality attributes for consumer acceptance. When using organic acid salts in ready-to-eat meat products, meat processors should carefully evaluate the effects on quality and sensory properties while achieving improved product safety and shelf life.

[1]Karaline A. Poovey is a master's graduate student in the Animal Science Department. Dennis E. Burson and Roger W. Mandigo are professors in the Animal Science Department. Susan L. Cuppett and Harshavardhan Thippareddi are professor and associate professor, respectively, in the Department of Food Science and Technology.

Explanation Of Statistics Used In This Report

Pigs treated alike vary in performance due to their different genetic makeup and to environmental effect we cannot completely control. When a group of pigs is randomly allotted to treatments it is nearly impossible to get an "equal" group of pigs on each treatment. The natural variability among pigs and the number of pigs per treatment determine the expected variation among treatment groups due to random sampling.

At the end of an experiment, the experimenter must decide whether observed treatment differences are due to "real" effects of the treatments or to random differences due to the sample of pigs assigned to each treatment. Statistics are a tool used to aid in this decision. They are used to calculate the probability that observed differences between treatments were caused by the luck of the draw when pigs were assigned to treatments. The lower this probability, the greater confidence we have that "real" treatment effects exist. In fact when this probability is less than .05 (denoted **P < .05** in the articles), there is less than a 5% chance (less than 1 in 20) that observed treatment differences were due to random sampling. The conclusion then is that the treatment effects are "real" and caused different performance for pigs on each treatment. But bear in mind that if the experimenter obtained this result in each of 100 experiments, 5 differences would be declared to be "real" when they were really due to chance. Sometimes the probability value calculated from a statistical analysis is P < .01. Now



the chance that random sampling of pigs caused observed treatment differences is less than 1 in 100. Evidence for real treatment differences is very strong.

It is commonplace to say differences are significant when P < .05, and highly significant when P < .01. However, P values can range anywhere between 0 and 1. Some researchers say that there is a tendency that real treatment differences exist when the value of P is between .05 and .10. Tendency is used because we are not as confident that differences are real. The chance that random sampling caused the observed differences is between 1 in 10 and 1 in 20.

Sometimes researchers report **standard errors of means (SEM)** or **standard errors (SE)**. These are calculated from the measure of variability and the number of pigs in the treatment. A treatment mean may be given as 11 $\pm$ .8. The 11 is the mean and the .8 is the SEM. The SEM or SE is added and subtracted from the treatment mean to give a range. If the same treatments were applied to an unlimited number of animals the probability is .68 (1 = complete certainty) that their mean would be in this range. In the example the range is 10.2 to 11.8.

Some researchers report **linear (L)** and **quadratic (Q)** responses to treatments. These effects are tested when the experimenter used increasing increments of a factor as treatments. Examples are increasing amounts of dietary lysine or energy, or increasing ages or weights when measurements are made. The L and Q terms describe the shape of a line drawn to describe treatment means. A straight line is linear and a curved line is quadratic. For example, if finishing pigs were fed diets containing .6, .7, and .8% lysine gained 1.6, 1.8 and 2.0 lb/day, respectively we would describe the response to lysine as linear. In contrast, if the daily gains were 1.6, 1.8, and 1.8 lb/day the response to increasing dietary lysine would be quadratic. Probabilities for tests of these effects have the same interpretation as described above. Probabilities always measure the chance that random sampling caused the observed response. Therefore, if P < .01 for the Q effect was found, there is less than a 1 % chance that random differences between pigs on the treatments caused the observed response.

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