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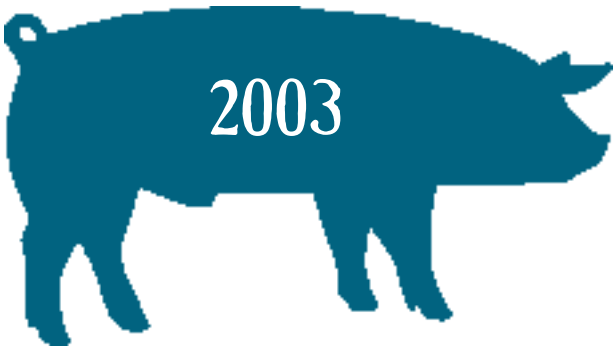

NEBRASKA SWINE REPORT

- Nutrition
- Economics
- Housing
- Meats

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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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2003 Nebraska Swine Report

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Growth Performance, Carcass Characteristics, and Economics of Pigs Fed Diets Containing a Corn Germ-Corn Bran Product

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Summary and Implications

Due to an increased number of corn milling plants in Nebraska, it is necessary to evaluate the use of corn by-products in swine diets. In these experiments, the inclusion of a corn germ-corn bran product into swine diets was evaluated for its effects on growth performance, carcass composition, carcass quality traits, and economic value. In Experiment 1, individually housed growing-finishing pigs were fed: 1) corn-soybean, 2) corn-soybean meal-4% bleachable tallow, or 3) corn-soybean meal-8% corn germ-bran diets. During the 93-day trial there were no differences for average daily gain (ADG; P > 0.10) or average daily feed intake (ADFI; P > 0.10) among treatments. The numerical improvements of ADG and ADFI when pigs were fed the diet containing tallow resulted in a 9% improvement in feed efficiency (ADFI/ADG; P < 0.001). Fat-O-Meter data suggested that pigs fed the diet containing tallow were leaner than pigs fed the corn-soybean meal diet (P < 0.07). Treatments imposed upon group-housed growing-finishing pigs in Experiment 2 were: 1) corn-soybean meal, 2) corn-soybean meal-4% bleachable tallow, 3) corn-soybean meal-8% corn germ-bran, and 4) corn-soybean meal-16% corn germ-bran. During the 102-day trial there were no differences among treatments for ADG (P > 0.10). Pigs fed the diet containing tallow had a 5.3% reduction in ADFI (P < 0.007) and 8.7% improvement in feed efficiency (ADFI/ADG: P < 0.005) compared to all other treatments. Ultrasound scans revealed no differences (P > 0.10) in longissimus muscle area among treatments and an increased (P < 0.02) backfat depth for pigs fed the 4% tallow diet compared to other treatments. Calculated (NPPC, 1991) carcass lean content of pigs fed the 4% tallow diet was less than (P < 0.06) the other treatments. Dressing percentage was greater (P < 0.05) for pigs fed diets containing tallow compared to pigs fed diets containing corn germ-bran. In general, longissimus muscle quality was improved for pigs fed a control (corn-soybean meal) diet versus other treatments; however, all treatment means were within acceptable ranges for muscle quality traits. Depending on the corn price (we used values between $1.75 and $3.00/bu) and market price for market hogs (we used values between $10 and $50/cwt live), the value of corn germ-corn bran in growing-finishing diets ranges between $0 and $104 per ton.

Background and Introduction

Corn germ is a by-product of the corn wet milling industry. Typically, oil from corn germ is extracted. However, when the price of competing vegetable oils is low, the price for corn oil and, therefore, corn germ decreases. The germ contains the predominant portion of the oil in the kernel. The bran (or hull) is the outer coating of the corn kernel and is primarily composed of nondigestible carbohydrate. Some corn milling plants do not separate the bran from the germ, thus, producing a by-product that is a high fat-high fiber product. Although liquid fat (animal sources) can (depending on the corn price) be economically feasible, there are some potential drawbacks. The initial costs of purchasing and maintaining fat tanks can be cost prohibitive for some producers. Mixing supplemental fat in swine diets can be difficult with some feed processing and mixing equipment. Additionally, maintaining fat quality can be a challenge if the swine operation does not use the fat in a timely manner. An alternative to liquid fat is dry fat. However, dry fat is rarely cost effective compared to other energy sources (e.g., corn, liquid fat, etc.) in swine diets. Because liquid fat is often physically difficult to handle for small to medium size pork producers and dry fat is often cost prohibitive, it was hypothesized that corn germ may be an economical alternative to other fat sources.

The goal of this research was to evaluate the feeding value of a corn germ-corn bran product (Table1) relative to corn-soybean meal or corn-soybean meal-tallow diets.

Procedures

Experiment 1

A total of 36 barrows were used in a 93-day growth study. Pigs averaged 52 and 245 lb at the initiation and termination of the experiment, respectively. Pigs were blocked by location of the room (n=3) and randomly assigned to one of three dietary treatments: 1) corn-soybean meal (Control); 2) corn-soybean meal-4% bleachable tallow (Tallow); and 3) corn-soybean meal-8% corn germ-corn bran (8% Germ). Pigs and feeders were weighed initially and at each feeding phase change thereafter. Four feeding phases were used and all treatments were changed at a constant time point (Phase 1, d 0 to 17; Phase 2, d 18 to 40; Phase 3, d 41 to 67; Phase 4, d 68 to

(Continued on next page)

Table 1. Nutrient composition of corn germ-bran (as-fed).

Nutrient	
Ether extract[a], %	50.70
Starch[b], %	0
Ash[a], %	1.28
Acid detergent fiber[c], %	24.56
Crude protein[a], %	12.05
Lysine[c], %	0.55
Digestible lysine[d], %	0.36
Net energy[e], Mcal/lb	1.63

[a]Analyzed in our laboratory.
[b]Assumed to be zero.
[c]Average of several analyses of commercial laboratory.
[d]True ileal digestibility coefficient from AmiPig 2000.
[e]Predicted from Noblet, 1994.

93). Diets (Table 2) were calculated to contain equal digestible lysine:net energy ratios. The net energy of the corn germ/corn bran product was estimated by the prediction equation of Noblet, 1994: NE kcal/kg = [2,790 + (41.2 × % EE) + (8.1 × % Starch) – (66.5 × % Ash) – (47.2 × % ADF)], where EE is ether extract and ADF is acid detergent fiber. At the termination of the experiment, pigs were ultrasonically scanned at the tenth-rib for backfat and longissimus muscle area and transported to a commercial slaughter facility where backfat depth, longissimus muscle depth, and lean content was predicted.

Experiment 2

A total of 120 gilts and 120 barrows were used in a 102-day growth study. Pigs averaged 71 and 258 lb at the initiation and termination of the experiment, respectively. Gilts and barrows were separately blocked by weight (n = 3) and randomly assigned to one of four dietary treatments: 1) corn-soybean meal (Control), 2) corn-soybean meal-4% bleachable tallow (Tallow), 3) corn-soybean meal-8% corn germ-bran (8% Germ), and 4) corn-soybean meal-16% corn germ-bran (16% Germ). Each pen housed five pigs of each gender, with a total of 24 pens. Pigs and feeders were weighed initially and every two weeks thereafter. Four feeding phases (Phase 1, d 0 to 13; Phase 2, d 14 to 42; Phase 3, d 43 to 70; Phase 4, 71 to 102) were used and all treatments were changed at the

Table 2. Ingredient and calculated nutrient composition of diets, as-fed (Exp. 1).

Phase 1.	Treatment		
Ingredients, %	Control	Tallow	8% Germ
Corn	63.93	57.54	54.42
Soybean meal, 46.5% CP	33.35	35.77	34.88
Corn germ/corn bran			8.00
Bleachable tallow		4.00	
Dicalcium phosphate	1.17	1.16	1.16
Limestone	0.40	0.38	0.39
Salt	0.35	0.35	0.35
Vitamin premix[a]	0.70	0.70	0.70
Trace mineral premix[b]	0.10	0.10	0.10
Calculated nutrient composition			
Lysine, %	1.10	1.15	1.16
Digestible Lysine, %	0.97	1.02	1.02
NE[c] Mcal/lb	1.00	1.05	1.04
Dig. Lys/NE, g/Mcal	4.40	4.40	4.43
Crude fat, %	3.50	7.32	7.17
Crude fiber, %	2.37	2.29	4.59
Ca, %	0.70	0.70	0.70
P, %	0.63	0.63	0.63
P, avail. %	0.29	0.29	0.29

Phase 2.	Treatment		
Ingredients, %	Control	Tallow	8% Germ
Corn	68.67	62.44	59.33
Soybean meal, 46.5% CP	29.00	31.25	30.35
Corn germ/corn bran			8.00
Bleachable tallow		4.00	
Dicalcium phosphate	0.81	0.80	0.80
Limestone	0.37	0.36	0.37
Salt	0.35	0.35	0.35
Vitamin premix[a]	0.70	0.70	0.70
Trace mineral premix[b]	0.10	0.10	0.10
Calculated nutrient composition			
Lysine, %	0.99	1.03	1.04
Digestible Lysine, %	0.87	0.91	0.91
NE[c], Mcal/lb	1.01	1.06	1.06
Dig. Lys/NE, g/Mcal	3.90	3.90	3.91
Crude fat, %	3.55	7.37	7.22
Crude fiber, %	2.37	2.28	4.58
Ca, %	0.60	0.60	0.60
P, %	0.54	0.54	0.55
P, avail. %	0.22	0.22	0.22

Phase 3.	Treatment		
Ingredients, %	Control	Tallow	8% Germ
Corn	75.70	69.81	66.71
Soybean meal, 46.5% CP	22.08	24.00	23.10
Corn germ/corn bran			8.00
Bleachable tallow		4.00	
Dicalcium phosphate	0.69	0.69	0.68
Limestone	0.36	0.35	0.36
Salt	0.35	0.35	0.35
Vitamin premix	0.70	0.70	0.70
Trace mineral premix	0.10	0.10	0.10
Calculated nutrient composition			
Lysine, %	0.82	0.85	0.85
Digestible Lysine, %	0.71	0.75	0.75
NE[c], Mcal/lb	1.02	1.08	1.09
Dig. Lys/NE, g/Mcal	3.14	3.14	3.18
Crude fat, %	3.62	7.44	7.30
Crude fiber, %	2.34	2.26	4.56
Ca, %	0.55	0.55	0.55
P, %	0.49	0.49	0.50
P, avail. %	0.19	0.19	0.19

Table 2. continued.

Phase 4.	Treatment		
Ingredients, %	Control	Tallow	8% Germ
Corn	83.63	78.11	74.99
Soybean meal, 46.5% CP	14.30	15.82	14.93
Corn germ/corn bran			8.00
Bleachable tallow		4.00	
Dicalcium phosphate	0.58	0.58	0.57
Limestone	0.35	0.35	0.35
Salt	0.35	0.35	0.35
Vitamin premix[a]	0.70	0.70	0.70
Trace mineral premix[b]	0.10	0.10	0.10
Calculated nutrient composition			
Lysine, %	0.62	0.64	0.65
Digestible Lysine, %	0.53	0.56	0.56
NE[c], Mcal/lb	1.04	1.09	1.08
Dig. Lys/NE, g/Mcal	2.31	2.31	2.34
Crude fat, %	3.69	7.52	7.37
Crude fiber, %	2.32	2.23	4.53
Ca, %	0.50	0.50	0.50
P, %	0.44	0.44	0.44
P, avail. %	0.16	0.16	0.16

[a]Supplied per lb of diet: retinyl acetate, 1,400 IU; cholecalciferol, 175 IU; α-tocopherol acetate, 7 IU; menadione sodium bisulfite, 1.05 mg; riboflavin, 1.75; d-pantothenic acid, 7 mg; niacin, 10.5 mg; choline, 35 mg; vitamin B_{12}, 6.8 ug.

[b]Supplied per lb of diet: Zn (as ZnO), 50 mg; Fe (as $FeSO_4 \cdot H_2O$), 50 mg; Mn (as MnO), 10 mg; Cu (as $CuSO4 \cdot 5\ H_2O$), 5 mg; I (as $Ca(IO_3) \cdot H_2O$, .01 mg; Se (as Na_2SeO_3), .136 mg.

[c]NE: Net energy.

same time. Similar to Experiment 1, diets (Table 3) were calculated to contain equal digestible lysine:net energy ratios in an attempt to maintain equal amino acid intake. On day 102, pigs were ultrasonically scanned at the tenth-rib for backfat and longissimus muscle area and transported to a commercial slaughter facility. Hot carcass weight was collected immediately after slaughter. Longissimus muscle marbling, pH, firmness, drip loss, and objective color scores were collected 24 hour post mortem. Carcass fat-free lean content was predicted from the equation developed by NPPC (1991).

Economic calculations were based on average daily feed intake (ADFI) for each feeding Phase and overall body weight gains (Table 5) of the Control and 16% Germ treatments from Experiment 2. The price of corn germ-bran was adjusted to match the return after feed cost (considers feed intake, cost of feed, pounds of gain, and the value of gain) compared to a corn-soybean meal diet. This was done for each scenario of corn price (from $1.75 to $3.00/bu) and live hog price (from $10 to $50/cwt live).

Results and Discussion

Experiment 1

There were no differences for average daily gain (ADG) or ADFI among treatments during the four feeding phases with the exception that pigs fed diets containing tallow had a 10.3% improvement in ADG during days 41 to 67 (Table 4). Pigs fed Tallow had improved feed efficiency (ADFI/ADG) compared to pigs fed Control during days 18 to 40 and 41 to 67, resulting in an overall improvement of 7.1% (2.35 vs 2.53; $P < 0.01$). Pigs in the Tallow group had improved feed efficiency compared to pigs fed 8% Germ during all phases ($P < 0.02$) of the experiment leading to a 10.8% (2.35 vs 2.63; $P < 0.005$) overall improvement. During the entire growing-finishing period, feeding diets containing tallow to pigs resulted in a 9% improvement ($P < 0.01$) in ADFI/ADG compared to all other treatments. Pigs fed Control and 8% Germ had similar ($P > 0.11$) ADFI/ADG throughout the feeding period.

Backfat depth detected by Fat-O-Meter (FOM) was greater ($P < 0.03$) for pigs fed Control compared to pigs fed Tallow. Ultrasonically scanning the pigs indicated a similar numeric ranking of treatments compared to FOM for backfat depth but no differences ($P > 0.10$) among treatments. Longissimus muscle depth detected by FOM indicated no differences ($P > 0.10$) among treatments. Similarly, there were no treatment differences ($P > 0.10$) observed for longissimus muscle area as detected by ultrasonically scanning the pigs prior to slaughter. Ranking treatments for percent lean was similar using calculations from ultrasonically scanned pigs (prior to slaughter) or by the commercial packer's inputs; however, only the commercial calculation showed a trend (main effect, $P < 0.08$) for increased ($P < 0.03$) lean percentage for pigs fed Tallow compared to pigs fed the Control diet.

It was surprising to observe a decreased backfat depth and increased percent lean of pigs fed diets containing tallow as compared to corn-soybean meal diets. However, these pigs were housed in a clean, thermoneutral facility and lean deposition may have been limited merely by energy intake (versus amino acid intake, pathogen exposure, crowding, etc.).

Experiment 2

With the exception of days 0 to 13, ADG of pigs was not affected by the dietary treatment ($P > 0.10$) for the overall growing-finishing period (Table 5). During days 0 to 13, ADFI was reduced ($P < 0.03$) for pigs fed diets containing tallow and 16% corn germ-bran compared to pigs fed the Control diet. The reduction in feed intake for pigs fed Tallow compared to other treatments existed for most other feeding periods and the overall growing-finishing period (5.3% reduction, $P < 0.05$). The improvement in feed efficiency is due to an increase in energy density of the diet. The reduction in ADFI for pigs fed the 16% corn germ-bran diet only occurred during days 0 to 13 and was most likely a result of an adaptation to diet composition. Apparently, this was not due to an increase in dietary energy density because efficiency of gain was not similar to pigs

(Continued on next page)

fed Tallow during the first 13 days and this effect was not observed during the remainder of the trial. Feed intake of pigs fed diets containing corn germ-bran was similar (P > 0.10) to pigs fed Control during the entire growing-finishing period. Feed efficiency was improved (P < 0.02) for pigs fed the diet containing tallow by 8.7 % compared to the other treatments during the entire growing-finishing period. Throughout the experimental period, no differences (P > 0.10) in feed efficiency were observed among pigs fed diets containing corn germ-bran (3.19 and 3.18; 8% and 16% corn germ-bran, respectively) and corn-soybean meal (3.09) diets.

Backfat depth was approximately one-tenth inch greater (P < 0.05) for pigs fed the diet containing tallow compared to pigs fed other diets with no differences (P > 0.10) among treatments for longissimus muscle area. Increased tenth-rib backfat of pigs fed the diet containing tallow contributed to nearly one percentage unit less carcass percent lean compared (P < 0.07) to other treatments. Pigs fed corn-soybean meal diets had greater (P < 0.02) marbling than pigs fed diets containing tallow and 16% corn germ-bran, with pigs fed diets containing 8% corn germ-bran being intermediate. There was a trend for increased (main effect, P < 0.08) post mortem (24 hour) longissimus muscle pH for pigs that had consumed Control compared to pigs fed Tallow and 8% Germ. Although drip loss was unaffected (P > 0.10) by dietary treatment, there was a trend (P < 0.09) for improved subjective muscle firmness score for pigs fed corn-soybean meal diets as compared to other treatments. Longissimus muscle color score was not affected by dietary treatment, with the exception that Minolta a* was greater (P < 0.01) for pigs that had consumed diets containing tallow compared to other treatments.

The treatment means of overall body weight gain and ADFI were used to calculate the economic feeding value of the corn germ-bran product (Table 6). This analysis suggests that when corn price is $2.75/bu and live hog

Table 3. Ingredient and calculated nutrient composition of diets, as-fed (Exp. 2).

Phase 1.	Treatment			
Ingredients, %	Control	Tallow	8% Germ	16% Germ
Corn	63.98	57.92	54.81	47.33
Soybean meal, 46.5% CP	33.35	35.43	34.53	34.00
Corn germ/corn bran			8.00	16.00
Bleachable tallow		4.00		
Dicalcium phosphate	1.45	1.44	1.44	1.44
Limestone	0.53	0.52	0.53	0.53
Salt	0.35	0.35	0.35	0.35
Vitamin premix[a]	0.20	0.20	0.20	0.20
Trace mineral premix[b]	0.15	0.15	0.15	0.15
Calculated nutrient composition				
Lysine, %	1.10	1.14	1.15	1.16
Digestible Lysine, %	0.97	1.01	1.01	1.01
NE[c], Mcal/lb	1.00	1.04	1.04	1.09
Dig. Lys/NE, g/Mcal	4.40	4.39	4.40	4.21
Crude fat, %	3.50	7.18	7.23	10.98
NDF, %	9.11	8.71	11.57	14.05
Ca, %	0.70	0.70	0.70	0.70
P, %	0.68	0.68	0.68	0.68
P, avail. %	0.34	0.34	0.34	0.34

Phase 2.	Treatment			
Ingredients, %	Control	Tallow	8% Germ	16% Germ
Corn	70.07	64.15	61.03	53.55
Soybean meal, 46.5% CP	27.43	29.36	28.48	27.94
Corn germ/corn bran			8.00	16.00
Bleachable tallow		4.00		
Dicalcium phosphate	1.26	1.26	1.25	1.26
Limestone	0.55	0.53	0.54	0.55
Salt	0.35	0.35	0.35	0.35
Vitamin premix[a]	0.20	0.20	0.20	0.20
Trace mineral premix[b]	0.15	0.15	0.15	0.15
Calculated nutrient composition				
Lysine, %	0.95	0.99	1.00	1.01
Digestible Lysine, %	0.83	0.87	0.87	0.87
NE[c], Mcal/lb	1.01	1.06	1.05	1.10
Dig. Lys/NE, g/Mcal	3.73	3.74	3.74	3.59
Crude fat, %	3.56	7.24	7.29	11.04
NDF, %	9.17	8.77	11.63	14.10
Ca, %	0.65	0.65	0.65	0.65
P, %	0.62	0.62	0.63	0.63
P, avail. %	0.30	0.30	0.30	0.30

Phase 3.	Treatment			
Ingredients, %	Conrol	Tallow	8% Germ	16% Germ
Corn	76.25	70.58	67.46	59.99
Soybean meal, 46.5% CP	21.49	23.17	22.29	21.75
Corn germ/corn bran			8.00	16.00
Bleachable tallow		4.00		
Dicalcium phosphate	1.03	1.02	1.01	1.02
Limestone	0.63	0.62	0.63	0.64
Salt	0.35	0.35	0.35	0.35
Vitamin premix[d]	0.15	0.15	0.15	0.15
Trace mineral premix[e]	0.10	0.10	0.10	0.10
Calculated nutrient composition				
Lysine, %	0.80	0.83	0.84	0.85
Digestible Lysine, %	0.70	0.73	0.73	0.73
NE [c], Mcal/lb	1.03	1.07	1.07	1.11
Dig. Lys/NE, g/Mcal	3.08	3.09	3.09	2.97
Crude fat, %	3.62	7.31	7.36	11.10
NDF, %	9.23	8.84	11.70	14.17
Ca, %	0.60	0.60	0.60	0.60
P, %	0.55	0.55	0.56	0.56
P, avail. %	0.25	0.25	0.25	0.25

Table 3. continued

Phase 4.	Treatment			
Ingredients, %	Control	Tallow	8% Germ	16% Germ
Corn	80.39	74.97	71.85	64.38
Soybean meal, 46.5% CP	17.54	18.97	18.08	17.55
Corn germ/corn bran			8.00	16.00
Bleachable tallow		4.00		
Dicalcium phosphate	0.83	0.83	0.83	0.83
Limestone	0.64	0.63	0.64	0.65
Salt	0.35	0.35	0.35	0.35
Vitamin premix[d]	0.15	0.15	0.15	0.15
Trace mineral premix[e]	0.10	0.10	0.10	0.10
Calculated nutrient composition				
Lysine, %	0.70	0.73	0.74	0.75
Digestible Lysine, %	0.61	0.63	0.63	0.63
NE[c], Mcal/lb	1.03	1.08	1.08	1.12
Dig. Lys/NE, g/Mcal	2.65	2.65	2.65	2.54
Crude fat, %	3.66	7.35	7.40	11.15
NDF, %	9.28	8.89	11.75	14.22
Ca, %	0.55	0.55	0.55	0.55
P, %	0.50	0.50	0.50	0.50
P, avail. %	0.21	0.21	0.21	0.21

[a]Supplied per lb of diet: retinyl acetate, 2,005 IU/lb; cholecalciferol, 181 IU; α-tocopherol acetate, 10.8 IU; menadione sodium bisulfite, 1.60 mg; riboflavin, 4; d-pantothenic acid, 8 mg; niacin, 12 mg; vitamin B_{12}, 11.8 ug.
[b]Supplied per lb of diet: Zn (as ZnO), 57.5 mg; Fe (as $FeSO_4 \cdot H_2O$), 57.5 mg; Mn (as MnO), 13.6 mg; Cu (as $CuSO4 \cdot 5\ H_2O$), 4.75 mg; I (as $Ca(IO_3) \cdot H_2O$, .13 mg; Se (as Na_2SeO_3), .135 mg.
[c]NE: Net energy.
[d]Supplied per lb of diet: retinyl acetate, 1,503 IU/lb; cholecalciferol, 135 IU; α-tocopherol acetate, 8.1 IU; menadione sodium bisulfite, 1.20 mg; riboflavin, 3 mg; d-pantothenic acid, 6 mg; niacin, 9 mg; vitamin B_{12}, 8.9 ug.
[e]Supplied per lb of diet: Zn (as ZnO), 38.3 mg; Fe (as $FeSO_4 \cdot H_2O$), 38.3 mg; Mn (as MnO), 9.1 mg; Cu (as $CuSO4 \cdot 5\ H_2O$), 3.2 mg; I (as $Ca(IO_3) \cdot H_2O$, 0.09 mg; Se (as Na_2SeO_3), 0.09 mg.

price is $30/cwt, the most one should pay for corn germ-bran is $51/ton. When hog prices are $40/cwt live and corn is $2.75/bu, the economic value of corn germ-bran is approximately $30/ton. Therefore, as the value of body weight gain (i.e., live market price) increases, the relative value of corn germ-bran decreases. This is because pigs fed 16% corn germ-bran gained approximately 10 lb less compared to pigs fed the corn-soybean meal diet. It is important to note that feeding corn germ-bran can have a negative impact on return after feed costs. For example, when corn price is $1.75/bu and live hog price $40/cwt, we project that the economic value of corn germ-bran is less than $0/ton. The low relative value of corn germ-bran in this example is due to the relatively high value of the body weight gain.

Conclusion/Implication

Both experiments showed approximately 9% improvement in feed efficiency for pigs fed diets with 4% tallow compared to diets containing corn,

(Continued on next page)

Table 4. Growth performance and carcass characteristics (Exp. 1).

		Treatment					Contrast, P value[i]		
Criteria, units		Control	Tallow	8% Germ	SEM	Trt	Con vs Tal	Con vs Germ	Tal vs Germ
Number of pigs		12	12	12					
d 0 to 17,	ADG[b]	1.79	1.87	1.78	0.05	NS[a]			
	ADFI[c]	3.14	3.10	3.21	0.04	NS			
	ADFI/ADG	1.75	1.66	1.80	0.01	< 0.04	> 0.10	> 0.35	< 0.02
d 18 to 40,	ADG	2.16	2.23	2.07	0.05	NS			
	ADFI	4.81	4.47	4.63	0.14	NS			
	ADFI/ADG	2.21	2.00	2.22	0.01	< 0.02	< 0.02	> 0.95	< 0.01
d 41 to 67,	ADG	2.19	2.40	2.17	0.03	< 0.02	< 0.02	> 0.85	< 0.01
	ADFI	5.71	5.69	5.95	0.08	NS			
	ADFI/ADG	2.60	2.36	2.74	0.01	< 0.001	< 0.01	> 0.11	< 0.0001
d 68 to 93,	ADG	2.09	2.09	2.02	0.03	NS			
	ADFI	6.59	6.37	6.73	0.25	NS			
	ADFI/ADG	3.15	3.03	3.33	0.01	< 0.04	< 0.29	> 0.10	< 0.01
d 0 to 93,	ADG	2.08	2.17	2.03	0.05	NS			
	ADFI	5.27	5.11	5.35	0.15	NS			
	ADFI/ADG	2.53	2.35	2.63	0.01	< 0.001	< 0.01	> 0.15	< 0.005
FOM[d] fat depth, in		1.04	0.85	0.91	0.06	< 0.07	< 0.03	> 0.11	> 0.42
FOM LMD[e], in		2.25	2.29	2.25	0.08	NS			
Plant lean percent[f]		49.60	52.68	51.61	0.92	< 0.08	< 0.03	> 0.14	> 0.40
Dressing, %		74.76	76.23	74.15	0.86	< 0.06	> 0.10	> 0.49	< 0.03
10^{th} rib backfat depth, in		0.84	0.71	0.75	0.04	NS			
10^{th} rib LMA[g], in^2		6.57	6.81	6.37	0.07	NS			
Carcass fat-free lean[h], %		50.06	51.38	50.57	0.67	NS			

[a]NS = Main effect was P > 0.10, therefore differences in contrasts were not reported.
[b]ADG = average daily gain, lb.
[c]ADFI = average daily feed intake, lb.
[d]Fat-O-Meter.
[e]LMD = longissimus muscle depth.
[f]Estimated by: Percent lean = 58.86 – (0.61 × fat depth, mm) + (0.012 × longissimus muscle depth, mm).
[g]LMA = longissimus muscle area.
[h]Calculated from equation of NPPC, 1991.
[i]Con = Control; Tal = Tallow; Germ = 8% Germ.

Table 5. Growth performance and carcass characteristics (Exp. 2).

Criteria, units		Treatment						Contrast, P Value[j]					
		Control	Tallow	8% Germ	16% Germ	SEM	Trt	Con vs Tal	Con vs 8%	Con vs 16%	Tal vs 8%	Tal v 16%	8% v 16%
Number of pens		6	6	6	6								
d 0 to 13,	ADG[b]	1.62	1.59	1.56	1.48	0.03	< 0.02	> 0.36	> 0.14	< 0.005	> 0.54	< 0.02	< 0.05
	ADFI[c]	3.47	3.31	3.39	3.34	0.04	< 0.05	< 0.02	> 0.16	< 0.03	> 0.17	> 0.65	> 0.34
	ADFI/ADG	2.18	2.08	2.16	2.25	0.01	< 0.005	> 0.19	> 0.45	< 0.01	< 0.06	< 0.001	< 0.05
d 14 to 42,	ADG	2.00	2.03	1.96	1.97	0.03	NS[a]						
	ADFI	5.22	4.90	5.16	5.09	0.05	< 0.002	< 0.001	> 0.40	> 0.09	< 0.005	< 0.02	> 0.34
	ADFI/ADG	2.61	2.41	2.64	2.59	0.01	< 0.001	< 0.001	> 0.65	> 0.66	< 0.0005	< 0.005	> 0.38
d 43 to 70,	ADG	1.84	1.79	1.84	1.79	0.06	NS						
	ADFI	6.09	5.79	6.13	5.99	0.09	< 0.07	< 0.03	> 0.79	> 0.42	< 0.02	> 0.13	> 0.29
	ADFI/ADG	3.30	3.24	3.34	3.35	0.01	NS						
d 71 to 102,	ADG	1.82	1.89	1.66	1.66	0.01	NS						
	ADFI	6.71	6.24	6.62	6.45	0.16	NS						
	ADFI/ADG	3.69	3.29	3.98	3.88	0.01	< 0.07	> 0.10	> 0.32	> 0.50	< 0.02	< 0.03	> 0.73
d 0 to 102,	ADG	1.85	1.86	1.78	1.75	0.04	NS						
	ADFI	5.72	5.35	5.67	5.57	0.07	< 0.007	< 0.005	> 0.63	> 0.15	< 0.005	< 0.05	> 0.32
	ADFI/ADG	3.09	2.88	3.19	3.18	0.01	< 0.005	< 0.02	> 0.28	> 0.30	< 0.005	< 0.005	> 0.96
	BW gain[d]	188.42	189.23	181.27	178.80	4.28	NS						
10th rib backfat depth, in		0.91	1.01	0.93	0.89	0.02	< 0.02	< 0.01	> 0.59	> 0.52	< 0.05	< 0.005	> 0.24
10th rib LMA[e], in^2		6.41	6.56	6.45	6.38	0.07	NS						
Carcass fat-free lean[f], %		48.87	48.09	48.88	49.29	0.28	< 0.06	< 0.07	> 0.98	> 0.31	< 0.07	< 0.01	> 0.32
Dressing, %		75.19	75.56	74.89	75.06	0.16	< 0.05	> 0.11	> 0.19	> 0.55	< 0.01	< 0.05	> 0.45
Marbling[g]		3.29	2.88	3.05	2.79	0.11	< 0.02	< 0.02	> 0.12	< 0.005	> 0.27	> 0.54	< 0.10
Muscle pH		5.66	5.60	5.61	5.63	0.02	< 0.08	< 0.02	< 0.06	> 0.25	> 0.54	> 0.14	> 0.37
Firmness[h]		3.33	3.07	3.09	3.01	0.09	< 0.09	< 0.05	< 0.08	< 0.05	> 0.71	> 0.81	> 0.55
Drip loss[i], %		30.88	37.81	37.32	35.40	3.37	NS						
Minolta a* color		6.66	7.27	6.48	6.64	0.15	< 0.007	< 0.01	> 0.40	> 0.92	< 0.005	< 0.01	> 0.45
Minolta b* color		1.43	1.84	1.72	1.46	0.13	NS						
Minolta L* color		45.12	45.84	46.01	45.29	0.35	NS						

[a]NS = Main effect was P > 0.10, therefore differences in contrasts were not reported.
[b]ADG = average daily gain, lb.
[c]ADFI = average daily feed intake, lb.
[d]Overall body weight gain, lb.
[e]LMA = longissimus muscle area.
[f]Calculated from equation of NPPC, 1991.
[g] Subjective score of 1 to 4, where 1 = practically devoid of marbling and 4 = moderate to slightly abundant marbling.
[h]Subjective score of 1 to 4, where 1 = very soft and 4 = very firm.
[i]Drip loss was measured as a subjective percentage of filter paper that is saturated by moisture from longissimus muscle purge.
[j]Con = Control; Tal = Tallow; 8% = 8% Germ; 16% = 16% Germ.

Table 6. Maximum value of corn germ-bran in a corn-soybean meal diet for growing-finishing pigs, $/ton.[a]

Live hog price, $/cwt	Corn price, $/bushel					
	1.75	2.00	2.25	2.50	2.75	3.00
10	52	63	73	84	95	104
15	42	52	62	73	83	93
20	31	42	52	62	73	83
25	21	31	41	51	62	72
30	10	20	31	41	51	62
35	*[b]	10	20	30	41	51
40	*	*	9	20	30	40
45	*	*	*	9	19	29
50	*	*	*	*	9	19

[a]Used average daily feed intake from feeding Phases 1, 2, 3, and 4 and overall bodyweight gains for Control and 16% Germ treatments from Table 5. Assumes soybean meal price of $175/ton and no effect on carcass premiums/discounts.
[b]* Indicates that the maximum purchase price for corn germ-bran product is less than $0/ton.

soybean meal, and corn germ-corn bran. The high dietary fiber from corn germ-bran decreased the feeding value of the product. Additionally, it appears that the lipid component of corn germ may not be readily digested by the pig, and resulted in a decreased feeding value relative to its chemical composition. Therefore, producers and nutritionists should evaluate the current pricing and compare the relative feeding value of corn germ-bran (or other by-products) prior to use in growing-finishing swine diets.

[1]Steven J. Kitt is a graduate student, Phillip S. Miller is an associate professor, Duane E. Reese is an Extension Swine Specialist, and Robert L. Fischer is a graduate student and research technologist in the Department of Animal Science.

Vitamin B_{12} Requirement for Weanling Pigs

Sara S. Blodgett
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Summary and Implications

An experiment was conducted to further define the vitamin B_{12} requirement of the 11- to 44-lb pig. Pigs (initial weight 11.20 lb) were fed one of six diets for a total of 35 days: 1) Negative control, common nursery diet with no added vitamin B_{12}; 2) 1X, common nursery diet with the addition of 100% the 1998 NRC-requirement for the 11- to 22-lb pig for vitamin B_{12} (7.94 µg/lb of diet), 3) 2X, common nursery diet with the addition of 200% the 1998 NRC-requirement for the 11- to 22-lb pig for vitamin B_{12} (15.87 µg/lb of diet), 4) 4X, common nursery diet with the addition of 400% the 1998 NRC-requirement for the 11- to 22-lb pig for vitamin B_{12} (31.75 µg/lb of diet), 5) 8X, common nursery diet with the addition of 800% the 1998 NRC-requirement for the 11- to 22-lb for vitamin B_{12} (63.49 µg/lb of diet), and 6) 16X, common nursery diet with the addition of 1600% the 1998 NRC-requirement for the 11- to 22-lb pig for vitamin B_{12} (126.98 µg/lb of diet). Pig weights and feed disappearances were measured weekly to determine average daily gain (ADG), average daily feed intake (ADFI), and feed efficiency (ADG/ADFI). Pigs were visually scored to assess any visual signs of vitamin B_{12} deficiencies on d 14, 21, 28, and 35. During Phase I, there was no growth or feed intake response to supplemental vitamin B_{12}. During Phase II and the overall experimental period, there were no feed intake responses. During Phase II, there were quadratic responses of ADG ($P < 0.009$) and feed efficiency responses ($P < 0.02$) to supplemental vitamin B_{12}. Overall (Phase I +II), there was a tendency for a linear growth response ($P < 0.1$) and there was a quadratic feed efficiency response ($P < 0.02$). There were no differences among groups based on visual assessment of vitamin B_{12} deficiencies. Based on these results the vitamin B_{12} requirement of the 11- to 22-lb pig is similar to that recommended by the 1998 NRC (7.94 µg/lb). However, the 22- to 44-lb pigs responded to vitamin B_{12} concentrations between 4 and 8 times that currently recommended by the 1998 NRC (6.8 µg/lb of diet). These data suggest that many pork producers are feeding vitamin B_{12} at concentrations well below those observed to maximize growth and feed efficiency. The data from this experiment should be used in the reassessment of the vitamin B_{12} requirement for weanling pigs.

Introduction

Our group previously reported that pigs fed four times the 1998 NRC requirement for vitamin B_{12} had greater ADG during phase II (d 15 to 35 post-weaning) and a greater ADG and improved feed efficiency during the overall (d 0 to 35 post-weaning) experimental period as compared to pigs not fed supplemental vitamin B_{12}. In another study, we reported that pigs fed supplemental vitamin B_{12} had greater ADG and improved feed efficiencies during phase II and the overall experimental period. Based on these findings there was interest in reassessing the current vitamin B_{12} requirement in weanling pigs (11- to 44-lb).

The objective of this study was to determine the vitamin B_{12} requirement of 11- to 22-lb pigs and 22- to 44-lb pigs. Our hypothesis was that the vitamin B_{12} requirement of the 11- to 22-lb pigs will be near that currently recommended by the 1998 NRC (7.94 µg/lb of diet) and that the vitamin B_{12} requirement of the 22- to 44-lb pigs will be greater than that currently suggested by the 1998 NRC (6.8 mg/lb).

Materials and Methods

Experimental Design

One hundred forty-four crossbred pigs [Danbred × (Danbred × Nebraska White Line)] were allotted based on initial weight and litter of origin, to one of six treatments using a completely randomized design. Treatments were arranged as a regression surface design. There were six replications per treatment and four pigs per pen. Pigs were weaned at 14 to 17 d of age with an average initial weight of 11.2 lb. Average final weight was 45.8 lb. The duration of the trial was 35 d and it was divided into two phases, (phase I was from d 0 to 14 and phase II was from d 15 to 35).

The six diets included (Table 1): 1) *Negative control*, common nursery diet with no added vitamin B_{12}; 2) *1X*, common nursery diet with the addition of 100% the 1998 NRC-requirement for the 11- to 22-lb pig for vitamin B_{12} (7.94 µg/lb of diet), 3) *2X*, common nursery diet with the addition of 200% the 1998 NRC-requirement for the 11- to 22-lb pig for vitamin B_{12} (15.87 µg/lb of diet), 4) *4X*, common nursery diet with the addition of 400% the 1998 NRC-requirement for the 11- to 22-lb pig for vitamin B_{12} (31.75 µg/lb of diet), 5) *8X*, common nursery diet with the addition of 800% the 1998 NRC-requirement for the 11- to 22-lb for vitamin B_{12} (63.49 µg/lb of diet), and 6) *16X*, common nursery diet with the addition of 1600% the 1998 NRC-requirement for the 11- to 22-lb pig for vitamin B_{12} (126.98 µg/lb of diet). All Phase-I diets were formulated to contain 22% CP, 1.60% total lysine, 0.90% Ca, and 0.80% P. Phase-II diets were

(Continued on next page)

similar to diets used in phase I, except diets were formulated to contain 21% CP, 1.40% total lysine, 0.85% Ca, and 0.74% P.

Live Animal Care and Measurements

Pigs and feeders were weighed every 7 d to determine average daily gain (ADG), average daily feed intake (ADFI), and feed efficiency (ADG/ADFI). Two individuals visually examined the pigs on d 14, 21, 28, and 35 and evaluated the pigs on a scale of 1 to 5 (1 having extensive deficiency signs and 5 showing no signs of deficiency). Visual assessment was based on physical appearances, such as skin and hair coat characteristics.

Pigs were housed in pens (6.3 x 3.4 ft) that had plastic-coated wire flooring, one nipple waterer, and one four-hole stainless steel feeder. Pigs had ad libitum access to feed and water throughout the experiment. Heat lamps and comfort boards were provided during Phase I. The relative humidity (ranging between 38% and 70%) and room temperature (maintained at 78°F) were monitored continuously using temperature and humidity recorders.

Results and Discussion

The response of ADG, ADFI, and ADG/ADFI to dietary treatments are shown in Figures 1 a, b, and c, respectively. During Phase I, there were no growth or feed intake responses to supplemental vitamin B_{12}. During Phase II, ADG responded quadratically to vitamin B_{12} supplementation ($P < 0.007$) with pigs fed 8 times the NRC recommendation having the greatest ADG (1.34 lb). In addition, feed efficiency responded quadratically ($P < 0.02$) to vitamin B_{12} supplementation with pigs fed the 4X diet exhibiting the greatest feed efficiency (0.721 lb/lb). For the overall experimental period, there was a tendency for a linear and quadratic growth response ($P < 0.07$ and $P < 0.09$, respectively) of ADG to vitamin B_{12} supplementation with pigs fed the 8X diet having the greatest ADG (1.05 lb). Feed efficiency responded quadratically during the

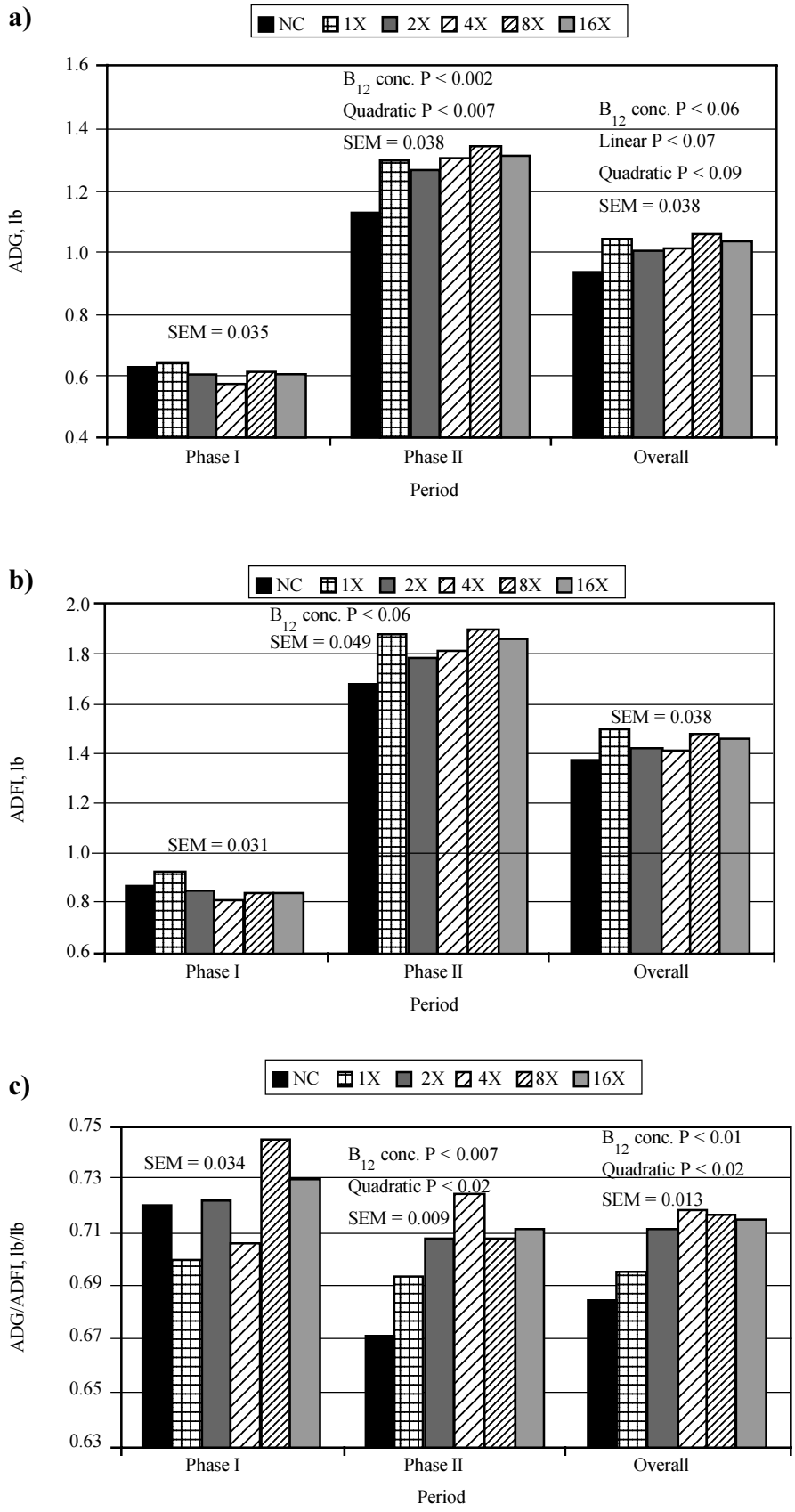

Figure 1. The response of a) average daily gain (ADG), b) average daily feed intake (ADFI), and c) ADG/ADFI in weanling pigs to 44 lb. SEM = standard error of the mean. NC = Negative control, 1X = 100%, 2X = 200%, 4X = 400%, 8X - 800%, and 16X = 1,600% the 1998 NRC requirment recommendation for the 11- to 22-lb pig.

Table 1. Composition of experimental diets, as-fed basis.

	Phase I[a]						Phase II[a]					
Ingredient	NC	1X	2X	4X	8X	16X	NC	1X	2X	4X	8X	16X
Corn	30.19	30.19	30.19	30.19	30.19	30.19	45.13	45.13	45.13	45.13	45.13	45.13
Soybean meal, 46.5% CP	11.00	11.00	11.00	11.00	11.00	11.00	30.62	30.62	30.62	30.62	30.62	30.62
Soy protein concentrate	7.50	7.50	7.50	7.50	7.50	7.50						
Whey	30.00	30.00	30.00	30.00	30.00	30.00	15.00	15.00	15.00	15.00	15.00	15.00
Blood cells							2.00	2.00	2.00	2.00	2.00	2.00
Animal plasma	8.00	8.00	8.00	8.00	8.00	8.00						
Lactose	4.00	4.00	4.00	4.00	4.00	4.00						
Corn oil	5.00	5.00	5.00	5.00	5.00	5.00	3.00	3.00	3.00	3.00	3.00	3.00
Limestone	0.68	0.68	0.68	0.68	0.68	0.68	0.53	0.53	0.53	0.53	0.53	0.53
Dicalcium phosphate	1.30	1.30	1.30	1.30	1.30	1.30	1.60	1.60	1.60	1.60	1.60	1.60
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
Vitamin mix[b]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral[c]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-Lysine•HCl	0.15	0.15	0.15	0.15	0.15	0.15	0.01	0.01	0.01	0.01	0.01	0.01
DL-Methionine	0.10	0.10	0.10	0.10	0.10	0.10	0.01	0.01	0.01	0.01	0.01	0.01
ZnO	0.40	0.40	0.40	0.40	0.40	0.40	0.30	0.30	0.30	0.30	0.30	0.30
Mecadox®, 50 g/ton	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Vitamin B_{12}, µg/lb		7.94	15.87	31.75	63.49	126.98		7.94	15.87	31.75	63.49	126.98

[a]NC = Negative control, 1X = 100%, 2X = 200%, 4X = 400%, 8X = 800%, 16X = 1,600% the 1998 NRC requirement for the 11- to 22-lb pig.
[b]Supplied per kilogram of diet: retinyl acetate, 5,500 IU; cholecalciferol, 550 IU; alpha-tocopherol acetate, 30 IU; menadione sodium bisulfite, 4.4 mg; riboflavin, 11 mg; d-pantothenic acid, 22.05 mg; niacin, 30 mg.
[c]Supplied per kilogram of diet: Zn (as ZnO), 125 mg; Fe (as $FeSO_4 \cdot H_2O$), 125 mg; Mn (as MnO), 15 mg; Cu (as $CuSO_4 \cdot 5\ H_2O$), 10 mg; I (as $Ca(IO_3) \cdot H_2O$), 0.25 mg; Se (as Na_2SeO_3), 0.3 mg.

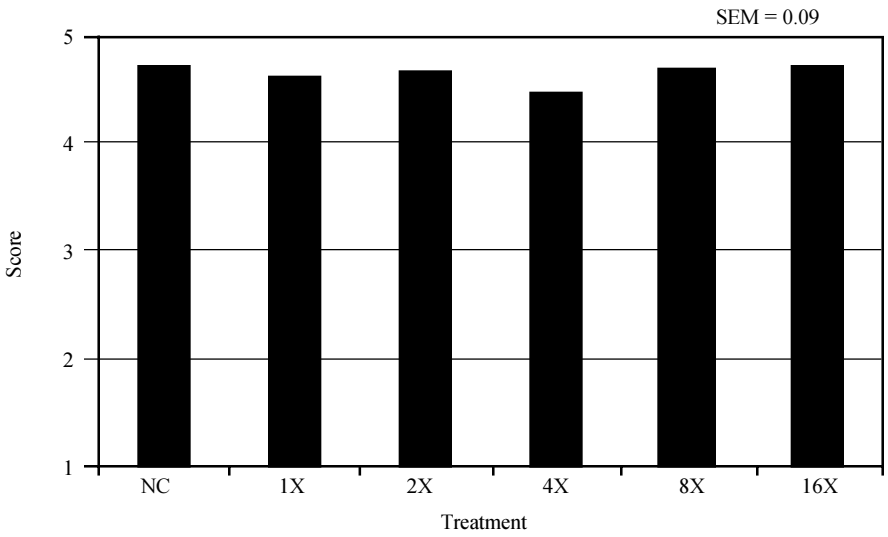

Figure 2. Visual assessment of deficiency signs. Data based on a scale of 1 to 5, with 1 having extensive deficiency signs and 5 having no deficiency signs. SEM = standard error of the mean.

overall experimental period ($P < 0.02$). Pigs supplemented with 4 times the NRC recommendation had the greatest feed efficiency (0.718 lb/lb). There was a significant main effect ($P < 0.06$) of feed intake due to vitamin B_{12} supplementation during Phase II.

The growth and feed efficiency data for the 4X and 8X supplemental groups were similar during Phase II and overall. Pigs fed supplemental vitamin B_{12} consistently had improved growth characteristics compared to the negative control group during Phase II. This suggests that the vitamin B_{12} requirement for the 22-to-44 lb pig may be well above concentrations currently recommended by the 1998 NRC.

Visual scores for B-vitamin assessment for each group are shown in Figure 2. There were no differences among groups based on visual assessment of vitamin B_{12} deficiencies.

Conclusion

The vitamin B_{12} requirement of the 11- to 22-lb pig appears to be similar to that recommended by the 1998 NRC (7.94 µg/lb). During phase II (22- to 44-lb), pigs responded to vitamin B_{12} concentrations between 4- and 8-fold greater than those currently recommended by the 1998 NRC (6.8 µg/lb of diet). Those concentrations are similar to only about 25% of the vitamin B_{12} levels used in the feed industry for weanling pigs (28.63 µg/lb of diet) according to a recent survey.

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Vitamin B_{12} and Mecadox® Supplementation in Weanling Pig Diets

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Summary and Implications

An experiment was conducted to assess the responsiveness of weanling pigs to an antibiotic-like compound (Mecadox®) and vitamin B_{12}. Pigs (initial weight 11.3 lb) were fed one of four diets for a total of 35 days: 1) Negative control, common nursery diet with no added Mecadox® or vitamin B_{12}; 2) Mecadox®, common nursery diet with 50 g/ton added Mecadox®; 3) B_{12}, common nursery diet with 36.28 µg/lb added vitamin B_{12}; and 4) Positive control, common nursery diet with 50 g/ton added Mecadox® and 36.28 µg/lb added vitamin B_{12}. Pig weights and feed disappearance were measured weekly to determine average daily gain (ADG), average daily feed intake (ADFI), and feed efficiency (ADG/ADFI). Pigs were visually scored to assess any potential vitamin B_{12} deficiencies on d 14, 21, 28, and 35. No Mecadox® × vitamin B_{12} interactions were observed. During Phase I, pigs fed Mecadox® had greater ($P < 0.02$) ADG and a greater ADFI ($P < 0.003$) compared to pigs not fed Mecadox®. During Phase II and overall, pigs fed vitamin B_{12} had a greater ADG ($P < 0.003$), ADFI ($P < 0.04$), and improved feed efficiency ($P < 0.02$ and $P < 0.03$, respectively) compared to pigs not fed diets containing supplemental vitamin B_{12}. During Phase II, pigs fed Mecadox® had a greater ADFI ($P < 0.02$) compared to pigs not fed Mecadox®. For the overall experimental period, pigs fed Mecadox® had a greater ($P < 0.02$) ADG and ADFI ($P < 0.004$) versus pigs which were not fed Mecadox®. During Phase II and the overall experimental period, pigs fed Mecadox® had lower feed efficiencies ($P < 0.02$ and $P < 0.04$, respectively) than those not fed diets containing supplemental Mecadox®. There were no differences among groups for visual assessment of B-vitamin deficiencies. Vitamin B_{12} may be a partial alternative to Mecadox® for 22- to 44-lb pigs. The vitamin B_{12} requirement of the 22- to 44-lb pig may be greater than the current NRC requirement recommendation.

Introduction

B-vitamins have received little attention by swine nutritionists since the 1950s and 1960s. During the past 40 to 50 years, pigs with higher protein accretion rates have been developed, and that may increase their B-vitamin requirements. Vitamins are important for normal body growth and maintenance and support the bodies immune system. Vitamins are important to consider when formulating diets, especially the water-soluble vitamins, because the body cannot synthesize these vitamins and there is little storage in the body. In addition, vitamin requirements are

Table 1. Composition of experimental diets, as fed basis.

	Phase I				Phase II			
Ingredient, %	NC[a]	Mecadox®	Vitamin B_{12}	PC[a]	NC[a]	Mecadox®	Vitamin B_{12}	PC[a]
Corn	31.81	31.81	31.81	31.81	41.93	41.93	41.93	41.93
Soybean meal, 46.5% CP	12.16	12.16	12.16	12.16	28.24	28.24	28.24	28.24
Soy protein concentrate	6.25	6.25	6.25	6.25				
Whey	30.00	30.00	30.00	30.00	20.00	20.00	20.00	20.00
Blood cells					2.00	2.00	2.00	2.00
Animal plasma	8.00	8.00	8.00	8.00				
Lactose	4.00	4.00	4.00	4.00				
Corn oil	5.00	5.00	5.00	5.00	3.00	3.00	3.00	3.00
Limestone	0.65	0.65	0.65	0.65	0.50	0.50	0.50	0.50
Dicalcium phosphate	1.28	1.28	1.28	1.28	1.50	1.50	1.50	1.50
Salt	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Vitamin mix[b]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral[c]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-Lysine•HCl	0.05	0.05	0.05	0.05	0.12	0.12	0.12	0.12
DL-Methionine	0.11	0.11	0.11	0.11	0.03	0.03	0.03	0.03
Mecadox®, 50 g/ton		1.00	1.00			1.00		1.00
Vitamin B_{12}, µg/lb			36.28	36.28			36.28	36.28

[a]NC = Negative control and PC = Positive control.
[b]Supplied per kilogram of diet: retinyl acetate, 5,500 IU; cholecalciferol, 550 IU; alpha-tocopherol acetate, 30 IU; menadione sodium bisulfite, 4.4 mg; riboflavin, 11 mg; d-pantothenic acid, 22.05 mg; niacin, 30 mg.
[c]Supplied per kilogram of diet: Zn (as ZnO), 125 mg; Fe (as $FeSO_4 \cdot H_2O$), 125 mg; Mn (as MnO), 15 mg; Cu (as $CuSO_4 \cdot 5\ H_2O$), 10 mg; I (as $Ca(IO_3) \cdot H_2O$), 0.25 mg; Se (as Na_2SeO_3), 0.3 mg.

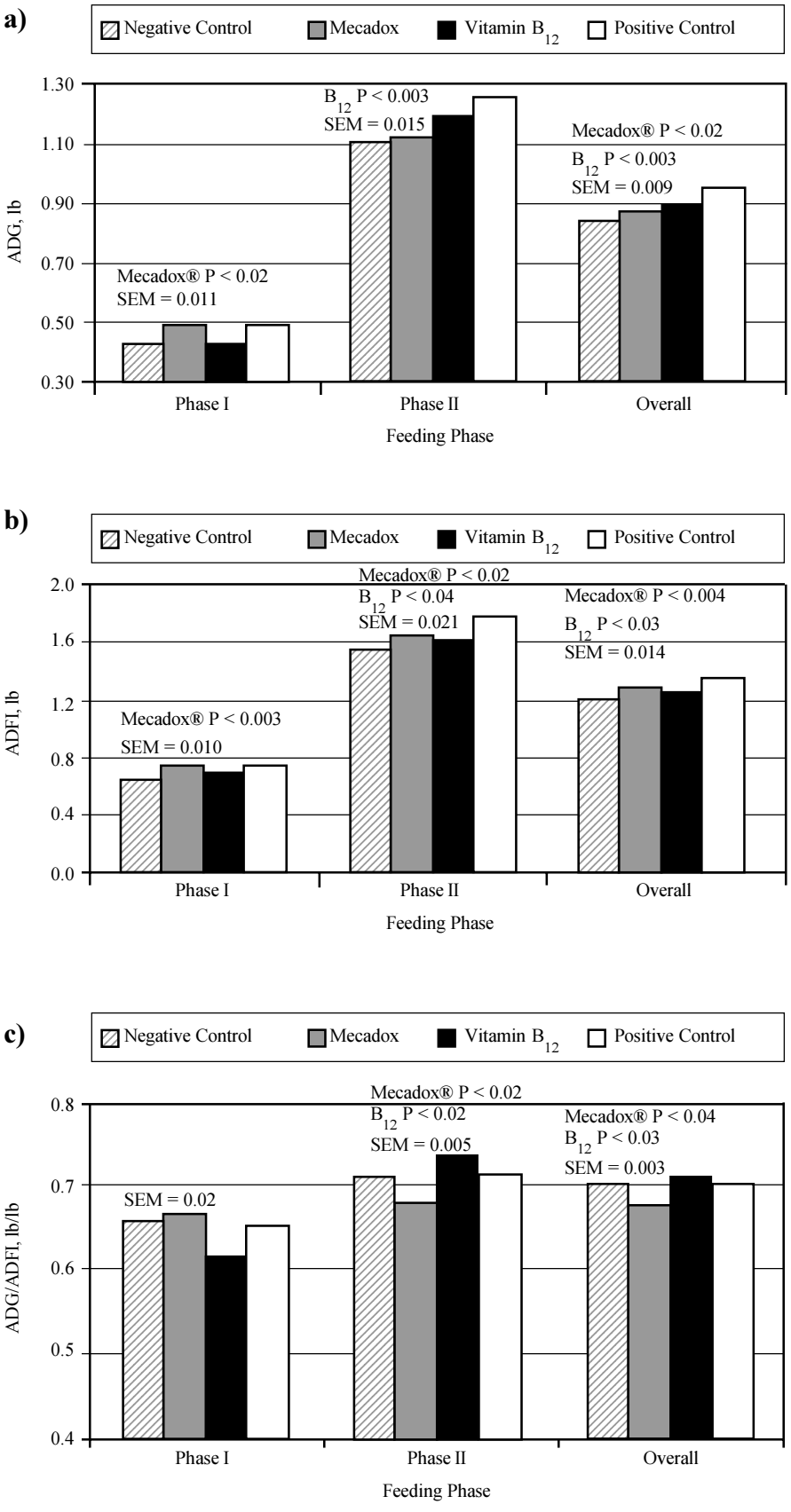

Figure 1. The response of a) average daily gain (ADG), b) average daily feed intake (ADFI), and c) ADG/ADFI in weanling pigs. SEM = standard error of the mean.

affected by many factors, including herd health status, age, and previous nutrition. In a recent survey published by BASF of 27 companies that produce swine feeds or raise pigs, the average addition of vitamin B_{12} to starter diets (weaning to 44 lb body weight) was 18.62 µg/lb of feed. Companies representing the highest 25% of vitamin B_{12} concentrations reported were adding an average of 28.63 µg/lb of feed and the lowest 25% were adding an average of 12.10 µg/lb of feed. These findings indicate that the industry is adding vitamin B_{12} at concentrations well above current 1998 NRC recommendations.

With the possibility of a ban on antibiotics, it is important to look at how the removal of antibiotics may affect the requirements of other nutrients. Because vitamin B_{12} is involved in immune function, its status could be affected by the removal of antibiotics. Therefore, vitamin B_{12} may serve as a partial alternative to feeding antibiotics for disease prevention and growth promotion.

The objective of this study was to investigate factors affecting the vitamin B_{12} requirement of weanling pigs, specifically antibiotics (Mecadox®). Our hypothesis was that pigs fed diets containing supplemental Mecadox® or vitamin B_{12} would have greater average daily gain and improved feed efficiency compared to pigs fed a negative control diet.

Materials and Methods

Experimental Design

Ninety-six crossbred pigs [Danbred × (Danbred × Nebraska White Line)] were allotted based on initial weight and litter of origin, to one of four treatments using a randomized complete block design. Treatments were arranged as a 2 × 2 factorial. There were four replications per treatment and six pigs per pen. Pigs were weaned at 14 to 16 d post-farrowing with an average initial weight of 11.3 lb. Average final weight was 42.4 lb. The duration of the trial was 35 days, which was divided

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into two phases (Phase I was from days 0 to 14 and Phase II was from days 15 to 35).

The four diets included (see Table 1): 1) *Negative control*, common nursery diet with no added Mecadox® or vitamin B_{12}; 2) *Mecadox®*, common nursery diet with 50 g/ton added Mecadox®; 3) *B_{12}*, common nursery diet with 36.28 µg/lb added vitamin B_{12}; and 4) *Positive control*, common nursery diet with 50 g/ton added Mecadox® and 36.28 µg/lb added vitamin B_{12}. None of the diets contained ZnO. All Phase-I diets were formulated to contain 22% CP, 1.5% total lysine, 0.9% Ca, and 0.78% P. Phase-II diets were similar to diets used in phase I, except diets were formulated to contain 21% CP, 1.4% total lysine, 0.86% Ca, and 0.74% P.

Live Animal Care and Measurements

Pigs and feeders were weighed every 7 days to determine average daily gain (ADG), average daily feed intake (ADFI), and feed efficiency (ADG/ADFI). Two individuals visually examined the pigs on days 14, 21, 28, and 35 and evaluated the pigs using a scale of 1 to 5 (1 having extensive deficiency signs and 5 showing no signs of deficiency). This assessment was based on physical appearance, such as skin lesions and hair coat characteristics.

Pigs were housed in pens (6.3 × 3.4 ft) that had plastic-coated wire flooring, one nipple waterer, and one four-hole stainless steel feeder. Pigs had ad libitum access to feed and water throughout the experiment. Heat lamps and comfort boards were provided during Phase I of the trial. The relative humidity (ranging between 50% and 60%) and room temperature (maintained at 78°F) were monitored continuously using a temperature and humidity recorder.

Results and Discussion

The response of ADG, ADFI, and ADG/ADFI to dietary treatments are shown in Figures 1 a, b, and c, respectively. No Mecadox® × vitamin B_{12} interactions were observed. During Phase I, pigs fed Mecadox® had a greater ($P < 0.02$) ADG (0.49 lb vs. 0.43 lb) and a 0.07 lb greater ADFI ($P < 0.003$) versus pigs not fed an antibiotic. During Phase II, pigs fed diets containing supplemental vitamin B_{12} had greater ($P < 0.003$) ADG (1.11 lb vs. 1.23 lb), 0.10 lb greater ADFI ($P < 0.04$), and improved ($P < 0.02$) feed efficiency (0.72 vs. 0.69) compared to pigs not fed diets containing supplemental vitamin B_{12}. During Phase II, pigs fed Mecadox® had greater ($P < 0.02$) ADFI (1.71 lb vs. 1.60 lb) compared to pigs not fed supplemental Mecadox®. During the overall experimental period, pigs fed supplemental vitamin B_{12} had a greater ($P < 0.003$) ADG (0.92 lb vs. 0.85 lb), greater ($P < 0.03$) ADFI (1.31 lb vs. 1.24 lb), and improved ($P < 0.03$) feed efficiency (0.70 vs. 0.68) versus pigs not fed supplemental vitamin B_{12}. Overall, pigs fed Mecadox® had a greater ($P < 0.02$) ADG (0.91 lb vs. 0.86 lb) and 0.10 lb greater ADFI ($P < 0.004$) versus pigs not fed supplemental Mecadox®. During Phase II and the overall experimental period, pigs fed supplemental Mecadox® had lower feed efficiencies ($P < 0.02$ and $P < 0.04$, respectively) compared to pigs not fed diets containing supplemental Mecadox®.

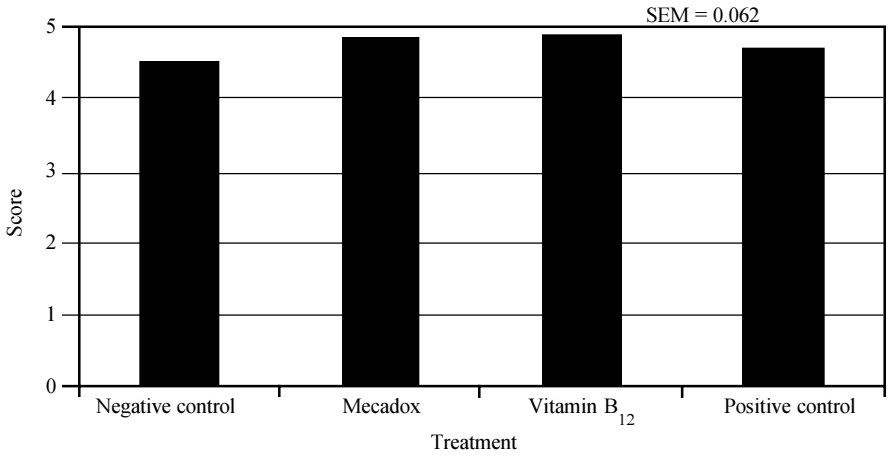

Figure 2. Visual assessment of deficiency signs. Data based on a scale of 1 to 5, with 1 having extensive deficiency signs and 5 having no deficiency signs. SEM = standard error of the mean.

Visual scores to assess B-vitamin status for each group are shown in Figure 2. No B-vitamin deficiencies were observed throughout the 5-week study and there were no differences among treatment groups.

The vitamin B_{12} concentration of the negative control and vitamin B_{12} supplemented diets were calculated to be 3.13 and 39.41 µg/lb of diet, respectively, and the NRC requirement for the 22- to 44-lb pig is 6.80 µg/lb of diet. Thus, as expected, supplemental vitamin B_{12} and antibiotics improved growth performance. All of the growth response due to vitamin B_{12} supplementation was observed in Phase II. A response to vitamin B_{12} during phase I may not have been observed because sows' milk has a high concentration of vitamin B_{12} and perhaps the pigs had sufficient stores of vitamin B_{12} at weaning to supply vitamin B_{12} for the first two weeks post-weaning.

Conclusion

The data suggest that vitamin B_{12} may be a partial alternative to Mecadox® for 22- to 44-lb pigs. The results from this study indicate that the vitamin B_{12} requirement of 22- to 44-lb pigs may be greater than the current NRC requirement recommendation. Further research is needed to more precisely define the vitamin B_{12} requirement of the 22- to 44-lb pig.

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Do Crowded Pigs Respond to Paylean®?

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Summary and Implications

Paylean® is a feed additive that improves feed efficiency, daily gain and carcass merit in finishing pigs. Restrictions in space allocation are known to reduce daily feed intake and daily gain. Thus, pigs may not respond as expected to dietary additions of Paylean® if feed intake is reduced due to crowding. A 2 x 2 factorial design was used to examine the potential interaction of Paylean® and space allocation. Experimental treatments were: 1) 14 or 19 pigs per pen (8.0 vs 5.9 ft²/pig); and 2) Paylean® for four weeks prior to slaughter (0 or 9 g/T). In this experiment, there were no interactions between space allocation and dietary Paylean® additions for overall daily gain, daily feed intake, feed conversion, carcass weight, carcass yield, carcass merit, carcass fat free lean, or daily fat free lean gain. Crowded pigs grew slower with no difference in feed conversion efficiency versus the uncrowded treatment. Pigs fed 9 g/T Paylean® for four weeks prior to slaughter had no difference in daily gain or final weight, but did have an increase in carcass yield (75.3 vs 74.6%), loin depth (2.71 vs 2.64 in.), carcass percent lean (56.0 vs 55.5%), and carcass premium ($5.99 vs $5.54/cwt) versus those fed 0 g/T. Incidence of and severity of tail biting were recorded on day 86 and there were no differences due to space allocation or Paylean® addition. These results suggest the response to dietary Paylean® additions is independent of the response to space allocation. In addition, the lack of treatment effects on tail biting score on day 86 suggests neither space allocations nor dietary Paylean® addition were the cause of the tail biting observed in this experiment.

Introduction

The response to Paylean® by finishing pigs is dose dependent. At low inclusion levels (4.5 g/T), Paylean® impacts pig performance by improving gain, feed efficiency and carcass leanness. As the amount of Paylean® in the diet is increased (4.5 to 18 g/T), there generally is an improvement in carcass leanness and further improvements in feed efficiency. While diets are formulated with a specific amount of Paylean® (g/T), management factors can alter the daily feed intake of finishing pigs, influencing the intake of Paylean®. One management factor that alters feed intake is space allocation. When pigs are given less space per pig, feed intake almost always declines, with a resultant decrease in daily gain. Feed conversion efficiency may or may not be impacted by a reduction in space allocation. The following experiment was conducted to investigate the interaction of space allocation and Paylean® on pig performance and carcass characteristics.

Methods

The experiment was conducted at the University of Nebraska's Haskell Ag Lab Swine Research Unit near Concord, Neb. Pigs were housed in a double curtain, naturally ventilated, fully slatted confinement facility with 16 pens and daily fresh water, under slat flushing for manure removal. Each pen measured 8 ft x 14 ft and contained one two-hole wean-to-finish feeder and one wean-to-finish cup drinker.

There were four replications of each combination of the following experimental treatments:

1) Space allocation from arrival
   a) 5.9 ft²/pig (19 pigs/pen)
   b) 8.0 ft²/pig (14 pigs/pen)
2) Paylean® in the diet for 4 weeks prior to slaughter
   a) 0 g/T
   b) 9 g/T

Crossbred barrows (Danbred USA, Seward, NE) were vaccinated for *H parasuis, M hyopneumonia,* and erysipelas. All pigs that died during the experiment were examined for cause of death by a consulting veterinarian. Pen size was not adjusted in the event of pig removal or death. Feed disappearance was adjusted for dead and removed pigs prior to data analysis.

The experimental diets are listed in Table 1. Diets were switched on the week individual pens achieved target weights. All diets contained 100g/T Tylan from arrival to 80 lb, 40 g/T from 80 to approximately 180 lb, and 0 g/T thereafter.

Pigs were weighed every three weeks for the first nine weeks of the experiment. Pigs were weighed biweekly or weekly thereafter as necessary to determine the starting time for Paylean® treatments and to determine when to market pigs. The target slaughter weight for pigs fed Paylean® was 240 pounds and pigs were fed 0 or 9 g/T Paylean® diets for a four-week period prior to slaughter. Pigs on the uncrowded treatment were switched to the Paylean®

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treatments on day 58 while pigs on the crowded treatment were switched on day 65 of the experiment based on projected daily gain prior to slaughter.

Individually identified pigs were slaughtered at IBP, Inc., Madison, Neb. for determination of carcass composition and premiums. All pigs within a space allocation treatment (crowded vs uncrowded) were marketed on the same day. Fat free lean (FFL) and daily FFL gain were estimated on individual pigs using the loin and muscle depth values reported by IBP for individual pigs and the equations for FFL as published in Composition and Quality Assessment Procedures (National Pork Producers Council, 2000).

Either 10 or seven predetermined pigs per pen (5.9 or 8.0 ft^2/pig) were bled via vena puncture on the same day as weighing and scanning. Plasma was harvested and frozen for analysis for plasma urea by the Non-Ruminant Nutrition Laboratory in the Animal Science Department at the University of Nebraska.

On day 86, all pigs were individually rated for injury due to tail biting using a 1 to 4 scale, with 1 being no injury evident and 4 being severe tail biting injury.

Results were analyzed using the ProcMixed procedure of SAS (SAS Institute, Cary, N.C,). The model included space, Paylean® addition and their interaction as fixed effects, and replication as a random effect. The pen of pigs was the experimental unit for all statistical comparisons. Death loss and pig removal was examined by Chi-square analysis.

Results and Discussion

Table 2 presents pig deaths and removal by pen, and experimental treatment. Because pen size was not adjusted in the event of pig death or removal, space allocation increased with death or removal. Two of the crowded pens had a space allocation at slaughter of 7.0 ft^2/pig, two were at 6.2, and four were the original 5.9. In no instance did the space allocation of a crowded treatment pen become

Table 1. Experimental diets.

	Period				
	65- 80 lb	80-130 lb	130- Paylean®	0 g/T Paylean®	9 g/T Paylean®
Ingredient, %					
Corn	67.13	72.68	80.38	74.73	74.68
Soybean meal, 46.5% CP	27.75	22.75	15.25	21.00	21.00
Fat[a]	2.00	2.00	2.00	2.00	2.00
Dicalcium $PO_{4,}$ 18.5%	1.20	0.85	0.70	0.70	0.70
Limestone	0.80	0.75	0.80	0.75	0.75
Salt	0.30	0.30	0.30	0.30	0.30
Vitamin premix	0.30	0.275	0.2125	0.2125	0.2125
Trace mineral premix	0.25	0.20	0.1625	0.1625	0.1625
L-lysine	0.15	0.15	0.15	0.15	0.15
Tylan 40	0.125	0.05	0.05	0	0
Paylean® premix	0	0	0	0	0.05
Calculated composition					
ME, kcal/lb	1545	1553	1557	1557	1557
Crude protein, %	18.6	16.8	13.9	16.1	16.1
Lysine, %	1.10	0.97	0.77	0.92	0.92
Avail P, %	0.29	0.22	0.19	0.19	0.19
Total P, %	0.60	0.52	0.46	0.48	0.48
Ca, %	0.77	0.64	0.59	0.59	0.59
Laboratory Analysis[b]					
Crude protein, %	18.8	18.2	16.7	17.1	17.1
Lysine, %		1.00	0.93	0.98	0.97
Ca, %	0.79	0.42	0.66	0.60	0.55
P, %	0.55	0.44	0.51	0.46	0.51
Particle size, microns		985	771	877	896

[a]CW-3800, Feed Energy Co., Des Moines, IA
[b]Ward Laboratories, Kearney, Neb.

Table 2. Effect of experimental treatments on pig death, removal, and final stocking density.

Pen no.	Density, ft^2/pig		Paylean®, g/T	Day of death/removal	Cause	
	Initial	Final			Death	Removal
23	8.0	8.0	0			
28	8.0	9.3	0	29	Ulcer	
				64		Tail bitten
32	8.0	10.2	0	57		Failure to gain
				64		Injury
				72	Streptococcus infection	
34	8.0	8.6	0	47	Gastric torsion	
21	8.0	8.0	9			
25	8.0	8.0	9			
33	8.0	8.6	9	43	PRRS/pneumonia	
38	8.0	8.6	9	43		Tail bitten
22	5.9	5.9	0			
24	5.9	5.9	0			
35	5.9	6.2	0	72	PRRS	
36	5.9	7.0	0	39	Unknown	
				43	PRRS/pneumonia	
				71		Tail bitten
26	5.9	7.0	9	2	Gastric torsion	
				8	PRRS/pneumonia	
				86		Tail bitten
27	5.9	5.9	9			
31	5.9	5.9	9			
37	5.9	6.2	9	57		Tail bitten

Table 3. Effect of experimental treatments on pig performance.

Item	Space, ft²/pig		Paylean®, g/T[a]		SE	P Values		
	5.9	8.0	0	9		Space x Paylean®	Space	Paylean®
No. pens	8	8	8	8				
Pig weight, lb								
Initial	65.0	65.5	65.3	65.2				
Paylean® initiation[a]	183.5	176.8	179.7	180.5	1.6	0.273	0.014	0.715
Final[b]	239.0	235.6	236.2	238.3	2.0	0.895	0.257	0.429
Coefficient of variation for within pen weight, %								
Initial	10.2	10.8						
Final	9.0	9.0	8.2	9.8	0.6	0.073	0.981	0.073
Average daily gain, lb								
Day 0 to Paylean® initiation	1.85	1.95	1.90	1.91	0.03	0.374	0.025	0.739
Paylean® to final	2.02	2.13	2.05	2.10	0.06	0.821	0.108	0.480
Day 0 to final	1.89	2.00	1.93	1.96	0.02	0.971	0.010	0.496
Average daily feed, lb								
Day 0 to Paylean® initiation	4.72	4.80	4.74	4.78	0.08	0.266	0.461	0.718
Paylean® to final	6.00	6.30	6.35	5.95	0.07	0.465	0.020	0.004
Day 0 to final	5.11	5.30	5.25	5.11	0.07	0.481	0.071	0.340
Feed: gain								
Day 0 to Paylean® initiation	2.55	2.46	2.51	2.51	0.03	0.623	0.063	0.939
Paylean® to final	2.99	2.97	3.10	2.85	0.07	0.675	0.697	0.001
Day 0 to final	2.70	2.65	2.72	2.64	0.03	0.452	0.208	0.069
Tail biting score on day 86[c]	1.4	1.3	1.3	1.5	0.1	0.485	0.729	0.303

[a]Initiated on day 65 for 5.9 ft²/pig treatment and day 58 for 8.0 ft²/pig treatment.
[b]Day 93 for 5.9 ft²/pig treatment and day 86 for 8.0 ft²/pig treatment.
[c]1 = none; 4 = severe.

Table 4. Effect of experimental treatments on carcass measurements.

Item	Space, ft²/pig		Paylean®, g/T[a]		SE	P Values		
	5.9	8.0	0	9		Space x Paylean®	Space	Paylean®
IBP[b] measures								
Carcass wt., lb	179.9	178.7	177.2	181.4	2.0	0.663	0.659	0.134
Carcass yield, %	74.8	75.1	74.6	75.3	0.3	0.389	0.459	0.097
Backfat, in.	0.59	0.62	0.61	0.60	0.02	0.253	0.080	0.536
Loin depth, in	2.644	2.705	2.639	2.710	0.021	0.506	0.011	0.005
Lean, %	55.70	55.80	55.50	56.00	0.07	0.060	0.682	0.001
Carcass premium, $/cwt	5.72	5.82	5.54	5.99	0.13	0.449	0.543	0.017
NPPC Standardized Fat Free Lean (FFL)								
% FFL	51.6	51.5	51.4	51.6	0.2	0.380	0.470	0.406
FFL daily gain, lb	0.750	0.798	0.760	0.788	0.009	0.505	0.003	0.046

[a]Initiated on day 65 for 5.9 ft²/pig treatment and day 58 for 8.0 ft²/pig treatment.
[b]IBP Inc., Madison, Neb.

equal to the uncrowded allocation of 8.0 ft²/pig.

Table 3 presents the main effects of space and Paylean® on pig performance. There were no interactions between space allocation and Paylean® addition to the diet for final weight, daily gain, daily feed intake, feed conversion efficiency, or tail biting score. The interaction between space allocation and Paylean® for the coefficient of variation of within pen weight at time of sale for slaughter is due to an increase in within pen CV for pigs fed 9 g/T Paylean® and given 5.9 ft²/pig versus 0 g/T Paylean® (10.5 vs 7.5 %) and no difference in within pen CV for either Paylean® treatment at 8 ft²/pig (9.0 vs 9.0%).

Pigs given 5.9 ft²/pig grew slower from the time of arrival to the beginning of the Paylean® treatments. Unlike previous research results, there was no effect of space allocation on feed intake prior to the initiation of the Paylean® treatments. However, crowded pigs had a reduction in feed intake during the four week Paylean® treatment period. This resulted in a tendency for a reduction in feed intake due to a restriction in space allocation from arrival to slaughter.

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There was a tendency for crowded pigs to have a poorer feed conversion efficiency from arrival to the initiation of the Paylean® treatments. However, there was no effect of space allocation on feed efficiency during the Paylean® treatment period or overall.

There was no effect of 9 g/T Paylean® addition in the diet for four weeks prior to slaughter on final weight compared to 0 g/T Paylean® in the diet. There was no effect of Paylean® addition on daily gain, either during the four-week period it was in the experimental diets or overall. The addition of 9 g/T Paylean® to the diet did result in a decrease in daily feed intake during the four-week inclusion period and a significant improvement in feed:gain for the four-week treatment period. This improvement was large enough to result in an overall improvement in feed:gain compared with the 0 g/T treatment.

There was no effect of experimental treatments on death loss or the number of pigs removed for tail biting or poor performance. Tail biting scores on day 86 (Table 3) suggest no effect of experimental treatments on tail biting. In general, the incidence of tail biting was not considered severe in this experiment.

Similar to the live performance data, there were minimal interactions between space allocation and Paylean® treatments for any of the IBP carcass traits reported (Table 4). There was no effect of experimental treatments on carcass weight, similar to the lack of treatment effect on live weight at slaughter. However, carcass yield was increased slightly for pigs fed 9 g/T Paylean® versus 0 g/T. Crowded pigs had a slight reduction in carcass backfat depth when compared to uncrowded pigs. Loin muscle depth was decreased for the crowded versus the uncrowded pigs. However, there was no effect of space allocation on carcass percentage lean, carcass premium or fat free lean percentage. Because of the slower daily live weight gain, there was a decrease in daily FFL gain for the crowded versus uncrowded pigs.

Table 5. Effect of experimental treatments on plasma urea, mg/100 ml.

Day	Space, ft^2/pig		Paylean®, g/T[a]			P Values		
	5.9	8.0	0	9	SE	Space x Paylean®	Space	Paylean®
2	22.3	23.4	23.5	22.2		0.133	0.341	0.238
23	24.6	25.0	25.0	24.6		0.996	0.713	0.708
44	22.2	24.2	23.4	23.0		0.306	0.068	0.691
65	20.5	27.2	23.3	24.3		<0.001	<0.001	0.365
86	24.9	26.1	26.4	24.6	0.8	0.184	0.279	0.105

[a]Initiated on day 65 for 5.9 ft^2/pig treatment and day 58 for 8.0 ft^2/pig treatment.

Table 6. Experimental treatment interactions on plasma urea, day 65, mg/100 ml.

	Space, ft^2/pig					P Values		
	5.9		8.0			Space x		
Paylean®, g/T[a]:	0	9	0	9	SE	Paylean®	Space	Paylean®
Plasma urea	20.3	20.7	26.4	28.0	0.8	<0.001	<0.001	0.365

[a]Initiated on day 65 for 5.9 ft^2/pig treatment and day 58 for 8.0 ft^2/pig treatment.

Pigs fed 9 g/T Paylean® for four weeks prior to slaughter had an increase in loin muscle depth, carcass lean percentage and carcass premium compared to pigs fed 0 g/T Paylean®. There was no effect of Paylean® treatment on FFL percentage, but there was an increase in daily FFL gain for the 9 g/T Paylean® treatment.

On day 44, pigs given 5.9 ft^2/pig had a lower plasma urea concentration compared with pigs given 8.0 ft^2/pig (Table 5). The interaction between space and Paylean® treatments for plasma urea on day 65 (Table 6) is due to the day Paylean® treatments began. Pigs on the 8.0 ft^2/pig treatment had been on the .92% lysine diet associated with the Paylean® treatments for 7 days while pigs on the 5.9 ft^2/pig treatment were switched to the higher lysine diet following sampling on day 65. The trend toward an increase in plasma urea on day 86 for the 0 g/T Paylean® treatment versus the 9 g/T Paylean® treatment suggests the dietary lysine level was in excess of the pigs needs for lean tissue deposition for the 0 g/T Paylean® treatment.

Conclusion

In this experiment, there were no interactions between space allocation and dietary Paylean® additions for overall daily gain, daily feed intake, feed conversion, carcass weight, carcass yield, carcass premium, carcass fat free lean, or daily fat free lean gain. The interactions between space allocation and Paylean® treatments on days 65 and 86 were most likely due to the seven-day difference in when Paylean® treatments were applied to the 5.9 vs 8.0 ft^2/pig treatments.

These results suggest the response to dietary Paylean® additions is independent of the response to space allocation. In addition, the lack of treatment effects on tail biting score on day 86 suggests neither space allocations nor dietary Paylean® addition were the cause of the tail biting observed in this experiment.

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Comparison of Swine Performance When Fed Diets Containing Corn Root Worm Protected Corn, Parental Line Corn, or Conventional Corn Grown During 2000 in Nebraska

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Summary and Implications

This experiment was conducted to evaluate growth performance and carcass quality measurements in growing-finishing pigs fed diets containing either Corn Root Worm Protected Corn (CRW0586), the parental control corn (RX670), or two commercial sources of non-genetically modified corn (DK647 and RX740). The experiment used 72 barrows and 72 gilts with an average initial body weight of 50 lb. The pigs were allotted to a randomized complete block design with a 2 × 4 factorial arrangement of treatments (two sexes × four corn hybrids). The experiment continued until the average body weight was 260 lb, at which time all pigs were slaughtered. Real-time ultrasound measurements were taken on the final day of the experiment. Carcass quality measurements were made 24 hours postmortem. Corn hybrid did not affect average daily gain (ADG) or average daily feed intake (ADFI), but there was an effect of sex, with barrows having greater (P < 0.01) ADG and ADFI than gilts. Feed efficiency was not affected by the different corn hybrids, but gilts had improved (P < 0.01) feed efficiency compared to barrows during Finisher 1 (0.37 versus 0.35) and Finisher 2 (0.32 versus 0.30). Real-time ultrasound measurements were similar among corns; however, a sex effect was detected for backfat (BF) depth, with gilts having less (P < 0.01) BF than barrows (0.78 versus 0.98 in). There were no differences in carcass midline BF measurements among corns, but there was a significant difference between barrows and gilts, with gilts having less (P < 0.05) BF than barrows. Hot carcass weight was greater (P < 0.01) in barrows than gilts (210 versus 190 lb). Also, the percent carcass lean was greater (P < 0.01) in gilts than barrows (51.7 versus 49.5%). Longissimus muscle quality scores were similar among corns and between barrows and gilts. Analysis of longissimus muscle composition revealed no main effect of corn (P > 0.20) or sex (P > 0.30) for protein, fat, and water percentages. However, Corn Root Worm Protected Corn (73.1%) differed (P < 0.04) from parental control corn (73.6%) but not commercial corns (73.3 and 73.3%) in longissimus water content. In summary, there were no differences in growth performance or carcass measurements in growing-finishing pigs fed diets containing either Corn Root Worm Protected Corn, the parental control corn, or two commercial sources of non-genetically modified corn. Thus, the replacement of non-transgenic corn with Corn Root Worm Protected Corn in growing-finishing diets will result in similar growth performance and(or) carcass measurements.

Introduction

Transgenic crops offer producers a wide variety of agronomic benefits. Crops with microbial Bt formulations contain the Cry (crystalline protein inclusions) insect control proteins. Following a single acute exposure, Cry proteins bind to specific receptors in the midgut cells of susceptible insects and form ion-selective channels in the cell membrane. The cells swell due to an influx of water which leads to cell lysis, the insect stops eating and dies. The test event, MON 863, produces a variant of the wild type Cry3Bb1 protein, which protects against Corn Root Worm (CRW, *Diabrotica*).

The objective of this study was to compare growth performance and carcass quality measurements in growing-finishing pigs fed diets containing either Corn Root Worm Protected Corn (CRW0586), the parental control corn (RX670), or two commercial sources of non-genetically modified corn (DK647 and RX740).

Procedures

Animals and Treatment

A total of 144 crossbred [Danbred × (Danbred × NE White Line)] barrows and gilts with an average initial body weight (BW) of 50 lb were used. The pigs were allotted to a randomized complete block experiment with a 2 × 4 factorial arrangement of treatments. Blocks were based on initial weight and pen location within the building. There were two sexes (barrows and gilts) and four genetic corn lines (CRW0586, RX670, DK647, and RX740). Diets (Table 1) contained corn and soybean meal and were fortified with vitamins and minerals to meet or exceed the NRC (1998) requirements for 44- to 264-lb pigs. There were four

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diet phases during the experiment (Grower 1, Grower 2, Finisher 1, and Finisher 2). Each diet phase was 28 days, except Finisher 2 which was 20 days, this resulted in a total experimental period of 104 days.

The pigs were housed in a modified-open-front building with 24 pens (pen dimensions 4.9 × 15.7 ft), and each pen contained six pigs. Pigs had ad libitum access to feed and water throughout the experimental period. Pigs remained on the experiment until the average BW of the pigs reached approximately 260 lb (d 104), at which time all pigs were removed from the experiment.

Data and Sample Collection

Pigs were weighed and feed intakes were measured biweekly to determine average daily gain (ADG), average daily feed intake (ADFI), and feed efficiency. Real-time ultrasound measurements were taken at the end of the experiment by a certified technician, and tenth-rib backfat (BF) depth and longissimus muscle area (LMA)

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

	Dietary Phases[a]			
Ingredients, %	Grower 1	Grower 2	Finisher 1	Finisher 2
Corn	68.65	74.79	78.66	82.47
Soybean meal (46.5% CP)	26.00	20.25	16.25	12.75
Tallow	3.00	3.00	3.00	3.00
Dicalcium phosphate	1.25	0.85	0.93	0.75
Limestone	0.40	0.40	0.40	0.40
Salt	0.30	0.30	0.30	0.30
Vitamin premix [b c]	0.20	0.20	0.15	0.15
Trace mineral premix [d e]	0.15	0.15	0.10	0.10
Tylosin, 40 g/lb	---	---	0.13	---
L-Lysine•HCl	0.05	0.06	0.08	0.08
Calculated nutrient content				
Crude protein, %	18.10	15.80	14.30	12.10
Lysine, %	1.00	0.85	0.75	0.65
ME [f], Mcal/lb	1.56	1.57	1.57	1.57
Calcium, %	0.70	0.60	0.60	0.55
Phosphorus, %	0.60	0.50	0.50	0.45

[a]The only difference in the four diets within each dietary phase was the addition of the different genetic corn lines.
[b]Supplied per pound of complete feed in grower diets: retinyl acetate, 1,995 IU; cholecalciferol, 200 IU; α-tocopherol acetate, 11 IU; menadione sodium bisulfite, 1.6 mg; riboflavin, 4.0 mg; d-pantothenic acid, 8.0 mg; niacin, 12.0 mg; vitamin B_{12}, 12.0 µg.
[c]Supplied per pound of complete feed in finisher diets: retinyl acetate, 1,500 IU; cholecalciferol, 150 IU; α-tocopherol acetate, 8.2 IU; menadione sodium bisulfite, 1.2 mg; riboflavin, 3.0 mg; d-pantothenic acid, 6.0 mg; niacin, 9.0 mg; vitamin B_{12}, 9.0 µg.
[d]Supplied per pound of complete feed in grower diets: Zn (as ZnO), 58 mg; Fe (as $FeSO_4•H_2O$),58 mg; Mn (as MnO), 13.6 mg; Cu (as $CuSO_4•5\ H_2O$), 5 mg; I (as $Ca(IO_3)•H_2O$), 0.12 mg; Se (as Na_2SeO_3), 0.14 mg.
[e]Supplied per pound of complete feed in finisher diets: Zn (as ZnO), 38.5 mg; Fe (as $FeSO_4•H_2O$), 38.5 mg; Mn (as MnO), 9.1 mg; Cu (as $CuSO_4•5\ H_2O$), 3.2 mg; I (as $Ca(IO_3)•H_2O$), 0.08 mg; Se (as Na_2SeO_3), 0.09 mg.
[f]Metabolizable energy.

Table 2. Growth performance of barrows and gilts.

	Genetic Line				Sex			P-Value [a]		
Item	CRW0586	RX670	DK647	RX740	Barrows	Gilts	Pooled SEM	Trt	Sex	Trt x Sex
No. Pens	6	6	6	6	12	12				
Initial Wt., lb	50.12	50.08	50.12	49.94	50.10	50.05	0.236	NS	NS	NS
Final Wt., lb	260.48	258.67	255.43	259.66	270.66	246.45	4.941	NS	< 0.01	NS
Grower 1										
ADG, lb [b]	1.63	1.68	1.63	1.61	1.72	1.57	0.037	NS	< 0.01	NS
ADFI, lb [c]	3.22	3.29	3.20	3.22	3.35	3.09	0.064	NS	< 0.01	NS
ADG/ADFI	0.51	0.51	0.51	0.50	0.51	0.50	0.007	NS	NS	NS
Grower 2										
ADG, lb	2.07	2.03	2.01	2.06	2.18	1.87	0.064	NS	< 0.01	NS
ADFI, lb	5.01	4.87	4.81	4.83	5.27	4.50	0.150	NS	< 0.01	NS
ADG/ADFI	0.42	0.41	0.42	0.42	0.42	0.42	0.011	NS	NS	NS
Finisher 1										
ADG, lb	2.29	2.27	2.23	2.25	2.40	2.12	0.073	NS	< 0.01	NS
ADFI, lb	6.48	6.22	6.24	6.33	6.87	5.76	0.205	NS	< 0.01	NS
ADG/ADFI	0.36	0.37	0.36	0.36	0.35	0.37	0.011	NS	< 0.01	NS
Finisher 2										
ADG, lb	2.12	2.09	2.05	2.21	2.21	2.03	0.079	NS	< 0.01	NS
ADFI, lb	6.90	6.77	6.59	6.88	7.30	6.28	0.236	NS	< 0.01	NS
ADG/ADFI	0.31	0.31	0.31	0.32	0.30	0.32	0.009	NS	< 0.01	NS
Overall										
ADG, lb	2.07	2.07	1.98	2.07	2.12	1.90	0.046	NS	< 0.01	NS
ADFI, lb	5.27	5.18	5.09	5.18	5.56	4.81	0.135	NS	< 0.01	NS
ADG/ADFI	0.38	0.39	0.39	0.39	0.38	0.39	0.007	NS	< 0.01	NS

[a]Trt = treatment; and NS = nonsignificant effect , P > 0.10.
[b]ADG = average daily gain.
[c]ADFI = average daily feed intake.

Table 3. Ultrasound and carcass measurements .

Item	Genetic Line				Sex		Pooled SEM	P-Value[a]				
	CRW0586	RX670	DK647	RX740	Barrows	Gilts		Trt	Sex	Trt x Sex	GMO vs P [b]	GMO vs Conv.[c]
No. pens	6	6	6	6	12	12						
Ultrasound measurements												
Backfat, in	0.87	0.88	0.85	0.91	0.98	0.78	0.051	NS	< 0.01	NS	NS	NS
LMA [d], in^2	7.26	7.27	7.08	7.09	7.24	7.12	0.188	NS	NS	NS	NS	NS
Ultrasound lean measurements [e i]												
Total lean, lb [f]	101.45	100.86	99.38	99.82	102.18	98.59	1.603	NS	< 0.01	NS	NS	NS
Percent lean [f]	50.40	50.36	50.61	49.96	48.76	51.90	0.821	NS	< 0.01	NS	NS	NS
Lean gain, lb/d	0.82	0.81	0.80	0.81	0.83	0.79	0.015	NS	< 0.01	NS	NS	NS
Carcass measurements [g]												
Hot carcass weight, lb	202.09	200.70	196.91	200.52	209.89	190.23	4.101	NS	< 0.01	NS	NS	NS
First rib BF, in	1.64	1.65	1.62	1.66	1.76	1.53	0.059	NS	< 0.01	NS	NS	NS
Tenth rib BF, in	1.06	1.08	1.06	1.08	1.16	0.98	0.044	NS	< 0.01	NS	NS	NS
Last rib BF, in	1.07	1.09	1.12	1.07	1.19	0.98	0.035	NS	< 0.01	NS	NS	NS
Last lumbar BF, in	0.88	0.88	0.89	0.96	1.00	0.81	0.032	0.08	< 0.01	< 0.05	NS	NS
LMA, in^2	10.06	9.64	9.49	9.57	9.78	9.60	0.260	NS	NS	NS	NS	< 0.05
Carcass lean measurements [h i]												
Total lean, lb [f]	102.47	101.21	98.65	101.61	103.77	98.19	1.985	NS	< 0.01	NS	NS	NS
Percent lean [f]	50.83	50.50	50.25	50.85	49.50	51.72	0.358	NS	< 0.01	NS	NS	NS
Lean gain, lb/d	0.83	0.82	0.79	0.82	0.84	0.79	0.019	NS	< 0.01	NS	NS	NS

[a]Trt = treatment; GMO = genetically modified organism; P = parental control line; Conv = conventional lines; and NS = nonsignificant effect , P > 0.10.
[b]Transgenic line (CRW0586) comparison with parental control line (RX670).
[c]Transgenic line (CRW0586) comparison with conventional lines (DK647 and RX740).
[d]Longissimus muscle area.
[e]National Pork Producers Council 2000 fat-free lean equation using ultrasound data: (0.833 × sex (barrow=1 and gilt=2) - (16.498 × ultrasound 10th rib BF (in)) + (5.424 × ultrasound 10th rib LMA (in^2)) + (0.291 × live wt. (lb)) - 0.534.
[f]Figured on a fat-free lean basis.
[g]Backfat measurements were taken at the midline.
[h]National Pork Producers Council 2000 fat-free lean equation using carcass data: 23.568 - (21.348 × last rib BF (in)) + (0.503 × warm carcass wt. (lb)).
[i]Lean gain calculation: $\frac{\text{Final fat-free lean} - \text{Initial fat-free lean}^{[j]}}{104}$

[j]Initial fat-free equation: .95 * [-3.95 + (.418 × live weight, lb)]

were recorded. At the termination of the experiment, the pigs were shipped to SiouxPreme Packing Co. in Sioux Center, Iowa, where carcass characteristics were measured on individually identified pigs. At 24 hours postmortem, midline BF measurements (first rib, tenth rib, last rib, and last lumbar) and LMA traces at the tenth rib were collected on all the carcasses. Carcass quality tests were also performed at 24 hours postmortem. These tests were on the longissimus muscle at the tenth rib and included pH; firmness and marbling scores; and Minolta L*, a*, and b* values. A longissimus muscle sample was collected from each carcass at the tenth rib and loin samples from three pigs per pen were used to determine longissimus muscle composition.

Statistical Analysis

Data were analyzed as a randomized complete block design using PROC MIXED of SAS (1999). The main effects in the statistical model were sex (barrows and gilts) and genetic corn line (CRW0586, RX670, DK647, and RX740). Also, the sex x corn line interaction was included in the model. Contrasts were performed to compare the transgenic line with its parental control and with the two commercial reference lines. In all analyses, pen was the experimental unit.

Results

Growth Performance

Average daily gain, ADFI, and ADG/ADFI for the four diet phases and the entire experimental period are shown in Table 2. During the four diet phases, ADG, ADFI, and feed efficiency were not affected ($P > 0.10$) by corn. Average daily gain was greater (1.72, 2.18, 2.40, and 2.21 lb versus 1.57, 1.87, 2.12, and 2.03 lb; $P < 0.01$) in barrows than gilts, respectively, during the four diet phases. Also, ADFI was greater (3.35, 5.27, 6.88, and 7.30 lb versus 3.09, 4.50, 5.76, and 6.28 lb; $P < 0.01$) in barrows than gilts during the four diet phases. During the Finisher 1 and 2 periods, gilts had improved (0.37 and 0.35 versus 0.32 and 0.30; $P < 0.01$) feed efficiency compared to barrows, with no differences ($P \geq 0.10$) between barrows and gilts during the Grower 1 and 2 periods. Results of the overall experimental period indicate no differences

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Table 4. Longissimus muscle quality scores and composition.

Item	Genetic Line				Sex		Pooled SEM	P-Value[a]				
	CRW0586	RX670	DK647	RX740	Barrows	Gilts		Trt	Sex	Trt x Sex	GMO vs P [b]	GMO vs Conv.[c]
Longissimus muscle quality scores												
Marbling [d]	2.67	2.44	2.28	2.28	2.48	2.36	0.193	NS	NS	NS	NS	< 0.05
Firmness [e]	2.94	3.08	2.86	3.08	2.91	3.07	0.147	NS	NS	NS	NS	NS
pH	5.58	5.57	5.57	5.56	5.58	5.55	0.039	NS	NS	NS	NS	NS
Minolta L*	47.20	46.65	46.53	46.62	46.86	46.64	0.712	NS	NS	NS	NS	NS
Minolta a*	6.99	7.21	6.72	6.84	6.96	6.93	0.210	NS	NS	NS	NS	NS
Minolta b*	2.27	2.19	1.76	1.85	2.09	1.94	0.227	NS	NS	NS	NS	< 0.05
Longissimus muscle composition, %												
Protein	23.43	22.94	23.20	23.02	23.15	23.15	0.324	NS	NS	NS	NS	NS
Fat	2.30	2.22	2.03	2.27	2.28	2.13	0.204	NS	NS	NS	NS	NS
Water	73.11	73.62	73.34	73.37	73.31	73.41	0.236	NS	NS	< 0.05	<0.05	NS

[a]Trt = treatment; GMO = genetically modified organism; P = parental control line; Conv = conventional lines; and NS = nonsignificant effect , P > 0.10.
[b]Transgenic line (CRW0586) comparison with parental control line (RX670).
[c]Transgenic line (CRW0586) comparison with conventional lines (DK647 and RX740).
[d]Scored on a scale of 1 to 4, where 1 = practically devoid of marbling and 4 = moderate to slightly abundant marbling.
[e]Scored on a scale of 1 to 4, where 1 = very soft and 4 = very firm.

($P > 0.10$) among corn varieties for ADG, ADFI, and feed efficiency. However, overall ADG (2.12 versus 1.90 lb) and ADFI (5.56 versus 4.81 lb) were greater ($P < 0.01$) in barrows than gilts, and overall feed efficiency was improved (0.39 versus 0.38; $P < 0.01$) in gilts than barrows.

Carcass Characteristics

Real-time ultrasound and carcass measurements are summarized in Table 3. Ultrasound measurements of tenth-rib BF and LMA did not differ ($P > 0.10$) among corns, but tenth-rib BF was greater ($P < 0.01$) in barrows (0.98 in) than gilts (0.78 in). Carcass BF (first rib, tenth rib, and last rib) measurements were similar ($P > 0.10$) among corns, but differences (1.76, 1.16, and 1.19 in versus 1.53, 0.98, and 0.98 in; $P < 0.01$) between barrows and gilts for carcass first, tenth, and last rib BF measurements, respectively were detected with no differences ($P > 0.10$) in LMA. Last lumbar BF depth was influenced by corn hybrid ($P = 0.08$). Pigs fed the commercial line RX740 (0.96 in) had a greater amount of last lumbar BF compared to pigs fed CRW0586 (0.88 in), RX670 (0.88 in), and DK647 (0.89 in). Also, a treatment × sex interaction ($P < 0.05$) was detected for last lumbar backfat depth. Hot carcass weight was not affected by corn hybrid, but was greater for barrows than gilts (210 lb versus 190 lb; $P < 0.01$). However, gilts had a greater (51.72% versus 49.50%; $P < 0.01$) percentage of carcass fat-free lean compared to barrows.

Longissimus Muscle Quality Scores and Composition

Longissimus muscle quality scores for pH; marbling and firmness; Minolta L*, a*, and b* values, and longissimus muscle composition are summarized in Table 4. Longissimus muscle quality scores were not affected ($P \geq 0.10$) by sex or corn hybrid. However, the Corn Root Worm Protected Corn (CRW0586) had a greater marbling score (2.67 versus 2.28; $P < 0.05$) and Minolta b* color score (2.27 versus 1.81; $P < 0.05$) compared the two commercial corn varieties (DK647 and RX740). Protein, fat, and water percentage of the longissimus muscle were similar ($P \geq 0.10$) between barrows and gilts and among corns. However, a treatment x sex interaction ($P < 0.05$) was detected for longissimus muscle water percentage. Also, the transgenic corn (CRW0586) versus parental (RX670) comparison resulted in a difference ($P < 0.05$) in longissimus muscle water percentage with pigs fed the transgenic corn (73.11%) having less water than pigs fed the parental corn (73.62%).

Discussion

The results indicate no significant differences among the corn treatments for ADG, ADFI, or feed efficiency. However, in the present study, expected sex differences between gilts and barrows were observed in growth performance. Recent experiments using barrows and gilts during the finishing period have shown that barrows have greater ADG and ADFI than gilts. However, in these same experiments, gilts had superior feed efficiency compared to barrows. Results of the current experiment support the results of previous experiments and indicate the same differences in ADG, ADFI, and feed efficiency between barrows and gilts.

Dietary treatment did not affect ultrasound and carcass measurements, however a difference in backfat depth between barrows and gilts was detected, with no difference in longissimus muscle area. The difference in backfat depth between barrows and gilts is supported by the results of other researchers, however in those experiments gilts had greater longissimus muscle area than barrows, which is in contrast to the results of the present experiment. The similar longissimus muscle area between barrows and gilts may be a result of feeding the barrows and gilts the same lysine concentration throughout the four-phase growing-

finishing experiment. Previous research has shown that gilts require higher dietary concentrations of lysine compared to barrows to maximize growth performance and carcass leanness. The significant effect of sex on hot carcass weight is a result of terminating the experiment on a constant time basis resulting in a significant difference in final weight between barrows and gilts.

Longissimus muscle pH is related to pork quality. The pH value is correlated to the quality traits of color and water holding capacity as well as various eating quality traits, such as tenderness. In the present study, corn and (or) sex did not affect pH. Most previous studies have indicated that 24-h postmortem pH measurements are similar between barrows and gilts. The pH values were similar to previous experiments and the pH values were within the normal range for measurements taken 24 h postmortem. The subjective measurements of marbling and firmness of the longissimus muscle were similar among corns and between barrows and gilts. The marbling and firmness values in the present study were numerically similar to those of previous experiments where pigs were fed a corn-soybean meal diet.

Corn line and sex had minimal influence on longissimus muscle color scores (Minolta L*, a*, and b*). The Minolta L* values, which measure the lightness (0-100) of the sample, were within a normal range of 42 to 50 and were in agreement with other data. Although, Minolta a* and b* values, which measure the amount of red (+a*) or green (-a*) and the amount of yellow (+b*) or blue (-b*) in a meat sample, were not affected by corn or sex, the numerical values of the present study were lower than those of previously reported experiments.

The percentages of protein, fat, and water in longissimus muscle in the present experiment were not affected by corn or sex. This finding is similar to that of previous researchers, who reported no treatment effects on chemical composition of muscle. Although the main effect of corn on longissimus muscle water was not significant at the $P < 0.05$ level, individual contrasts indicated less water ($P < 0.05$) in the Corn Root Worm Protected Corn group (73.11%) than the parental control group (73.62%). However, Corn Root Worm Protected Corn group did not differ ($P > 0.20$) from the two commercial varieties (73.34% and 73.37%).

Conclusion

This experiment demonstrates that the feeding value of Corn Root Worm Protected Corn (CRW0586) is similar to that of conventional corns (DK647 and RX740). Therefore, the replacement of non-transgenic corn with Corn Root Worm Protected Corn in swine diets will result in similar growth performance and(or) carcass measurements.

[1]Robert L. Fischer is a research technologist and graduate student, Phillip S. Miller is an associate professor, Sara S. Blodgett is a graduate student, and Steven J. Kitt is a graduate student in the Department of Animal Science. References are available from the authors upon request.

Energy and Nitrogen Utilization of Roundup Ready® Corn (Event nk603) and Non-Transgenic Corn in Young Pigs

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Summary and Implications

This experiment was conducted to compare the nutritional value, measured by digestible and metabolizable energy, and nitrogen digestibility in young pigs fed either Roundup Ready corn (DKC5740) or non-transgenic corn (DKC5738). The experiment used 12 barrows with an initial body weight of 76.3 lb. The pigs were housed in stainless steel metabolism crates and were randomly allotted to one of two corn treatments, either Roundup Ready corn or control corn. The diets were formulated to contain 97.5% of one of the two varieties of corn and 2.5% minerals and vitamins. The duration of the experiment was 14 days, which included a seven-day adaptation period followed by a seven day total fecal and urine collection period. Feed intake was based on initial body weight and pigs had ad libitum access to water. The digestible energy intakes (dry matter basis; 3.74 versus 3.75 Mcal/d) and the energy digestibility, as a percentage of dry matter intake, (86.6 versus 86.9%) were similar (P > 0.60) between the Roundup Ready corn and control corn. The metabolizable energy intakes (dry matter basis; 3.64 versus 3.66 Mcal/d) and the metabolizable energy, as a percentage of dry matter intake, (84.5 versus 84.8%) were similar (P > 0.60) between the Roundup Ready and control corn. The nitrogen balance data indicated no differences (P > 0.40) between the Roundup Ready corn and control corn for nitrogen intake (0.038 versus 0.040 lb/d), nitrogen digested (0.031 versus 0 .032 lb/d), nitrogen retained (0.014 versus 0.014 lb/d), or nitrogen digestibility (80.1 versus 81.3%). The results of this experiment

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indicate that energy and nitrogen utilization is similar between diets containing either the Roundup Ready corn or non-transgenic control corn when fed to young pigs. Thus, this transgenic corn can be fed to young pigs without negatively affecting nitrogen or energy digestibility.

Introduction

Monsanto is developing a second generation Roundup Ready corn containing event nk603 that has been genetically modified to tolerate Roundup (glyphosate) treatment. Researchers have demonstrated Roundup Ready corn containing event nk603 to be equivalent in composition to genetically similar, non-transgenic corn. Two previous swine finishing studies demonstrated that Roundup Ready corn containing event nk603 had similar feeding value to that of control and conventional reference varieties. In support of these findings, the current study was conducted to determine the digestible energy, metabolizable energy, and nitrogen digestibility of Roundup Ready corn line DCK5740 in young pigs.

Procedures

Animals and Treatments

Twelve crossbred [Danbred × (Danbred × Nebraska White Line)] barrows with an average initial body weight of 76.3 lb were used in a completely randomized design. Two diets were formulated to contain 97.5% of one of two varieties of corn (Roundup Ready corn; DCK5740 or non-transgenic control corn; DCK5738) and 2.5% minerals and vitamins (Table 1). Amino acid composition of the two corn lines is documented in Table 2. Diets were formulated such that the test grain was the only source of protein and energy. Diets were fortified with vitamins and minerals to meet or exceed the NRC (1998) requirements for 45-lb pigs. Pigs were housed in stainless steel metabolism crates (4.9 × 1.6 ft) that allowed separate collection of feces and urine. The pigs were housed in an environmentally controlled room and allowed ad libitum access to water through a nipple waterer.

Table 1. Ingredient and chemical composition of diets, as-fed basis.

Item	DKC5740[a]	DKC5738[a]
Ingredient, %		
Corn[b]	97.50	97.50
Dicalcium phosphate	1.25	1.25
Limestone	0.70	0.70
Salt	0.30	0.30
Vitamin premix[c]	0.15	0.15
Trace mineral premix[d]	0.10	0.10
Chemical composition		
Dry matter[e], %	89.14	89.38
Crude protein[e], %	8.86	8.87
Gross energy[e], Mcal/kg	3.84	3.86
Calcium[f], %	0.70	0.70
Phosphorus[f], %	0.60	0.60

[a]DKC5740 – Roundup Ready corn and DKC5738 – control corn.
[b]Amino acid composition of the two corn varieties shown in Table 2.
[c]Supplied per pound of complete feed in grower diets: retinyl acetate, 1,995 IU; cholecalciferol, 200 IU; α-tocopherol acetate, 11 IU; menadione sodium bisulfite, 1.6 mg; riboflavin, 4.0 mg; d-pantothenic acid, 8.0 mg; niacin, 12.0 mg; vitamin B_{12}, 12.0 µg.
[d]Supplied per pound of complete feed in finisher diets: retinyl acetate, 1,500 IU; cholecalciferol, 150 IU; α-tocopherol acetate, 8.2 IU; menadione sodium bisulfite, 1.2 mg; riboflavin, 3.0 mg; d-pantothenic acid, 6.0 mg; niacin, 9.0 mg; vitamin B_{12}, 9.0 µg.
[e]Analyzed values.
[f]Calculated values.

Table 2. Amino acid analysis of individual ingredients, as-fed basis.

	Corn	
Item	DKC5740[a]	DKC5738[a]
Amino acids, %		
Alanine	0.56	0.61
Arginine	0.29	0.29
Aspartic acid	0.50	0.56
Cystine	0.18	0.20
Glutamic acid	1.37	1.53
Glycine	0.30	0.31
Histidine	0.21	0.21
Isoleucine	0.22	0.23
Leucine	0.84	0.93
Lysine	0.23	0.25
Methionine	0.19	0.17
Phenylalanine	0.36	0.37
Serine	0.36	0.40
Threonine	0.29	0.30
Tyrosine	0.27	0.23
Valine	0.31	0.33

[a]DKC5740 – Roundup Ready corn and DKC5738 – control corn.

Data and Sample Collection

Pigs were fed in two equal feedings daily (at 0800 and 1700 hours) in a mash form. The metabolism study consisted of a seven-day adjustment period to facilities and diets followed by a seven-day period of separate but total collection of feces and urine. During the seven-day adjustment period, a daily feed intake equivalent to 3.75% of initial body weight was achieved and

Table 3. Energy and nitrogen balance[a].

Item	DKC5740 [b]	DKC5738 [b]	SEM	P-Value [c]
No. pigs	6	6		
Initial weight, lb	76.12	76.56	1.014	NS
Final weight, lb	82.91	84.23	1.627	NS
Dry matter intake/d, lb	2.42	2.49	0.115	NS
Apparent dry matter digestibility, %	88.40	88.76	0.456	NS
Gross energy intake, Mcal/d	4.74	4.87	0.224	NS
Apparent digestible energy intake, Mcal/d	3.74	3.75	0.023	NS
Apparent digestible energy, % of DM intake	86.69	86.98	0.555	NS
Metabolizable energy intake, Mcal/d	3.64	3.66	0.024	NS
Metabolizable energy, % of DM intake	84.59	84.86	0.548	NS
Apparent digestible energy, Mcal/lb [d]	1.63	1.56	0.098	NS
Metabolizable energy, Mcal/lb [d]	1.59	1.53	0.094	NS
Nitrogen intake, lb/d	0.038	0.040	0.002	NS
Nitrogen digested, lb/d	0.031	0.032	0.001	NS
Nitrogen retained, lb/d	0.014	0.014	0.001	NS
Nitrogen digestibility, %	80.16	81.37	1.106	NS
Nitrogen retention, % of intake	34.92	35.92	1.153	NS
Nitrogen retention, % of absorbed	43.57	44.15	1.316	NS

[a]The pigs were housed in stainless steel metabolism crates and were randomly allotted to one of two corn treatments. The duration of the experiment was 14 days, which included a 7-day adaptation period followed by a 7-day total fecal and urine collection period. Feed intake was based on initial BW (3.75%) and pigs had ad libitum access to water.
[b]DKC5740 – Roundup Ready corn and DKC5738 – control corn.
[c]NS = nonsignificant effect, P > 0.10.
[d]Apparent digestible and metabolizable energy calculated on a 100% corn basis.

maintained throughout the seven-day collection period. Fecal and urine collections started at 0800 hour on day seven and ended at 0800 hour on day 14 of the experimental period. Total feces were collected, weighed, composited for each pig, and stored at 0°F until subsequent analyses. Urine was collected once daily into a plastic bottle containing 25 mL of 6 N HCl. Each morning the urine collection from the previous day was strained through glass wool to remove particulate matter and a 10% aliquot was retained, recorded, composited for each pig, and stored frozen at 0°F.

Statistical Analysis

Data were analyzed as a completely randomized design using PROC MIXED of SAS (1999). The main effect in the statistical model was genetic corn line (DCK5740 and DCK5738). In all analyses crate was the experimental unit.

Results and Discussion

Dry matter percentage, crude protein percentage, and gross energy density of the two corn varieties were similar (Table 1). The digestibility of dry matter was similar between the corn varieties 88.40 and 88.76%; $P > 0.50$; Table 3). Daily gross energy intake on a dry-matter basis was similar between the two corn varieties. The digestible and metabolizable energy intakes (3.74 versus 3.75 Mcal/d; and 3.64 versus 3.66 Mcal/d; respectively) were similar ($P > 0.60$) between corn varieties. Expressed as a percentage of dry matter intake, digestible and metabolizable energy (86.69 versus 86.98% and 84.59 versus 84.86%; respectively) were similar ($P > 0.60$) between the corn varieties. The values calculated in this experiment for dry matter digestibility, digestible energy as a percentage of dry matter intake, and metabolizable energy as a percentage of dry matter intake are similar to previously published values.

Total nitrogen intake was similar ($P > 0.60$) between the corn varieties (Table 3). The amount of nitrogen digested (0.031 and 0.032 lb/d) and retained (0.014 and 0.014 lb/d) were similar ($P > 0.60$) between the corn varieties. Also, nitrogen digestibility (80.16 and 81.37%; $P > 0.40$) was similar between the two corn varieties. The values for nitrogen digestibility of the corn varieties used in this experiment are similar to the values published previously for corn.

In conclusion, results of energy and nitrogen balance with growing pigs demonstrate that the feeding value of Roundup Ready corn (DKC5740) is equivalent to that of the non-transgenic control variety (DKC5738). Therefore, Roundup Ready® corn can be used in swine diets without negatively affecting energy and(or) nitrogen digestibility.

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[1]Robert L. Fischer is a research technologist and graduate student and Phillip S. Miller is an associate professor in the Department of Animal Science. References available from the authors upon request.

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Effect of a Low Phytate, Nutrient Dense Corn on Pig Performance

Michael C. Brumm[1]

Summary and Implications

An experiment was conducted to determine the effects of a low phytate, nutrient dense corn variety on pig performance, fecal phosphorus and fecal nitrogen. Experimental treatments were: 1) corn-soybean meal diets formulated with purchased yellow corn; 2) similar diets formulated with 500 FTU/kg phytase; 3) diets formulated with a nutrient dense corn variety having reduced phytic acid, elevated lysine, and higher energy compared to yellow corn; and 4) diets formulated with the nutrient dense corn variety and phytase at 500 FTU/kg to 130 lb BW and blended with yellow corn thereafter based on estimated available phosphorus. There was no difference in daily gain or daily feed for pigs fed the normal yellow corn diets with or without phytase or the nutrient dense corn without phytase. However, when phytase was added to the nutrient dense corn from arrival to 130 lb and the estimated available phosphorus was balanced by blending normal yellow corn and the nutrient dense corn from 130 lb to slaughter, daily gain and daily feed intake were reduced. Phosphate in the feces was reduced for all diets compared to the yellow corn diet without phytase. However, nitrogen was increased in the feces from pigs fed diets containing the nutrient dense corn due to its higher crude protein compared to yellow corn. These results suggest that when diets are formulated on an equal lysine, energy and available phosphorus basis, pigs have similar performance for diets formulated with yellow corn, yellow corn plus phytase and a nutrient dense corn variety. However, these results do not support blending of yellow corn and the nutrient dense variety based on available phosphorus content. Further research is warranted to determine the cause for the depression in daily gain and daily feed reported for this treatment.

Introduction

A majority of the phosphorus in corn and soybean meal is in the form of phytic acid, a form relatively unavailable to pigs and other nonruminant animals. There is a growing awareness of the amount of phosphorus in swine manure that comes from this undigested phytate phosphorus. An increasing number of regulatory agencies regulate land application of stored swine manure based on the total phosphorus content of the manure and the crop removal of this applied phosphorus. These factors have led to increased usage of phytase in swine diets, which increases the digestibility of phytate phosphorus and reduces the amount of phosphorus in the manure by as much as 30%. Plant breeders have also released corn and soybean varieties that have a lower percentage of their total phosphorus in the phytate form, resulting in an estimated increase in the amount of digestible phosphorus. Breeders are also developing cereal grain varieties with elevated lysine and energy compared to yellow corn. The purpose of the following experiment was to determine the impact of a nutrient dense, low phytate corn variety and phytase on pig performance and fecal nutrient content when included in grower-finisher diets.

Methods

The experiment was conducted at the University of Nebraska's Haskell Ag Lab Swine Research Unit near Concord, Neb. Danbred USA (Seward, Neb.) terminal crossbred barrows (192 pigs) were housed in two naturally ventilated, partially slatted confinement facilities. Each pen measured 6 x 15 ft and had 12 pigs (7.5 ft^2/pig). Each pen had one two-hole wean-to-finish feeder located on the slatted portion of the pen and one nipple drinker located immediately adjacent to the feeder.

There were two replications of each experimental treatment in each facility, for a total of four replications per treatment. Experimental treatments were:

1) Corn-soybean meal diets formulated with yellow corn purchased at the feed mill (**YC**);
2) Diets similar to treatment 1 formulated with 500 FTU/kg phytase (**YC+Phy**);
3) Diets formulated with a nutrient dense, low phytate corn variety (Nutridense-LP) (**LP**);
4) Diets formulated with Nutridense-LP and either 500 FTU/kg phytase or normal corn based on total dietary digestible phosphorus levels (**LP+**).

For treatment LP+, phytase was added to Nutridense-LP corn based diets for pigs from arrival to 130 lb BW. For diets fed from 80 to 130 lb, the increased available phosphorus estimate for the Nutridense-LP grain, when combined with phytase, meant no dicalcium phosphate was necessary to meet the estimated available phosphorus requirement of the barrows (Table 2). The diet was formulated for pigs from 130 lb to slaughter with a blend of Nutridense-LP corn and normal yellow corn to meet the estimated available phosphorus need of finishing barrows (Table 3).

Diets were formulated according to the recommendations of the University of Nebraska for pigs of high lean gain potential. Lysine concentrations were formulated to be 1.10% from arrival to 80 lb BW, 0.97% from 80 to 130 lb, 0.77% from 130 to 190 lb and 0.62% from 190 lb to slaughter (259

Table 1. Ingredient profiles used to formulate experimental diets.

Nutrient	Yellow Corn[a]	Nutridense-LP[b]	SBM, 46.5% CP[a,c]	Fat[d]
ME, kcal/lb	1555	1612	1536	3800
Crude protein, %	8.3	10.0	46.5	
Lysine, %	0.26	0.31	2.91	
Calcium, %	0.03	0.03	0.34	
Phosphorus, %				
Total	0.28	0.32	0.69	
Available	0.04	0.22	0.16	

[a]Nebraska and South Dakota Swine Nutrition Guide. EC95-273, Cooperative Extension, University of Nebraska, Lincoln.
[b]ExSeed Genetics, LLC., Decatur, IL.
[c]SBM = soybean meal.
[d]Feed Energy Company, Des Moines, IA.

Table 2. Experimental diets from arrival to 130 lb body weight.

	Arrival to 80 lb				80 to 130 lb			
	YC[a]	YC+Phy	LP	LP+	YC	YC+Phy	LP	LP+
Ingredient, lb/ton								
Yellow corn	1334	1339.3			1446.5	1451.8		
Nutridense LP corn[b]			1412	1417.3			1528.5	1527.8
Soybean meal, 46.5% CP	555	555	525	525	455	455	425	425
Dicalcium phosphate 18.5% P	24	13	10	0	17	6	2	0
Calcium carbonate	17	24	26	32	17	24	26	27
L-lysine•HCl	3	3	3	3	3	3	3	3
Salt		6	6	6	6	6	6	6 6
Vitamin premix	6	6	6	6	5.5	5.5	5.5	5.5
Trace mineral premix	5	5	5	5	4	4	4	4
Fat[c]	50	47	7	4	46	43	0	0
Natuphos 600-G[d]		1.7		1.7		1.7		1.7
Calculated composition								
ME, kcal/lb	1558	1557	1555	1553	1561	1560	1558	1558
Crude protein, %	18.6	18.6	19.4	19.5	16.7	16.7	17.7	17.7
Lysine, %	1.10	1.10	1.10	1.10	0.97	0.97	0.97	0.97
Total P, %	0.60	0.50	0.50	0.41	0.52	0.42	0.41	0.39
Avail P, %[e]	0.29	0.29	0.29	0.30	0.22	0.22	0.22	0.30
Total Ca, %	0.70	0.70	0.70	0.70	0.61	0.61	0.60	0.59
Analyzed composition								
Crude protein, %[f]	19.5	19.0	20.0	20.0	17.8	17.8	18.2	17.8
Ca, %[f]	0.82	0.74	0.88	0.82	0.65	0.71	0.72	0.71
P, %[f]	0.57	0.44	0.45	0.37	0.48	0.38	0.38	0.37
Lysine, %[f]	1.08	1.08	1.11	1.08	0.99	0.98	0.91	0.89
Phytase, FTU/kg[d]		680		750		870		640

[a]YC = diets formulated with yellow corn to University of Nebraska recommendations; YC+Phy = diets formulated with yellow corn and 500 FTU/kg phytase; LP = diets formulated with Nutridense LP to University of Nebraska recommendations; LP+ = diets formulated with Nutridense LP and 500 FTU/kg phytase.
[b]Exseed Genetics, LLC., Decatur, IL.
[c]Feed Energy Co., Des Moines, IA.
[d]BASF Inc., Mt Olive, NJ 07828.
[e]Includes phytase available P credit for YC+Phy and LP+ diets.
[f]Ward Laboratories, Kearney, Neb.

lb). The estimated composition of the feedstuffs used to formulate the experimental diets is presented in Table 1 and the diets are presented in Tables 2 and 3. All diets contained 100 g/T Tylan from arrival to 80 lb BW and 40 g/T Tylan thereafter. Diets were switched on the week individual pens achieved their target weight.

Within lysine concentration, all diets were formulated to contain the same energy, lysine and calcium amounts. Natuphos 600-G (BASF Inc) was added to provide 500 FTU/kg of phytase activity and the total available phosphorus concentration of the corn-soybean meal diets was credited for 0.1% digestible phosphorus from phytase addition. There was no adjustment made to calcium, lysine or energy with the addition of the phytase to the experimental diets.

At arrival, pigs were ear tagged, individually weighed and assigned to experimental treatments. Weight blocks were not used in the assignment of pigs to treatments. Pigs were vaccinated for erysipelas, M *hyo* and H *parasuis*. All pigs that died during the experiment were examined for cause of death by a consulting veterinarian. Pen size was not adjusted when a pig death occurred.

On every Wednesday during the experiment, a fecal sample was collected from the slatted floor portion of every pen and immediately frozen. At the completion of the experiment, the fecal samples were submitted to a commercial laboratory for determination of nitrogen and phosphorus content.

The pen of pigs was the experimental unit for all statistical analysis. Results were analyzed using the ProcMix procedure of SAS (SAS Institute, Cary, NC). The model included building as a random effect. Experimental diets were in the model as fixed effects. Final weight was used as a covariate for analysis of carcass data.

Results and Discussion

The calcium concentration of the diets for pigs was greater than expected. The trace mineral premix contained 23% to 27% calcium versus no calcium in previous trace mineral premixes used at the research center. Thus, the total dietary calcium was elevated 0.06% for pigs from arrival to 80 lb, 0.05% for pigs from 80 to 130 lb, 0.04% for pigs from 130 to 190 lb and 0.03% for pigs from 190 lb to slaughter compared to the calculated analysis presented in Tables 2 and 3.

There was no effect of experimental treatments on death loss, with only one pig dying on the YC+Phy, LP and LP+ treatments, respectively. There was no death loss for the YC treatment.

(Continued on next page)

The 0 to 36 day interval was chosen for calculation of pig performance because it represented the time period when all of the pigs on the LP+ treatment were fed experimental diets formulated with phytase. There was no effect of experimental treatments on pig weight, daily gain, daily feed intake or feed conversion efficiency for the 0 to 36 day period (Table 4).

Pig weight on day 98 was lowest for pigs fed LP+ diet. Compared with pigs fed the LP diet, daily gain was slower for the 36 to 98 day period (P = 0.086) and overall (P = 0.104). While there was an improvement in feed conversion for LP+ versus LP diet for the 36 to 98 day period, feed intake was depressed. Overall there was no difference in feed conversion, but the depression in daily feed remained.

There was no difference in daily gain for YC versus LP for any of the time periods reported. However, pigs fed LP diet had an increase (P = 0.094) in daily feed for the 36 to 98 day period, resulting in a poorer feed conversion compared with pigs fed YC diet. This poorer feed conversion during this period resulted in a poorer feed conversion overall for the LP versus YC fed pigs.

When formulated on a lysine basis, diets containing Nutridense LP were higher in crude protein content than diets formulated with yellow corn (Tables 2 and 3). This higher crude protein resulted in an increase in fecal nitrogen percentage for pigs fed LP versus YC. There was a decrease in fecal phosphate content for YC+Phy and LP compared with YC. Fecal phosphate was reduced in the LP+ versus the LP fed pigs. Treatment LP+ had the lowest fecal phosphate content. This suggests that if one of the goals of diet formulation is to reduce fecal phosphate, diets formulated using the nutrient dense, low phytate variety should be formulated on an available phosphorus basis using both phytase and yellow corn similar to the LP+ treatment. Phytase additions to diets formulated with yellow corn (YC + Phy) was also effective in reducing fecal phosphate.

Unlike previous research results, in this experiment pigs fed diets formulated with phytase (YC + Phy) had an increase in backfat, resulting in a decrease in carcass lean percentage at slaughter compared with YC fed pigs (Table 5). There was no difference in backfat, loin depth, or carcass lean percentage for the YC versus LP fed pigs or LP versus LP+ fed pigs.

For the first 36 days of the experiment, there was no effect of experimental treatment on pig performance. Pigs fed diets formulated with either corn source performed similarly. However, from day 36 to day 98, pigs fed diets containing a blend of yellow corn and the nutrient dense variety (LP+) grew slower than pigs fed diets containing either normal corn (YC) or the nutrient dense variety (LP).

The reason for the decrease in daily feed for the LP+ versus LP fed pigs is unclear, especially since feed intake for LP versus YC fed pigs increased for the 36 to 98 day period. The LP+ diets contained 10% and 28.8% YC for the 130 to 190 lb and 190 lb to market periods, versus 74.1% and 60.2% LP corn, respectively for the same periods (Table 3). This blending of corn types should not have reduced intake to a point lower than either corn type alone.

Table 3. Experimental diets from 130 lb body weight to slaughter.

	130 to 190 lb				190 lb to market			
	YC[a]	YC+Phy	LP	LP+	YC	YC+Phy	LP	LP+
Ingredient, lb/ton								
Yellow corn	1597.5	1602.8		200	1714.6	1720		576
Nutridense LP corn[b]			1687.5	1482.5			1811.6	1203.6
Soybean meal, 46.5% CP	305	305	270	270	190	190	150	165
Dicalcium phosphate 18.5% P	14	4	0	0	12	0	0	0
Calcium carbonate	17	23	26	26	16	24	24	24
L-lysine•HCl	3	3	3	3	3	3	3	3
Salt	6	6	6	6	6	6	6	6
Vitamin premix	4.25	4.25	4.25	4.25	2.8	2.8	2.8	2.8
Trace mineral premix	3.25	3.25	3.25	3.25	2.6	2.6	2.6	2.6
Fat[c]	50	47		5	53	50		17
Natuphos 600-G[d]		1.7				1.7		
Calculated composition								
ME, kcal/lb	1571	1570	1567	1567	1580	1578	1575	1577
Crude protein, %	13.9	13.9	14.9	14.7	11.7	11.7	12.7	12.5
Lysine, %	0.77	0.77	0.77	0.77	0.62	0.62	0.62	0.62
Total P, %	0.46	0.37	0.36	0.36	0.42	0.31	0.34	0.33
Avail P, %[e]	0.19	0.19	0.21	0.19	0.16	0.15	0.21	0.16
Total Ca, %	0.55	0.55	0.55	0.55	0.50	0.51	0.50	0.50
Analyzed composition[f]								
Crude protein, %	15.0	14.2	15.7	15.0	12.1	12.1	13.7	13.7
Ca, %	0.77	0.66	0.59	0.61	0.49	0.53	0.52	0.43
P, %	0.49	0.39	0.36	0.34	0.42	0.31	0.36	0.32
Lysine, %	0.73	0.77	0.66	0.77	0.61	0.64	0.71	0.69
Particle size, microns	881	927	714	743	820	885	870	926

[a]YC = diets formulated with yellow corn to University of Nebraska recommendations; YC+Phy = diets formulated with yellow corn and 500 FTU/kg phytase; LP = diets formulated with Nutridense LP to University of Nebraska recommendations; LP+ = diets formulated with Nutridense LP and YC to an available P equal to YC diets.
[b]Exseed Genetics, LLC., Decatur, IL.
[c]Feed Energy Co., Des Moines, IA.
[d]BASF Inc., Mt Olive, NJ 07828.
[e]Includes phytase available P credit for YC+Phy diets.
[f]Ward Laboratories, Kearney, Neb.

Conclusion

When diets were formulated on a equal lysine, energy and available phosphorus basis, pigs had similar daily gain for diets formulated with yellow corn, yellow corn plus phytase and Nutridense LP. However, there was a depression in daily gain for pigs fed diets formulated with Nutridense LP corn blended with yellow corn to an

Table 4. Effect of experimental diets on pig performance and fecal nutrient content.

Item	Dietary treatments[a] YC	YC+Phy	LP	LP+	SE	Treatment	Contrast P values: YC vs YC+Phy	YC vs LP	LP vs LP+
No. pens	4	4	4	4					
Pig weight, lb									
Initial	61.8	61.7	61.7	61.8	0.1	NS	NS	NS	NS
d 36	126.6	125.9	124.9	123.2	1.7	NS	NS	NS	NS
d 98	251.2	253.0	245.6	239.5	4.2	0.012	NS	NS	NS
Average daily gain, lb									
0 - d 36	1.80	1.78	1.76	1.71	0.05	NS	NS	NS	NS
d 36 - d 98	2.01	2.05	1.95	1.88	0.08	0.004	NS	NS	0.086
0 - d 98	1.93	1.95	1.88	1.82	0.04	0.011	NS	NS	0.104
Average daily feed, lb									
0 - d 36	3.59	3.65	3.57	3.63	0.12	NS	NS	NS	NS
d 36 - d 98	6.08	6.39	6.38	5.88	0.15	0.027	0.085	0.094	0.011
0 - d 98	5.17	5.38	5.35	5.05	0.10	NS	NS	NS	0.070
Feed:gain									
0 - d 36	2.00	2.05	2.04	2.12	0.05	NS	NS	NS	NS
d 36 - d 98	3.03	3.12	3.28	3.14	0.07	0.021	NS	0.003	0.060
0 - d 98	2.68	2.76	2.85	2.78	0.04	0.033	NS	0.085	NS
Fecal nutrient content, dm basis[d]									
Nitrogen, %	3.99	3.92	4.32	4.20	0.05	<0.001	NS	<0.001	NS
Phosphate, %	4.37	3.39	3.54	3.23	0.10	<0.001	<0.001	<0.001	0.046

[a]YC = diets formulated with yellow corn to University of Nebraska recommendations; YC+Phy = diets formulated with yellow corn and 500 FTU/kg phytase; LP = diets formulated with Nutridense LP to University of Nebraska recommendations; LP+ = diets formulated with Nutridense LP and 500 FTU/kg phytase to 130 lb followed by diets formulated on available phosphorus basis with a blend of yellow corn and Nutridense LP.
[b]NS = Not significant (P > 0.1).
[c]IBP Inc., Madison, Neb.
[d]Ward Laboratories, Kearney, Neb., average of weekly samples.

Table 5. Effect of experimental diets on carcass traits, least squares means.

Item	Dietary treatments[a] YC	YC+Phy	LP	LP+	SE	Treatment	Contrast P values: YC vs YC+Phy	YC vs LP	LP vs LP+
Backfat, in[b]	0.71	0.79	0.72	0.76	0.02	0.080	0.013	NS[c]	NS
Loin depth, in[b]	2.73	2.67	2.71	2.63	0.05	0.038	NS	NS	NS
Carcass lean, %[b]	55.4	54.8	55.1	54.9	0.2	<0.001	0.023	NS	NS

[a]YC = diets formulated with yellow corn to University of Nebraska recommendations; YC+Phy = diets formulated with yellow corn and 500 FTU/kg phytase; LP = diets formulated with Nutridense LP to University of Nebraska recommendations; LP+ = diets formulated with Nutridense LP and 500 FTU/kg phytase to 130 lb followed by diets formulated on available phosphorus basis with a blend of yellow corn and Nutridense LP.
[b]Collected at IBP Inc., Madison, Neb.
[c]NS = Not significant (P > 0.1).

equivalent available phosphorus basis. Based on pig performance, these results do not support blending of yellow corn and Nutridense LP corn in swine diets based on available phosphorus content, and further research is warranted to determine the cause for the depression in daily gain reported for this treatment.

Fecal phosphate was similar for pigs fed diets formulated with either yellow corn and phytase or Nutridense LP corn, and both of these treatments were lower than phosphate from pigs fed diets formulated with yellow corn and dicalcium phosphate. Fecal phosphate was lowest for pigs fed diets formulated with Nutridense LP corn and phytase and Nutridense LP corn and yellow corn on an available phosphorus basis.

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Omega-3 Fatty Acids and Swine Reproduction — A Review

Duane E. Reese[1]

Summary and Implications

A literature review was conducted to examine the role dietary omega-3 fatty acids may play in swine reproduction. Omega-3 fatty acids are not normally present to any great extent in practical swine diets, but they are increasingly important in human and pet health. Swine nutritionists have focused primarily on the effect omega-3 fatty acids may have on litter size, piglet preweaning mortality, and boar fertility. Feeding omega-3 fatty acids to sows has not generally improved litter size. Piglet preweaning mortality may be improved by omega-3 fatty acid supplementation provided sows are allowed to farrow naturally (without induction). Boar fertility seems to be positively influenced by feeding omega-3 fatty acids. The optimum amount of omega-3 fatty acids to add to breeding herd diets, which aspect(s) of the reproductive cycle they should be provided for best results, and the preferred sources require greater clarification.

Introduction

The role of fat and oil in sow diets received considerable attention by researchers 20 to 30 years ago. Interest was centered on improving piglet preweaning survival and reducing the nutrient drain experienced by lactating sows. Those investigations showed that supplemental fat provided to the sow prefarrowing generally improves preweaning survival, but its role in reducing nutrient drain during lactation is less meaningful. Fat and oil has basically served as a source of energy in swine diets.

Fats and oils consist of fatty acids. Each fat or oil source has a unique fatty acid profile that distinguishes one fat or oil source from another. Nutritionists have been examining the health benefits of specific fatty acids, especially omega-3 fatty acids, in pet and human health for several years. More recently, the role of omega-3 fatty acids in swine reproduction has been investigated and pork producers are presented with the option to include omega-3 fatty acids in their swine diets. The purpose of this paper is to review published research results that pertain to omega-3 fatty acids and swine reproduction.

Background on Fatty Acids

Fatty acids vary in length from two to 22 carbon chains. Some fatty acids are saturated meaning they lack double bonds in their carbon chain while others are unsaturated and have from one to six double bonds in their carbon chain. The final carbon atom at one particular end of the carbon chain is called the "omega" carbon. This carbon atom is usually designated as "n." Polyunsaturated fatty acids (fatty acids with more than one double bond) are classified according to the location and number of double bonds that they contain. Omega-3 fatty acids (n-3) contain their first double bond at the third carbon atom while omega-6 fatty acids (n-6) have their first double bond at the sixth carbon atom in the carbon chain (Figure 1).

Table 1 shows the fatty acid profile of several fat and oil sources. The name of each fatty acid is listed along with a description of its structure (number of carbon atoms and number of double bonds in its chain) and its type (n-3, n-6, etc). The omega-3 fatty acids are linolenic; eicosapentaenoic, (EPA); and docosahexaenoic, (DHA). Linseed (flax) is the most abundant source of linolenic acid; canola oil is the next best source, while negligible amounts are found in the other sources of fats and oils. In contrast, fish oils are the only sources of the other two omega-3 fatty acids (EPA and DHA). It is evident from this table that practical swine diets in the USA contain an abundance of linoleic acid (from corn) and

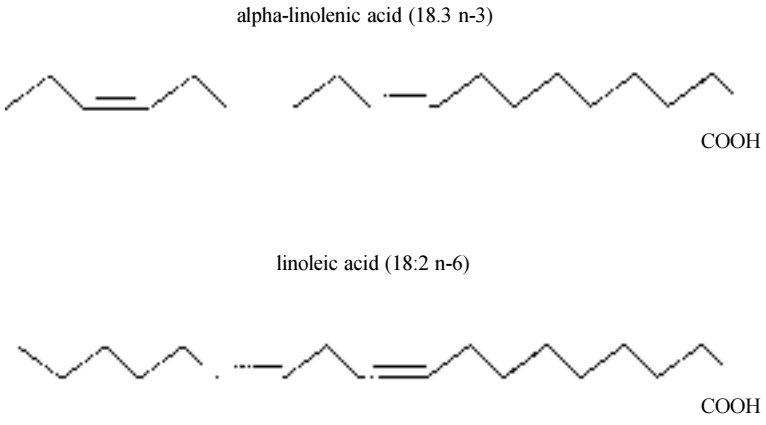

Figure 1. Structure of alpha-linolenic acid (an omega-3 fatty acid) and linolenic acid (an n-6 fatty acid). A carbon atom is located at the end of each line. Double lines indicate location of double bonds in the carbon chain.

Table 1. Fatty acid composition of fats and oils (%).[a]

Name Structure (no. carbons: no. double bonds) Type	Lauric 12:0	Myristic 14:0	Palmitic 16:0	Palmitoleic 16:1 n-7	Stearic 18:0	Oleic 18:1 n-9	Linoleic 18:2 n-6	α-Linolenic 18:3 n-3	Arachidic 20:0	Gadoleic 20:1 n-9	Arachidonic 20:4 n-6	Eicosapentaenoic (EPA) 20:5 n-3	Docosahexaenoic (DHA) 22:6 n-3
Canola oil		0.1	4.1	0.3	1.8	60.9	21.0	8.8	0.7	1.0			
Coconut oil	47.1	18.5	9.1		2.8	6.8	1.9	0.1	0.1				
Corn oil		0.1	10.9	0.2	2.0	25.4	59.6	1.2	0.4				
Cottonseed oil	0.1	0.7	21.6	0.6	2.6	18.6	54.4	0.7	0.3				
Linseed (flax) oil			5.3		4.1	20.2	12.7	53.3					
Olive oil			9.0	0.6	2.7	80.3	6.3	0.7	0.4				
Palm oil	0.3	1.1	42.9	0.2	4.6	39.3	10.7	0.4	0.3				
Palm kernel oil	48.2	16.2	8.4		2.5	15.3	2.3		0.1	0.1			
Peanut oil		0.1	11.1	0.2	2.4	46.7	32.0		1.3	1.6			
Safflower oil		0.1	6.8	0.1	2.3	12.0	77.7	0.4	0.3	0.1			
Soybean oil		0.1	10.6	0.1	4.0	23.2	53.7	7.6	0.3				
Sunflower oil		0.1	7.0	0.1	4.5	18.7	67.5	0.8	0.4	0.1			
Sunflower oil (high oleic)		3.7	0.1	5.4	81.3	9.0		0.4					
Beef tallow	0.1	3.2	24.3	3.7	18.6	42.6	2.6	0.7	0.2	0.3			
Chicken fat	0.1	0.8	25.3	7.2	6.5	37.7	20.6	0.8	0.2	0.3			
Lard (pork fat)	0.1	1.5	26.0	3.3	13.5	43.9	9.5	0.4	0.2	0.7			
Milk fat	3.1	10.8	28.8	2.5	13.3	27.6	2.5	1.6	0.1	0.1			
Anchovy oil		10.6	16.1	11.4	2.8	10.2	1.0	0.4	0.4	0.5	1.7	24.6	9.8
Cod liver oil		6.2	10.5	7.4	1.6	14.3	0.9	0.5		18.6	0.4	12.8	8.0
Menhaden oil		8.6	21.2	10.6	3.3	15.0	7.0	1.3	0.4	1.2	1.9	13.41	1.4
Salmon oil (wild)		5.3	15.8	9.3	3.3	15.5	3.4	1.0	2.5	1.0	0.3	16.6	13.4
Sardine oil		6.7	18.9	8.8	3.4	17.1	1.1	0.1	0.1	2.5	1.6	19.1	11.0

[a]Adapted from Timothy Carr, University of Nebraska, 2002.

only trace amounts of omega-3 fatty acids.

Research results

Sow Nutrition

Researchers have focused primarily on the role fatty acids may play in litter size and piglet preweaning mortality. In 1970 Canadian researchers fed 30 gilts either a wheat/barley-soybean meal control diet, the control diet with 4 % safflower oil (rich source of linoleic acid) or the control diet with 4% olive oil (rich source of oleic acid) from the day of first estrus through to day 35 of gestation (gilts were mated on their second estrus). Diet had no effect on ovulation rate, but there were 2.7 to 3.2 more embryos present in gilts that were fed either olive or safflower oil compared to those fed the control diet. Also, there was approximately 26% more DHA in embryos from sows fed the supplemental oils. The DHA was initially thought to have originated from the oleic or linoleic acid additions to the diet; however, more recently is has been established that DHA is formed from linolenic acid, not from linoleic acid . Although an omega-3 fatty acid source was not provided to the gilts in this experiment, these results suggest that it may be valuable to increase the DHA content of the embryo.

Also, in 1970 Ohio State University researchers fed gilts either a corn-soybean meal control diet or the control diet with 6% whole fish meal for two successive reproductive cycles. Treatment diets were fed from 30 days prior to breeding until weaning following the second lactation period. Litter size (total and born alive) was significantly higher in sows fed the fish meal supplemented diet (Table 2). Sows fed the fish meal supplemented diet farrowed 133 more live pigs during the course of the experiment than sows fed the control diet.

However, in 1974 researchers from the University of Illinois suggested that these responses were likely due to better selenium nutrition in the fish meal-fed sows (fish meal is high in selenium). The diets used in the Ohio State study contained no supplemental vitamin E or selenium. The fish meal supplemented diet in the Ohio State study probably contained 0.15 ppm additional selenium assuming fish meal contains 2.2 ppm selenium. The addition of selenium to practical sow diets has generally not improved litter size, therefore it is unlikely that the selenium provided by the fish meal had much role in the improved reproductive rate observed by the Ohio State researchers. Also, the control and fish meal diets contained similar amounts of fat (2.34 vs 2.61%), suggesting that the fish meal contributed only a small

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amount of omega-3 fatty acids to the diet. Therefore, it is not clear what contributed to the increase in the reproductive rate observed in the Ohio State study.

In the University of Illinois study, researchers fed sows either a corn-soybean meal control diet or the control diet with 3% menhaden fish meal for two successive gestation periods. The diets were fortified with vitamin E (10 IU/lb), but no selenium. Litter size (total and born alive) was not affected by diet.

In 1995 Virginia researchers fed 86 gilts either a corn-soybean meal control diet, the control diet with 4 % coconut oil (rich source of lauric, myristic, and palmitic acid), the control diet with 4% soybean oil (supplied linolenic acid), or the control diet with menhaden oil (rich source of EPA and DHA). The diets were fed from day 10 to 17 after the first estrus to day 37 to 45 after breeding. Gilts were mated on their third estrus. Also, a total of 46 sows were fed the diets beginning day 1 postweaning until day 37 to 45 of gestation. Overall there was no significant difference in fetal survival rate due to treatment. However, in one of the two gilt trials, fetal survival rate was improved by providing menhaden oil (93.7 vs 78.8%, respectively).

In 1998 Scottish researchers fed 14 sows a diet supplemented with either 3% soybean oil or tuna oil (rich source of DHA) from d 90 to 94 of gestation through to day seven of lactation. Sows were induced to farrow on d 113 of gestation. Piglet viability decreased with tuna oil feeding. In humans gestation length is increased when the intake of omega-3 fatty acids is increased. The authors suggested that the "natural" gestation length might be longer for sows fed tuna oil; thus, piglets from soybean oil-fed sows may have been more mature at farrowing. Results also indicate that feeding tuna oil increased the proportion of long chain fatty acids in the tissues of piglets at birth.

In 2000, Scottish researchers assigned 30 sows to one of three treatments from three to four days post breeding to weaning. Corn/wheat-based diets were supplemented with either 1.75% corn oil (rich source of n-6 fatty acids), 1.75% tuna oil, or 1.75% of a combination of corn and linseed oil (rich source of linolenic acid) and fed during gestation. During lactation sows continued on the same diets except 1.75% additional corn oil was added to each diet. Sows were induced to farrow on day 113 of gestation. Fewer piglets from corn oil-fed sows died or were removed from the experiment prior to weaning than from other sows (6.4, 28.3 and 25.5% for corn, tuna and linseed oil, respectively). The authors speculated that inducing the sows to farrow may have resulted in piglets from sows offered omega-3 fatty acids to have been born more prematurely in respect to the natural gestation length of the sow.

In 2001, Scottish researchers fed 198 sows either a wheat-based control diet or the control diet containing 1.65% salmon oil (rich source of EPA and DHA) from day three post mating to weaning. Sows were weaned at 21 to 28 days of lactation and returned to a standard commercial diet. Subsequent conception rate, farrowing rate and litter size were recorded. Sows were not induced to farrow. There were no differences in total litter size or in the number pigs born alive (Table 3). Preweaning mortality was lower for piglets from salmon-fed sows than control sows (10.2 vs 11.7%) even though they were lighter at birth (3.2 vs 3.4 lb). No difference was observed in litter weaning weight. Gestation length was longer for the salmon oil-fed sows (115.9 vs 115.4 d). The authors speculated that gestation length was increased because of a reduction in the amount of arachidonic acid available for synthesis of prostaglandin, a hormone involved in parturition. This reduction may have also contributed to lower piglet birth weight. During the subsequent gestation period, no differences in mean conception (95%) and farrowing (78%) rates, or in litter size (control, 11.8; salmon oil, 12.4) were observed.

In order to make practical use of fish oil in sow diets to improve piglet mortality it is necessary to establish the amount of fish oil to add to sow diets which results in an increase in DHA in the piglets while minimizing a decrease in arachidonic acid. Other Scottish researchers have determined that 1% salmon oil in the sow diet will meet these criteria in piglet brain tissue.

Table 2. Effect of whole fish meal on sow reproductive performance.[a]

Item	Control	Control + 6 % whole fish meal
No. litters produced[b]	65	74
Total pigs born/litter[c]	7.9	8.7
Pigs born alive/litter[c]	7.4	8.3
Total no. pigs born alive	481	614
Piglet birth weight, lb	2.7	2.8
Pigs weaned/litter	6.5	7.1

[a]Palmer et.al., 1970.
[b]Fifty-four gilts were assigned to each treatment at the beginning of the experiment.
[c] $P < 0.05$.

Table 3. Effect of salmon oil in sow diets.[a]

Item	Control	Control + 1.65% salmon oil
No. of sows	84	114
Total pigs born	11.9	12.3
Pigs born alive	11.6	11.8
Piglet birth weight, lb[b]	3.4	3.2
Preweaning mortality, %	11.7	10.2
Gestation length, d [b]	115.4	115.9
Litter weaning weight, lb	172.3	177.3

[a]Rooke et.al., 2001.
[b]$P < 0.05$.

Boar Nutrition

Pig spermatozoa contains a significant amount of DHA. It is probable that DHA is essential for optimal fertility in the boar. Supplemention of boar diets with omega-3 fatty acids may improve sperm characteristics and litter size. That has been the focus of four studies.

In 1999, Norwegian researchers used 29 boars to determine the effect of a daily dose of 75 ml of cod liver oil (source of EPA and DHA) on resistance to cold shock and on freezability of boar semen. Cod liver oil was supplemented for 12 weeks. The concentration of DHA increased in the semen from boars given the cod liver oil from 25.5 to 32.1%; no change in the fatty acid composition of semen from the unsupplemented boars was observed. Despite the higher content of DHA in the semen from cod liver oil-fed boars, their semen did not withstand cold shock or freeze better than that from control boars.

In 2001 British researchers reported feeding 35 boars a diet with or without a supplement containing DHA and specific antioxidants (PROSPERM™). Due to the large number of double bonds in long chain, polyunsaturated fatty acids, an antioxidant is necessary to prevent oxygen from attacking the double bonds and altering the biological activity of the fatty acid. Four hundred and seventy-eight gilts were artificially inseminated with semen either from boars that received the dietary supplement or those that did not. Significant improvements were observed for conception rate (control, 83%; supplemented, 90%), number of pigs born alive (control, 10.2; supplemented, 10.6), and the number of pigs born alive per 100 services (control, 846; supplemented, 954). The supplement increased the proportion of DHA in boar spermatozoa.

In 2001, British and Italian researchers reported feeding 14 boars a diet with or without supplemental DHA and antioxidants (PROSPERM™) for 16 weeks. Sperm concentration increased (571 vs 695 million sperm cells per ml) when the supplement was provided. Similar to the previous study, the supplement increased the amount of DHA in spermatozoa.

Scottish researchers in 2001 fed 10 boars either a barley/wheat-rapeseed control diet or the control diet supplemented with 3% tuna oil. Both diets were supplemented with approximately 295 ppm α-tocopherol acetate (vitamin E) to serve as an antioxidant. Semen was collected at week 0, 3, 5, and 6 following initiation of the study. Tuna oil increased sperm viability and the proportion of spermatozoa with progressive motility and normal acrosome score. Also, tuna oil increased the proportion of DHA in sperm after 5 and 6 weeks of feeding.

In the studies where PROSPERM™ was provided to boars it is unclear which component of the product (DHA or the antioxidants) contributed to the observed improvement in semen characteristics and reproductive performance. The Scottish work, where the only variable in the study was the level of tuna oil in the diet, does suggest a role for supplemental DHA in the diet of boars.

Synthesis of EPA and DHA from Linolenic Acid

It is interesting from a scientific and practical standpoint to know whether pigs can make sufficient quantities of EPA and DHA from linolenic acid. If pigs can elongate linolenic acid sufficiently, pork producers could feed flaxseed or soybean oil and expect similar results to feeding fish oil. Some researchers have examined if piglet tissue levels of EPA and DHA are increased to the same extent by providing them preformed in the sow's diet vs adding linolenic acid to the diet. Virginia researchers concluded that the developing fetus was not able to elongate soybean oil linolenic acid and it was unable to obtain the same level of EPA and DHA from soybean oil as it did from menhaden oil. A subsequent trial in Scotland concluded that offering linseed oil as a source of linolenic acid to sows was ineffective at increasing EPA and DHA concentration in piglets. Therefore, to maximize benefits that EPA and DHA may impart on litter size and piglet mortality, it seems necessary to add them preformed to the diet. In practical situations, that can be accomplished only by adding fish oil or fish products to the diet.

Omega-3 fatty acid stability

As mentioned previously, omega-3 fatty acids are unstable and therefore easily loose their biological activity if not protected by antioxidants such as vitamin E or ethoxyquin. In some of research reviewed for this report, it is clear that attention was given to protect the omega-3 fatty acids from oxidation. It is possible that some of the variability observed in the response to omega-3 fatty acids in the published literature is due to differences in how well the omega-3 fatty acid sources were stabilized.

Conclusion

Omega-3 fatty acids appear to influence some aspects of swine reproduction. Given the large body of information that is available on the role of omega-3 fatty acids in humans and pets, it is becoming evident that the decision to add fat or oil to sow and boar diets should be based on more than just an energy source consideration. However, until results from studies that involve hundreds of sows or boars fed corn and soybean meal-based diets supplemented with omega-3 fatty acids are published, it is difficult to establish the economic value of omega-3 fatty acid supplements for sows and boars. Additional clarification is needed for:1) the optimum amount of omega-3 fatty acids to add to breeding herd diets, 2) which aspect(s) of the reproductive cycle omega-3 fatty acids should be provided to enhance reproductive performance and piglet survival, and 3) the preferred sources of omega-3 fatty acids.

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[1]Duane E. Reese is extension swine specialist in the Department of Animal Sciences. References are available from the author by request.

Effects of Glutamine on Growth Performance and Intestinal Development of Immune Challenged Weanling Pigs Fed Chemically Defined Diets

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Robert L. Fischer[1]

Summary and Implications

Glutamine is currently considered a nonessential amino acid for pigs. In this study we investigated whether glutamine is essential during an acute immune challenge. Thirty-six individually housed 20-day old pigs were blocked by location and allotted to one of three purified dietary treatments: 1) contained no L-glutamine (CON), 2) contained 5% L-Glutamine (GLN), or 3) contained no L-glutamine but was equalized to GLN diet on a nitrogen basis with other nonessential amino acids (AA). Pigs were fed these diets for a 14-day growth assay. On day 7, one half of the pigs from each treatment were injected with 200 μg • kg BW^{-1} lipopolysaccharide (LPS; the endotoxin synthesized from E. coli) and the remaining pigs were injected with an equal volume of physiologic saline (SAL). Average daily gain (ADG; P > 0.21), average daily feed intake (ADFI; P > 0.79), and feed efficiency (ADG/ADFI; P > 0.26) were similar among treatments prior to LPS or SAL injection. During the period after LPS or SAL injection, LPS reduced ADG (0.46 vs. 0.24 lb/d; P < 0.0001), ADFI (0.63 vs. 0.47 lb/d; P < 0.005) and ADG/ADFI (0.74 vs. 0.50; P < 0.001) by 48%, 25%, and 32%, respectively. However, there were no differences for ADG (P > 0.39), ADFI (P > 0.95), or ADG/ADFI (P > 0.24) between pigs injected with LPS and SAL and fed GLN (Diet × LPS interaction, P < 0.06). Intestine length (P < 0.0001), full weight (P < 0.005), and empty weight (P < 0.0005) were reduced by LPS injection compared to SAL injection. Pigs fed GLN and injected with LPS had similar empty small intestine weight compared to pigs fed GLN and injected with SAL (diet × LPS interaction, P < 0.07). These data suggest that glutamine is beneficial to

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

	Treatment[d]		
Ingredients, %	CON	GLN	AA
Corn starch	32.92	27.92	27.00
Lactose	15.00	15.00	15.00
Sucrose	15.00	15.00	15.00
Corn oil	5.00	5.00	5.00
Solka floc	3.00	3.00	3.00
L-Arginine	0.64	0.64	0.64
L-Histidine•HCl•H_2O	0.55	0.55	0.55
L-Lysine•HCl	1.95	1.95	1.95
L-Tyrosine	0.60	0.60	0.60
L-Tryptophan	0.21	0.21	0.21
L-Phenylalanine	0.66	0.66	0.66
DL-Methionine	0.47	0.47	0.47
L-Cystine	0.47	0.47	0.47
L-Threonine	0.86	0.86	0.86
L-Leucine	1.33	1.33	1.33
L-Isoleucine	0.86	0.86	0.86
L-Valine	0.92	0.92	0.92
Glycine	1.33	1.33	2.51
L-Proline	0.44	0.44	1.63
L-Glutamic Acid	10.82	10.82	10.82
L-Glutamine		5.00	
L-Alanine			1.18
L-Asparagine			1.18
L-Serine			1.18
Dicalcium phosphate	3.03	3.03	3.03
Limestone	0.46	0.46	0.46
Sodium bicarbonate	1.20	1.20	1.20
Magnesium potassium sulfate	0.22	0.22	0.22
Salt	0.91	0.91	0.91
Potassium chloride	0.51	0.51	0.51
Trace mineral premix[a]	0.15	0.15	0.15
Vitamin premix[b]	0.30	0.30	0.30
Choline chloride	0.20	0.20	0.20
Calculated nutrient composition			
Lysine, %	1.54	1.54	1.54
ME[c], kcal/lb	1,269	1,269	1,269
Crude fat, %	5.00	5.00	5.00
Crude fiber, %	3.00	3.00	3.00
Ca, %	0.90	0.90	0.90
P, %	0.58	0.58	0.58
P, avail. %	0.55	0.55	0.55

[a]Supplied per lb of diet: Zn (as ZnO), 57.5 mg; Fe (as $FeSO_4$•H_2O), 57.5 mg; Mn (as MnO), 13.6 mg; Cu (as CuSO4•5 H_2O), 4.75 mg; I (as $Ca(IO_3)$•H_2O, .13 mg; Se (as Na_2SeO_3), .135 mg.
[b]Supplied per lb of diet: Vitamin A (as retinyl acetate), 2,993 IU; Vitamin D (as cholecalciferol), 299 IU; Vitamin E (as α-tocopherol acetate), 16.3 IU; Vitamin K (as menadione sodium bisulfite), 2.39 mg; riboflavin, 6; d-pantothenic acid, 12 mg; niacin, 18 mg; vitamin B_{12}, 17.7 ug.
[c]ME = Metabolizable energy
[d]CON = Control; GLN = Control + 5% L-Glutamine; AA = Control + equalized with GLN on nitrogen from nonessential amino acids. [h]NS = P > 0.10.

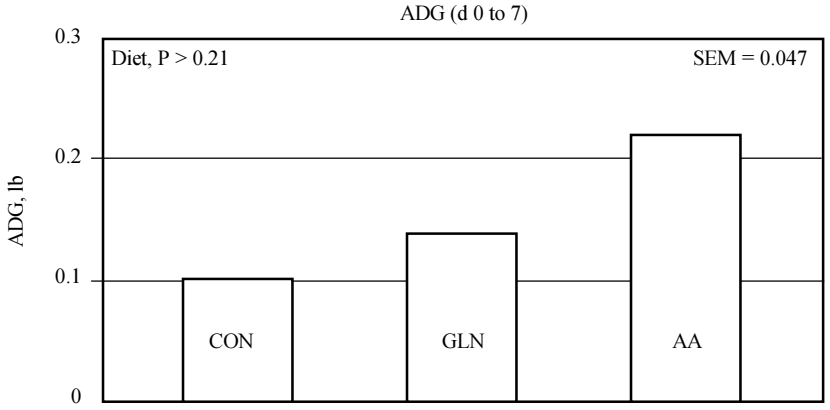

Figure 1. Effect of diet on average daily gain (d 0 to 7); Con = Control diet; GLN = 5 % Glutamine diet; AA = Nonessential amino acid diet (isonitrogenous to GLN).

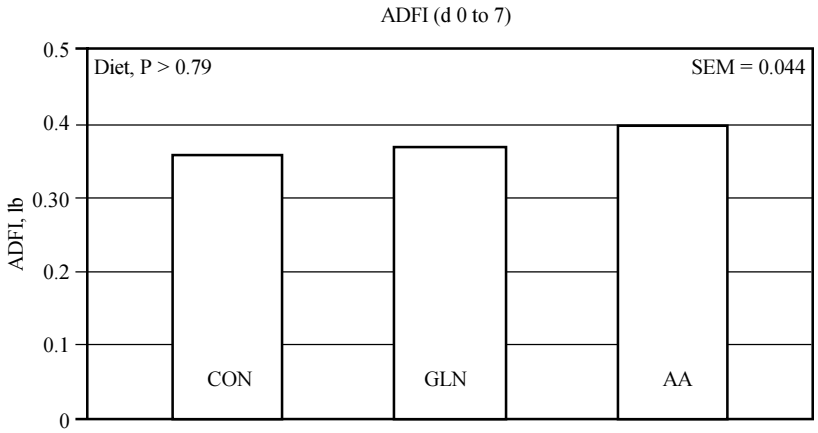

Figure 2. Effect of diet on average daily feed intake (d 0 to 7); Con = Control diet; GLN = 5 % Glutamine diet; AA = Nonessential amino acid diet (isonitrogenous to GLN).

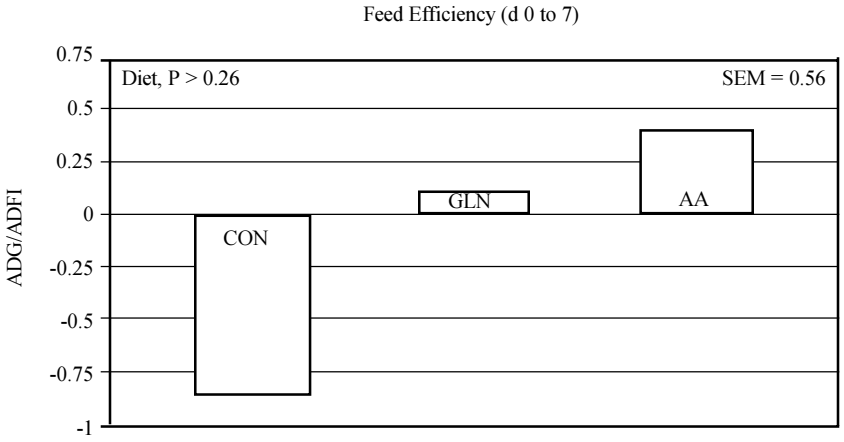

Figure 3. Effect of diet on feed efficiency (d 0 to 7); Con = Control diet; GLN = 5 % Glutamine diet; AA = Nonessential amino acid diet (isonitrogenous to GLN).

maintaining growth performance after an acute immune challenge. In the future, it will be important for researchers to quantify glutamine in typical feedstuffs (spray-dried animal plasma, blood meal, fish meal, soybean meal, etc.). This may allow the use protein-bound glutamine as a way to improve the growth and health of weanling pigs after an immune challenge.

Background and Introduction

Glutamine is considered a nonessential (not required in the diet) amino acid for pigs. However, it has been documented that glutamine is an important energy source for the absorptive cells of the small intestine and cells of the immune system. Other researchers have shown that pigs fed diets with four concentrations of crystalline glutamine and abdominally inoculated with *E. coli* showed increased (in a dose-response fashion) serum IgG against *E. coli* antigens. Therefore, during an acute immune challenge, glutamine may be required in the weanling pig diet. Our aim was to investigate the effects of glutamine on growth performance of immune-challenged weanling pigs fed diets with or without glutamine. Because glutamine is ubiquitous in all protein sources and there is currently no assay to quantify glutamine, it was necessary to use purified diets.

Procedures

Thirty-six individually-housed pigs were used in this 14-day experiment. Pigs were weaned at 20 days of age, blocked by location (n = 6), and randomly assigned to one of three purified dietary treatments (Table 1) that: 1) contained no L-glutamine (CON), 2) contained 5% L-Glutamine (GLN), or 3) contained no L-glutamine but was equalized to GLN diet on a nitrogen basis with other nonessential amino acids (AA). On day 7, one-half of the pigs from each treatment were injected intramuscularly with 200 µg • kg BW^{-1} lipopolysaccharide (LPS) from E. coli or an equal volume of physiologic saline (SAL). LPS is the endotoxin that is produced by E. coli. Injection of LPS causes clinical symptoms of a septic state such as vomiting, diarrhea, and lethargy. Pigs and feeders were weighed on day 0, 7, and 14 to assess average daily gain (ADG), average daily feed intake

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Table 2. Day 0 to 14 combined growth performance and small intestine characteristics at day 14.

	CON[a]		GLN[b]		AA[c]			P value[h]		
Criteria, units	SAL[d]	LPS[e]	SAL	LPS	SAL	LPS	SEM	Diet	LPS	Diet x LPS
ADG[f], d 0 to 14, lb	0.26	0.15	0.25	0.27	0.34	0.20	0.06	NS	< 0.05	NS
ADFI[g], d 0 to 14, lb	0.53	0.38	0.42	0.51	0.50	0.42	0.04	NS	NS	< 0.05
ADG/ADFI, d 0 to 14	-0.49	0.20	0.42	0.34	0.60	0.44	0.40	NS	NS	NS
Small intestine length, m	10.48	8.92	10.44	9.51	10.54	9.13	0.29	NS	< 0.0001	NS
Small intestine full wt., g	292.33	229.50	281.67	290.83	340.67	256.67	16.34	< 0.09	< 0.005	< 0.03
Small intestine empty wt., g	334.15	258.00	327.83	314.00	358.00	257.33	18.34	NS	< 0.0005	< 0.07

[a]CON = Control diet.
[b]GLN = 5% glutamine diet.
[c]AA = Nonessential amino acid diet (isonitrogenous to GLN).
[d]SAL = Saline injection.
[e]LPS = Lipopolysaccharide injection.
[f]ADG = average daily gain.
[g]ADFI = average daily feed intake.
[h]NS = P > 0.10.

(ADFI), and feed efficiency (ADG/ADFI). On day 14, all pigs were anesthetized, the body cavity was opened, and the small intestine was removed. After samples were collected from the small intestine, pigs were euthanized. The small intestine length, full (including feed) intestine weight, and empty intestine weight were recorded.

Results and Discussion

During days 0 to 7, diet did not affect ADG (Figure 1; P > 0.21), ADFI (Figure 2; P > 0.79), or ADG/ADFI (Figure 3; P > 0.26). This suggests that pigs do not possess a dietary requirement for glutamine in situations where the immune system is not vigorously activated.

After the LPS injection (day 8 to 14), pigs grew 48% slower (Figure 4; P < 0.0001) compared to pigs injected with SAL. Additionally, LPS reduced ADFI (Figure 5; P < 0.005) and ADG/ADFI (Figure 6; P < 0.001) by 25 and 32%, respectively. Pigs fed GLN and injected with LPS had similar ADG (P > 0.39), ADFI (P > 0.95), and ADG/ADFI (P > 0.24) compared to pigs fed GLN and injected with SAL (Diet × LPS; P < 0.06).

Average daily gain was decreased (P < 0.05) by LPS versus SAL during days 0 to 14 (Table 2). However, LPS did not decrease feed efficiency (P > 0.64) of pigs when days 0 to 7 and 8 to14 were combined. Pigs fed GLN and injected with LPS had greater ADFI compared pigs fed GLN and injected with SAL during days 0 to 14; whereas, pigs fed AA and CON and injected with LPS had decreased ADFI (LPS × Diet, P < 0.05).

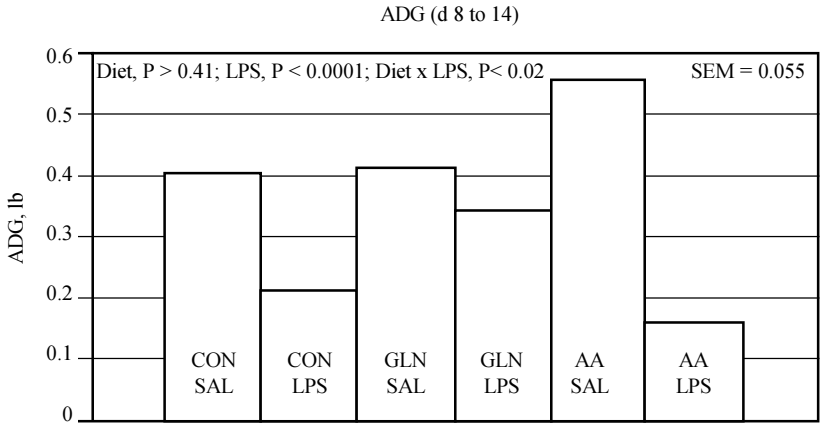

Figure 4. Effect of diet and immune challenge on average daily gain (d 8 to 14); Con = Control diet; GLN = 5 % Glutamine diet; AA = Nonessential amino acid diet (isonitrogenous to GLN); SAL = Saline injection; LPS = Lipopolysaccharide injection.

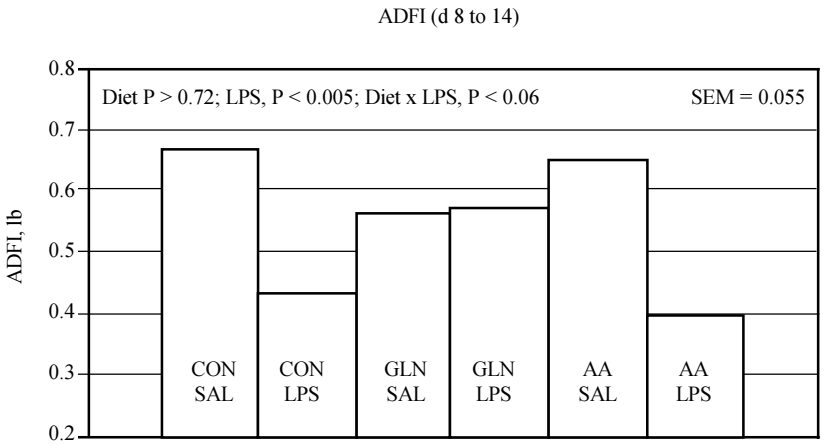

Figure 5. Effect of diet and immune challenge on average daily feed intake (d 8 to 14); Con = Control diet; GLN = 5 % Glutamine diet; AA = Nonessential amino acid diet (isonitrogenous to GLN); SAL = Saline injection; LPS = Lipopolysaccharide injection.

Injecting pigs with LPS caused a 12 % reduction (P < 0.0001) in small intestine length compared to pigs injected with SAL (Table 2). Pigs fed

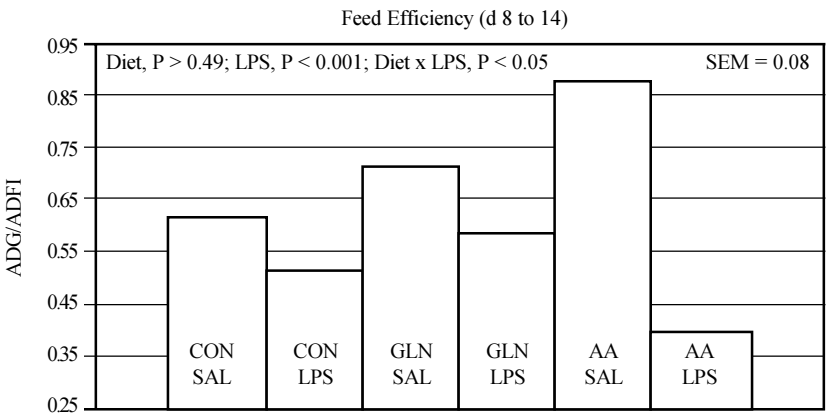

Figure 6. Effect of diet and immune challenge on feed efficiency (d 8 to 14); Con = Control diet; GLN = 5 % Glutamine diet; AA = Nonessential amino acid diet (isonitrogenous to GLN); SAL = Saline injection; LPS = Lipopolysaccharide injection.

GLN had similar small intestine weights (full and empty) compared to pigs fed GLN and injected with SAL; however, pigs fed either CON or AA and injected with SAL had reduced small intestine weight compared to their GLN counterparts (Diet × LPS, $P < 0.07$). The response of small intestine weight to treatments was similar to the response observed for ADG. It is possible that the effects observed on intestine weight may be related to body weight and (or) feed intake (indirect effects of glutamine) and not a direct effect of glutamine; however, glutamine is known to be an important source of energy for the small intestine.

Conclusion

From these data, it is apparent that dietary glutamine is an essential nutrient during an acute immune challenge. Whether all acute or chronic immune challenges would respond to dietary glutamine is unknown. However, dietary glutamine may play a role in modulating the immune response of E. coli infection and possibly other infections. It will be important to quantify glutamine concentrations in feedstuffs in order to better understand the function of glutamine and specific ingredients in improving growth and health of weanling pigs.

[1]Steven J. Kitt is a graduate student, Phillip S. Miller is an associate professor, and Robert L. Fischer is a graduate student and research technologist in the Department of Animal Science.

Influence of Crystalline or Protein-Bound Lysine on Growth Performance, Body Protein Deposition and Lysine Utilization in Nursery Pigs

Janeth J. Colina
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Austin J. Lewis
Robert L. Fischer[1]

Summary and Implications

Experiments have shown that the efficiency of utilization of crystalline amino acids may be lower than that of amino acids bound in protein. A four-week experiment was conducted to determine whether the efficiency of utilization of crystalline lysine was lower than that of lysine in soybean meal for growth and body protein deposition in nursery pigs. A total of 30 pigs (15 barrows and 15 gilts) with initial body weight of 13 lb were blocked by sex and randomly allotted, one per pen, to 30 pens in two nursery facilities. There were six replications per treatment. Six pigs (three barrows and three gilts) were killed at the beginning of the experiment to determine initial body composition. Pigs were fed five dietary treatments that consisted of a basal diet (1.05% lysine) and diets containing 1.15 and 1.25% lysine which were achieved by adding lysine to the basal diet from either soybean meal (SBM) or L-Lysine.HCl (crystalline). Blood samples were collected on the last day of the experiment and plasma was analyzed for urea concentration. Average daily gain (ADG), average daily feed intake (ADFI), and feed efficiency (ADG/ADFI) were similar (P > 0.10) among treatments. The total lysine intake increased as the lysine concentration in the diet increased (P < 0.01). Body protein content was affected by diet (P <0.01). For pigs fed diets containing 1.15% lysine, body protein percentage was greater (P < 0.01) for pigs consuming crystalline lysine, versus SBM-supplemented diets. However, body deposition rates of protein were not different among treatments. Body fat concentration and body fat deposition were affected by

(Continued on next page)

diet (P = 0.05 and P < 0.10 respectively,) but were similar between the two sources of dietary lysine. No differences were observed among treatments for body lysine concentration or lysine deposition rate. The efficiency of lysine utilization for protein deposition was greatest in pigs fed the basal diet and the crystalline supplemented diet at 1.15% total lysine. However, at the dietary concentration of 1.25% lysine, the efficiency was similar between sources. Pigs fed diets supplemented with SBM had greater (P < 0.01) plasma urea concentrations than pigs supplemented with crystalline lysine. Based on these results, it is concluded that there are no differences in the efficiency of utilization between SBM-bound lysine and lysine from L-lysine•HCl for growth and protein deposition in nursery pigs.

Introduction

Nursery pigs require a diet with a balanced and unique pattern of indispensable amino acids for optimum performance. Protein supplements usually represent 20% of the diet but make up approximately 35% of diet cost. Therefore, it is important to maximize the efficiency with which dietary amino acids are used for protein deposition or lean gain in nursery pigs. Generally, it is less expensive to use intact proteins to provide most of the amino acid needs. Also, crystalline amino acids are now available at prices that allow their inclusion in the diet. However, it has been shown that the efficiency of utilization of crystalline amino acids for protein deposition may be lower than that of amino acids bound in protein. This is probably related to some evidence showing that the efficiency of utilization of crystalline amino acids is lower than the efficiency of amino acids in intact protein when feed is restricted. It has been reported that when feed intake is regulated by force-feeding pigs three times daily, it is possible that the infrequent feeding may have contributed to the lower efficiency. This is also true for lysine. Supplements of crystalline lysine in diets for growing pigs fed once daily are used with an efficiency of half that with which crystalline lysine is used when the pigs are fed frequently.

The efficiency of dietary protein utilization for muscle growth depends on a number of factors, including the amino acid balance in the protein source, the amino acids composing the protein, and the bioavailability and efficiency of utilization of lysine, (typically the first limiting amino acid in swine diets). Thus, when lysine is the first limiting amino acid, its dietary concentration may affect protein deposition. The objective of this study was to determine the efficiency of crystalline lysine utilization relative to the lysine in soybean meal (SBM) for growth and body protein deposition in nursery pigs. The hypothesis was that the metabolic efficiency of lysine utilization is lower for crystalline lysine than for lysine contained in soybean meal protein.

Table 1. Composition of experimental diets, as-fed basis.

Source	Basal	Crystalline		Soybean Meal	
Lysine, %	1.05	1.15	1.25	1.15	1.25
Ingredient, %					
Corn	32.96	32.96	32.96	32.96	32.96
Cornstarch	7.00	6.87	6.74	3.50	0.00
Soybean meal, 46.5% CP	10.00	10.00	10.00	13.50	17.00
Spray-dried plasma protein	4.00	4.00	4.00	4.00	4.00
Fish meal, menhaden	4.00	4.00	4.00	4.00	4.00
Sunflower meal	17.50	17.50	17.50	17.50	17.50
Lactose	15.00	15.00	15.00	15.00	15.00
Dicalcium phosphate	1.35	1.35	1.35	1.35	1.35
Limestone	0.15	0.15	0.15	0.15	0.15
Corn oil	5.00	5.00	5.00	5.00	5.00
Vitamin premix[a]	1.00	1.00	1.00	1.00	1.00
Trace mineral premix[b]	0.10	0.10	0.10	0.10	0.10
Salt	0.25	0.25	0.25	0.25	0.25
Zinc oxide	0.42	0.42	0.42	0.42	0.42
Antibiotic (Mecadox-50)®	1.00	1.00	1.00	1.00	1.00
L-Tryptophan	0.05	0.05	0.05	0.05	0.05
L-Threonine	0.13	0.13	0.13	0.13	0.13
DL-Methionine	0.09	0.09	0.09	0.09	0.09
L-Lysine•HCl		0.13	0.26		
Nutrient composition,%					
Crude protein[c]	18.93	19.13	19.98	20.70	22.90
Lysine[c]	0.93	1.05	1.16	1.03	1.15
Calcium[d]	0.90	0.90	0.90	0.91	0.92
Phosphorus[d]	0.71	0.71	0.71	0.72	0.74
ME[e], Mcal/lb	1.46	1.46	1.46	1.45	1.43

[a]Supplied per kilogram of diet: retinyl acetate, 3,088 IU; cholecalciferol, 386 IU; alpha-tocopheryl acetate, 15 IU; menadione, 2.3 mg; riboflavin, 3.9 mg; d-pantothenic acid, 15.4 mg; niacin, 23.2 mg; choline, 77.2 mg; cyanocobalamin (vitamin B_{12}), 15.4 µg.
[b]Supplied per kilogram of diet: Cu (as $CuSO_4 \cdot 5H_2O$), 11 mg; I (as $Ca(IO_3) \cdot H_2O$), 0.22 mg; Zn (as ZnO), 110 mg; Fe (as $FeSO_4 \cdot H_2O$), 110 mg; Mn (as MnO), 22 mg; Se (as Na_2SeO_3), 0.3 mg.
[c]Analyzed composition.
[d]Calculated composition.
[e]ME = Metabolizable energy.

Procedures

Animals

Thirty-six crossbred nursery pigs (18 barrows and 18 gilts; weaned at 15 days of age; initial body weight of 13 lb) were used. At 21 days of age, 30 pigs (15 barrows and 15 gilts) were blocked by sex and randomly allotted, one per pen, to 30 pens in two nursery facilities. There were six replications per treatment. The remaining six pigs (three barrows and three gilts) were killed to determine initial body composition.

Dietary Treatments

During the first six days after weaning, all pigs were fed the same standard prestarter diet to allow them to adapt to the stress of weaning. For the next 28 days, pigs were fed one of five dietary

Table 2. Performance and plasma urea concentrations of pigs fed lysine-limiting diets at three different concentrations.

Source	Basal	Crystalline		Soybean Meal			P-Value			
Lys, %	1.05	1.15	1.25	1.15	1.25	SEM[a]	Diet [b]	Basal vs others[c]	CRYST vs SBM (1.15%)[c]	CRYST vs SBM (1.25%)[c]
Item										
ADG, lb	1.20	1.23	1.20	1.26	1.26	0.06	NS	NS	NS	NS
ADFI, lb	1.87	1.89	1.79	1.94	1.94	0.09	NS	NS	NS	NS
ADG/ADFI	0.64	0.62	0.67	0.65	0.65	0.04	NS	NS	NS	NS
TLI,[d] g/d	7.90	8.95	9.55	8.98	10.07	0.44	< 0.01	< 0.01	NS	NS
SLI,[e] g/d		1.03	1.87	0.88	1.94	0.06	< 0.01	< 0.01	=0.05	NS
PUC[f], mg/100 mL	29.75	26.26	30.54	37.43	38.00	2.59	< 0.01	NS	< 0.01	< 0.05

[a]SEM= Standard error of the mean.
[b]Significance of main effect of diet.
[c]Significance of contrasts. CRYST = crystalline lysine and SBM = lysine from soybean meal.
[d]TLI = Total lysine intake.
[e]SLI = Supplemental lysine intake.
[f]PUC = Plasma urea concentration.

treatments. A basal diet was formulated based on a preliminary experiment that was conducted to identify the limiting range of dietary lysine concentrations for nursery pigs. Two additional diets were formulated by adding soybean meal, and the two remaining diets were supplemented with crystalline lysine in amounts that were equal to the total lysine concentration in the soybean meal diets. All diets were formulated to meet all nutrient requirements of nursery pigs except lysine. The following three limiting amino acid concentrations (threonine, methionine, and tryptophan) were supplemented in all diets to meet the requirements for these amino acids in the basal diet and in the remaining diets. Pigs were allowed *ad libitum* access to the five experimental diets. Diets (Table 1) used were: 1) lysine-deficient diet as basal (1.05% total lysine), 2) basal diet + 0.13% L-lysine•HCl (1.15% total lysine), 3) basal diet with + 0.26% L-lysine•HCl (1.25% total lysine), 4) basal diet + 3.5% soybean meal (1.15% total lysine), 5) basal diet + 7.0% soybean meal (1.25% total lysine).

Environmental Conditions

This experiment was conducted in two nursery facilities with a total of 30 slotted-floor pens. Each pen contained a nipple waterer and a three-hole stainless steel feeder. During the first two weeks, pigs were provided with comfort boards and heat lamps. A recorder was placed in the nursery facility to monitoring humidity and environmental temperature.

Growth Performance

To determine growth performance, pigs and feeders were weighed weekly. Average daily gain (ADG), average daily feed intake (ADFI), and ADG/ADFI were recorded. Total lysine intake (TLI) and supplemental lysine intake (SLI) were calculated based on ADFI and lysine concentrations of the diets.

Blood samples

At the end of the experiment, all pigs were bled from the jugular vein and blood samples were collected in heparinized evacuated tubes. On the day of collection, samples were centrifuged and plasma was separated and frozen at 0°F.

Slaughter Procedures

The six pigs at the start and the 30 pigs fed experimental diets were killed by injecting an overdose of sodium pentobarbital. Gut contents (any remaining digesta) were removed and the whole body of the pigs (including the gastrointestinal tract) were weighed (empty body weight; EBW) and frozen at 0°F until further processing. The frozen empty body was ground through a commercial grinder with a 12.5-mm die. The ground body was thoroughly mixed to ensure homogeneity and a sample of approximately 9.0 lb was obtained. Subsequently, each sample was ground three times using a smaller grinder with successively smaller dies each time. Frequent grab samples of approximately 100 g were taken at random, mixed thoroughly to obtain a total sample of 500 g and frozen at 0°F until laboratory analyses were conducted. Samples were analyzed in duplicate for dry matter (DM), ash, CP, fat, and lysine.

Statistical Analyses

Initial EBW and chemical body composition of the pigs slaughtered at the start of the experiment were used to estimate the initial EBW and body chemical composition of pigs slaughtered at the end of the experiment. Deposition rates of water, CP, fat, ash, and lysine in the whole body were estimated as the difference between the total weight of chemical components at the end and start of the experiment divided by the number of days of the experiment (28 days). Data were analyzed as a randomized block design. Pig was considered the experimental unit. Linear contrasts were used to compare diets supplemented with crystalline lysine and soybean meal. The contrasts were: basal diet versus the other diets, and crystalline lysine

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Table 3. Effect of diet on body chemical composition and accretion rates of pigs slaughtered at the end of the experiment.

Source	Basal	Crystalline		Soybean Meal			P-Value			
Lys, %	1.05	1.15	1.25	1.15	1.25	SEM[a]	Diet [b]	Basal vs others[c]	CRYST vs SBM (1.15%)[c]	CRYST vs SBM (1.25%)[c]
Item										
Initial BW[d], lb	13.40	13.50	13.24	13.57	13.46	0.66	NS	NS	NS	NS
Initial EBW[d] lb	13.00	13.00	13.00	13.00	13.00	0.60	NS	NS	NS	NS
Final BW[d], lb	46.90	48.00	45.52	48.82	48.71	1.98	NS	NS	NS	NS
Final EBW[e], lb	44.44	45.76	43.12	45.91	45.80	1.96	NSN	S	NS	NS
Body composition, %										
Lysine	4.88	4.71	4.89	4.79	4.89	0.70	NS	NS	N	S
Water	66.79	66.87	67.62	67.15	67.42	0.48	NS	NS	NS	NS
Protein	15.13	15.92	15.99	14.73	15.88	0.24	< 0.01	< 0.10	< 0.01	NS
Fat	13.64	13.06	12.06	13.74	12.67	0.51	= 0.05	NS	NS	NS
Ash	2.59	2.65	2.49	2.40	2.44	0.07	NS	NS	< 0.05	NS
Body deposition, g/d										
Water	333.06	347.89	326.00	351.08	352.36	20.28	NS	NS	NS	NS
Protein	79.71	88.77	82.45	80.38	88.27	5.28	NS	NS	NS	NS
Fat	76.52	75.14	61.92	1.25	72.19	6.42	< 0.10	NS	NS	NS
Ash	18.70	19.82	17.40	17.96	18.12	1.10	NS	NS	NS	NS
Efficiency of lysine utilization. %[f]	50.44	48.44	44.35	44.11	44.51	1.93	< 0.05	< 0.05	= 0.08	NS

[a]SEM= Standard error of the mean.
[b]Significance of mean effect of diet.
[c]Significance of contrasts. CRYST = crystalline lysine and SBM = lysine from soybean meal.
[d]BW = body weight.
[e]EBW = empty body weight.
[f]Calculated as: (Lysine retained in the body)/(Total lysine intake-maintenance lysine requirements). It is assumed that the maintenance lysine requirements are 36 mg/kg BW $^{0.75}$.

versus SBM at the concentration of 1.15 and 1.25% total dietary lysine, respectively. Three linear regression equations were determined to evaluate the relationship of ADG, protein deposition, and lysine deposition versus total lysine intake. The efficiency of utilization of lysine intake above maintenance requirements for protein deposition (PD) was calculated for individual pigs from the observed PD multiplied by the lysine content in PD divided by total lysine intake above maintenance lysine requirements (36 mg/kgEBW$^{0.75}$).

Results

Growth Performance and Lysine Intake

Growth variables are shown in Table 2. The relationship between total lysine intake and ADG (Figure 1) shows that for each additional gram/day of lysine intake there was a 0.08 lb/day increase in gain. Although pigs fed the diets supplemented with soybean meal had slightly greater ADG and ADFI than pigs fed the basal diet or diets with crystalline lysine, these differences were not significant. Feed efficiency was also similar among treatments. The TLI increased as the dietary lysine concentration increased ($P < 0.01$), and was similar between lysine sources with the same dietary lysine concentration. The SLI was also affected by lysine concentration ($P < 0.01$). Pigs fed the SBM-supplemented diet at the level of 1.15% dietary lysine had a greater SLI than pigs fed the crystalline diets ($P < 0.05$) at the same concentration. However, the linear contrasts indicated no differences between sources at 1.25% dietary lysine.

Body Composition and Deposition

Body composition and deposition rates are shown in Table 3. The EBW was similar among dietary treatments. The percentage and deposition rates of body water and ash were similar among treatments. The body protein concentration was affected by diet ($P < 0.01$). Pigs fed the basal diet tended to have lower protein concentration than pigs fed the other diets ($P < 0.10$). At 1.15% total dietary lysine, pigs fed the crystalline-supplemented diets had a greater body protein concentration ($P < 0.01$) than pigs fed the SBM-supplemented diets. However, body protein deposition rates were similar among treatments. The linear relationship between total lysine intake and PD indicated that PD increased by 5.78 g/day of additional lysine intake (Figure 2). Body fat content was affected by dietary lysine concentration ($P = 0.05$) but was similar between the two sources of dietary lysine compared at the same concentration. Deposition rate of body fat tended to decrease as dietary lysine concentration increased within sources ($P < 0.10$), but was similar between sources. Body lysine concentration (Table 3) and daily lysine deposition (Figure 3), were similar when comparing the two sources of lysine.

The efficiency of lysine utilization for protein deposition is shown in Table 3. At 1.15% total dietary lysine concentration, the efficiency of utilization of crystalline lysine was greater than for the SBM-supplemented diet ($P = 0.08$). However, at 1.25% dietary lysine, the efficiency of utilization was similar for both sources.

Plasma urea concentration (Table

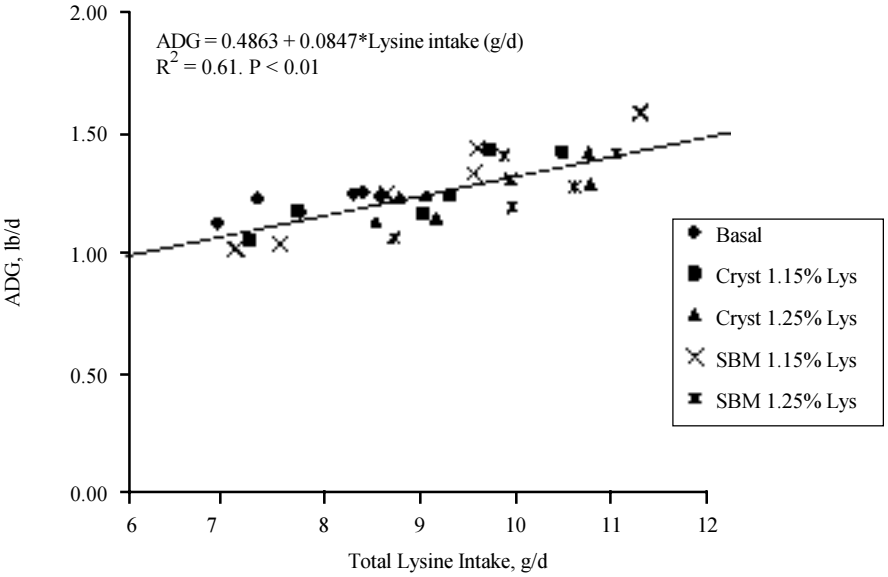

Figure 1. The response of average daily gain (ADG) to total lysine intake.

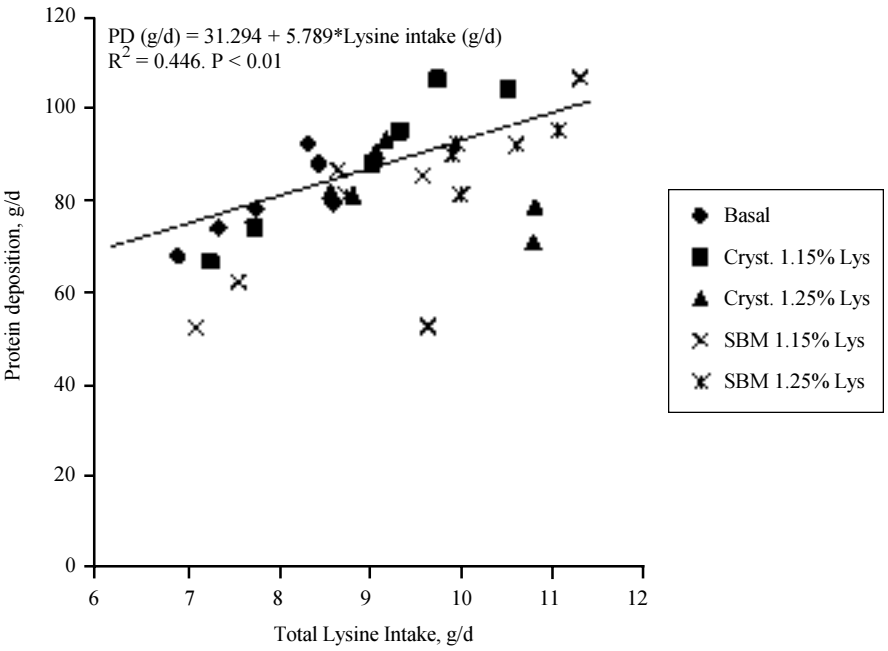

Figure 2. The response of protein deposition (PD) to total lysine intake.

2) was higher for pigs supplemented with SBM than those supplemented with crystalline lysine ($P < 0.01$).

Discussion

The results reported herein indicate that growth performance variables were similar for pigs fed the crystalline lysine and SBM-supplemented diets. Average daily gain did not respond to supplemental lysine intake. On the contrary, ADG numerically decreased with increasing dietary lysine from crystalline source and was similar for SBM supplemented diets. Although pigs fed the SBM-supplemented diets had the greatest feed intake, it was not different from the crystalline diets. Feed efficiency was similar between lysine sources. The lack of a growth response to increasing dietary lysine concentrations may be related to the high feed intake observed in this study. Pigs were fed individually, and this may have accounted for the greater feed intakes. This greater feed intake is a result of a total lysine intake that includes the lysine content of the ingredients in the basal diet (corn, sunflower meal, and soybean meal) plus the amount of supplemented lysine, 0.10 and 0.20% coming from SBM or L-lysine.HCl to equalize the total lysine content to 1.10 and 1.25% in both sources. However, as feed intake increases, the amount of lysine from the basal diet (1.05% total lysine) is greater than that of pigs fed the supplemented-diets. Therefore, the amount of weight gain attributed to lysine supplemented (above the basal diet) from SBM or L-lysine•HCl was very low.

In general, these responses indicate that lysine was absorbed and utilized similarly by pigs fed either of the two lysine sources. Body fat content and fat deposition decreased with increasing dietary lysine. However, these variables were similar between sources indicating that probably fat deposition is not uniquely affected by feeding nursery pigs with crystalline lysine or SBM-supplemented diets.

As expected the efficiency of lysine utilization was numerically greater for the basal diet. Although the efficiency of utilization of lysine was greater for the crystalline–supplemented diets at the concentration of 1.15% dietary lysine, this response was not observed at the level of 1.25% dietary lysine. In addition, a linear response of ADG to graded amounts of lysine did not result in an increased efficiency of lysine utilization. According with this result, a difference between the two sources of lysine can not be established.

The low level of plasma urea for diets supplemented with L-lysine.HCl is the result of the low protein content of these diets. For diets in which supplemental lysine was provided by SBM, urea concentrations were greater, because of the higher protein content of these diets compared to the crystalline supplemented diets.

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Conclusions

Based on these results, there are no differences in the efficiency of utilization between SBM-bound lysine and L-lysine•HCl for growth and protein deposition in nursery pigs. Because this study was conducted using individually fed pigs (resulting in a greater feed intakes) the data derived should be applied cautiously to pigs raised in commercial conditions. The lack of differences in these criteria between pigs fed crystalline lysine and SBM-supplemented diets suggest that incomplete utilization of crystalline amino acids occurs when pigs are given restricted access to feed and that difference in utilization is minimal when pigs are given *ad libitum* access to feed. Possibly, when pigs are allowed *ad libitum* access to feed, an improved balance of amino acids is absorbed, leading to similar rates of oxidation of excess indispensable amino acids from diets containing either free or protein-bound lysine. Pork producers have to take into account that the use of crystalline amino acids in nursery diets depends on amino acid cost and the cost of grain and supplemental protein sources. Also, it is important to consider that several factors can affect the utilization of crystalline amino acids.

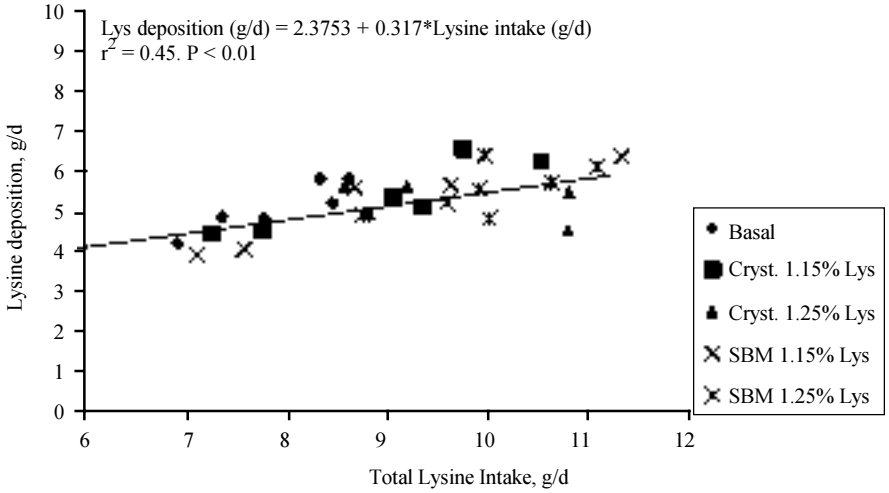

Figure 3. The response of lysine deposition to total lysine intake.

[1]Janeth J. Colina is a graduate student, Phillip S. Miller is an associate professor, Austin J. Lewis is a professor emeritus, and R. L. Fischer is a research technologist in the Department of Animal Science.

Influence of Crystalline or Protein-Bound Lysine on Lysine Utilization for Growth in Pigs

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Summary and Implications

Two experiments were conducted to determine the efficiency of utilization of crystalline lysine relative to the lysine in soybean meal for growth in barrows and gilts fed individually or in groups. One hundred twelve growing pigs (56 barrows and 56 gilts; average initial body weight of 39.6 lb) were used in each experiment. Pigs were fed individually (I) or in groups of three (G). There were 28 individually penned and 84 in 28 pens with three pigs/pen). There were two replications per treatment in each experiment for a total of four replications. For the 28-day experiments, pigs were fed one of seven dietary treatments in both experiments. Dietary treatments consisted of a basal diet (0.55% lysine) and diets containing 0.65, 0.75, and 0.85% lysine that were achieved by adding lysine to the basal diet from either soybean meal (SBM) or L-lysine•HCl (crystalline). Average daily (ADG), average daily feed intake (ADFI), and feed efficiency (ADG/ADFI) were recorded. Total lysine intake (TLI) and supplemental lysine intake (SLI) were calculated. At the end of the experiments, all pigs were scanned using real-time ultrasound to determine tenth-rib backfat depth and longissimus muscle area (LMA) to calculate fat-free lean gain (FFLG). Blood samples were taken from all pigs weekly to determine plasma urea concentration (PUC). Growth performance was similar between pigs fed crystalline lysine or SBM. Average daily gain was affected by dietary lysine concentration ($P < 0.01$) but was similar for both sources of lysine. Pigs fed individually had a greater ADG than pigs fed in groups ($P < 0.05$). No differences among dietary treatments ($P > 0.10$) were observed in ADFI. However, pigs fed individually had a greater ADFI ($P < 0.05$) than pigs fed in groups. Feed efficiency improved as the lysine concentration in the diet increased ($P < 0.01$). Backfat depth was similar among treatments ($P > 0.10$), and LMA increased ($P < 0.01$) as the lysine concentration increased for both sources of lysine. Gilts had a greater LMA ($P < 0.01$) than barrows. Fat-free lean gain increased ($P < 0.01$) as dietary lysine

Table 1. Composition of diets, as-fed basis.

Diets:	BASAL	CRYSTALLINE			SOYBEAN MEAL		
Lysine, %:	0.55	0.65	0.75	0.85	0.65	0.75	0.85
Ingredient, %							
Corn	52.44	52.44	52.44	52.44	52.44	52.44	52.44
Cornstarch	13.00	12.61	12.23	11.85	9.64	6.33	2.97
Soybean meal, 46.5% CP	7.50	7.50	7.50	7.50	10.80	14.10	17.40
Sunflower meal	21.20	21.50	21.50	21.50	21.50	21.50	21.50
Tallow	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Dicalcium phosphate	2.20	2.20	2.20	2.20	2.10	1.95	1.85
Limestone	0.47	0.47	0.47	0.47	0.50	0.55	0.57
Salt	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Vitamin premix[a]	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Trace mineral premix[b]	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-Lysine•HCl		0.13	0.26	0.39			
L-tryptophan	0.05	0.08	0.12	0.14	0.06	0.07	0.08
L-threonine	0.10	0.23	0.33	0.46	0.17	0.21	0.28
DL-methionine	0.07	0.19	0.29	0.39	0.14	0.20	0.25
Nutrient Composition[c]							
Crude protein, %	14.80	14.90	15.00	15.40	16.30	17.80	19.30
Lysine, %	0.55	0.65	0.75	0.85	0.65	0.75	0.85
Calcium, %	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Phosphorus, %	0.60	0.60	0.60	0.60	0.60	0.60	0.60
ME[d], Mcal/lb	1.38	1.37	1.36	1.35	1.37	1.36	1.35

[a]Supplied per kilogram of diet: retinyl acetate, 5,500 IU; cholecalciferol, 550 IU; alpha-tocopheryl acetate, 30 IU; menadione, 4.4 mg; riboflavin, 11 mg; d-pantothenic acid, 22.05 mg; niacin, 30 mg; cyanocobalamin (vitamin B_{12}), 33.0 µg.
[b]Supplied per kilogram of diet: Cu (as $CuSO_4 \cdot 5H_2O$), 10.5 mg; I (as $Ca(IO_3) \cdot H_2O$), 0.26 mg; Zn (as ZnO), 125 mg; Fe (as $FeSO_4 \cdot H_2O$), 125 mg; Mn (as MnO), 30 mg; Se (as Na_2SeO_3), 0.3 mg.
[c]Calculated composition.
[d]ME = Metabolizable energy.

concentration increased regardless of lysine source. Gilts were leaner than barrows (P < 0.01). Total lysine intake increased with increasing dietary lysine in both sources of lysine (P < 0.01). Pigs that were fed individually consumed more total lysine than pigs fed in groups (P < 0.05). Pigs fed individually receiving the diet supplemented with 0.30% lysine from the crystalline source consumed 0.30 g/d less than pigs fed the diet supplemented with the same amount of lysine from SBM (P < 0.10). There was a diet × week interaction (P < 0.01) for PUC. The PUC decreased for pigs consuming crystalline-supplemented diets and increased for pigs consuming SBM-supplemented diets during the 4-wk experimental period. The results indicate no significant differences in growth performance and carcass traits of pigs fed supplemented diets from L-lysine•HCl and soybean meal, suggesting that the efficiency of lysine utilization from SBM-bound lysine is similar to crystalline lysine.

Introduction

A previous experiment conducted with nursery pigs indicated that the efficiency of lysine utilization from crystalline lysine or in soybean meal was similar. However, these results may not apply to the growing phase, because additional factors such as the type of intake (restricted or *ad libitum*), individual or group feeding, and sex differences may affect the efficiency of lysine utilization. Several studies have evaluated the effect of stocking density on the responses of growing pigs to dietary lysine. It has been reported that there are no interactions between dietary lysine concentration and individual vs group feeding on growth traits. However, individually penned animals had greater feed intakes and growth rate than groups-penned animals.

Another factor that requires special attention when evaluating lysine utilization is the variation associated with sex. Gilts and barrows have a different pattern of lean and fat deposition. Gilts require greater dietary amino acid concentrations than barrows, and probably both sexes differ in the efficiency of amino acid utilization. Based on these observations, and considering the differences in the growth response observed in pigs fed individually or in groups, a study was designed to determine the efficiency of utilization of crystalline lysine relative to the lysine in soybean meal for growth in barrows and gilts individually fed or fed in groups.

Procedures

Animals and Facilities

This study consisted of two experiments replicated in time. One hundred twelve (112) growing pigs (56 barrows and 56 gilts; average initial body weight of 39.6 lb) were used in each experiment. There were two rooms with 28 pens each. Each pen contained a nipple waterer and a one-hole feeder. There were 56 gilts (14 individually penned and 42 in 14 pens with three pigs/pen) and 56 barrows (14 individually penned and 42 in 14 pens with three pigs/pen) used in the feeding experiment. There were two replications per treatment in each experiment for a total of four replications.

Dietary Treatments

Diets were limiting only in lysine. For the 28-day experiment, pigs were allowed ad libitum access to the seven experimental diets and water. The seven diets used (Table 1) consisted of a basal diet (0.55% lysine) and diets containing 0.65, 0.75, and 0.85% total lysine that were achieved by adding lysine to the basal diet from either soybean meal (SBM) or L-lysine•HCl (crystalline). Tryptophan, methionine, and threonine were added to the diets to meet the requirements for these amino acids in the basal diet and to the other diets to provide an amino acid pattern relative to lysine similar to the pattern in the basal diet.

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Growth Performance and Carcass Traits

Pigs and feeders were weighed weekly to determine average daily gain (ADG), average daily feed intake (ADFI), and feed efficiency (ADG/ADFI). Total lysine intake (TLI) and supplemental lysine intake (SLI) were estimated based on ADFI and analyzed lysine concentration of the diets. At the end of the experiment (week four), all pigs were scanned using real-time ultrasound to measure tenth-rib backfat depth and longissimus muscle area (LMA). These measurements were used to calculate the fat-free lean gain (FFLG) using the National Pork Producers Council prediction equation.

Blood Samples

Blood samples were taken from 28 pigs at the beginning of each experiment and from all pigs weekly (weeks one, two, three and four). These samples were collected in heparinized evacuated tubes and put in ice. Plasma was separated by centrifugation and frozen at 0 °F until analysis for plasma urea concentration.

Statistical Analyses

The treatment design was 2 × 3 × 2 × 2 + 4 factorial arrangement of treatments: 2 lysine sources (SBM and L-Lysine•HCl) × 3 lysine concentrations (0.65, 0.75, and 0.85%) × 2 sexes (barrows and gilts) × 2 feeding methods (group and individual) + 4 (basal diets). Growth performance data were analyzed as a split-plot in time with repeated measurements in time. Pen was considered the experimental unit. Carcass data were analyzed as a complete randomized design. Linear contrasts were used to compare the five dietary treatments. The contrasts were: basal diet vs the other diets and comparisons between lysine supplemented from crystalline lysine vs soybean meal at the lysine concentrations of 0.65%, 0.75%, and 0.85%, respectively.

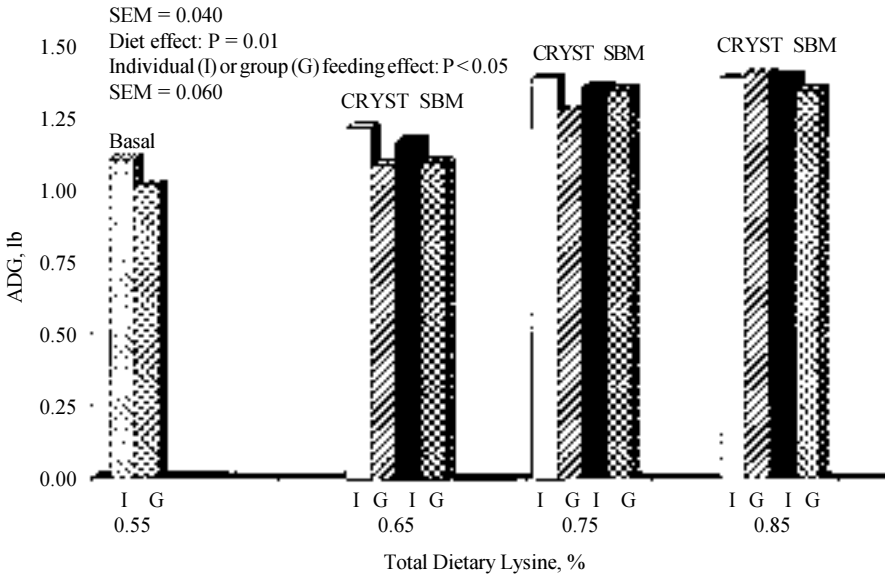

Figure 1. Response of average daily gain (ADG) to experimental diets in pigs fed individually (I) or in groups.

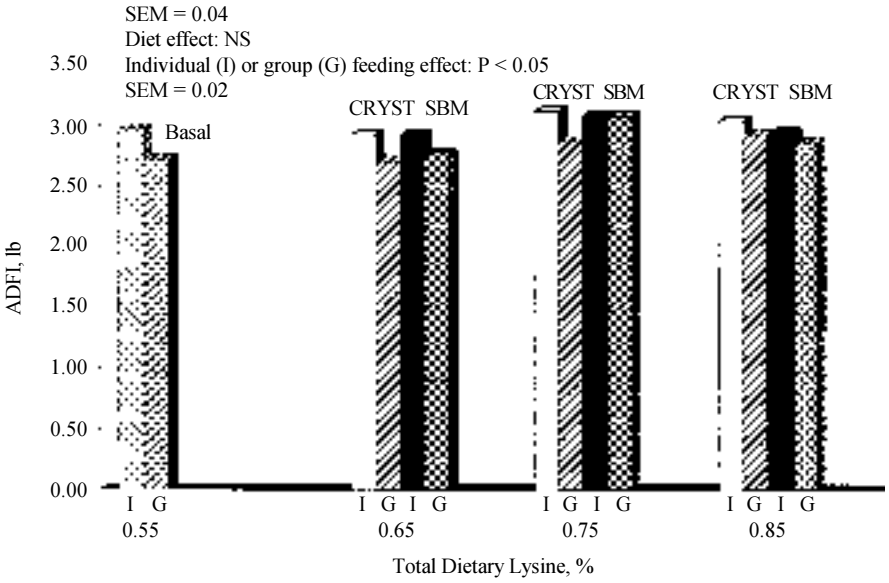

Figure 2. Response of average daily feed intake (ADFI) to experimental diets in pigs fed individually (I) or in groups (G).

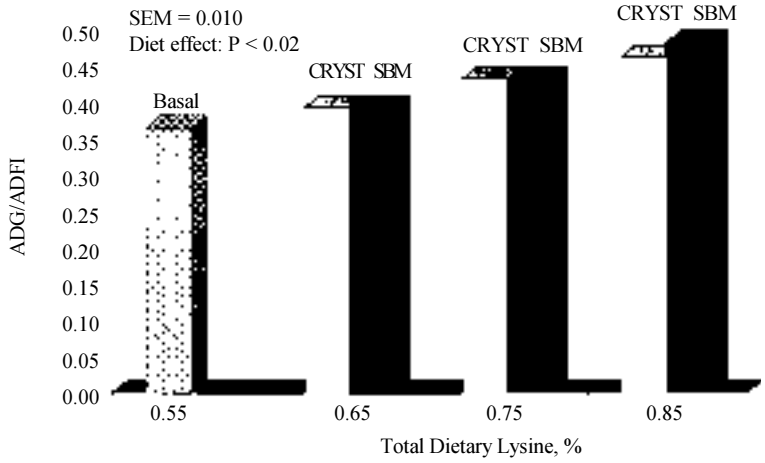

Figure 3. Overall response of feed efficiency (ADG/ADFI) to experimental diets.

Table 2.The response of body weight and carcass traits to dietary treatments.

Source	BASAL	CRYSTALLINE			SOYBEAN MEAL				P-Value		
Lysine, %	0.55	0.65	0.75	0.85	0.65	0.75	0.85	SEM[a]	Diet[b]	Basal vs others[c]	CRYST vs SBM (0.85%)[c]
Item											
Initial BW[d], lb	41.25	40.80	41.19	40.50	40.47	41.96	40.68	0.818	NS	NS	NS
Final BW, lb	71.50	73.77	79.14	80.50	72.06	80.72	79.75	1.624	< 0.01	< 0.01	NS
Backfat depth, in	0.40	0.40	0.40	0.38	0.39	0.40	0.37	0.011	NS	NS	NS
LMA[e] in^2	1.88	2.08	2.23	2.44	1.99	2.21	2.28	0.050	< 0.01	< 0.01	< 0.05
FFLG[f], lb/d	0.44	0.51	0.59	0.67	0.49	0.59	0.63	0.015	< 0.01	< 0.05	NS

[a]SEM = Standard error of the mean.
[b]Significance of main effect.
[c]Significance of contrasts. CRYST = crystalline lysine and SBM = lysine from soybean meal.
[d]BW = Body weight.
[e]LMA = Longissimus muscle area.
[f]FFLG = Fat-free lean gain calculated as: Final fat-free lean gain – Initial fat-free lean gain[g].
[g]Initial fat-free equation: $\frac{0.95 * [-3.65 + (0.418 * \text{live weight , lb})]}{28 \text{ d}}$

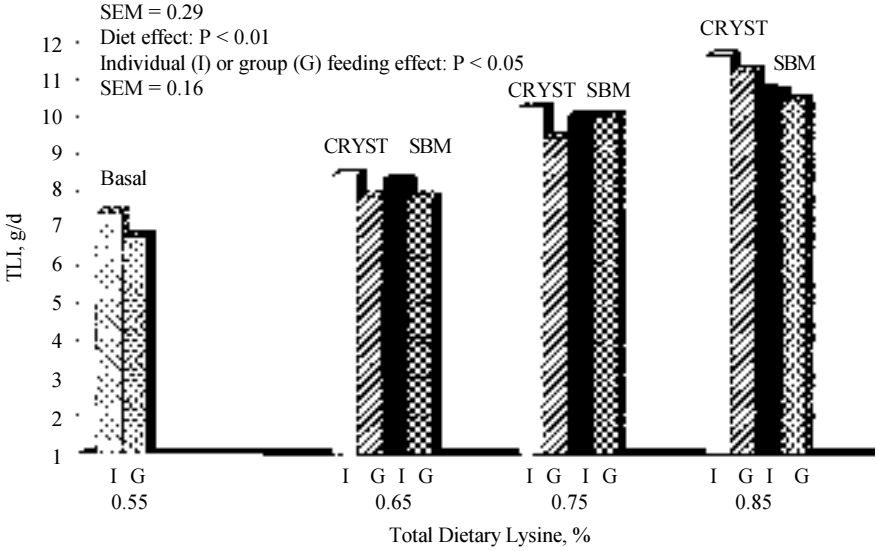

Figure 4. Response of total lysine intake (TLI) to experimental diets in pigs fed individually (I) or in groups (G).

Results and Discussion

Growth Performance

Average daily gain was affected by dietary lysine concentration (P < 0.01) but was similar for both sources of lysine (Figure 1). Pigs fed individually had a greater ADG than pigs fed in groups (P < 0.05). No differences among dietary treatments (P > 0.10) were observed in ADFI (Figure 2). However, pigs fed individually had a greater ADFI (P < 0.05) compared with pigs fed in groups (3.0 lb vs 2.8 lb, respectively). Feed efficiency increased as the lysine concentration in the diet increased (P < 0.01; Figure 3). Pigs fed individually or in groups had a similar feed efficiency. Linear contrasts indicated no differences between pigs fed crystalline lysine and lysine from soybean meal for feed efficiency. Growth performance criteria were similar between barrows and gilts (P > 0.10).

Carcass Traits

Carcass traits are shown in Table 2. Pigs fed the basal diet had the lowest final body weight (BW) (P < 0.01). There were no differences in backfat depth of pigs fed the seven dietary treatments (P > 0.10). However, LMA increased (P < 0.01) as the lysine concentrations increased for both lysine sources. Gilts had a greater LMA (P < 0.01) than barrows. There was a similar LMA for both lysine sources at the 0.65 and 0.75% lysine concentrations. However, pigs fed the diet supplemented with 0.30% crystalline lysine (0.85% total lysine) had 0.16 in^2 greater LMA than pigs fed the same percentage of lysine from SBM (P < 0.05). Fat-free lean gain increased (P < 0.01) as the dietary lysine concentrations increased for both lysine sources in a similar manner. Gilts were leaner than barrows (P < 0.01).

Lysine intake

As expected, TLI increased with increasing dietary lysine (P < 0.01; Figure 4). Pigs fed the basal diet had a lower TLI than pigs fed the other six dietary treatments (P < 0.01). The TLI was 0.85 g/d more for pigs fed diets supplemented with 0.30% crystalline lysine (0.85% total lysine) than in pigs fed the SBM at the same lysine concentration (P < 0.05). Pigs that were fed individually consumed 0.47 g/d additional total lysine than group-fed pigs (P < 0.05). There was a significant interaction of diet × individual or group feeding (P < 0.10) for SLI (Figure 5). Pigs fed individually receiving the diet supplemented with 0.30% lysine from the crystalline source consumed 0.30 g/d less vs pigs fed the diet supplemented with

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the same amount of lysine from SBM ($P < 0.10$).

Plasma Urea Concentration

There was a diet × week interaction ($P < 0.01$) for PUC (Figure 6). The PUC decreased for pigs consuming crystalline-supplemented diets and increased for pigs consuming SBM-supplemented diets during the four-week experimental period.

Discussion

Growth Performance

The results indicate no significant differences in growth performance and carcass traits of pigs fed lysine deficient diets supplemented with lysine using L-Lysine•HCl and soybean meal in growing pigs between 41 and 77 lb body weight. The increasing responses in ADG and feed efficiency indicate that the diets were limiting in lysine. These responses were similar for both sources. All diets were formulated to be limiting in lysine because the efficiency of utilization of amino acids consumed depends on whether lysine intake is limiting or in excess. Excess of dietary lysine will be preferentially used for energy and be used at a reduced efficiency for muscle growth. Dietary treatments did not affect ADFI, indicating that pigs had a similar feed intake regardless of the dietary source, dietary lysine concentration, or sex. However, the usual response when pigs are fed individually or in groups was observed. In this study, pigs fed individually had a greater feed intake than pigs fed in groups (n = 3).

Carcass Traits

Backfat thickness was not different among treatments, indicating that fat deposition was similar among pigs regardless of lysine source, lysine concentration, sex, and, individual or group feeding. Differences in LMA between pigs fed crystalline-supplemented diets and pigs fed SBM-supplemented diets at the highest dietary lysine concentration may be attributed to greater carcass leanness as lysine approached the requirement.

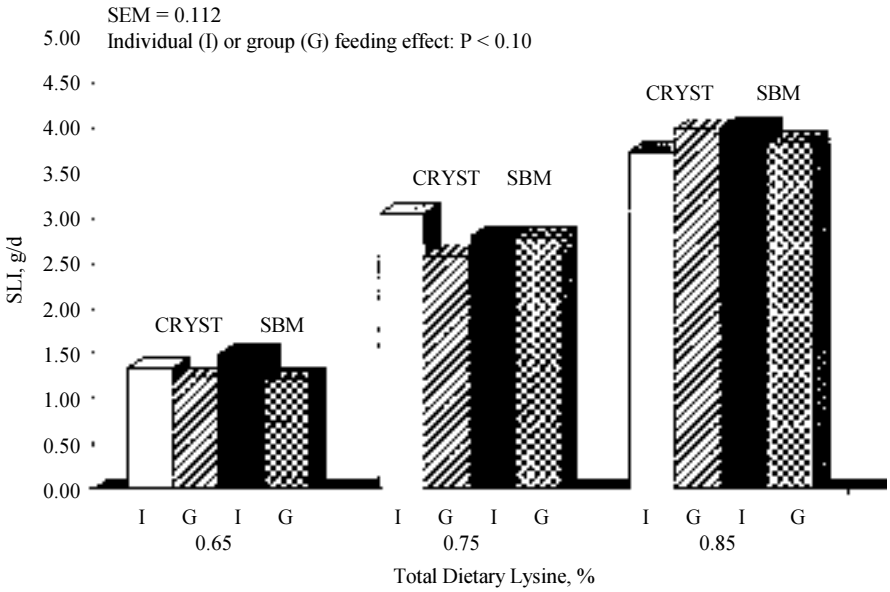

Figure 5. Response of supplemental lysine intake (SLI) to experimental diets in pigs fed individually (I) or in groups (G).

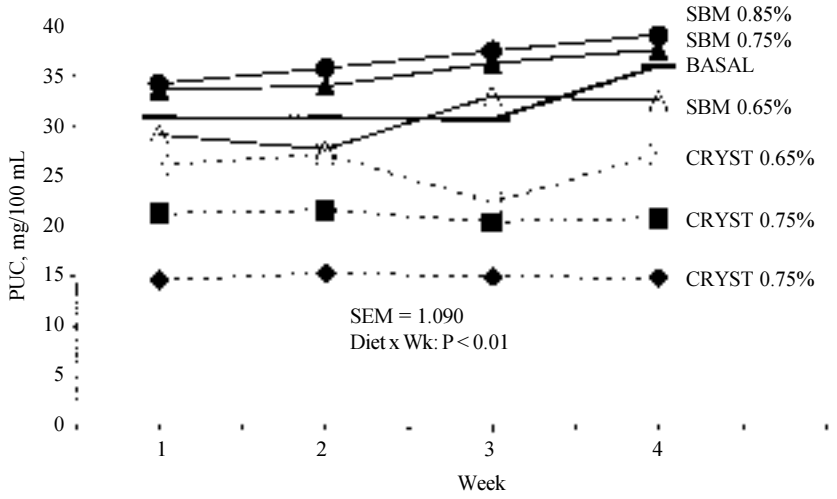

Figure 6. Response of plasma urea concentration PUC) to experimental diets by week.

Lysine Intake. The differences observed in TLI between crystalline or SBM-bound lysine were observed only at the highest lysine concentration (0.85% lysine). The increased TLI was greater for pigs fed the crystalline-supplemented diets and is attributed to an increase in feed intake. The SLI represents only the portion of intake due to the supplemental lysine from either crystalline or SBM additions to the basal diet.

Plasma Urea Concentration

A reduction in PUC has been previously determined in pigs fed concentrations of crystalline lysine below the requirement. The decrease in PUC concentration for diets with increasing additions of L-lysine•HCl indicated that lysine was deficient throughout the range of diets fed. The increased PUC in the SBM-supplemented diets presumably reflected the greater crude protein content in these diets as the dietary lysine concentrations increased to achieve the same concentrations of the crystalline-supplemented diets. Also, crystalline

amino acids were added to these diets to maintain a similar ratio of essential amino acids relative to lysine in all dietary treatments, which may increase PUC.

Conclusions

The results from this study indicate that when pigs are given *ad libitum* access to feed there are no differences in growth performance between pigs fed diets supplemented with L-Lysine•HCl and lysine from SBM. The majority of the studies indicate that protein-bound lysine in SBM is highly absorbed and utilized when compared with other protein sources. A relatively reduced efficiency of utilization of crystalline lysine has been attributed to the rapid absorption of crystalline amino acids relative to amino acids derived from intact protein. However, according with those results, reduced efficiency of utilization resulting from differences in time course of absorption between protein-bound and crystalline lysine probably do not occur when pigs are allowed *ad libitum* access to feed. Some studies have reported that pigs fed SBM-supplemented diets had a greater ADG and improved feed efficiency than pigs fed crystalline-lysine supplemented diets. However, these differences between the two sources seem may be attributable to differences in gut fill, because such differences were not detected on the basis of carcass weight. Therefore, according to the response in growth and carcass traits reported from this study, a further study is needed to determine protein deposition in pigs fed crystalline and SBM-supplemented diets. We are now studying the lysine utilization for protein deposition in these pigs. Results from this study will determine whether lysine from both sources is absorbed and utilized with the same efficiency.

[1]Janeth J. Colina is a graduate student, Phillip S. Miller is an associate professor, Austin J. Lewis is a professor emeritus, and R. L. Fischer is a research technologist in the Department of Animal Science.

Progress in Estimating Setback Distances for Livestock Facilities

Richard Koelsch
Dennis Schulte
Lakshmi Koppolu[1]

Summary and Implications

The University of Minnesota has introduced a tool used by county planners and livestock producers for developing a science-based estimate of setback distances between a livestock facility and neighbors. This paper provides an overview of the tool and an example illustrating the process for estimating setback distances. Minnesota's development efforts have resulted in the first scientifically based tool being used in the United States for public policy decisions for location of livestock facilities. More recently, University of Nebraska faculty have initiated a cooperative development effort with the Minnesota team to develop a Nebraska Odor Footprint tool which will perform a similar estimate of setback but with several unique options. This tool will consider wind direction, terrain, and Nebraska weather conditions in estimating directionally varying setbacks. It should assist producers gain approval for construction of new and expanded livestock facilities in Nebraska.

Background

Rural communities are struggling to balance odor issues with the presence and growth of the livestock industry. Currently the type of animal facility, odor control measures, prevailing wind direction, atmospheric conditions, and a community's tolerance to some degree of odor are largely ignored in the planning process because scientific tools that incorporate this information are lacking. Without such tools, decisions on setback distances and acceptable type and size of facilities are influenced by a range of arguments, often emotional in nature. In addition, livestock producers are without tools for evaulating a new facility's impact on a rural community relative to alternative sites, facility animal capacity, and odor control measures.

The role of state and federal agencies relative to livestock air quality issues is likely to increase. For example, Colorado now mandates covers on all manure storage and lagoons. New Iowa legislation will establish thresholds for odor, hydrogen sulfide, and ammonia. Minnesota has a maximum ambient hydrogen sulfide level of 30 ppb (three times lower than the Nebraska standard). United States EPA is reviewing potential regulation of ammonia and dust emission from livestock sources.

Scientifically Based Setback Tools

Recently, several tools have been developed with which to make scienfically based estimates of separation distances needed to minimize odor complaints. Ontario's Minimum Distance Setback Distance guideline has been used since the 1970's for siting of livestock facilities and residences in rural communities. The guidelines is a cross between science-based rules and personal experience. Europeans have developed several models including

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an Austrian model which determines recommended setback distances for animal housing only. Two European models, including the Austrian model, were the foundation for a Purdue model that was applied to both buildings and outdoor manure storages. Most recently, OFFSET, a tool developed in Minnesota to assess odor movement from livestock facilities, is being applied as a community odor planning tool in three Minnesota counties. Cooperative efforts between the UNL and the University of Minnesota have the potential to improve this odor modeling tool and adapt the OFFSET concept to Nebraska. Critical limitations for use of OFFSET in Nebraska include differences in weather conditions, lack of emissions data for anaerobic lagoons and open feedlots, and its current prediction of odor emissions without regard for wind direction. In addition, the Minnesota model does not handle odors from area sources well (e.g. open feedlots, large buildings, or large manure storages or lagoons).

Minnesota OFFSET Tool[2]

Recognizing the increasing number of nuisance-related conflicts between the livestock industry and rural neighbors, the Minnesota State Legislature funded an effort to develop the "Odor From Feedlots Setback Estimation Tool" (OFFSET). The University of Minnesota Biosystems and Agricultural Engineering Department under the guidance of a stakeholder advisory committee has initiated three major activities contributing to the implementation of

OFFSET:

1. Collection of a large data base of odor emission rates from a wide range of animal housing and manure storage systems. This data base is the foundation for selection of an appropriate odor emission factor that is used to define the magnitude of an odor source. Odor emissions factors have been published for common cattle, swine, and poultry housing types (Table 1) and manure storage options including earthen basins, formed manure storage tanks, and crusted manure stockpiles (Table 2). In addition, the Minnesota model recognizes the odor control benefits of different technologies (Table 3)
2. Adaption of an air dispersion computer model, INPUFF-2, to predict downwind concentrations of odors based upon meteorology and odor emission factors. This model has facilitated the recommendation of separation distances based upon total odor emissions and annoyance free levels (Figure 1).
3. Validation of this tool in repeated experiments with 20 individual farm sites.

This tool has two primary applications in Minnesota at this time. It is being used by producers prior to the construction of a new facility or expansion of an existing facility to forecast potential impacts of the planned development on neighbors and identify appropriate setback distances. The tool also allows producers to evaluate alternative odor control practices for their ability to reduce setback requirements and encourages a better fit for a

Table 1. Odor emission number for animal housing with average management level.

Species	Animal Type	Housing Type	Odor Emission Number (Rate)
Cattle	Beef/Dairy	Dirt/concrete lot	4
	Dairy	Free stall. Scrape.	6
		Free Stall. Deep pit	6
		Loose housing, scrape	6
		Tie stall, scrape	2
Swine	Gestation	Deep pit, natural or mechanical	50
		Pull plug, natural or mechanical	30
	Farrowing	Pull plug, natural or mechanical	14
	Nursery	Deep pit, natural or mechanical	42
		Pull plug, natural or mechanical	42
	Finishing	Deep pit, natural or mechanical	34
		Pull plug, natural or mechanical	20
		Hoop barn, deep bedded, scrape	4
		Cargil (open front), scrape	11
		Loose housing, scrape	11
		Open concrete lot; scrape	11
Poultry	Broiler	Litter	1
	Turkey	Litter	2

Table 2. Odor emission number for liquid or solid manure storage.

Storage Type	Odor Emission Number (Rate)
Earthen basin, single or multiple cells*	13
Steel or concrete tank, above or below ground	28
Crusted stockpile	2

*Earthen basins are designed for manure storage without any treatment. Treatment lagoons may have less odor.

Table 3. Odor control factors.

Odor Control Technology		Odor Control Factor
Biofilter on 100% of building exhaust fans		0.1
Geotextile cover (> = 2.4 mm)		0.5
Straw or natural crust on manure	2" thick	0.5
	4" thick	0.4
	6" thick	0.3
	8" thick	0.2
Impermeable cover		0.1
Oil sprinkling		0.5

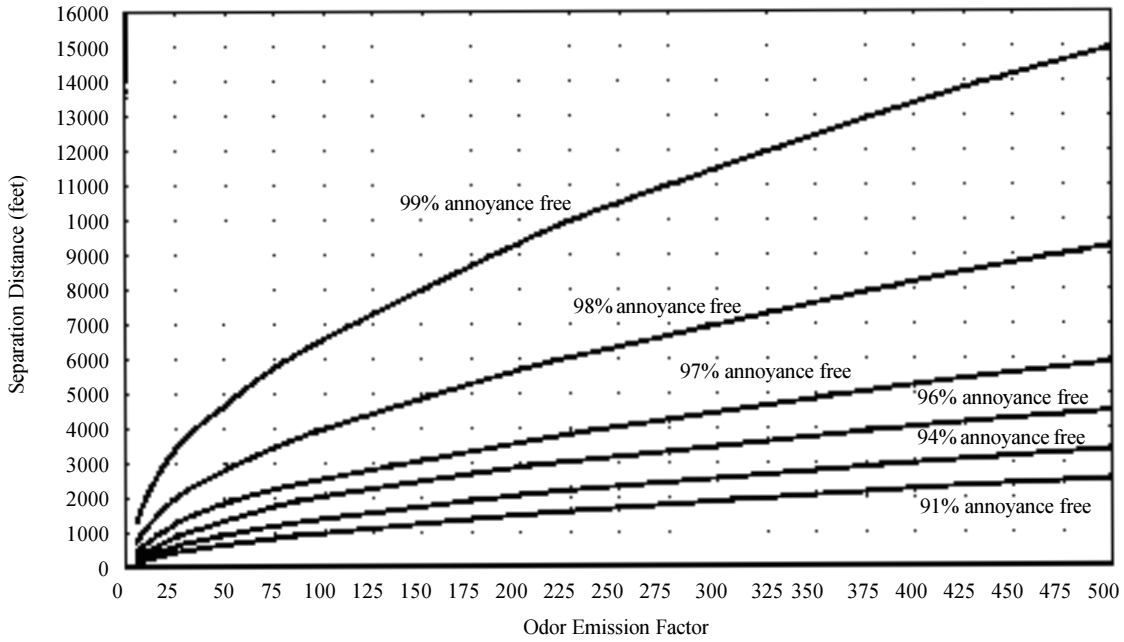

Figure 1. Estimated setback distances from animal operations at different odor annoyance-free requirements of surrounding community leeward of the prevailing wind from animal operations.

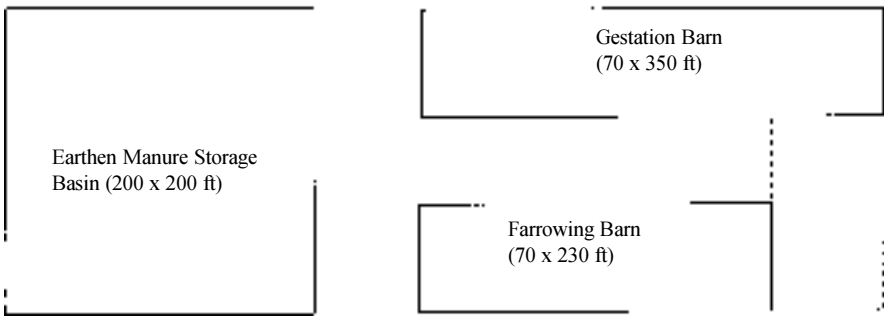

Figure 2. Layout of facilities for sample problem and other required information for using OFFSET to evaluate recommended setback distances.

proposed facility within a community. The tool is being pilot tested by three Minnesota counties for the purpose of county zoning review of proposed facilities and the appropriate setback required for that facility.

Sample Application of OFFSET

A farmer proposes a 1,200-head sow gestation and farrowing operation with mechanical ventilation and pull-plug gutters and a single-stage earthen basin (Figure 2). The county has established setbacks equal to the 97% annoyance-free curve at the nearest community. Currently, the nearest neighbor is 0.5 miles (2,640 feet) from the farm. Does this farm meet the county guidelines?

Step 1. There are three odor sources at the site, i.e. two buildings and one basin. The three source names are listed in Column A of Table 4 along with the odor emission numbers for each source from Tables 1 and 2.

Step 2. The dimensions of the gestation building and farrowing building are 70 x 350 ft. and 70 x 230 ft., respectively. The areas are 24,500 ft^2 and 16,100 ft^2, respectively for these two buildings (Area = Width x Length). The dimensions of the basin are 200 x 200 ft (40,000 ft^2 of surface area). These areas are entered in Column C of Table 4.

Step 3. There is no odor control technology for this site, so 1 is entered in Column D of Table 4 for each source.

Step 4. The odor emission factor (Column E) for each source is found by multiplying the above three numbers and dividing by 10,000.

Step 5. The three odor emission factors in Column E are summed to determine the Total Odor Emission Factor (TOEF) for the site. In this case the TOEF is 148.

Step 6. In Figure 1, locate 148 on the x-axis. Then move vertically to the 97% "odor annoyance-free" curve. Moving horizontally to the vertical axis shows the minimum setback distance to achieve 97% annoyance-free is approximately 3,000 ft. If neighbors live within 3,000 feet of the proposed site for this facility, this site may

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be determined to be unacceptable and would not meet county zoning standards. Therefore, this farm does not comply with the county guidelines because the community will experience annoying odors greater than the allowable 3% per month (22 hours per month from April through October).

To comply with county regulations, the farmer must reduce odor emissions from his animal production site or consider alternative sites. The question then becomes how much odor emission reduction is necessary to meet the 97% annoyance-free standard. The farmer contemplates the addition of a biofilter on the two buildings (odor control factor of 0.1 from Table 3) and a geotextile cover on the manure storage (odor control factor of 0.5 from Table 3). Table 5 indicates the changes in odor emissions with these two modifications. Note that Columns A, B, and C did not change between Table 4 and Table 5.

With a new Odor Emission Total estimated, go to Figure 1 and find 30.5 on the horizontal scale. For this TOEF the 97% annoyance-free level is achieved within 1,700 feet. Only the 99% annoyance-free curve is not reached by a 0.5 mile distance to the nearest neighbor. The odor control technologies used in this example are presently available. Although not common, they can be seen on demonstration farms. Additional cost to the producer to implement these odor control measures should be weighed against the expenses incurred in trying to find an alternative site.

Strengths and Weaknesses of OFFSET

The Minnesota OFFSET tool for estimating neighbor exposure to odor is a major advancement in the application of science-based tools to this issue. It provides a simple mechanism by which producers and county planners can make reasonable judgements as to the degree of impact a facility may have on the community. The University of Minnesota faculty who developed this tool are to be commended for

Table 4. Summary table for calculating the total odor emission factor for a 1,200-sow unit with no odor control practices.*

Column A Odor Source	Column B Odor Emission Number	Column C Area (sq. ft)	Column D Odor Control Factor	Column E Odor Emission Factor (B x C X D/10,000)
Gestation Barn	**30 OU/ft^2**	**24,500**	**1**	**73.7**
Farrowing Barn	**14 OU/ft^2**	**16,100**	**1**	**22.5**
Manure Storage	**13 OU/ft^2**	**40,000**	**1**	**52.0**
Total Odor Emission Factor (sum of Column E)				**148.0**
Setback Distance from Figure 1 for **97%** Annoyance Free Curve				**3,000 feet**

*Text in bold is entered by producer and is specific to individual operations.

Table 5. Summary table for calculating the total odor emission factor for a 1,200-sow unit with some odor control practices.*

Column A Odor Number	Column B Odor Emission (sq. ft)	Column C Area Factor	Column D Odor Control (B x C X D/10,000)	Column E Odor Emission Factor
Gestation Barn	**30 OU/ft^2**	**24,500**	**0.1**	**7.4**
Farrowing Barn	**14 OU/ft^2**	**16,100**	**0.1**	**2.3**
Manure Storage	**13 OU/ft^2**	**40,000**	**0.4**	**26.0**
Total Odor Emission Factor (sum of Column E)				**35.7**
Setback Distance from Figure 1 for **97%** Annoyance Free Curve				**1,700 feet**

*Text in bold is entered by producer and is specific to individual operations.

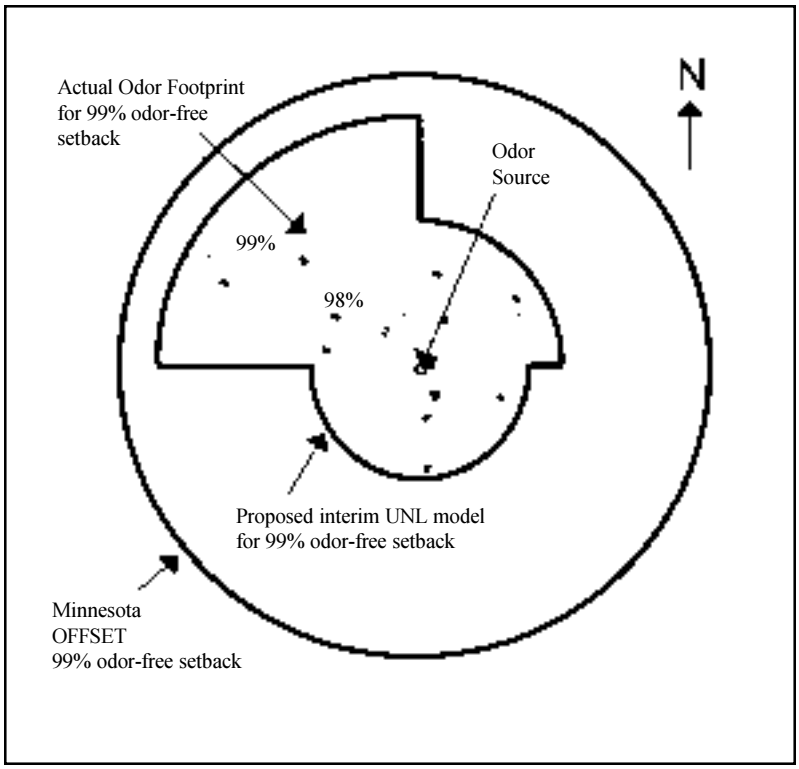

Figure 3. Predicted odor-free exposure frequencies for a livestock facility based upon the Nebraska Odor Footprint tool, a proposed interim tool, and the Minnesota OFFSET model.

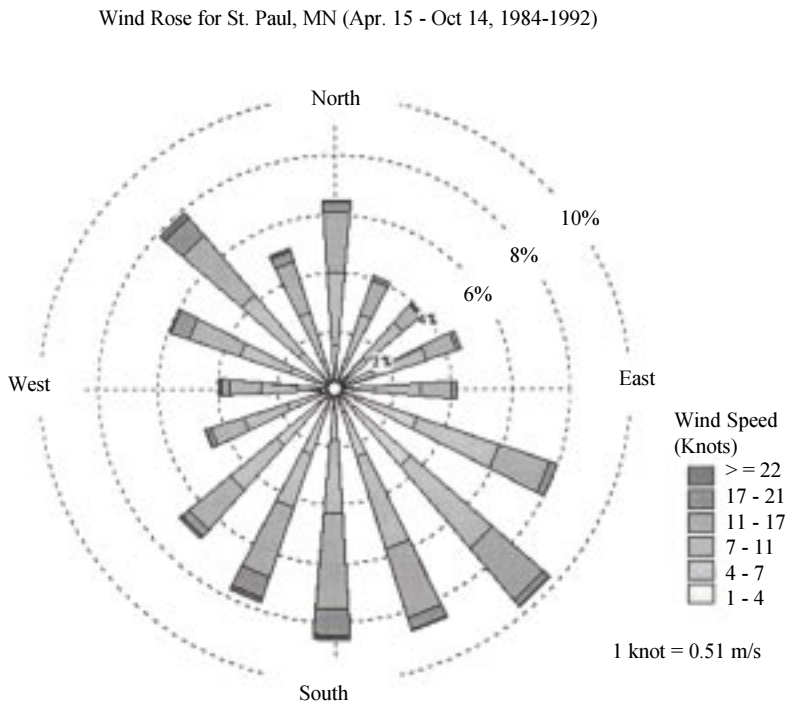

Figure 4. Wind rose used to compare Minnesota OFFSET and Nebraska Odor Footprint model (see Figure 3 illustration).

leading this effort to utilize science in assisting with a highly controversial issue.

However, the model has several limitations if it were to be applied outside Minnesota. They include:

1. The emission factors were estimated for animal housing and manure storage facilities common to Minneota. These emission factors may not always be applicable to other states or include facilities common in other states. For example, application of OFFSET to Nebraska would require development of emission factors for open beef feedlots, anaerobic lagoons, and runoff holding ponds.
2. The tool that predicts "annoyance-free" setback distances is based upon Minnesota meteorology. Differences in wind speed, temperature, and solar radiation characteristics affect the stability or instability of air and the distance required to dilute odorous air to below nuisance levels. Minnesota weather conditions are likely to predict a more conservative value for setback for most Nebraska conditions. Regionally specific weather data will need to be used for reproducing Figure 1 for locations outside Minnesota.

Two additional potential shortfalls of the current OFFSET tool need to be evaluated in the development of future models and tools. Those concerns include:

1. The predicted setback distance by OFFSET is for prevailing wind conditions. However, this setback distance is currently applied in all directions from a livestock facility. This leads to an over-estimate of the necessary setback in directions other than prevailing wind direction.
2. The current model assumes that all odor from a livestock facility originates from a single point. In reality, many livestock facilities, including beef cattle feedlots, should be considered as an area source of odor. Tools which model a livestock facility as an area source will be critical for correctly predicting setback distances from feedlots, anaerobic lagoons, and larger confinement barns.

The Proposed Nebraska Odor Footprint Tool

UNL has been working with Minnesota to rectify these shortcomings and, through the use of a new model, we hope to be able to improve the ability to estimate the frequency of exposure to annoying levels of odor while using NE conditions (Figure 3 and 4). We currently are focussing on:

- field evaluation of odor emission rates for anaerobic lagoons and feedlots, and validation in Nebraska of Minnesota emission rates for other facilities,
- integration of Nebraska weather data into the improved model, and
- development of a planning device (the Footprint tool) for Nebraska industry and community use.

Currently we are equipping a portable wind tunnel (emissions rate chamber) with appropriate gas sampling equipment and we will measure preliminary odor emission rates during the fall of 2002 to test the equipment and procedures. A second period of data collection will occur over a six-month period (March through August 2003) on emissions from 10 single-stage anaerobic lagoons in Nebraska. Samples will be collected at each lagoon on three occasions (early spring, early summer, and late summer). Within the limits of the ten lagoons to be sampled, we will identify a range of lagoon designs (different loading rates and conditions such as purple vs. non-purple). Odor samples will be shipped overnight to the University of Minnesota olfactometry lab for intensity measurement.

Odor emission rates will be expressed as odor units per square foot per hour and grouped to account for seasonal effects and lagoon design. Existing weather data (Nebraska) and the Minnesota emission rate data set will be integrated with the lagoon odor emission rates to produce the initial Nebraska Odor Footprint tool. An advisory committee will be established to review project procedures and

(Continued on next page)

results, to provide guidance on Nebraska Odor Footprint tool development and application, and to develop consensus on issues that may be controversial. Representatives of producer associations, Farm Bureau, Nebraska Association of County Officials, Nebraska Department of Environmental Quality (air quality division), and other organizations would potentially fulfill this role.

The Nebraska Odor Footprint tool will be refined with a user-friendly interface having specific outputs for producers and for planners. With the completion of this tool, an educational program targeted at producers and county public policy and planning officials will be delivered. All of these activities are dependent upon access to sufficient labor and financial resources. UNL and the Nebraska Pork Producers Association have provided some resources to move the Nebraska Odor Footprint tool forward.

It is hoped that the Nebraska Odor Footprint tool will assist producers in gaining approval for construction of new and expanded livestock facilities in Nebraska. A successful project will provide them with an ability to determine the intensity and frequency/infrequency of neighbor exposure to their odor footprint, based upon the size and type of housing, manure storage and odor control technologies they plan to use. It will also allow producers to compare neighborhood impact of alternative sites for new facilities. In addition, it will give county officials a way to understand the likelihood, magnitude and impacted area of odors for a proposed facility.

With this they can then make more informed and better decisions on new and expanded facilities. Finally, producers and community leaders will have a common basis with which to evaluate alternative technology options (odor control, housing type, and manure storage type) for reducing odor emissions and the anticipated odor footprints with these options.

Weather conditions leading to higher odors in the neighborhood of a facility will be analyzed in the Odor Footprint tool. Odor episodes classified based on the time of the day or season of the year will enable producers to identify the situations when such episodes can potentially occur. Odor control technologies implemented only during these occurrence periods will help the producer minimize odors in the neighborhood more economically.

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[2]The authors would like to recognize that significant information about the OFFSET model for this paper was adapted from University of Minnesota publications authored by Larry Jacobson, David Schmidt, Kevin Janni, and Susan Wood. Permission was granted by Larry Jacobsen.

The Economic Potential of Methane Recovery: Projected Impacts of Various Public-Policy Scenarios

Richard Stowell
Christopher Henry[1]

Summary and Implications

Economic analyses were performed on anaerobic digestion of manure from swine finishing operations. The main factors considered were facility size (1,000 head; 3,500 head; and 10,000 head) and method of financial support provided (cost-share program, no-interest loans, tax subsidies, and subsidized electrical sales). Installation of a digester system is a significant investment that is currently very difficult to justify economically to Nebraska producers based upon consideration of currently available income and expense estimates, regardless of facility size. Swine finishing operations looking to invest in this technology would benefit most from a no-interest loan or cost-share program — policies that relate directly to the capital cost incurred. Larger operations are more likely to place a value on odor control and would experience a lower unitized effective cost than smaller operations. The effective cost may still be unwieldy in an industry with tight profit margins, however.

Analysis of Anaerobic Digesters in Nebraska

Methane recovery is often promoted as a renewable energy resource and as a means of managing manure solids and controlling odors on livestock farms. With or without electricity generation, however, methane recovery is generally not expected to be a profitable venture for most operations in Nebraska. To better understand the costs incurred and the likely impact of public policy decisions on the financial feasibility of anaerobic digesters, we evaluated the

following direct and indirect support mechanisms: grants (cost-share program), no-interest loans, tax subsidies, and subsidized electrical sales.

EPA's Ag Star software program *Farmworks 2.0* (1997) was used to evaluate the feasibility of anaerobic digesters in Nebraska. Local values for farm energy costs, propane usage, etc. were obtained to more closely represent Nebraska conditions. Three possible incentive programs were considered that would subsidize anaerobic digestion. First, we considered the use of a no-interest loan for capital purchases. Second, we evaluated a cost-share program that would subsidize 20% of the capital cost of installing a digester. Third, tax credits of $0.001 and $0.01 per kWh generated were considered. Wind power sources currently receive a $0.017 per kWh federal tax credit. Finally, we considered the sale of excess generated electricity to the utility for $0.02 per kWh (approximate utility production cost) and $0.04 per kWh (twice the expected utility production cost).

In our analysis, we considered livestock farms that would be the most likely to utilize this technology. For swine, the most likely situation would be that of finishing facilities with under-floor pits or pull-plug manure storage and removal systems. These facilities could utilize a complete-mix digester and were evaluated on that basis. Systems having very diluted manure (flushing, treatment lagoons, runoff collection ponds, etc.) or solid manure (bedded pack, separated solids, etc.) do not lend themselves well to controlled anaerobic digestion and were not evaluated.

We also evaluated the relationship between size of operation and feasibility to determine the impact of farm scale. For this evaluation, 1,000-head; 3,500-head; and 10,000-head finishing facilities were considered.

The impacts of the policy/pricing scenarios on economic return were modeled for the types and sizes of operations described. The control scenario in each case assumed the following:

- 20% down-payment made on capital investment (equity investment)
- Remainder financed at 8% on a 10-year loan
- Discount rate for farm capital = 10%
- Straight-line depreciation and 35% tax rate
- Operating and maintenance costs = 1.5%/year
- Electricity purchase price (retail price paid to utility) = $0.06/kWh
- Excess electricity not valued (distributed to neighbor or returned to utility free of charge)

The first five assumptions were based upon general values used in similar types of evaluations. We believe the 1.5% annual charge for operation and maintenance to be low, especially for smaller operations, but could not find any recent data to suggest a more appropriate value. Using limited data from systems installed in the '70s and '80s would not accurately reflect improvements implemented since then. The other assumptions were based upon discussions with local livestock producers and utility representatives.

Table 1. Modeled electricity production and base cost of power generation for swine finishing operations.

	Finishing capacity		
	1,000 head	3,500 head	10,000 head
Capital cost	$125,000	$234,000	$491,000
Max. annual electric output	82,000 kWh	287,000 kWh	820,000 kWh
Excess electricity	0 kWh	7,000 kWh	38,000 kWh
Break-even electric price	23 ¢ / kWh	12 ¢ / kWh	8.5 ¢ / kWh

Table 2. Modeled return on investment from electric power generation for several policy/price scenarios on swine finishers (as a function of finishing capacity).

	Net present value (x $1,000)			Simple payback (years)			Internal rate of return (%)		
Scenario	1,000	3,500	10,000	1,000	3,500	10,000	1,000	3,500	10,000
No policy (control)	-54	-64	-78	20	11	8.2	< 0	< 0	< 0
No-interest loan	-36	-30	-6	20	11	8.2	< 0	< 0	9
Cost-share = 20%	-39	-35	-16	16	8.8	6.6	< 0	< 0	4
Tax credit									
0.1 ¢ / kWh	-54	-63	-72	20	11	8.2	< 0	< 0	< 0
1.0 ¢ / kWh	-49	-47	-27	20	11	8.2	< 0	< 0	1
Sell electricity									
2 ¢ / kWh	-54*	-64	-73	20*	11	8.2	<0	< 0	< 0
4 ¢ / kWh	-54	-63	-68	20	11	8.2	<0	< 0	< 0

*There is no excess electricity for this size operation.

Table 3. Effective cost of methane recovery from swine finishing operations for odor control (no electricity generation).

	Finishing capacity					
Scenario	1,000 head		3,500 head		10,000 head	
No policy (control)	$57,000	$57/hd	$98,000	$28/hd	$188,000	$19/hd
No-interest loan	$43,000	$43/hd	$72,000	$20/hd	$134,000	$13/hd
Cost-share = 20%	$45,000	$45/hd	$76,000	$22/hd	$142,000	$14/hd

Results

The model outputs are presented in Tables 1-3. Table 1 addresses the

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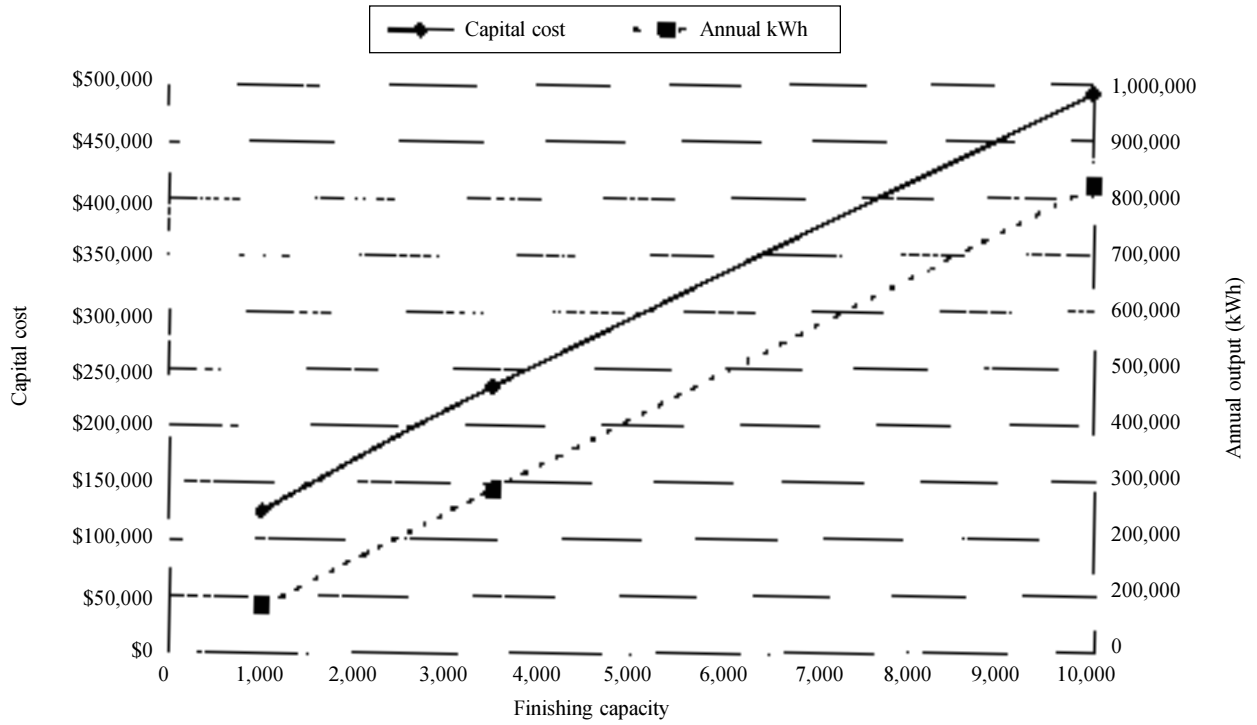

Figure 1. Modeled capital cost and maximum annual electric output of a digester on swine finishing operations as affected by herd size.

base cost of power generation on a farm. Capital costs include: digester construction, engineering costs, engine generator, solids separator and mix tank. Excess electricity refers to electricity that would not be used for normal operations. The break-even electric price represents the price charged by the utility at which the technology may be economically feasible without any policy changes.

The modeled capital cost of a digester and a system for electricity generation ranged from $125,000 to $490,000 or from $125 to $50 per pig space. These costs should be considered baseline values for a bare-bones system. Cost figures from recent farm installations indicate that total start-up costs are likely to exceed these values. Unfortunately, there aren't enough installations in place to provide more accurate values. The expected capital costs and electric output were projected to increase at fairly similar rates for the complete-mix systems (Figure 1). The bottom line was that the break-even electric price at the largest facility size ($0.085/ kWh) exceeds what most producers are currently paying in Nebraska (closer to $0.06-0.07/kWh).

Some operations on livestock farms are fixed consumers of electricity. As a result, smaller farms consume proportionately more energy per head, and little if any excess (saleable) electricity generation should be expected. Note also that the software we used models swine finishing operations as having mechanically ventilated facilities. This makes power generation more attractive than with naturally ventilated facilities since the full electric cost of operating the fans is recouped (at $0.06/ kWh) compared to giving away excess electricity or selling it at less than the retail purchase price. Many Nebraska producers choose to naturally ventilate their facilities, so these producers should understand that investments in electricity generation would have higher break-even electric prices and lower rates of return on their operations than indicated here.

Table 2 shows the net present value, simple payback period and internal rate of return for each of the scenarios. Net present value (NPV) is the current value of all cash inflows and outflows of a project at the given discount rate over the life of the project. Simple payback period is the number of years it takes to pay back the capital cost of a project without discounting future revenues or costs. Internal rate of return is the discount rate that makes the NPV of an investment equal to zero. Since the livestock producer is assuming risk with this investment, an economically good investment will have a positive NPV and an internal rate of return that exceeds the farm's discount rate (10% assumed). Some farm operators like to see a short payback period, such as less than 5 or 10 years, while for others, an internal rate of return greater than zero or close to the loan rate is acceptable for facilities that are not expected to be primary profit centers.

Without a change in public policy, a positive net present value or rate of

return was not obtained for any of the farm sizes. This indicates that methane-fueled electricity generation is not projected to be a profit center on Nebraska finishing operations and confirms the previous findings that the break-even electric price is greater than that currently charged. For the 10,000-head facility, the payback period was less than 10 years, which might be viewed as acceptable by some for long-term investments.

For the finishing facility sizes considered, no policy/price scenarios were projected to make digestion of manure for electricity generation profitable. The no-interest loan and 20% cost-share scenarios were the most advantageous scenarios for finishing operations for each finishing capacity considered.

Table 3 shows the modeled effective cost of recovering methane with a digester for the sole purpose of controlling odor. In this scenario, no electricity was generated and the cost of electric generators was excluded. The effective cost is simply the net present value of the investment (which would be negative) made into a positive number, and equals the capital cost plus the current discounted value of expected future operating costs and tax implications. The benefits of a no-interest loan and a cost-share program are shown (in terms of their reduced effective cost) compared to the current situation where no subsidization is available. For finishing operations, the model projected a unitized effective cost ranging from $13 per pig space for a 10,000-head operation taking advantage of a no-interest loan to $57 per pig space for the 1,000-head finisher under current policies.

Conclusions and Implications

Clearly, installation of a digester system is a significant investment. It is also an investment that is currently very difficult to justify economically to Nebraska livestock producers based upon consideration of current income and expense estimates, regardless of facility size. Modest energy costs are generally advantageous, but they make energy-related investments less attractive to Nebraska producers than to producers in other regions.

As the size of a livestock operation increases, the fixed capital costs of a digester system can be spread over more animal production units, making both generation of electricity and use of a digester primarily for odor control more advantageous.

Swine finishing installations likely would benefit most from a no-interest loan or cost-share program — policies that relate directly to the capital cost incurred.

To compare the effect of the same policy change between species, 1,000 milking cows are nearly equivalent to 3,500 finishing hogs, on an animal-unit basis (1 pig = 0.4 AU; 1 cow = 1.4 AU). Strategies that may work for dairy operations are not feasible for the same 'size' of swine operation, however. This can be traced to the fact that the same "size" dairy generates about 3 times the electricity for 20% higher capital costs (data for dairies not shown).

Installing a digester solely to capture methane and reduce odor emissions involves an expense that producers need to be able to justify. Small producers will likely find the costs prohibitive for obtaining odor control. Larger operations are more likely to place a value on odor control and would experience a lower unitized effective cost than smaller operations. The cost may still be considered unwieldy in an industry with tight profit margins, however.

As more information becomes available about the cost of odor-control strategies, it will be interesting to see how anaerobic digestion compares with other odor-control methods. For illustration, a more rudimentary approach to odor control is to cover a treatment lagoon or manure storage, usually with a floating geotextile fabric. The projected capital cost of covering a manure storage — where more intense odor will be generated than for a treatment lagoon and the area to be covered is less — is a little over $5/pig space for finishing pigs for a 3,500- to 4,000-head facility. An additional likely advantage to using a digester is that since the manure is treated, there would be fewer odors generated during application of the manure. Since this is a relatively infrequent activity, one must weigh this benefit against the additional costs incurred.

Low retail energy prices relative to other regions and a lack of consumer understanding of the value derived are major barriers to adoption of anaerobic digestion in Nebraska. Therefore, it seems clear that, unless industry-wide changes in operating practice occur, some sort of public policy incentive will be necessary to allow this technology to penetrate the farm sector. Financial credit is not provided for the environmental and social (odor-control) benefits of this technology so, under current economic conditions, the technology is not economically appealing for individual producers.

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*This report was developed with technical input from Rick Koelsch and Dennis Schulte (UNL Biological Systems Engineering), Frank Thompson (Nebraska Public Power District), and Jeff Keown (UNL Animal Science).

Agricultural Management Advisory Groups for Pork Producers

Allen Prosch[1]

Summary and Implications

Pork producers face complex management decisions and they need assistance with this complexity. Pork producers need to increase their awareness of the value of intangible assets such as relationships and knowledge. Pork producers must value, employ, and extract value from the use of intangible assets. Agricultural management advisory services assist producers in extracting value from the use of intangible assets such as knowledge. Pork producers need to participate in advisory services. Pork producers can use group efforts to effectively create such services. Advisory services can improve the well being of producers by increasing their knowledge of and ability to deal with external influencers that affect their businesses.

Introduction

The most dramatic changes occurring in agriculture might best be described in terms of changes in the fundamental business proposition and the ways of doing business. A managerial implication is that agricultural managers will need to learn how to appreciate, employ, and extract value from the use of intangible assets.

Critical to understanding this change is the recognition that the concept of assets employed by an operation is more comprehensive than the perspective of resources used in the past. Previously physical and human resources were the primary assets. Now the operation's resources may include intangible assets such as marketing systems, decision-making processes, coordinating systems, and established patterns of production. Production and marketing systems empowered and continually refreshed by new knowledge gained from the firm's operations can be powerful sources of competitive advantage.

Producer Needs

In the United States, family farmers have traditionally made decisions by themselves with whatever information they might gather. Producers today feel the overload of data as much as any business person. The ability to assimilate all data, turn it into decision making information and acting on that information is difficult. Increasingly, the data needed is outside the normal expertise and reach of producers.

Pork producers represent a group as challenged by the need to extract value from knowledge as any segment of agriculture. Pork production has changed dramatically consolidating into fewer larger units. Pork producers need to increase their knowledge of external influencers that affect businesses. External problems experienced with environmental and social issues do not always have tangible solutions. Producers are pinched by low margins and feel disenfranchised in their industry. Producers leave the industry despite having operations that are cost-effective. They exit the industry for a variety of reasons including production, economic, educational, environmental, and social issues, many of which are intangible.

The skills that create competitive advantage and result in higher reward are changing. Producers need to have trusted resources to improve their information. They need to have greater knowledge of the value of their products. They need to have a better awareness and understanding of what changes to make in their operation. Producers need to be able to create and manage intangible assets such as information and relationships. Producers need to capture more knowledge out of their operations and capture more knowledge out of the transactions with both input suppliers and output buyers to improve their competitive advantage.

Producers who have a support system that can improve their ability to manage knowledge and extract value from that knowledge are likely to have increased success. Producers need help to accomplish all these activities.

Consulting Services

Pork producers who are already better able to extract value from such knowledge now have a competitive advantage. Those producers may hire consultants or have staff that can deal with these issues. The ability of an individual to obtain accurate, timely advice that is tailored to the individual unit is limited. Private consultants are challenged to provide in depth service while expanding a client base. Limited contact reduces the producer's ability to trust and rely on the advice.

In either case, whether hiring a consultant or hiring staff, the producer with higher volume can obtain a greater degree of individual attention. That individual attention given to extracting value from intangible assets, be that specific knowledge or a relationship, gives producers a new competitive advantage. It increases a businesses' ability to understand and to deal with complex issues.

While U.S. producers have been expected to develop these resources and abilities and implement them on their own, other countries have notable variations. Danish agricultural producers have a producer-owned system that gives farmers advise on technical, economic, educational, information technology, and social issues.

The key issue is whether pork producers would join together to form an entity that would provide advice

that is focused on their individual unit's needs. To do so they would need to work together to spread the cost over sufficient production. In doing so, they would not have to become expert at extracting value from intangible assets, nor would they be required to acquire all the data to make decisions. Together they could gain many of the competitive advantages now being enjoyed by a limited number of producers.

Producers do need to be able to trust and rely on the advisor. The focus needs to be on their unit and the best solutions for their operation. One method to accomplish that would be to create a business entity that hired the specialist needed. This would tend to minimize conflict of interest, avoid time spent on marketing the consulting business and allow the specialist to concentrate on providing high quality service.

Producers identify the highest priority needs and acquire persons with expertise to provide them with service. Items such as customer relations, price risk management, environmental regulatory compliance, zoning regulations and comprehensive nutrient management planning are issues of such complexity and such magnitudes of change that producers would benefit from advice specific to their operation.

Conclusion

Reducing the diversity of type and size of producer threatens the flexibility of the pork production industry. When challenged by new or unusual circumstances to meet societal goals production systems must meet objectives in environment and animal husbandry practices. Pork production must also provide the producers and employees with a livelihood that is satisfactory and that encourages future participation. Increasing the competitive advantage of a larger number of individual producers is important to the future of the industry.

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Case Ready and Enhanced Pork — How Do Ingredients Make Them Work?

Mike Baczwaski
Roger Mandigo[1]

Summary and Implications

Case ready pork products have grown at a tremendous rate since the early, large scale introductions of the mid 1990s. Estimates exceed 9 billion pieces in the near future, up from 500 million in 1997 and 1.2 billion in 2000. Estimates are that between 70-80% of the fresh pork at the supermarkets is now utilizing two technologies in the case-ready status. These two technologies include enhancement and marination. Enhancement is the application of a solution of water, salt and sodium phosphates, usually approximately a 12% solution. Marination expands the solution with flavor and texture profiles involving additional ingredients. The major value-added meat processors of case ready pork products are fresh-meat processors and retailer co-packers and the list continues to grow rapidly. Justification for pork producers, meat processors and consumers are many. These advantages include: better distribution of products or in-stock at retail and less out-of-stock on a 24 hour basis, labor availability at the retail level, less shrink, greater cost savings, and most importantly increased food safety, consumer satisfaction, consistency, tenderness and juiciness.

Introduction

There are several technologies that producers of case ready meats can utilize to improve product consistency and extend shelf life. Consistency is a goal that all producers strive for regardless of the industry segment. Case-ready pork allows consumers to experience more consistent fresh pork in regards to color, texture, and eating quality. Case-ready meat allows a shelf life of two to five weeks following addition of an enhancement solution and fabrication to retail cuts. This is compared to a five to 12 day shelf life seen with traditional pork cuts fabricated at the retail store and packaged with the conventional shrink wrapped fresh meat packaging. Extending case-ready meats shelf-life allows for improved processing at large, efficient, central fabrication plants close to the source of the pork. With case-ready concepts, only consumer products are shipped through distribution centers for filling of the needs of the local stores. Fat and bone removed have utilization and value maximized at a central location. Extended shelf life may be accomplished with modified atmospheres containing gases such as carbon dioxide, nitrogen and oxygen in different combinations. Marinated or enhanced products can be vacuum packaged to extend refrigerated product sales life. Cases-ready pork also reduces in-store meat cutting, preparation, and packaging which also has a beneficial effect on food safety due to reduced handling and improved temperature control.

Case-Ready Benefits

Case-ready pork will reduce the amount of out-of-stock merchandise in the retail case and increase availability of complete lines of products. Product management and inventory control is

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much more efficient without in-store meat cutting and packaging. There are new thrusts for case-ready pork that include enhanced or marinated products.

Enhancements and Marinades

Enhancement can be defined as fresh pork that is injected with a solution of water, salt, sodium phosphates and a potentially large range of natural flavors such as rosemary extract and lemon juice. The pork is usually pumped to 8-12% of original weight. A marinade typically contains the same ingredients as the enhancement solution plus flavor components such as caramel colorings and top dressings with whole and/or cracked spices and other flavors. Thus, there are a number of non-meat ingredients that have increased the opportunity for fresh and processed pork in the retail marketplace.

Functionality of Ingredients

The functionality of the non-meat ingredient varies. Non-meat ingredients contribute to product flavor and appearance. Ingredient functionality includes the role in water holding capacity, binding through salt bridges, swelling by phosphates, and impact on overall juiciness and texture properties on the finished product. While increasing yields with the use of non-meat ingredients is economically important to the processor, optimizing their functional impact on tenderness, juiciness, texture and flavor is the most important factor.

Water

The biggest non-meat ingredient used in case-ready pork is water. Water quality, with respect to hardness and possible contaminates, influences potential benefits of the ingredient. Hard water reduces the ability of certain non-meat ingredients to dissolve and reduces the solubility of phosphates, salt and other large molecular weight ingredients. Without properly dissolving in water, phosphates and other ingredients will precipitate and not go into solution. If these ingredients precipitate out, poor binding in meat proteins will occur, resulting in poor water retention. Contaminates in water, such as iron and copper, increase oxidation. Oxidation of color by lipid and protein oxidation causes a negative effect on flavor and appearance. High chlorine levels in water have an oxidative effect on finished product by increasing lipid rancidity and loss of color stability. Water retention can be effectively controlled through adjusting pH. The isoelectric point (pI) of meat is the point at which the net ionic charge is equal to zero. The pI for fresh post-mortem pork generally occurs at pH 5.3. At the pI, there are no free charges and the fibers are attracted to one another, resulting in minimal space between the fibers. Altering pH with the use of an enhancement solution or a marinade allows charges to cause repulsion of the fibers and attract free water. To accomplish this alteration of pH, alkaline phosphates are generally used. The use of phosphates increases water retention in pork during processing, distribution and final cooking or reheating.

Salt

Salt is a major non-meat component of any marinade or enhancement solution. Salt is needed for the solubilization of pork myofibrillar proteins. Through this process it binds small pieces to one another while allowing for subtle solubilization of proteins within the muscle. Salt can also create a negative effect by causing a rubber-like texture when excessive protein solubilization has taken place. In addition, subjecting pork to too much mechanical action in the presence of high salt and phosphate levels can be detrimental to desired texture. Typically, sodium chloride is the processor's salt of choice but in the cases where excess sodium content may cause problems, alternatives can be used. Potassium salts can be used but they tend to produce bitter or metallic aftertastes. In the case where there is a masking flavor such as with marination, these potassium salts work well.

Bulking and Water Binding Ingredients

Other non-meat ingredients that are common in case-ready meats include the broad category of hydrocolloid gums. These gums include carageenan, konjac flour, xanthan, and gellan gums. Their function is to increase water holding capacity and aid in retaining water throughout the cooking process. Gums are primarily used in pork products that are low-fat or fat-free.

Lactates and acetates are antimicrobial agents that extend shelf life. Lactates, usually sodium or potassium, are ingredients that are derived from corn or beet sugar. Lactates act as a bacteriostat by interfering with bacterial metabolism and increasing the lag phase of growth. Specifically, lactates inhibit growth of *Listeria monocytogenes, Staphylococcus, Salmonella and Clostridium botulinum.* By doing this, lactates decrease microbial growth therefore increasing shelf life. Research has shown that with the addition of lactate, fresh sausage shelf life can be increased from 30 to 70% and roast pork shelf life can be increased 50 to100%. The addition of lactate in pork products acts to protect against refrigeration challenges of transportation and retail storage and handling. In case ready pork products, temperature abuse comes in the form of retail refrigeration inconsistencies, consumer abuse after the product is purchased prior to home refrigeration and increased temperatures of home refrigeration units.

Sodium diacetate, a salt of acetic acid, is a biocide that reduces the initial microbial load, but has the potential for unwanted flavors and odors. Commonly a combination of lactate and diacetate allows for lower levels in the product while obtaining a combination of both bactericidal and bacteriostatic actions.

Reducing Agents

Reducing agents play a key role in case-ready meats. Such ingredients are sodium erythorbate and sodium ascorbate. While these ingredients are important in flavor, improving shelf life and keeping quality, the most important role of reducing agents is to reduce the tendency of fresh meat color to darken and turn more brown.

Traditionally, food processors have used synthetic antioxidants developed from fats and oils such as BHA and BHT. Since it is required to declare these ingredients on the product label, they are not often used in enhanced pork products. Instead, the use of natural antioxidants in the form of herbs, spice extracts and fruit pastes have become widely adapted. Lemon juice is also being used to offset flavors of the antioxidant due to its ability to mask off flavors as well as its potential antioxidant characteristics.

The popularity of case-ready pork products is increasing and utilizes the technologies of enhancement solutions and the more involved marinades. Benefits include product availability, convenience, consistency, improved retail meat management and the ever present need for increased food safety.

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[1]Mike Baczwaski is a graduate student, and Roger Mandigo is a professor in the Department of Animal Science.

Fresh vs. Frozen Bellies for Bacon

Carmina Robles
Roger Mandigo[1]

Summary and Implications

The use of frozen pork bellies is a common practice in the bacon manufacturing industry. Frozen bellies permit the leveling of supply with sliced bacon needs, seasonal variations and the increasing value recovery from the belly. Freezing provides an excellent means of storing bellies for more efficient use at later times. Concerns that quality does not improve with freezing and storage and a greater understanding of the impact of freezing bellies on bacon quality are very important. Bellies in this study were frozen for at least15 days prior to defrosting and the start of processing. Results suggest that the use of fresh or frozen bellies in the manufacture of bacon would lead to similar yields. Processing yields including percent pump, smokehouse yield, slicing and total bacon yield were very similar. Genetic line and sex of the pig impacted quantity measures including the processing yields of bacon. Longer storage times could have added to quality differences and concerns. Short-term frozen storage of bellies has minimal impact on sliced bacon quality and performance attributes.

Introduction

Curing meat has been an effective process for centuries and was used long before refrigeration provided for more than a seasonal means of preservation. The Greek and Roman civilizations were advanced in methods of meat preservation such as salting and pickling. In addition to preservation, curing and smoking adds unique flavors, textures, variety and convenience with new products. This study is a part of the National Pork Producers Council research effort on Lean Growth Modeling to improve the quantity and quality of pork. Through the years the emphasis of increased lean, reduced fat and leaner consumer products has been the impetus for more research of bacon. Freezing of raw bellies, a long practiced process, leads to potential concerns about loss of quality and quantity of sliced bacon. Freezing provides an excellent means of storing meat for long periods of time, but, the quality of meat could decrease. Ice crystals are formed within the food products during freezing. Damage could occur to the tissue, including changes in the water holding capacity, texture, and surface color.

During thawing, undesirable phenomena such as exudate loss, evaporation loss and deterioration of fat and protein occur. The effect of freezing and thawing on bellies on subsequent processing of the bacon has not been reported extensively in the literature. Besides industry processing practices there are other production factors that influence bacon characteristics. Today pigs are bred and fed to be leaner. Consumers prefer leaner pork today than ever before, and thus the industry is turning to raising leaner, heavier muscled pigs to meet these demands. Lean-to-fat ratio is a major decision factor in a shopper's selection of bacon. However, with these leaner pigs, bacon processing characteristics such as smokehouse yield and total bacon yield are often inversely related to carcass characteristics desired by others including producers, packers and consumers. The goal of this work is to understand the quality and quantity of sliced bacon as impacted by certain live hog factors and processing fresh and frozen bellies.

Procedures

A total of 578 bellies were randomly assigned to two treatments; fresh or frozen. The project included pigs from six genetic lines: Chester White, Berkshire, Duroc, Landrace, Poland China and Yorkshire (Table 1). Gilts and barrows were included in the study. After slaughter, the belly was removed

(Continued on next page)

Table 1. Least square means for loin eye area (LEA) and backfat (BF).

Effect	LEA (in^2)	BF (in)
Line	P<0.01*	
Berkshire	5.59[d]	1.20[a]
Chester White	5.92[c]	1.13[ab]
Duroc	6.47[a]	0.88[d]
Landrace	5.80[cd]	0.96[c]
Poland China	5.75[d]	1.17[a]
Yorkshire	6.30[b]	0.87[d]
Sex	P<0.01*	
Barrows	5.61[a]	1.15[a]
Gilts	6.32[b]	0.92[b]

[abcd]Means within the same column within a main effect with similar superscripts are not significantly different (P>0.05).
*P values from Analysis of Variance for each main effect within a variable.
LEA = Loin eye area.
BF = Backfat measured on the 10th rib.

from one side of pork, cut to industry standards (NAMP #409), vacuum packaged and shipped refrigerated to the University of Nebraska Meat Laboratory. They were assigned to treatments of either fresh/refrigerated (37°F) or frozen and stored for 15 days before processing. The frozen bellies were stored at least 15 days (5°F) prior to defrosting for processing. Following industry standards the raw bellies were injected and heat processed into cooked bacon slabs. Two days prior to production the frozen bellies were taken out of the freezer and were defrosted (37°F). On the day of production, either fresh or frozen bellies were placed in a water thawing tank, immersed in cold (40°F) air agitated water to insure complete thawing of frozen bellies and similar treatment of the fresh bellies. The bellies were cured by injection of a pickle solution that contained water, phosphate, salt, sugar, sodium nitrite (cure) and sodium erythorbate. The bellies were pumped to a target of 112% of green weight, on a multiple needle commercial bacon injector. Green weight and post-pump weight were recorded. The bellies were hung with combs, placed on smokehouse trucks and allowed one hour for cure equilibration before thermal processing. Bacon was cooked to 128°F and chilled at 37°F overnight. Bellies were weighed to determine smokehouse yield, vacuum packaged and stored (24°F) for subsequent commercial pressing. The pressed slabs were sliced to determine slice yield, number of slices, slice evaluation and camera visioned for lean and fat content.

Results and Discussion

Pumping percent in bellies previously frozen [frozen bellies] was significantly higher (P <0.01) than in fresh bellies. Frozen bellies retained 0.73% more brine than fresh bellies (Table 2). Research has demonstrated that frozen meat has a higher drip loss than fresh meat. Frozen meat suffers greater damage in cellular structure, resulting in cavities and free space between meat fibers where ice crystals can form during freezing. Perhaps this loss of water from the cell during thawing, coupled with distortion that the cells may have suffered during frozen storage, made the cells dryer and perhaps more flexible. Therefore, frozen bellies may be able to hold more injection pickle after pumping. There was no significant difference between fresh and frozen bellies with respect to smokehouse yield (Table 2).

The type of belly had a significant effect on slicing yield. Fresh bellies had significantly better slicing yields (P <0.05). Warmer freezing temperature (14°F vs. -7.6°F) causes larger ice crystals. Crystals formed between fibers (higher temperatures) will generate pressure which will separate fibers, while crystals formed at lower temperature form intracellularly and result in less damage in the fresh bellies as compared to the frozen bellies. There was no difference between fresh and frozen bellies in total yield.

Genetic Line Effect

There was a significant effect of genetic line and fresh vs. frozen belly type on pumping percent. Poland China pigs had the highest brine retention, significantly higher (P<0.05) than Yorkshire, Duroc, Berkshire and Landrace lines, but similar to Chester White for pumped yield. Poland China

Table 2. Least square means ± S.E. of percent pump, smokehouse yield, slicing yield and total yield as affected by line, sex and treatment.

Effect	Percent pump[e]	Smokehouse yield (%)[f]	Slicing yield (%)[g]	Total yield (%)[h]
Line	P<0.05*	P<0.01*	P>0.05*	P<0.01*
Berkshire	10.74 ± 0.15[ab]	98.20 ± 0.17[b]	87.25 ± 0.51	85.90 ± 0.52[d]
Chester White	10.87 ± 0.30[abc]	97.34 ± 0.33[a]	88.29 ± 0.98	83.14 ± 1.00[b]
Duroc	10.33 ± 0.14[b]	97.48 ± 0.15[a]	85.24 ± 0.46	80.49 ± 0.47[a]
Landrace	10.66 ± 0.38[ab]	95.91 ± 0.42[c]	85.65 ± 1.25	80.41 ± 1.28[ab]
Poland China	11.78 ± 0.40[c]	97.30 ± 0.44[a]	86.49 ± 1.31	83.44 ± 1.34[bcd]
Yorkshire	10.78 ± 0.16[a]	97.31 ± 0.17[a]	85.73 ± 0.53	80.79 ± 0.54[ac]
Sex	P>0.05*	P>0.05*	P<0.05*	P<0.01*
Barrows	10.80 ± 0.17	97.32 ± 0.19	86.86 ± 0.57[a]	3.83 ± 0.58[a]
Gilts	10.92 ± 0.14	97.19 ± 0.16	85.36 ± 0.47[b]	0.89 ± 0.48[b]
Treatment	P<0.01*	P>0.05*	P<0.05*	P>0.05*
Fresh	10.49 ± 0.15[a]	7.07 ± 0.17	86.98 ± 0.51[a]	82.61 ± 0.53
Frozen**	11.22 ± 0.16[b]	97.44 ± 0.18	85.24 ± 0.53[b]	82.10 ± 0.55

[abcd]Means within the same column and within a main effect with similar superscripts are not significantly different (P>0.05).
*P values from Analysis of Variance for each main effect within a variable.
**Frozen stands for bellies that were frozen at -5°F prior to processing.
[e]Percent pump = (weight of the pumped belly / initial belly weight) x 100.
[f]Smokehouse yield = (weight of the cooked belly / initial belly weight) x 100.
[g]Slicing yield = (weight of the center of the sliced bacon slab / weight bacon slab) x 100.
[h]Total yield = (weight of the complete sliced bacon slab, less incomplete end pieces / belly weight) x 100.

and Chester White lines had higher backfat thickness and lower loin eye area and were thus fatter and lighter muscled than the other breeds (Table 1), a result different from previous reports that light muscle and fat lines had lower percent pump. In this study, the lowest pumping yield was observed in the Duroc pigs which had the largest loin eye areas and low backfat content. Pigs in this study were comparatively leaner than some in previous work.

Genetic line had a highly significant effect ($P<0.01$) on smokehouse yields. Berkshire line had the highest yields and were different ($P<0.05$) than all other lines. Landrace had the lowest smokehouse yield and was significantly different that all other lines. Berkshire pigs had the highest backfat, Landrace, Yorkshire and Duroc pigs the lowest backfat. These results are in agreement with the previous studies that reported fatter bellies tended to loose less weight during the heating process. Genetic line had a significant effect on total bacon yield. Bacon slabs from Berkshire pigs had the best total yield performance, followed by the Poland China and Chester White pigs. These three lines had the highest backfat thickness, again showing the relationship between fat content and total yield.

Sex Effect

Sex had no statistical influence on pumping percent or smokehouse yield, important measurements followed during the manufacturing process in many commercial bacon plants. Sex had a significant impact on slicing yield with barrows having a greater slicing yield than gilts ($P < 0.05$). Barrows had significantly higher total bacon yield than gilts ($P < 0.05$). Barrows were fatter than gilts (Table 1). Slicing yield increases with bacon slabs that are fatter.

Fatty Acid Composition of Fresh Pork Bellies — Implications to Bacon Production?

Carmina Robles
Betsy Booren
Roger Mandigo[1,2]

Summary and Implications

Commercial bacon processors often raise concerns regarding the management practice of frozen storage of the bellies prior to curing and processing for sliced bacon. Deterioration of quality measures is a concern and is usually attributed to freezer storage. A secondary issue, in the production of bacon including those processed from frozen bellies, is the effect of breed and sex of pigs. Therefore, an experiment was conducted to determine the effect of a 15-day frozen storage time, the genetics, and sex of the pig on the quality and fatty acid profile of pork bellies. Frozen storage of fresh pork bellies did not pose any significant quality problems. However, significant differences in the fatty acid profile of fat from the bellies were observed between breeds of pigs. Fat accounts for about 60% of the composition of a slice of bacon. Thus, fatty acid differences of fresh bellies due to breed effects may have a significant impact on bacon fatty acid composition.

Introduction

Consumer demand for lean meat products certainly has extended to cured and smoked sliced bacon. Consumer purchases of bacon are based on leanness, rather than brand name reputation and price. The largest growth in demand for sliced bacon has been in the food service industry recently, where bacon is seen as a flavor contributor for sandwiches, casseroles, salads, and other condiment uses. Consumers say that the amount, composition and consistency of fat are very important to their purchasing decision-making process. Sliced bacon quality problems are associated with fat separation, color of fat, color of lean, consistency and flavor.

Understanding the role of fat in bacon begins with an understanding of the variables that impact the amount and quality of the fat found in the bacon. The fatty acid composition of the fat found in the belly will potentially impact the processing characteristics of the belly, such as the slicing, cooking and eating quality of the bacon. Many factors can influence fatty acid composition including the breed and sex of the pigs as well as other management strategies.

This study is a continuing effort of the National Pork Board to characterize lean growth in pigs and the production of pork products. Additionally, the bellies were evaluated to understand the impact of freezing of raw bellies prior to production of bacon. Frozen storage of fresh bellies is a common practice to manage the cyclical and seasonal supplies of pork bellies. Yet freezing does not usually improve the quality of meat and certainly not the quality of fat and its role on the ultimate eating quality of the bacon.

Procedures

The animals in this study included barrows and gilts (n=578) from six genetic lines: Chester White, Berkshire,

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[1]Carmina Robles is a graduate student, and Roger Mandigo, is a professor in the Department of Animal Science.

Table 1. Least square means ± S.E. of the fatty acid profile for sex, line and treatment effects.

Effect	14:0	16:0	16:1	18:0	18:1	18:2	18:3	20:1
Barrows	1.35±0.01	24.04±0.15^{a}	2.64±0.03	11.59±0.13	44.98±0.27	11.27±-.31	0.69±0.03	0.80±0.01
Gilts	0.32±0.01	23.17±0.13^{b}	2.58±0.03	11.36±0.11	45.27±0.23	12.06±0.26	0.69±0.02	0.77±0.00
Berkshire	1.36±0.01^{b}	25.09±0.14^{a}	2.88±0.03^{b}	11.89±0.12^{ab}	45.78±0.27^{ab}	9.45±0.27^{b}	0.42±0.03^{b}	0.76±0.00^{b}
Chester White	1.49±0.02^{a}	24.84±0.27^{ab}	3.07±0.06^{a}	11.45±0.24^{b}	45.48±0.48^{c}	9.74±0.54^{b}	0.45±0.06^{b}	0.80±0.01^{bc}
Duroc	1.30±0.01^{c}	22.27±0.12^{d}	2.13±0.02^{e}	11.99±0.11^{a}	41.90±0.22^{e}	15.66±0.25^{a}	1.15±0.02^{a}	0.78±0.00^{b}
Landrace	1.28±0.02^{cd}	23.20±0.33^{c}	2.61±0.07^{c}	11.27±0.30^{b}	47.28±0.66^{ab}	10.17±0.67^{b}	0.46±0.07^{b}	0.77±0.02^{bc}
Poland China	1.30±0.03^{cd}	24.31±0.35^{b}	2.66±0.08^{c}	11.54±0.32^{ab}	47.35±0.63^{a}	9.25±0.71^{b}	0.46±0.08^{b}	0.80±0.02^{ac}
Yorkshire	1.26±0.01^{d}	21.95±0.14^{d}	2.30±0.03^{d}	10.69±0.12^{c}	42.98±0.25^{d}	15.73±0.28^{a}	1.18±0.03^{a}	0.81±0.01^{ac}
Fresh	1.33±0.01	23.79±0.13^{a}	2.63±0.03	11.59±0.12	45.12±0.25	11.36±0.27	0.67±0.03	0.78±0.00
Frozen	1.34±0.01	23.42±0.14^{b}	2.59±0.03	11.35±0.12	45.14±0.26	11.97±0.28	0.70±0.03	0.78±0.00

^{a,b,c,d,e}Means within a column with different superscripts are significant P<0.05.

Table 2. Least square means ± S.E. for saturated and unsaturated fatty acid content by sex, line and treatment effect.

	Unsaturated Fatty Acids - %	Saturated Fatty Acids - %
Barrows	61.43±0.26^{a}	37.71±0.27^{a}
Gilts	62.51±0.22^{b}	36.59±0.23^{b}
Berkshire	60.20±0.23^{c}	39.05±0.24^{a}
Chester White	60.51±0.46^{c}	38.57±0.47^{a}
Duroc	62.89±0.21^{b}	36.22±0.22^{c}
Landrace	62.40±0.57^{b}	36.64±0.59^{bc}
Poland China	61.46±0.60^{c}	37.82±0.62^{ab}
Yorkshire	64.35±0.24^{a}	34.60±0.25^{d}
Fresh	61.69±0.23	37.44±0.23
Frozen	62.24±0.24	36.86±0.25

^{a,b,c}Means with a column for an effect with different superscripts are significant P<0.05.

Duroc, Landrace, Poland China and Yorkshire, slaughtered at markets weights starting at 245 pounds. After slaughter, the bellies were fabricated according to industry standards. Bellies were randomly assigned a treatment of fresh (stored only under refrigeration) or frozen (stored frozen for a minimum of 15 days). Prior to processing, frozen bellies were defrosted, removed from the storage packaging, a fat sample removed from the anterior end of the belly for fatty acid analysis. The samples were frozen for subsequent methylation and fractionation by gas chromatography. The fatty acid composition was determined for saturated fatty acids including myristic (C14:0), palmitic (C16:0), stearic and unsaturated fatty acids including palmitoleic(C:16:1), oleic (C18:1) linoleic (C18:2), linolenic (C18:3), and 11-eciosenoatic (C20:1). These were selected as they account for over 95% of the total fatty acids typically found in pork bellies. Each fatty acid was reported as a percentage of total.

Results and Discussion

Barrows and Gilts Comparisons

The only difference (P<0.05) observed between sexes (Table 1) showed a minor difference for palmitic (C16:0) acid, although this may not be of biological significance. Barrows had greater levels(P<0.05) of unsaturated fatty acids (Table 2) with 61.43% for barrows and 62.51% for gilts and saturated fatty acids 37.71% for barrows compared to 36.59% for gilts. Gilts had 1.08% more unsaturated fatty acids than barrows (P<0.05). This difference becomes part of the variability often seen during packaging of sliced bacon. This is well within the range that impacts slicing efficiency found in commercial slicing operations.

Breed Comparisons

Fatty acid profiles for the six different breeds were compared. Yorkshire pigs had the most unsaturated fat (64.35%), Landrace and Duroc were intermediate (62.40% and 62.89%) and the Poland China, Chester White and Berkshire were lower in unsaturated fatty acids (61.46%, 60.51% and 60.20%, respectively). The range for unsaturated fatty acids within the 6 breeds evaluated was 4.15 percentage units (Table 2).

The breed influence illustrated in the five largest percent fatty acids reflects the breed differences for specific fatty acids. For C 16:0 palmitic acid there was 3.14 percentage unit variation between the Berkshire (25.09%) and the Yorkshire pigs (21.95%). The other saturated fatty acid, C 18:0, stearic had low variability between the breeds represented in this study with a difference of only 1.40 percentage units from the Durocs (11.99%) to the Yorkshire pigs (10.69%). The most variation was found for fatty acids C 18:1 and 18:2, oleic and linoleic, both unsaturated fatty acids. The variation was 5.45 percentage units for the oleic and 6.48 percentage units

for the linoleic acid within the breeds evaluated. These results clearly show differences exist between breeds in the fatty acid profile belly fat. The magnitude, while statistically significant, would be hard to use for sorting and/or altered processing conditions in the commercial setting due to management problems associated with sorting or knowing the genetic background of the pigs. Understanding and recognizing this source of variation can aid management in refining processes and adjusting the machinery used to slice bacon.

Fresh vs. Frozen Bellies

The characterization of fresh and frozen storage involved a minimal freezing time of at least 15 days before processing. There was no significant ($P>0.05$) difference found between the fresh and frozen bellies. As would be expected, much longer freezing times would likely be needed to measure loss in quality, particularly of fat as a result of freezer storage. This was not possible in this study. It can be concluded that short time frozen storage had no effect of the bacon quality in this study. While longer storage times are often encountered, they would certainly be more likely undesirable. This study did demonstrate that the act of freezing the bellies posed little quality damage to the bacon nor changes in the fatty acid profiles, often a concern to processors.

[1]Carmina Robles and Betsy Booren are graduate students, and Roger Mandigo is a professor in the Department of Animal Science.
[2]Appreciation expressed to Tommi Jones and Jennifer Sherrill for laboratory assistance.

Effect of Post-Cooking Holding Time on Consumer Taste Panel Ratings of Enhanced Pork Loins

Christian Perversi
Kent Eskridge
Chris Calkins[1]

Summary and Implications

Sensory evaluation of food products is a valuable means of learning about their characteristics. Consumer taste panels are regularly used to evaluate properties of meat products such as pork loins. The objective of this research was to evaluate the effect of post-cooking holding time on the taste panel ratings of enhanced pork. The loins used in this project were enhanced with varying percentages (close to 10 %) of solutions containing water, salt, phosphates and natural juices or flavors. The loins came from 10 different suppliers and were served in randomly allotted groups of seven, throughout twenty, one-hour taste panel sessions. The meat was cooked, diced and kept in double boilers in order to maintain a steady temperature of approximately 122°F throughout the duration of the one-hour taste panel. Eight-point hedonic scales were used for juiciness, tenderness, flavor and overall acceptability. The order in which the panelists attended the taste panel throughout the hour was recorded. Significant first-degree interactions between time and tenderness, juiciness, flavor and overall acceptability were found. As expected, the ratings given by the panelists to the meat decreased as post-cooking holding time in the double boilers increased. Empirically, holding time should be minimized and samples should be replaced after no more than 30 minutes. Results showed that current American Meat Science Association (AMSA) guidelines for meat evaluation should be revised whereby samples are cooked while the taste panel is conducted. As such, it is important that proper facilities be used and positive air flow in the panel booths be maintained to minimize any carry-over effects from the aroma of cooking meat.

Introduction

In current taste panel practices samples are cooked, cut and kept warm in double boilers until they are served to panelists, according to AMSA Research Guidelines (AMSA, 1995). People that come at the end of a taste panel session get meat that has been in the double boilers for an hour.

It is rational to speculate about the physical and chemical transformations that the meat undergoes in the time that it is kept warm in double boilers throughout the hour that taste panels last. These alterations in the products' organoleptic properties may have an impact on the panelists' ratings with respect to juiciness, tenderness, flavor and overall acceptability.

Previous research has shown lower sample temperatures have significantly deleterious effects on flavor and juiciness of the product being tested. They recommended maintaining 122°F sample temperature in the double boilers, but no effort was made to look at the effects of holding time.

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Materials and Methods

Chop preparation

Commercially available loins (n=14) from each of 10 different suppliers were shipped fresh to the University of Nebraska meat laboratory and randomly numbered. They were cut into 1-inch thick chops, wrapped in freezer paper and frozen according to slaughter dates in order to obtain similar aging times (15 and 30 days respectively for each supplier).

Four chops per loin were thawed at 38-42° F for 24 hours and cooked to an internal core temperature of 165°F on Farberware Open Hearth Broilers. Samples were diced and placed in double boilers so that they would all be in the boilers by the time the taste panel began. The temperature was maintained about 122°F in the boilers throughout the taste panel.

Sensory evaluation

Panels (n = 20) were conducted six times per week. Each panel lasted for one hour and was composed of seven suppliers. Attendance was voluntary but rewarded with a piece of candy after the evaluation and a cash-prize drawing at the end of each week.

Random attendees (n= 26 to 35) evaluated seven samples per taste panel session and rated them on eight-point hedonic scales for juiciness, tenderness, flavor and overall acceptability. The sampling was done in individual booths with red lights and each panelist was given a cup of water and unlimited time for the evaluation. The order of the panelists was also recorded. Sampling order was later converted to a function of time and the panelists were separated into 6 specific time groups for the analysis. In this way, time group one contained the first one-sixth of the attendees and group six, the final one-sixth.

These groups approximate the time samples were held after cooking. Panelists did not necessarily arrive at equal time intervals. However, the time required by individual panelists for the actual sensory evaluation makes the order of evaluation a reasonable approximation of post-cooking holding time.

Statistical Analyses

The MIXED procedure of SAS was used to analyze the data as an unbalanced incomplete block, blocking by panel number and brand, with time as a covariate. Panel and panel by brand interaction were included as random effects. Second and third degree interactions for the effect of time were explored, but only the linear effect of time was found to be significant.

Table 1. Significance levels (P value) and linear effects of time on taste panel tenderness, juiciness, flavor and overall acceptability scores.

	Traits evaluated			
Item	Juiciness	Tenderness	Flavor	Overall Acceptability
Levels of significance	0.0155	0.0004	< 0.0001	< 0.0001
Linear effect of time (taste panel units/hr)	-0.17	-0.25	-0.36	-0.34

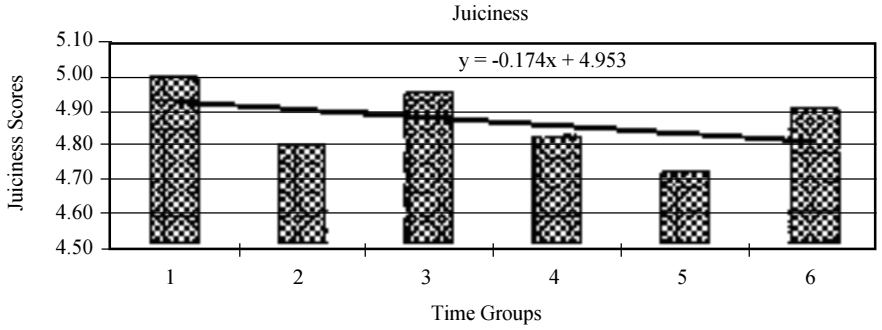

Figure 1. Effect of time (in groups of 10-minute intervals) on taste panel juiciness scores.

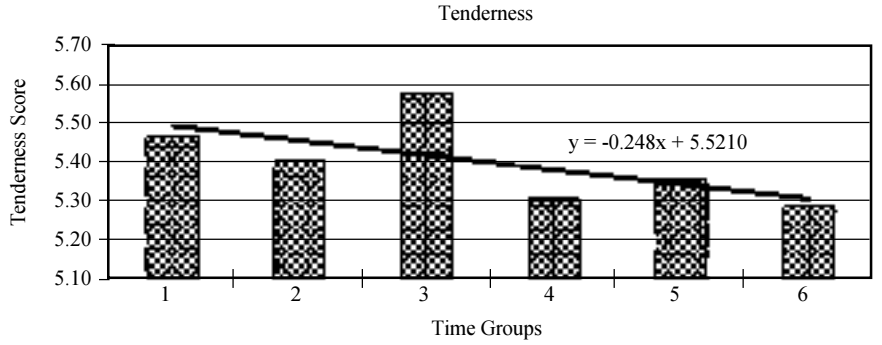

Figure 2. Effect of time (in groups of 10-minute intervals) on taste panel tenderness scores.

Results and Discussion

The linear effect of time was highly significant for all four sensory traits evaluated. The most negative impact was for flavor scores (Table 1). Overall acceptability scores were also significantly reduced by post-cooking holding time. Tenderness was negatively influenced as well and the trait least affected was juiciness.

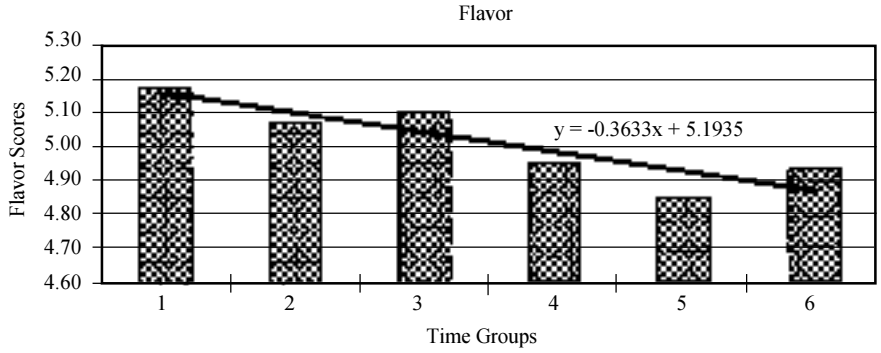

Figure 3. Effect of time (in groups of 10-minute intervals) on taste panel flavor scores.

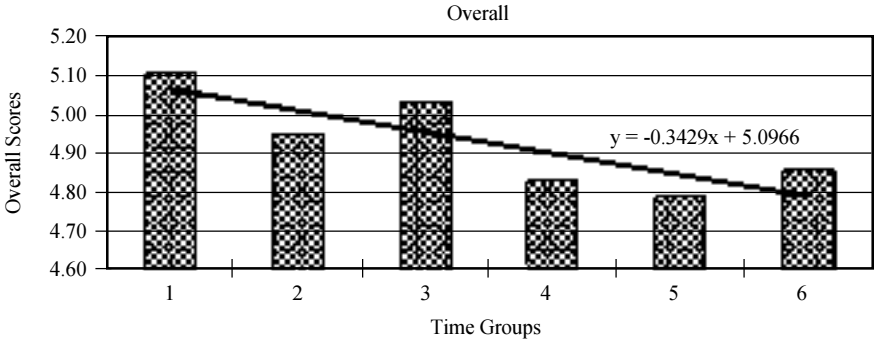

Figure 4. Effect of time (in groups of 10-minute intervals) on taste panel overall scores.

Flavor and overall acceptability mean scores dropped by 0.36 and 0.34 taste panel score points, respectively, throughout the duration of the taste panel sessions (one hour); juiciness and tenderness were lowered by 0.17 and 0.25 taste panel score points, respectively.

Panelists may have been less sensitive to differences in juiciness because of the enhancement solution injected into the product. The extra water in the product and the ingredients in the solution (such as the phosphates) likely enabled the product to be more efficient at retaining water despite the length of time held in the double boilers.

Since tenderness ratings are closely related to juiciness, it's possible the ability of the product to retain extra moisture also helped to prevent the meat from becoming tougher over time spent in the double boilers.

These data are only valid for enhanced pork samples, since it is reasonable to speculate that other species or products not processed with enhancement technologies will behave differently.

Flavor was the trait most seriously affected as the samples aged in the boilers. The transformation of compounds that give meat its characteristic flavor are likely responsible for the lower ratings that develop during post-cooking holding time.

The overall acceptability score is the sum of all of the previously mentioned effects, so it is expected that this trait carries with it the effects of many of the others.

Figures 1 through 4 show the effect of time on the mean taste panel palatability scores (juiciness, tenderness, flavor and palatability), with time being separated into six, ten-minute continuous intervals. Regression lines were fitted to each chart and the prediction equations are shown even though the variation is large.

Conclusion

These data indicate a decline in sensory ratings occurs over time during post-cooking holding time in double boilers. Empirically, holding time should be minimized and samples should be replaced after no more than 30 minutes. This will entail a change in protocol whereby samples are cooked while the taste panel is conducted. A such, it is important that proper facilities be used and positive air flow in the panel booths be maintained to minimize any carry-over effects from the aroma of cooking.

It must be noted, however, that these results are exclusive to the product tested and it is not appropriate to extrapolate these data to products from different species or processed with different technologies.

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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, five 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 ± .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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