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The effects of diet blending and feed budgeting on finishing pig growth performance, carcass characteristics, and economic return[1]

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ABSTRACT

Three experiments were conducted to compare different phase-feeding regimens with blending diets using an automated feed-delivery system (FeedPro; Feedlogic Corp., Willmar, MN) for finishing pigs on growth performance, carcass characteristics, and economic return. In Exp. 1 and 2, a total of 1,091 pigs and 19 replicate pens per treatment were used to compare phase feeding 4 diets to blending a high- and low-Lys complete diet to a set Lys curve and blending ground corn and a complete supplement to match diet composition within phases. Blending corn and a complete supplement resulted in poorer (0.338 vs. 0.348; $P < 0.04$) G:F than in curve-fed pigs in both experiments and reduced (92.5 vs. 95.4 kg; $P < 0.03$) HCW compared with standard phase feeding during Exp. 2. Pigs fed to a Lys curve had decreased ($P < 0.05$) ADG and ADFI in Exp. 2 compared with standard phase-fed pigs, but overall feed costs were also the lowest ($P < 0.01$) for curve-fed pigs. However, no differences in income over feed cost were detected between treatments. In Exp. 3, 252 pigs with 9 replicate pens per treatment were used to evaluate phase feeding 4 diets compared with feeding diets blended on a Lys curve or phase feeding diets over- and under-budgeted by 20% in each phase. Growth and carcass characteristics were similar across treatments, but curve pigs had the lowest feed cost (\$81.03 vs. \$85.59; $P < 0.03$). These studies show that feeding a corn-supplement blend resulted in poorer performance, feeding to a Lys curve resulted in lower feed costs, and over- and under-budgeting feed by 20% did not influence overall growth rate or economic return.

Key words: feed blending, feed budgeting, finishing pig, growth, phase feeding

INTRODUCTION

The swine industry has evolved from feeding as little as a single diet during the finishing period to more extensive programs using up to 7 diets; however, optimal nutrient concentrations vary with changes in lean growth and live weight, so there are frequently periods when the diet being fed is supplying excess nutrients (Moore and Mullan, 2009). In growing and finishing pigs, the rate of protein accretion in relation to live weight is curvilinear, increasing to a maximum then decreasing over time (Thompson et al., 1996). Additionally, feed intake increases further reduce nutrient requirements, and, as a result, amino acid concentrations are generally reduced in the diet as the pig

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becomes heavier. By more accurately matching the change in pig nutrient requirements with age and physiological state, N and P excretion can be decreased without reducing performance (Jongbloed and Lenis, 1992; Honeyman, 1996; Paik et al., 1996). Increasing the number of feeding phases was previously demonstrated to have economic and environmental benefits (Van der Peet Schwering et al., 1999; Pomar et al., 2007; Pomar et al. 2009), but in traditional systems these benefits have been shown to have a diminishing rate of return because of simultaneous increases in management and feed-storage costs (Boland et al., 1999).

Blend feeding, which involves mixing and delivering 2 diets in proportionate ratios, may provide feed-cost savings. A general trend for increasing average slaughter weights may also augment the cost benefits of phase feeding; Fowler (1984), Bikker et al. (1996), and Gill (1999) have shown that there is greater scope for reducing protein supply with increasing BW. The primary objective of the current research was to determine the effects of daily blending complete diets to a predetermined Lys curve compared with conventional phase-feeding strategies in finishing pigs. A secondary objective was to determine growth and economics of over- or under-budgeting a standard phase-feeding program.

MATERIALS AND METHODS

General

All practices and procedures used in these experiments were approved by the Kansas State University Institutional Animal Care and Use Committee. Experiments 1 and 3 were conducted at the Kansas State University Swine Teaching and Research Center in Manhattan. Pigs were housed in 1 of 2 identical rooms within the research barn, which contained 40 pens (2.4 × 3.1 m) with adjustable gates facing the alleyway, allowing for continuous provision of 0.93 m^2/pig. Each pen was equipped with a cup waterer and a single-sided, dry self-feeder with 2 eating spaces (Farmweld, Teutopolis, IL) located in the fence line. Pens were located over a completely slatted concrete floor with a 1.2-m pit underneath for manure storage. Experiment 2 was conducted at a commercial research finishing facility in southwestern Minnesota. The facility was double-curtain sided with completely slatted flooring. The barn contained 48 pens (3.05 × 5.49 m) equipped with a 5-hole conventional dry feeder (STACO Inc., Schaefferstown, PA) and a cup waterer to allow ad libitum consumption of feed and water. In both research facilities, an automated FeedPro feeding system (Feedlogic Corp., Willmar, MN) was used to deliver and record feeding amounts on an individual pen basis.

In all 3 trials, feed cost was calculated as the sum of individual diet cost plus grinding, mixing, and delivery (**GMD**) costs. The individual components of the GMD charges used were (1) grinding = $5.50/t, (2) mixing = $3.30/t, and (3) delivery = $7.70/t. In Exp. 1 and 2, the complete diets used in the standard and curve treatments received all 3 GMD charges. For the corn-supplement treatment, grinding was charged to the ground corn, mixing was charged to the supplement, and delivery was charged to both components. For Exp. 3, all treatments were charged with all GMD charges. Feed cost per pig and per kilogram of gain was calculated for each phase and the overall period of the experiment. Total revenue and income over feed cost (**IOFC**) were also determined within each experiment using a carcass price of $1.99/kg and current ingredient costs. Total revenue was influenced by sort loss discounts and grade premiums assigned on a per-pig basis by the abattoir based on a pricing matrix calculated using HCW and lean meat yield. The average feed cost was subtracted from the derived pig revenue to attain the IOFC per pen. All monetary values used in this paper are expressed as US dollars.

Exp. 1

A total of 283 mixed-sex pigs (TR4 × 1050; PIC, Hendersonville, TN; initial 35.0 ± 0.6 kg of BW) were used in a 97-d trial to compare phase-feeding regimens. Pens were allotted to 1 of 3 experimental treatments using a completely randomized design. Each treatment had 12 replicate pens and 8 pigs per pen (4 barrows and 4 gilts). The 3 experimental treatments were (1) a standard 4-phase complete feeding program (standard), (2) blending a high- and low-Lys complete diet over the entire experiment (curve), and (3) blending ground corn and a complete supplement within each phase (corn supplement). For the standard 4-phase feeding program, 4 finishing diets (Table 1) were formulated to provide 2.72, 2.30, 2.00, and 1.81 g of standardized ileal digestible (**SID**) Lys/Mcal of ME and were fed from 35 to 55 (d 0 to 21), 55 to 80 (d 21 to 42), 80 to 100 (d 42 to 71), and 100 to 126 kg of BW (d 71 to 97) for phases 1 to 4, respectively. For the curve treatment, a complete high- and low-Lys diet was formulated to provide 3.15 and 1.63 g of SID Lys/Mcal of ME, respectively. The complete high- and low-Lys diets were blended in varying ratios on a daily basis (Figure 1) to meet an SID Lys requirement curve, which was set using previously documented feed intake data collected using the FeedPro system in this facility. For the corn-supplement treatment, 4 complete supplements were formulated (Table 2) and stored separately from ground corn in feed-storage bins. The FeedPro system blended ground corn and the complete supplement in calculated ratios to be identical in dietary nutrient composition to those fed the standard phase-feeding program for each growing phase (Table 3). The SID Lys:ME ratios (g/Mcal) that were fed to pigs in each of the 3 treatments is shown in Figure 2. The figure illustrates the stair-step reduction of SID Lys:ME ratios used for the standard and corn-supplement treatments and the more gradual reduction in SID

Table 1. Diet composition of the standard and curve regimens, Exp. 1 (as-fed basis)

	Standard[1]				Curve[2]	
Item	Phase 1	Phase 2	Phase 3	Phase 4	High Lys	Low Lys
Ingredient, %						
Corn	78.42	83.11	86.54	88.45	73.75	90.53
Soybean meal, 46.5% CP	18.95	14.61	11.40	9.63	23.30	7.70
Monocalcium phosphate, 21% P	0.50	0.30	0.23	0.15	0.70	0.05
Limestone	0.95	0.95	0.90	0.90	0.96	0.89
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[3]	0.15	0.13	0.10	0.08	0.16	0.07
Trace mineral premix[4]	0.15	0.13	0.10	0.08	0.16	0.07
L-Lys HCl	0.30	0.26	0.24	0.22	0.34	0.20
DS-Met	0.03	—	—	—	0.05	—
L-Thr	0.07	0.04	0.03	0.03	0.10	0.03
Phytase[5]	0.13	0.13	0.13	0.13	0.13	0.13
Calculated analysis						
SID[6] amino acids, %						
Lys	0.91	0.77	0.67	0.61	1.05	0.55
Ile:Lys	61	63	64	66	60	67
Met:Lys	29	28	30	32	29	34
Met and Cys:Lys	56	58	62	66	55	70
Thr:Lys	62	62	63	65	62	66
Trp:Lys	16.5	16.5	16.5	16.5	16.5	16.5
Val:Lys	71	74	78	81	68	84
Total Lys, %	1.01	0.86	0.75	0.69	1.16	0.63
ME, kcal/kg	3,340	3,349	3,355	3,362	3,331	3,366
SID Lys:ME, g/Mcal	2.72	2.30	2.00	1.81	3.15	1.63
CP, %	15.83	14.14	12.90	12.22	17.53	11.48
Ca, %	0.54	0.49	0.45	0.43	0.60	0.40
P, %	0.46	0.40	0.37	0.35	0.51	0.32
Available P, %	0.28	0.23	0.21	0.19	0.33	0.17
Diet cost/t,[7] $	299.47	289.17	283.25	279.58	309.42	275.58

[1]Standard 4-phase complete diet feeding program where diets were fed from 35 to 55, 55 to 80, 80 to 100, and 100 to 126 kg of BW for phases 1 to 4, respectively.

[2]Feed delivery based on a Lys estimate curve where a complete high- and low-Lys diet was blended throughout the duration of the experiment.

[3]Provided the following per kilogram of premix: 4,409,200 IU of vitamin A; 551,150 IU of vitamin D_3; 17,637 IU of vitamin E; 1,764 mg of vitamin K; 3,307 mg of riboflavin; 11,023 mg of pantothenic acid; 19,841 mg of niacin; and 15.4 mg of vitamin B_{12}.

[4]Provided the following per kilogram of premix: 26.5 g of Mn from manganese oxide; 110 g of Fe from iron sulfate; 110 g of Zn from zinc sulfate; 11 g of Cu from copper sulfate; 198 mg of I from calcium iodate; and 198 mg of Se from sodium selenite.

[5]Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 600,533 phytase units/kg. Provided at levels to liberate 0.10% P.

[6]Standardized ileal digestible.

[7]Diet costs were calculated with $233.58/t of corn and $391.88/t of soybean meal, along with a $16.50/t manufacturing and delivery charge.

Lys:ME ratio for the curve treatment. The gradual reduction in SID Lys:ME ratio was achieved by changing the blending ratio on a daily basis. All complete diets, ground corn, and supplements were manufactured at the Kansas State Animal Science Feed Mill and were formulated to meet or exceed all nutrient requirement estimates (NRC, 1998).

Pigs were weighed and feed disappearance was determined at the end of each phase to calculate ADG, ADFI, and G:F (Table 4). At the end of the trial, pigs were weighed and transported (approximately 204 km) to an abattoir (Triumph Foods Inc., St. Joseph, MO). Pigs had been individually tattooed according to pen number to allow for data retrieval by pen and carcass data collection at the abattoir. Hot carcass weights were measured immediately after evisceration, and each carcass was evaluated for percentage yield, back fat, and loin depth (Table 5). Percentage yield was calculated by dividing HCW by live BW obtained at the farm before transport to the abattoir. Fat depth and loin depth were measured with an

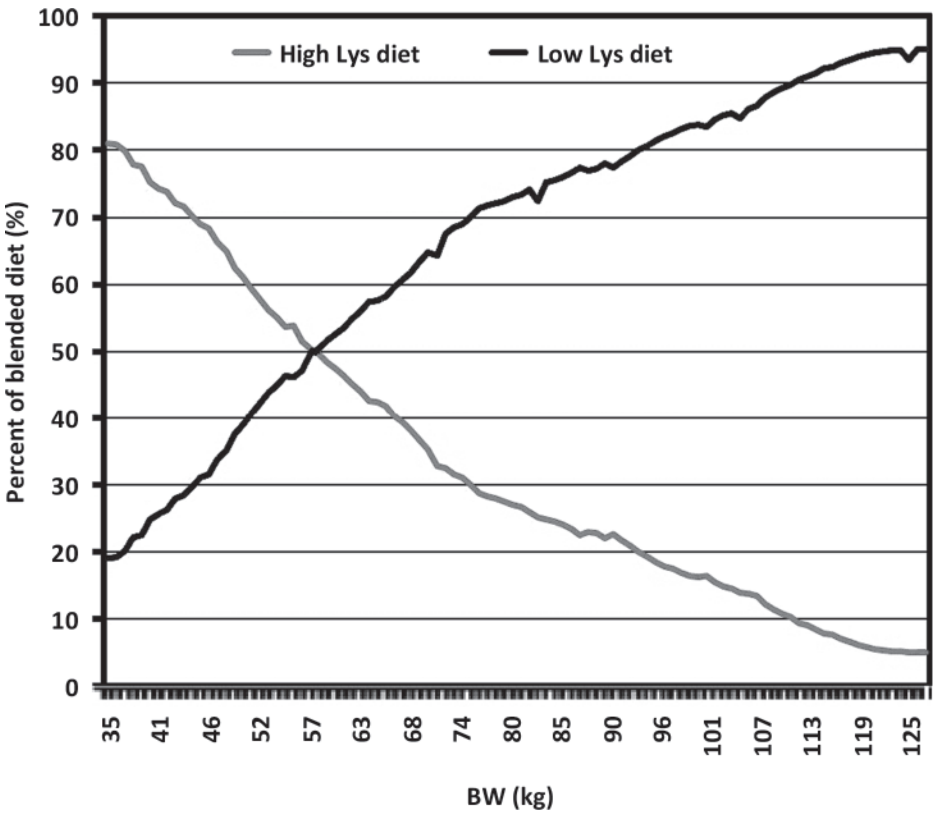

Figure 1. Percentage of the high- and low-Lys diets blended to a set Lys curve using the FeedPro system (Feedlogic Corp., Willmar, MN; Exp. 1).

optical probe (SFK Technology, Herlev, Denmark) inserted between the third and fourth ribs located anterior to the last rib at a distance approximately 7.1 cm from the dorsal midline. Percentage lean was calculated according to NPPC (1991) equations for lean-containing 5% fat, where lean (5% fat) = {2.83 + [0.469 × (0.4536 × HCW)] − [18.47 × (0.0394 × fat depth)] + [9.824 × (0.0394 × loin depth)]/(0.4536 × HCW)}. Grade premiums and sort loss discounts were also used to accurately determine the net revenue generated per pig.

Exp. 2

A total of 808 mixed-sex pigs (337 × 1050, PIC; initially 35.5 ± 0.7 kg of BW) were used in a 110-d trial to compare phase feeding with blending 2 complete finishing diets on a Lys curve in a commercial environment. Pens were randomly assigned to 1 of 3 treatments according to average BW within pen in a completely randomized design. There were 26 to 27 pigs per pen (no confounding due to random sex allocation) with 10 replicate pens per treatment. The 3 experimental treatments were (1) a standard 4-phase complete feed program (standard), (2) blending a high- and low-Lys complete diet (curve), and (3) blending ground corn and a complete supplement within each phase (corn supplement). For the standard 4-phase feeding program, 4 finishing diets (Table 6) were formulated to provide 2.83, 2.59, 2.32, and 2.05 g of SID Lys/Mcal of ME and were fed from 35 to 52 (phase 1), 52 to 71 (phase 2), 71 to 86 (phase 3), and 86 to 108 kg (phase 4), respectively.

For the curve treatment, a complete high- and low-Lys diet was formulated to provide 2.98 and 1.93 g of SID Lys/Mcal of ME, respectively. The complete high- and low-Lys diets were blended in different ratios daily (Figure 3) to meet a SID Lys requirement curve that was configured using previously determined SID Lys requirements in this facility with the same genetics. For the corn-supplement treatment, complete supplements were manufactured (Table 7) by phase, and the FeedPro system blended ground corn and the complete supplement in calculated ratios to be identical in dietary nutrient composition to the standard phase-feeding program for each growing phase. Figure 4 illustrates the stair-step reduction of SID Lys:ME ratios used for the standard and corn-supplement treatments and the more gradual reduction in SID Lys:ME ratio for the curve treatment. The gradual reduction in SID Lys:ME ratio was achieved by changing the ratio of the 2 diets provided on a daily basis. All complete diets, ground corn, and supplements were manufactured at the Kansas State Animal Science Feed Mill and were formulated to meet or exceed all nutrient requirements (NRC, 1998).

A common complete diet containing 5.0 mg/kg of ractopamine HCl (RAC; Paylean, Elanco Animal Health, Greenfield, IN) was fed to all 3 treatments for 22 d from 108 to 127 kg of BW immediately before marketing. This diet was formulated to contain 2.67 g of SID Lys/Mcal of ME.

All complete diets, ground corn, and supplements were manufactured at the New Horizons Feed Mill (Pipestone, MN) and were formulated to meet all requirement estimates (NRC, 1998). Feed samples of each treatment were collected from several feeders at a single time point within each dietary phase. These samples were homogenized and analyzed for Lys content (AOAC 982.30 Ea,b, chp. 45.3.05; AOAC, 2006) at the University of Missouri Agricultural Experiment Station Chemical Laboratories (Columbia; Table 8).

Pigs from each pen were weighed as a group, and feed disappearance was determined approximately every 21 d to determine ADG, ADFI, and G:F (Table 9). On d 88 of the experiment, the 4 heaviest pigs from each pen (determined visually) were weighed and removed in accordance with the normal marketing procedure of the farm. On d 110, pigs were transported (approximately 95 km) to a commer-

Table 2. Composition of the complete supplements (as-fed basis) and the proportion of ground corn and supplement by phase, Exp. 1[1,2]

	Complete supplement			
Item	Phase 1	Phase 2	Phase 3	Phase 4
Ingredient, %				
Soybean meal, 46.5% CP	87.85	86.51	84.66	83.37
Monocalcium P, 21% P	2.32	1.78	1.67	1.30
Limestone	4.40	5.63	6.69	7.80
Salt	1.62	2.07	2.60	3.03
Vitamin premix[3]	0.70	0.74	0.74	0.65
Trace-mineral premix[4]	0.70	0.74	0.74	0.65
L-Lys HCl	1.39	1.54	1.75	1.86
DL-Met	0.12	—	—	—
L-Thr	0.34	0.25	0.22	0.26
Phytase[5]	0.58	0.74	0.93	1.08
Blend				
Ground corn,[6] %	78	83	87	88
Complete supplement, %	22	17	13	12
Supplement cost/t,[7] $	452.13	445.22	449.00	449.01

[1]Diets were blended and feed budgeted to be identical in composition and nutrient analyses for each phase to those fed the standard 4-phase feeding program (Table 1).

[2]Diets were fed from 35 to 55, 55 to 80, 80 to 100, and 100 to 126 kg of BW for phases 1 to 4, respectively.

[3]Provided the following per kilogram of premix: 4,409,200 IU of vitamin A; 551,150 IU of vitamin D_3; 17,637 IU of vitamin E; 1,764 mg of vitamin K; 3,307 mg of riboflavin; 11,023 mg of pantothenic acid; 19,841 mg of niacin; and 15.4 mg of vitamin B_{12}.

[4]Provided the following per kilogram of premix: 26.5 g of Mn from manganese oxide; 110 g of Fe from iron sulfate; 110 g of Zn from zinc sulfate; 11 g of Cu from copper sulfate; 198 mg of I from calcium iodate; and 198 mg of Se from sodium selenite.

[5]Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 600,533 phytase units/kg.

[6]Ground corn was priced at $233.58/t and was charged a $13.20/t feed grinding and delivery charge.

[7]Supplement costs were calculated with $399.88/t of soybean meal and an $11.00/t feed mixing and delivery charge.

cial abattoir (JBS Swift and Company, Worthington, MN) for processing. Pigs had been individually tattooed according to pen number to allow for data retrieval by pen and carcass data collection at the abattoir. Hot carcass weights were measured immediately after evisceration, and each carcass was evaluated for percentage yield, back fat, and loin depth (Table 10). Percentage yield was calculated by dividing HCW by live BW obtained at the farm before transport to the abattoir. Fat depth and loin depth were measured with an optical probe (SFK Technology) inserted between the third and fourth ribs located anterior to the last rib at a distance approximately 7.1 cm from the dorsal midline. Fat-free lean index (**FFLI**) was calculated using NPPC (2000) guidelines for carcasses measured with the Fat-O-Meater (SFK Technology) such that FFLI = {15.31 + [0.51 × (0.4536 × HCW)] − [31.277 × 0.0394 × last-rib fat thickness)] + [3.813 × (0.0394 × loin muscle depth)]/(0.4536 × HCW)}. Grade premiums and sort loss discounts were included to accurately determine the net revenue generated per pig (Table 11). As a result of misidentification of pigs by abattoir personnel, of the original 10 replicates per treatment, carcass data could be obtained for 6 pens from the standard treatment, 10 pens from the curve group, and 7 pens from the corn-supplement treatment.

Exp. 3

A total of 252 mixed-sex pigs (327 × 1050, PIC; initial BW = 36.2 ± 0.4 kg of BW) were used in a 95-d trial to compare feed-budgeting strategies and blending 2 complete finishing diets on a Lys curve on growth performance, carcass characteristics, and economics. Pens were allotted to 1 of 4 experimental treatments using a randomized complete block design. Each treatment had 9 replicate pens and 7 pigs per pen (4 gilts and 3 barrows per pen). The 4 experimental treatments were (1) a standard 4-phase complete feed program (standard), (2) blending a high- and low-Lys complete diet over the entire experiment (curve), (3) treatment 1 diets with 20% greater feed budget for phases 1, 2, and 3 (over-budgeted), and (4) treatment 1 diets with 20% lower feed budget for phases 1, 2, and 3 (under-budgeted). All diets were dispensed using the FeedPro system and provided ad libitum access to feed. For the standard 4-phase feeding program as well as the over-budgeted and under-budgeted treatments, 4 finishing diets (Table 12) were formulated to provide 2.72, 2.30, 2.00, and 1.81 g of SID Lys/Mcal of ME.

Table 3. Economics of diet blending using the FeedPro system, Exp. 1[1,2]

Item	Standard	Curve	Corn-supplement	SEM
Feed cost/pig, $				
Phase 1	14.09[ab]	14.33[b]	13.70[b]	0.204
Phase 2	21.13	20.51	21.01	0.317
Phase 3	20.07	19.31	19.37	0.372
Phase 4	27.14[b]	25.70[a]	26.91[ab]	0.378
Total	82.44[y]	79.85[x]	80.99[xy]	0.992
Feed cost/kg of gain,[3] $				
Phase 1	0.722[b]	0.725[b]	0.695[a]	0.006
Phase 2	0.824[x]	0.854[y]	0.845[xy]	0.013
Phase 3	0.937[ab]	0.905[a]	0.969[b]	0.017
Phase 4	1.038[b,y]	1.000[a,x]	1.030[ab,y]	0.012
Overall	0.881	0.870	0.884	0.006
Total revenue,[4,5] $/pig	186.45	184.71	184.63	2.376
IOFC,[6] $/pig	104.01	104.85	103.63	1.811

[a,b; x,y]Within a row, means without a common superscript differ ($P < 0.05$) and tend to differ ($P < 0.10$).

[1]A total of 283 pigs (TR4 × 1050, PIC, Hendersonville, TN) were used in a 97-d trial with 12 replicate pens per treatment and approximately 8 pigs per pen.

[2]Standard = complete diets in each phase; curve = blending of high- and low-Lys diet fed to a set Lys curve; corn-supplement = blending of ground corn and complete supplement.

[3]Feed cost/kg of gain = (direct feed cost + GMD cost/pig) ÷ total live gain; assumed grinding = $5.50/t; mixing = $3.30/t; delivery and handling = $7.70/t. GMD = grinding, mixing, and delivery.

[4]Scenario 1: carcass base price = $1.99/kg.

[5]Total revenue = carcass price (including premiums or discounts for lean and yield) × HCW.

[6]IOFC, income over feed cost = total revenue/pig − feed cost/pig during trial period.

The FeedPro system was programmed to deliver a predetermined amount of feed from each diet to each pen and to automatically update allotted budgets when pigs were removed due to death or illness. Pigs fed the standard treatment were programmed to receive a set feed budget of 53.1, 62.6, 72.7, and 79.4 kg for diets 1 to 4, respectively. Pigs fed the over- and under-budgeted treatments were assigned feed budgets 20% higher and 20% lower than their standard counterparts for phases 1, 2, and 3, with phase 4 fed for the remainder of the trial after the phase-3 diet was consumed. When budgeted allotment of each phase was exhausted for the over-budgeted and under-budgeted treatments, the FeedPro system automatically switched phases on an individual pen basis.

Pigs from all treatments were weighed and feed disappearance was recorded on the date of phase changes for the standard treatment to establish equal periods for data compari-

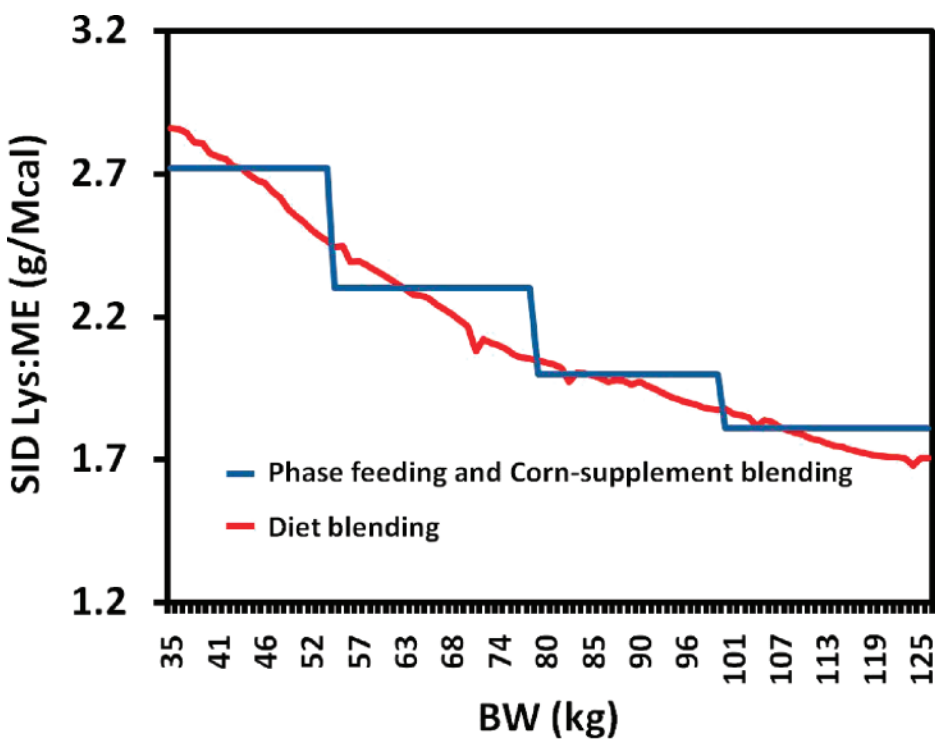

Figure 2. Standardized ileal digestible (SID) Lys:ME ratio (g/Mcal) provided to pigs according to a 4-phase feeding program using complete finishing diets, a blend of ground corn-supplement, or a blend of complete high- and low-Lys diets fed to a set Lys curve using the FeedPro system (Feedlogic Corp., Willmar, MN; Exp. 1). Color version available in the online PDF.

Table 4. Effects of diet blending using the FeedPro system on finishing pig growth performance, Exp. 1[1,2]

Item	Standard	Curve	Corn-supplement	SEM
Pig weight, kg				
Initial	35.0	35.0	35.0	0.61
d 21	54.5	54.5	54.7	0.73
d 47	80.0	78.7	79.7	1.01
d 71	101.2	100.2	99.7	1.18
d 97	127.2	125.9	125.9	1.38
Phase 1 (35 to 55 kg)				
ADG, kg	0.93	0.93	0.94	0.011
ADFI, kg	2.12	2.14	2.08	0.028
G:F	0.438[a]	0.435[a]	0.450[b]	0.004
Phase 2 (55 to 80 kg)				
ADG, kg	0.98	0.93	0.96	0.189
ADFI, kg	2.64	2.58	2.67	0.040
G:F	0.371	0.360	0.358	0.005
Phase 3 (80 to 100 kg)				
ADG, kg	0.89	0.90	0.83	0.023
ADFI, kg	2.77	2.69	2.73	0.050
G:F	0.321[ab]	0.334[a]	0.305[b]	0.007
Phase 4 (100 to 126 kg)				
ADG, kg	1.00	0.99	1.01	0.018
ADFI, kg	3.50[a]	3.35[b]	3.53[a]	0.046
G:F	0.286[a]	0.296[b]	0.286[a]	0.003
Overall (35 to 126 kg)				
ADG, kg	0.95	0.94	0.94	0.010
ADFI, kg	2.79	2.72	2.79	0.033
G:F	0.342[ab]	0.346[a]	0.336[b]	0.002

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

[1]A total of 283 pigs (TR4 × 1050, PIC, Hendersonville, TN) were used in a 97-d trial with 12 replicate pens per treatment and approximately 8 pigs per pen.

[2]Standard = complete diets in each phase; curve = blending of high- and low-Lys diets fed to a set Lys curve; corn-supplement = blending of ground corn and complete supplement.

Table 5. Effects of diet blending using the FeedPro system on carcass characteristics of finishing pigs, Exp. 1[1,2]

Item	Standard	Curve	Corn-supplement	SEM
HCW, kg	94.0	93.7	92.6	1.20
Yield,[3] %	73.9	74.4	73.6	0.44
Lean,[4,5] %	52.2[a]	52.3[a]	52.9[b]	0.18
Fat depth,[4] mm	21.1[a]	20.6[a]	19.3[b]	0.42
Loin depth,[4] mm	60.5	60.6	60.9	0.63

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

[1]A total of 283 pigs (TR4 × 1050, PIC, Hendersonville, TN) were used in a 97-d trial with 12 replicate pens per treatment and approximately 8 pigs per pen.

[2]Standard = complete diets in each phase; curve = blending of high- and low-Lys diet fed to a set Lys curve; corn-supplement = blending of ground corn and complete supplement.

[3]Percentage yield was calculated by dividing HCW by live weight obtained before transport to the abattoir.

[4]Data analyzed using HCW as a covariate.

[5]Calculated using NPPC (1991) guidelines for lean containing 5% fat. Lean % = 2.83 + [0.469 × (0.4536 × HCW)] − [18.47 × (0.0394 × fat depth)] + [9.824 × (0.0394 × loin depth)]/(0.4536 × HCW).

Table 6. Diet composition for the standard and curve regimens, Exp. 2 (as-fed basis)

	Standard[1]					Curve[2]	
Item	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	High Lys	Low Lys
Ingredient, %							
Corn	52.32	54.98	57.92	60.83	61.45	50.74	61.56
Soybean meal, 46.5% CP	15.43	12.84	10.06	7.18	16.56	17.01	6.50
Dried distillers grains with solubles	30.00	30.00	30.00	30.00	20.00	30.00	30.00
Limestone	1.25	1.20	1.10	1.10	1.03	1.23	1.10
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin and trace-mineral premix[3]	0.10	0.10	0.09	0.09	0.09	0.10	0.09
Biolys[4]	0.55	0.52	0.48	0.45	0.45	0.57	0.40
L-Thr	—	—	—	—	0.02	—	—
Phytase[5]	0.01	0.01	—	—	—	0.01	—
Ractopamine HCl[6]	—	—	—	—	0.05	—	—
Calculated analysis							
SID[7] amino acids, %							
Lys	0.95	0.87	0.78	0.69	0.90	1.00	0.65
Ile:Lys	69	70	72	75	69	68	78
Met:Lys	33	34	37	40	32	32	41
Met and Cys:Lys	67	70	75	81	65	65	85
Thr:Lys	63	65	67	71	65	62	73
Trp:Lys	17	17	17	17	18	17	17
Val:Lys	83	86	90	95	83	82	99
Total Lys, %	1.11	1.03	0.93	0.83	1.04	1.17	0.79
ME, kcal/kg	3,360	3,362	3,366	3,368	3,364	3,360	3,368
SID Lys:ME, g/Mcal	2.83	2.59	2.32	2.05	2.67	2.98	1.93
CP, %	20.19	19.20	18.12	17.00	18.71	20.81	16.71
Ca, %	0.55	0.53	0.48	0.47	0.47	0.55	0.47
P, %	0.47	0.46	0.45	0.43	0.43	0.47	0.43
Available P,[8] %	0.30	0.27	0.24	0.22	0.21	0.30	0.22
Diet cost/t,[9] $	289.33	285.59	281.36	277.05	329.21	291.77	275.54

[1]Phases 1 to 5 were fed from approximately 35 to 52, 52 to 71, 71 to 86, 86 to 108, and 108 to 127 kg of BW, respectively.

[2]Feed delivery based on a Lys requirement curve where a complete high- and low-Lys diet was blended for the duration of the experiment.

[3]Provided the following per kilogram of premix: 4,509,409 IU of vitamin A; 701,463 IU of vitamin D_3; 24,050 IU of vitamin E; 1,403 mg of vitamin K; 3,006 mg of riboflavin; 12,025 mg of pantothenic acid; 18,038 mg of niacin; and 15.0 mg of vitamin B_{12}. Also provided the following per kilogram of premix: 40.1 g of Mn from manganese oxide and manganese sulfate; 90.2 g of Fe from iron sulfate; 100.2 g of Zn from zinc oxide; 10.0 g of Cu from copper sulfate; 501 mg of I from ethylenediamine dihydroiodide; and 301 mg of Se from sodium selenite.

[4]Biolys, Evonik Degussa Corp., Kennesaw, GA.

[5]Optiphos 2000 (Enzyvia LLC, Sheridan, IN).

[6]Paylean (Elanco Animal Health, Greenfield, IN). Provides 5 mg/kg of ractopamine HCl when added at 0.05% of the diet.

[7]Standardized ileal digestible.

[8]Phytase provided 0.10% available P in diets 1 and 2 and the high-Lys blending diet.

[9]Diet costs were calculated with $233.58/t of corn and $391.88/t of soybean meal, along with a $16.50/t manufacturing and delivery charge.

son. Measurements of ADG, ADFI, and G:F were calculated at each of these phase changes (Table 13). Based on the feed budgeted for the standard treatment, the data periods were d 0 to 23 (phase 1), 23 to 49 (phase 2), 49 to 72 (phase 3), and 72 to 95 (phase 4).

For the curve treatment, a complete high-Lys and low-Lys diet was formulated to provide 2.97 and 1.75 g of SID Lys/Mcal of ME, respectively. The complete high- and low-Lys diets were blended in varying ratios on a daily basis (Figure 5) to meet an SID Lys requirement curve, which was set using previously documented feed-intake data in this facility. The SID Lys:ME ratios (g/Mcal) provided by the 4 feeding programs to pigs throughout the finishing period are shown in Figure 6, which illustrates the stair-step reduction of SID Lys:ME ratios used for the differ-

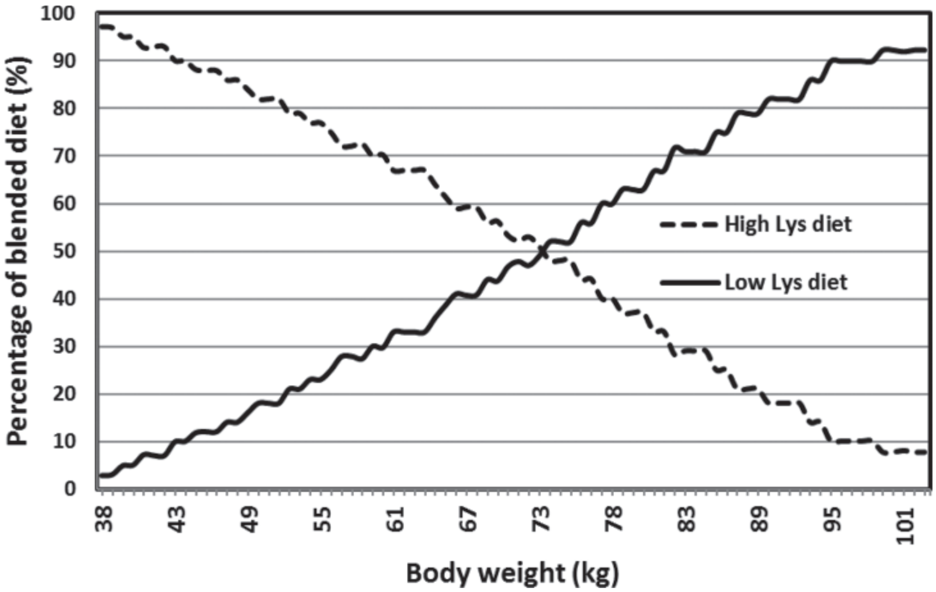

Figure 3. Percentage of the high- and low-Lys diets blended to a Lys requirement curve using the FeedPro system (Feedlogic Corp., Willmar, MN; Exp. 2).

ent phase-feeding treatments and the more gradual reduction in SID Lys:ME ratio for the diet-blending treatment. The gradual reduction in SID Lys:ME ratio was achieved by changing the ratio of the 2 diets provided on a daily basis. Feed was manufactured, sampled, and analyzed as in Exp. 1 and 2 (Table 14).

On d 84, pigs were weighed and transported (approximately 204 km) to an abattoir (Triumph Foods Inc.). Pigs were individually tattooed according to pen number to allow for data retrieval by pen and carcass data collection at the abattoir. Standard carcass criteria of percentage carcass yield, HCW, back fat depth, loin depth, and percentage lean were measured (Table 15). Hot carcass weights were measured immediately after evisceration, and percentage yield was calculated by dividing HCW by live BW obtained at the farm before transport to the abattoir. Carcass trait measurements were calculated as in Exp. 1, and grade premiums and sort loss discounts were included to accurately determine the net revenue generated per pig (Table 16).

Table 7. Composition of the complete supplements (as-fed basis) and the proportion of ground corn and supplement by phase, Exp. 2[1,2]

	Complete supplement			
Item	1	2	3	4
Ingredient, %				
Soybean meal (46.5%)	32.35	28.53	23.90	18.34
Dried distillers grains with solubles (DDGS)	62.92	66.64	71.29	76.59
Limestone	2.62	2.67	2.61	2.81
Salt	0.73	0.78	0.83	0.89
Vitamin and trace-mineral premix[3]	0.21	0.22	0.21	0.23
L-Lys HCl	1.15	1.16	1.14	1.14
Phytase[4]	0.02	0.01	0.01	—
Blend				
Ground corn,[5] %	52	55	58	61
Complete supplement, %	48	45	42	39
Supplement cost/t,[6] $	306.15	299.74	291.48	281.78

[1]Diets were blended and feed budgeted to be identical in composition and nutrient analyses for each phase to those fed in the standard 4-phase feeding program (Table 6).

[2]Phases 1, 2, 3, 4, and 5 were fed from approximately 35 to 52, 52 to 71, 71 to 86, 86 to 108, and 108 to 127 kg of BW, respectively.

[3]Provided the following per kilogram of premix: 4,509,409 IU of vitamin A; 701,463 IU of vitamin D_3; 24,050 IU of vitamin E; 1,403 mg of vitamin K; 3,006 mg of riboflavin; 12,025 mg of pantothenic acid; 18,038 mg of niacin; and 15.0 mg of vitamin B_{12}. Also provided the following per kilogram of premix: 40.1 g of Mn from manganese oxide and manganese sulfate; 90.2 g of Fe from iron sulfate; 100.2 g of Zn from zinc oxide; 10.0 g of Cu from copper sulfate; 501 mg of I from ethylenediamine dihydroiodide; and 301 mg of Se from sodium selenite.

[4]Optiphos 2000 (Enzyvia LLC, Sheridan, IN).

[5]Ground corn was priced at $233.58/t and was charged a $13.20/t feed grinding and delivery charge.

[6]Supplement costs were calculated with $399.88/t of soybean meal and $220.46/t of DDGS, along with an $11.00/t mixing and delivery charge.

Table 8. Analyzed dietary Lys content, Exp. 2 (as-fed basis)[1,2,3]

Sample, % (as-fed basis)	Standard	Curve	Corn-supplement
Phase 1 (35 to 52 kg)	1.06	1.06	0.85
Phase 2 (52 to 71 kg)	0.85	0.88	1.10
Phase 3 (71 to 86 kg)	0.88	0.80	0.72
Phase 4 (86 to 108 kg)	0.82	0.76	0.68

[1]Diets were blended and feed budgeted to be identical in composition and nutrient analyses for each phase to those fed in the standard 4-phase feeding program.

[2]Diet samples collected at each time point from several pens per treatment after delivery by the FeedPro system (Feedlogic Corp., Willmar, MN). Samples were analyzed for total Lys level at the University of Missouri Experiment Station Chemical Laboratories in Columbia.

[3]Standard = complete diets in each phase; curve = blending of high- and low-Lys diet fed to a set Lys curve; corn-supplement = blending of ground corn and complete supplement.

Statistical Analysis

In Exp. 1, data were analyzed as a completely randomized design using PROC GLM in SAS (SAS Institute Inc., Cary, NC). Experiments 2 and 3 used PROC MIXED in SAS for data analysis. Experiment 2 was analyzed as a completely randomized design, and Exp. 3 was analyzed as a randomized complete block design with treatments randomly assigned to blocks throughout the barn. In all 3 experiments, HCW was used as a covariate for fat depth, loin depth, lean percentage, and FFLI. When treatment effect was a significant source of variation, means were separated using the PDIFF option of SAS in Exp. 1 and 2 and by preplanned CONTRAST statements in Exp. 3. Least squares means were calculated for each independent variable. Statistical significance was set at $P \leq 0.05$ and trends at $P < 0.10$ for all statistical tests.

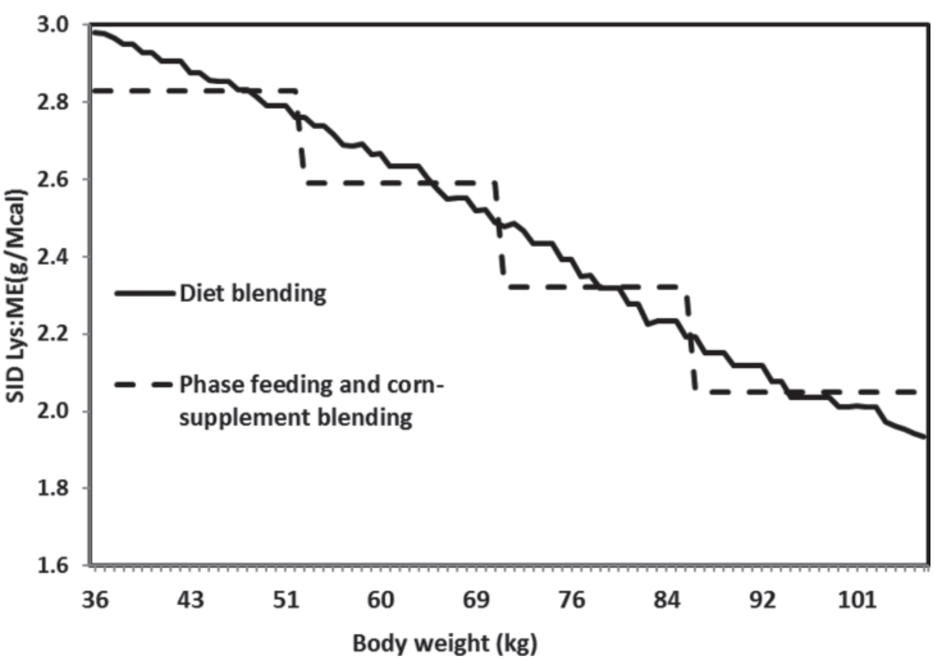

Figure 4. Standardized ileal digestible (SID) Lys:ME ratio (g/Mcal) provided to pigs according to a 4-phase feeding program using complete finishing diets, a blend of ground corn-supplement, or a blend of complete high- and low-Lys diets fed to a set Lys curve using the FeedPro system (Feedlogic Corp., Willmar, MN; Exp. 2).

RESULTS AND DISCUSSION

Diet Analysis

Diet samples collected for Exp. 1 were lost and therefore not available for analysis. The analyzed Lys levels for standard and curve regimens in Exp. 2 confirm the decreasing Lys content over the growing period and are within permitted analytical variation limits according to AAFCO (2005); however, the analyzed Lys levels for the corn-supplement blend varied more greatly compared with formulated levels than for standard and curve treatments (Table 7), suggesting that there either may have been sampling error or the FeedPro system could have inaccurately blended the corn and supplement. Analyzed Lys levels in diets from Exp. 3 are in general agreement with formulated Lys content.

Exp. 1

Average daily gain and pig BW were similar ($P > 0.12$) across treatments in each of the 4 phases. In phases 1 to 3, ADFI was also similar ($P > 0.14$), but in phase 4, pigs fed using curve diets had lower ($P < 0.03$) ADFI than pigs fed using standard phase feeding of complete diets or the corn-supplement blend. For feed efficiency, during phase 1 (35 to 55 kg) pigs fed the corn-supplement blend had greater ($P < 0.03$) G:F than pigs fed standard or curve diets; however, G:F was poorer ($P < 0.05$) in pigs fed the corn-supplement blend in phase 3 (80 to 100 kg) than in pigs fed standard or curve diets. In phase 4 (100 to 126 kg), pigs fed curve diets had poorer ($P < 0.04$) G:F than pigs fed using standard phase feeding of either complete diets or the ground corn-supplement blend. Overall (35 to 126 kg), ADG, ADFI, and final BW were similar ($P > 0.14$) across treatments, but pigs fed the corn-supplement blend had poorer ($P < 0.01$) G:F than pigs fed curve diets

Table 9. Effects of diet blending using the FeedPro system (Feedlogic Corp., Willmar, MN) on finishing pig growth performance, Exp. 2[1,2]

Item	Standard	Curve	Corn-supplement	SEM
Pig weight, kg				
Initial	35.9	35.6	35.0	0.69
d 21	53.0	52.1	51.7	0.89
d 42	72.1	70.6	70.2	1.18
d 63	88.0	85.9	85.6	1.10
d 88	110.6[b]	107.9[ab]	106.6[a]	1.04
d 110	129.1[y]	127.1[xy]	126.2[x]	0.98
Phase 1 (35 to 52 kg)				
ADG, kg	0.81[y]	0.78[x]	0.80[xy]	0.015
ADFI, kg	1.80[y]	1.72[x]	1.76[xy]	0.030
G:F	0.453	0.452	0.448	0.006
Phase 2 (52 to 71 kg)				
ADG, kg	0.91	0.88	0.88	0.018
ADFI, kg	2.36	2.27	2.32	0.045
G:F	0.385	0.391	0.379	0.008
Phase 3 (71 to 86 kg)				
ADG, kg	0.75	0.72	0.74	0.021
ADFI, kg	2.71[b]	2.46[a]	2.65[b]	0.042
G:F	0.278	0.294	0.278	0.009
Phase 4 (86 to 108 kg)				
ADG, kg	0.90[b]	0.88[b]	0.84[a]	0.012
ADFI, kg	2.80[b]	2.62[a]	2.65[a]	0.038
G:F	0.321[ab,x]	0.334[b,y]	0.316[a,xy]	0.005
Phase 1 to 4 (35 to 108 kg)				
ADG, kg	0.85[b]	0.82[a]	0.81[a]	0.008
ADFI, kg	2.43[b]	2.28[a]	2.36[ab]	0.030
G:F	0.348[a]	0.359[b]	0.345[a]	0.004
Phase 5 (108 to 127 kg)				
ADG, kg	0.94[y]	0.88[x]	0.94[y]	0.023
ADFI, kg	2.86[b]	2.79[a]	2.91[b]	0.037
G:F	0.329	0.316	0.323	0.008
Overall (35 to 127 kg)				
ADG, kg	0.86[b]	0.83[a]	0.84[a]	0.008
ADFI, kg	2.51[b]	2.37[a]	2.45[b]	0.027
G:F	0.344[ab]	0.350[b]	0.340[a]	0.003

[a,b; x,y]Within a row, means without a common superscript differ ($P < 0.05$) and tend to differ ($P < 0.10$).

[1]A total of 808 pigs (337 × 1050, PIC, Hendersonville, TN) were used in a 110-d trial with 27 pigs per pen and 10 replicate pens per treatment.

[2]Standard = complete diets in each phase; curve = blending of high- and low-Lys diet fed to a set Lys curve; corn-supplement = blending of ground corn and complete supplement.

and tended to have poorer ($P < 0.09$) G:F than pigs fed using the standard program.

For carcass characteristics, no differences were detected ($P > 0.18$) in HCW, percentage yield, or loin depth across treatments. Pigs fed using the corn-supplement blend had greater ($P < 0.03$) percentage lean and lower ($P < 0.04$) fat depth than pigs fed using standard phase-fed diets or curve diets blended using the FeedPro system.

Feeding curve diets tended ($P < 0.07$) to result in feed savings ($2.59/pig) versus the standard phase-feeding program. The majority of the difference for curve and standard diets was due to lower ADFI and better G:F observed in phase 4, which resulted in $1.44 reduction ($P < 0.01$) in feed cost per pig. For the ground corn-supplement blend, cost of mixing ($3.30/t) was not assessed for ground corn, which contributed to lower GMD cost and numerically lower feed costs per pig. Feed cost per kilogram of gain was lower ($P < 0.01$) for pigs fed the corn-supplement blend in phase 1 and lower ($P < 0.03$) for the curve diet in phases 3 and 4, but no overall differences ($P \geq 0.11$) were observed across the treatments. No ($P \geq 0.41$) differences were observed in total revenue or IOFC across all treatments.

Table 10. Effects of diet blending using the FeedPro system (Feedlogic Corp., Willmar, MN) on carcass characteristics of finishing pigs, Exp. 2[1,2]

Item	Standard	Curve	Corn-supplement	SEM
HCW, kg	95.4[b,y]	93.3[ab,x]	92.5[a,xy]	0.78
Yield, %	75.9	75.9	76.2	0.38
Fat depth,[3] mm	20.2	20.5	19.9	0.43
Loin depth,[3] mm	56.6	56.9	59.4	1.25
FFLI,[3,4] %	50.47	50.71	50.28	0.244

[a,b; x,y]Within a row, means without a common superscript differ ($P < 0.05$) and tend to differ ($P < 0.10$).

[1]Carcass data from 483 pigs. Standard (6 pens); curve (10 pens); corn-supplement (7 pens).

[2]Standard = complete diets in each phase; curve = blending of high- and low-Lys diet fed to a set Lys curve; corn-supplement = blending of ground corn and complete supplement.

[3]Adjusted with HCW as covariate.

[4]Fat-free lean index (FFLI) was calculated using NPPC (2000) guidelines for carcasses measured with the Fat-O-Meater (SFK Technology, Herlev, Denmark) such that FFLI = 15.31 + [0.51 × (0.4536 × HCW)] – [31.277 × (0.0394 × last rib fat thickness)] + [3.813 × (0.0394 × loin muscle depth)]/(0.4536 × HCW).

Exp. 2

In phase 1 (35 to 52 kg) and phase 2 (52 to 71 kg), growth performance and pig BW were similar ($P > 0.13$) across all treatments. For phase 3 (71 to 86 kg), ADG, G:F, and pig BW were not influenced ($P \geq 0.18$) by blending treatments, but pigs fed diets blended on a Lys curve had lower ($P < 0.01$) ADFI than pigs fed either standard phase diets or

Table 11. Economics of diet blending using the FeedPro system (Feedlogic Corp., Willmar, MN), Exp. 2[1,2]

Item	Standard	Curve	Corn-supplement	SEM
Feed cost/pig, $				
Phase 1	10.92[y]	10.50[x]	10.57[xy]	0.180
Phase 2	14.17	13.64	13.72	0.268
Phase 3	16.05[b,y]	14.62[a,xy]	15.39[b,x]	0.233
Phase 4	19.37[b]	18.21[a]	18.10[a]	0.261
Phase 5[3]	20.75[ab]	20.22[a]	21.09[b]	0.258
Total	81.25[b,y]	77.18[a,xy]	78.86[ab,x]	0.864
Feed cost/kg of gain,[4] $				
Phase 1	0.639	0.641	0.631	0.009
Phase 2	0.745	0.735	0.745	0.015
Phase 3	1.017	0.963	0.996	0.029
Phase 4	1.028	0.991	1.029	0.16
Phase 5	1.049[x]	1.102[y]	1.069[x]	0.029
Total	0.902	0.892	0.901	0.009
Total revenue,[5,6] $/pig	188.11	185.84	184.42	1.671
IOFC,[7] $/pig	106.86	108.66	105.55	1.521

[a,b; x,y]Within a row, means without a common superscript differ ($P < 0.05$) and tend to differ ($P < 0.10$).

[1]Data collected from 808 pigs (approximately 270 pigs per treatment).

[2]Standard = complete diets in each phase; curve = blending of high- and low-Lys diet fed to a set Lys curve; corn-supplement = blending of ground corn and complete supplement.

[3]Paylean (Elanco Animal Health, Greenfield, IN) diet delivered in same form across all treatments. Differences are due to variation in performance.

[4]Feed cost per kilogram of gain = (direct feed cost + GMD cost/pig) ÷ total live gain; assumed grinding = $5.50/t; mixing = $3.30/t; delivery and handling = $7.70/t. GMD = grinding, mixing, and delivery.

[5]Carcass base bid = $1.99/kg.

[6]Total revenue = carcass price (including premiums or discounts for lean and yield) × HCW.

[7]IOFC, income over feed cost = total revenue/pig − feed cost/pig.

Table 12. Diet composition for the standard and curve regimens, Exp. 3 (as-fed basis)

	Standard[1]				Curve[2]	
Item	Phase 1	Phase 2	Phase 3	Phase 4	High Lys	Low Lys
Ingredient, %						
Corn	78.42	83.10	86.46	88.45	75.80	89.11
Soybean meal, 46.5% CP	18.95	14.60	11.48	9.63	21.44	8.99
Monocalcium phosphate, 21% P	0.50	0.30	0.23	0.15	0.55	0.13
Limestone	0.95	0.95	0.90	0.90	0.96	0.93
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[3]	0.15	0.13	0.10	0.08	0.16	0.07
Trace-mineral premix[4]	0.15	0.13	0.10	0.08	0.16	0.07
L-Lys HCl	0.30	0.26	0.23	0.22	0.32	0.21
DL-Met	0.03	—	—	—	0.04	—
L-Thr	0.07	0.04	0.03	0.04	0.09	0.04
Phytase[5]	0.13	0.13	0.13	0.13	0.13	0.13
Calculated analysis						
SID[6] amino acids, %						
Lys	0.91	0.77	0.67	0.61	0.99	0.59
Ile:Lys	61	63	64	66	60	66
Met:Lys	29	28	30	32	29	32
Met and Cys:Lys	56	58	62	66	55	67
Thr:Lys	62	62	63	66	62	66
Trp:Lys	16.5	16.5	16.5	16.5	16.5	16.5
Val:Lys	71	74	78	81	69	82
Total Lys, %	1.01	0.86	0.75	0.69	1.10	0.67
ME, kcal/kg	3,340	3,349	3,355	3,362	3,336	3,362
SID Lys:ME, g/Mcal	2.72	2.30	2.00	1.81	2.97	1.75
CP, %	15.80	14.10	12.90	12.20	16.80	12.00
Ca, %	0.54	0.49	0.45	0.43	0.56	0.43
P, %	0.46	0.40	0.37	0.35	0.48	0.34
Available P,[7] %	0.28	0.23	0.21	0.19	0.29	0.19
Diet cost/t,[8] $	284.97	275.54	270.13	266.78	290.08	265.53

[1]Phases 1, 2, 3, and 4 were fed to standard phase feeding treatment from d 0 to 23, 23 to 49, 49 to 72, and 72 to 95, respectively. Over- and under-budgeted treatments underwent phase changes automatically when allotted budget was consumed.

[2]Feed delivery based on a Lys requirement curve where a complete high- and low-Lys diet was blended for the duration of the experiment.

[3]Provided per kilogram of premix: 4,409,200 IU of vitamin A; 551,150 IU of vitamin D_3; 17,637 IU of vitamin E; 1,764 mg of vitamin K; 3,307 mg of riboflavin; 11,023 mg of pantothenic acid; 19,841 mg of niacin; and 15.4 mg of vitamin B_{12}.

[4]Provided per kilogram of premix: 26.5 g Mn from manganese oxide; 110 g Fe from iron sulfate; 110 g Zn from zinc sulfate; 11 g Cu from copper sulfate; 198 mg I from calcium iodate; and 198 mg Se from sodium selenite.

[5]Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 600,533 phytase units phytase/kg.

[6]Standardized ileal digestible.

[7]Phytase provided 0.10% available P to the diet.

[8]Diet costs were calculated with $233.58/t of corn and $391.88/t of soybean meal along with a $16.50/t manufacturing and delivery charge.

those fed a corn-supplement blend. In phase 4 (86 to 108 kg), pigs fed the corn-supplement blend had poorer ($P < 0.04$) ADG than pigs fed either standard phase-feeding or blended diets on a Lys curve. In addition, pigs fed standard diets had improved ($P < 0.02$) ADFI compared with pigs fed curve diets or a corn-supplement blend; however, pigs fed curve diets had increased ($P < 0.03$) G:F compared with pigs fed the corn-supplement blend, with standard pigs intermediate. For BW in phase 4, pigs fed standard diets were heavier ($P < 0.02$) than pigs fed curve diets and tended to be heavier ($P < 0.02$) than those fed the corn-supplement blend. Within the overall trial period (35 to 108 kg), pigs fed standard diets had greater ($P < 0.02$) ADG compared with both blending treatments and had greater ADFI ($P < 0.01$) than pigs fed a curve diet, with those fed a corn-supplement blend intermediate. However, pigs fed curve diets had improved ($P < 0.04$) G:F compared

Table 13. Effects of diet blending using the FeedPro system (Feedlogic Corp., Willmar, MN) and over- or under-budgeting in phase-feeding programs on finishing pig growth performance, Exp. 3[1,2]

Item	Standard	Curve	Over-budgeted	Under-budgeted	SEM
Pig weight, kg					
Initial	36.2	36.2	36.2	36.2	0.39
d 23	59.0[xy]	58.2[x]	59.1[y]	59.0[xy]	0.56
d 49	81.3	80.2	80.7	80.7	0.80
d 72	109.6	107.8	108.8	108.7	1.11
d 95	132.8	131.1	131.8	132.0	1.31
Phase 1 (d 0 to 23)					
ADG, kg	1.00[b]	0.96[a]	1.00[b]	0.99[b]	0.012
ADFI, kg	2.12	2.09	2.10	2.10	0.028
G:F	0.469[ab]	0.457[a]	0.474[b]	0.472[b]	0.005
Phase 2 (d 23 to 49)					
ADG, kg	0.99	0.95	0.96	0.97	0.018
ADFI, kg	2.55[ab]	2.42[a]	2.48[ab]	2.57[b]	0.051
G:F	0.387[b,xy]	0.392[b,xy]	0.385[ab,y]	0.376[a,x]	0.004
Phase 3 (d 49 to 72)					
ADG, kg	1.08[b]	1.05[ab]	1.01[a]	1.07[b]	0.021
ADFI, kg	2.98	2.94	2.91	2.89	0.045
G:F	0.365	0.359	0.348[a]	0.371[b]	0.008
Phase 4 (d 72 to 95)					
ADG, kg	1.01	1.01	1.00	1.01	0.020
ADFI, kg	3.27	3.35	3.23	3.27	0.055
G:F	0.309	0.302	0.310	0.309	0.005
Overall (d 0 to 95)					
ADG, kg	1.02	0.99	0.99	1.01	0.012
ADFI, kg	2.72	2.69	2.67	2.71	0.037
G:F	0.374	0.369	0.371	0.373	0.004

[a,b; x,y]Within a row, means without a common superscript differ ($P < 0.05$) and tend to differ ($P < 0.10$).

[1]A total of 252 pigs (337 × 1050, PIC, Hendersonville, TN) were used in a 95-d trial with 9 replicate pens per treatment and 7 pigs per pen.

[2]Standard = complete diets in each phase; curve = blending of high- and low-Lys diet fed to a set Lys curve; over-budgeted = phase feeding diets with 20% greater feed budget per phase; under-budgeted = phase feeding with 20% lower feed budget per phase.

with other treatments. During phase 5 (108 to 127 kg), in which all pigs were fed a common diet containing ractopamine HCl, pigs previously fed the corn-supplement blended diets had greater ($P < 0.02$) ADFI than those previously fed curve diets. In addition, pigs formerly fed standard phase diets tended to be heavier ($P < 0.10$) than pigs formerly fed a ground corn-supplement blend.

Over the entire finishing period (35 to 127 kg), pigs fed standard diets had greater ($P < 0.04$) ADG than pigs fed either curve diets or a corn-supplement blend, and pigs fed standard diets or a corn-supplement blend had greater ($P < 0.05$) ADFI than curve pigs. Pigs fed curve diets, however, had improved ($P < 0.04$) G:F compared with pigs fed a corn-supplement blend. For carcass characteristics, no differences were observed ($P \geq 0.22$) in percentage yield, FFLI, back fat depth, or loin depth across all treatments, but pigs fed standard diets had heavier ($P < 0.03$) HCW than pigs fed a corn-supplement blend and tended to have heavier ($P < 0.07$) HCW than those fed curve diets.

Higher ADG and ADFI for pigs fed standard diets led to greater ($P < 0.01$) feed cost per pig compared with curve pigs and a trend ($P < 0.08$) for higher feed costs compared with pigs fed the corn-supplement blend. Because standard pigs experienced greater gain, however, feed cost per kilogram of gain was similar ($P > 0.10$) across all treatments overall and for most individual phases. Furthermore, no differences were observed ($P \geq 0.15$) in total revenue per pig. Although IOFC did not differ ($P \geq 0.15$) across treatments, pigs fed diets blended to a Lys curve had a \$1.80 and \$3.11 advantage in IOFC over standard and corn-supplement treatments, respectively.

Exp. 3

Although pen weights and feed disappearance were recorded on d 23, 49, 72, and 95 according to average phase changes in the standard treatment, phase changes in the over- and under-budgeted treatments took place when allotted feed budgets were exhausted on a per-pen basis. In the over-bud-

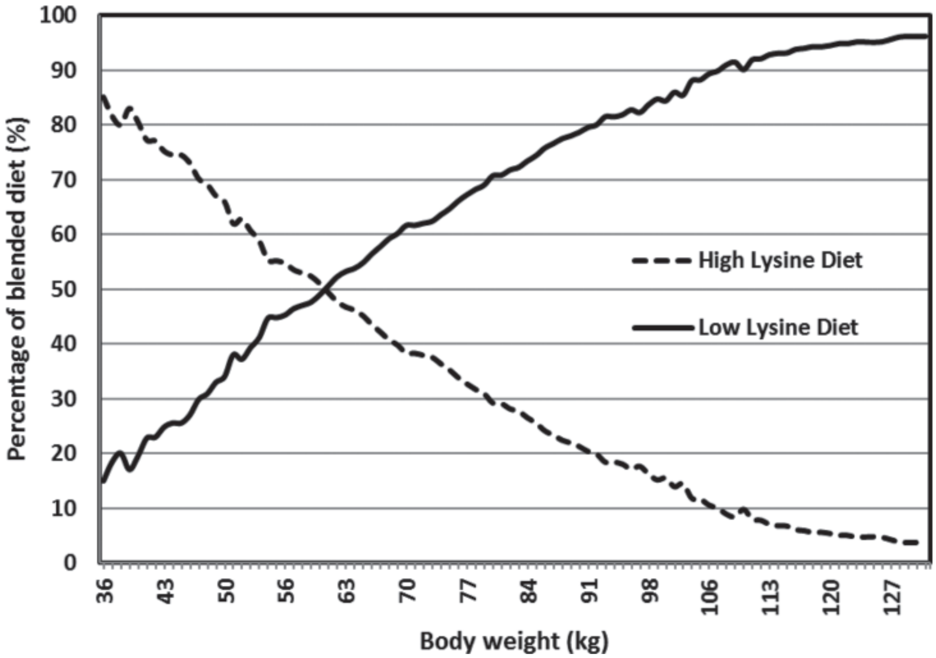

Figure 5. Percentage of high- and low-Lys diets blended to a set Lys curve using the FeedPro system (Feedlogic Corp., Willmar, MN; Exp. 3).

Table 14. Analyzed dietary Lys content, Exp. 3 (as-fed basis)[1]

Diet	Total Lys, %
Phase feeding[2]	
Phase 1	0.98
Phase 2	0.84
Phase 3	0.72
Phase 4	0.69
Feed blending[3]	
High Lys	1.03
Low Lys	0.64

[1]Diet samples collected after diet manufacturing. Samples were analyzed for total Lys level at the University of Missouri Experiment Station Chemical Laboratories in Columbia, Missouri.

[2]Phase 1, 2, 3, and 4 were fed to the standard phase-feeding treatment from d 0 to 23 (53.1 kg), 23 to 49 (62.6 kg), 49 to 72 (72.7 kg), and 72 to 95 (79.4 kg), respectively. Over- and under-budgeted treatments underwent phase changes automatically when allotted budget was consumed.

[3]Feed delivery based on a Lys requirement curve where a complete high- and low-Lys diet was blended for the duration of the experiment.

geted treatment, the average dates of diet change were d 29, 56, and 83 for phases 2, 3, and 4, respectively. In the under-budgeted treatment, the average dates of diet changes were d 18, 42, and 61 for phases 2, 3, and 4, respectively.

In phase 1 (d 0 to 23), ADG was lower ($P < 0.04$) in pigs fed the curve treatment compared with each of the 3 phase-fed programs. Although no differences ($P > 0.47$) in ADFI were seen across treatments, pigs fed the curve diet had poorer ($P < 0.04$) G:F than pigs fed over- and under-budgeted phase-feeding programs. Although ADG was similar ($P > 0.16$) across all treatments during phase 2 (d 23 to 49), under-budgeted pigs had higher ADFI ($P < 0.05$) than curve pigs and poorer ($P < 0.05$) G:F than pigs fed standard or curve diets. In phase 3 (d 49 to 72), pigs in the phase and under-budgeted treatments had greater ($P < 0.05$) ADG than pigs fed the over-budgeted treatment, with curve-fed pigs intermediate. Average daily feed intake was similar ($P > 0.18$) across treatments in phase 3, but pigs fed the under-budgeted treatment had improved ($P < 0.05$) G:F compared with pigs that were over-budgeted for each phase. In phase 4 (d 72 to 95), no differences ($P > 0.13$) were observed in ADG, ADFI, or G:F across treatments. Overall (d 0 to 95), no differences ($P > 0.11$) were detected in ADG, ADFI, G:F, or final BW across treatments.

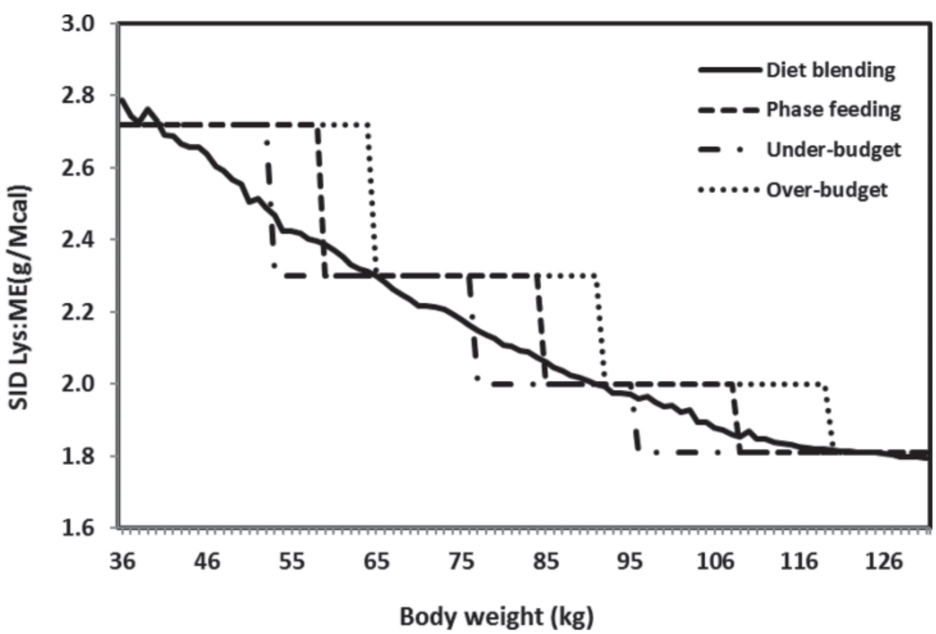

Figure 6. Standardized ileal digestible (SID) Lys:ME ratio (g/Mcal) delivered to pigs (36 to 132 kg of BW) based on a 4-phase feeding program with 3 different feed budgeting strategies compared with blending of high- and low-Lys diets based on a predetermined Lys curve using the FeedPro system (Feedlogic Corp., Willmar, MN; Exp. 3).

Table 15. Effects of diet blending using the FeedPro system (Feedlogic Corp., Willmar, MN) and over- or under-budgeting in phase-feeding programs on carcass characteristics of finishing pigs, Exp. 3[1,2]

Item	Standard	Curve	Over-budgeted	Under- budgeted	SEM
HCW, kg	99.7^{y}	97.6^{x}	97.9^{xy}	98.5^{xy}	0.97
Yield, %	75.1^{y}	74.5^{x}	74.4^{xy}	74.6^{xy}	0.24
Lean,[3,4] %	50.1	50.2	50.5	50.1	0.30
Fat depth,[3] mm	25.8	24.9	24.6	25.4	0.52
Loin depth,[3] mm	58.6	57.6	58.9	58.1	1.04

[x,y]Within a row, means without a common superscript tend to differ ($P < 0.10$).

[1]A total of 252 pigs (337 × 1050, PIC, Hendersonville, TN) were used in a 95-d trial with 9 replicate pens per treatment and 7 pigs per pen.

[2]Standard = complete diets in each phase; curve = blending of high- and low-Lys diet fed to a set Lys curve; over-budgeted = phase feeding diets with 20% greater feed budget per phase; under-budgeted = phase feeding with 20% lower feed budget per phase.

[3]Adjusted with HCW as covariate.

[4]Calculated using NPPC (1991) guidelines for lean containing 5% fat. Lean % = 2.83 + [0.469 × (0.4536 × HCW)] − [18.47 × (0.0394 × fat depth)] + [9.824 × (0.0394 × loin depth)]/(0.4536 × HCW).

For carcass characteristics, there was a trend ($P = 0.09$) for pigs fed the standard phase-feeding program to have higher-yielding carcasses than pigs over-budgeted or fed to a Lys curve. This result was driven by a trend ($P = 0.10$) for heavier HCW in pigs fed the standard rather than curve treatments. Across treatments, no differences ($P > 0.14$) were observed in percentage lean, fat depth, or loin depth.

Feeding diets blended to a Lys curve resulted in the lowest ($P < 0.03$) feed costs in phases 2 and 3 and overall, resulting in average feed savings per pig of $4.09 compared with the 3 phase-feeding strategies. For feed cost

Table 16. Economics of diet blending using the FeedPro system (Feedlogic Corp., Willmar, MN) and over- or under- budgeting in phase-feeding programs on finishing pig performance, Exp. 3[1,2]

Item	Standard	Curve	Over-budgeted	Under-budgeted	SEM
Feed cost/pig, $					
Phase 1	15.90	15.57	15.76	15.81	0.189
Phase 2	20.79^{b}	18.46^{a}	20.32^{b}	20.54^{b}	0.405
Phase 3	24.27^{b}	22.91^{a}	24.15^{b}	23.80^{ab}	0.386
Phase 4	24.62	24.09	24.73	24.67	0.355
Total	85.59^{b}	81.03^{a}	84.95^{b}	84.82^{b}	0.949
Feed cost/kg of gain,[4] $					
Phase 1	0.695^{ab}	0.709^{b}	0.687^{a}	0.694^{ab}	0.007
Phase 2	0.810^{b}	0.748^{a}	0.817^{b}	0.818^{b}	0.009
Phase 3	0.974^{ab,x}	0.948^{a,x}	1.047^{b,y}	0.965^{a,x}	0.027
Phase 4	1.064	1.037	1.078	1.060	0.019
Total	0.885^{ab,y}	0.861^{a,x}	0.902^{b,y}	0.885^{ab,y}	0.008
Total revenue, $/pig[5,6]	192.87^{y}	187.25^{x}	187.75^{x}	190.32^{xy}	2.161
IOFC, $/pig[7]	111.98^{y}	107.37^{x}	107.43^{x}	110.17^{xy}	1.953

[a,b; x,y]Within a row, means without a common superscript differ ($P < 0.05$) and tend to differ ($P < 0.10$).

[1]A total of 252 pigs (337 × 1050, PIC, Hendersonville, TN) were used in a 95-d trial with 9 replicate pens per treatment and 7 pigs per pen.

[2]Standard = complete diets in each phase; curve = blending of high- and low-Lys diet fed to a set Lys curve; over-budgeted = phase feeding diets with 20% greater feed budget per phase; under-budgeted = phase feeding with 20% lower feed budget per phase.

[3]Feed cost/kg of gain = (direct feed cost + GMD cost/pig) ÷ total live gain; assumed grinding = $5.50/t; mixing = $3.30/t; delivery and handling = $7.70/t. GMD = grinding, mixing, and delivery.

[4]Total revenue = carcass base price ($1.99/kg; includes premiums/discounts for lean and yield) × HCW.

[5]IOFC, income over feed cost = total revenue/pig − feed cost/pig.

per kilogram of gain, feeding curve diets resulted in higher ($P < 0.03$) costs compared with pigs fed over-budgeted diets during phase 1, with standard and under-budgeted treatments intermediate. Conversely, in phase 2 curve diets resulted in the most economical weight gain ($P < 0.001$) and in phase 3 pigs fed curve and under-budgeted diets had lower ($P < 0.04$) feed cost per kilogram of gain than those over-budgeted. Overall, delivering diets to a Lys curve resulted in lower ($P < 0.01$) cost per kilogram of gain than over-budgeting and tended ($P < 0.06$) to be lower than standard and under-budgeted treatments. Total revenue received per pig tended ($P < 0.10$) to be higher ($5.37/pig) for pigs fed standard diets compared with curve or under-budgeted treatments. This advantage was mainly due to the advantage in ADG in standard pigs, which resulted in heavier HCW. Pigs phase-fed a correctly estimated feed budget (standard) tended ($P < 0.09$) to have higher IOFC than curve ($4.61/pig) or over-budgeted ($4.55/pig) treatments, whereas pigs fed under-budgeted diets performed similarly ($P > 0.49$) to their standard phase-fed counterparts, sacrificing just $1.81 per pig.

With the advent of onsite computer programming and feed-delivery systems that can blend and deliver diets daily, the capability of modern feeding technology has radically evolved in recent years. These advances allow producers to exploit nutritional science that has been known for years, such as the decrease in Lys:ME requirements over the course of the growing period (Gill, 1999). Blending base diets daily according to known requirements offers potential benefits, including lower feed costs and the minimization of nutrient excretion while maintaining optimal growth performance. Although these perceived benefits are essential to the development of sustainable swine production systems (Honeyman, 1996), comprehensive evaluations of this practice using current technology on commercial farms are limited.

Although Pomar et al. (2007) reported faster growth rates for pigs fed using a daily Lys curve via an automated feed-delivery system compared with pigs fed a 3-phase diet, the results of the present study generally disagree, with consistent reductions in growth rate across all 3 experiments. The observed differences may be attributed to the fact that in Pomar et al. (2007), curve-fed pigs had greater total Lys intake than phase-fed pigs, whereas all pigs across treatments in the present study had similar Lys intake because phase-fed diets were formulated to SID Lys:ME ratios (Figure 2; Figure 4; Figure 6) that provided both an excess and shortage of nutrients based on expected requirements in each phase.

Overall feed efficiency improved in pigs fed diets blended to a Lys curve compared with those phase-fed a series of 4 diets, particularly in Exp. 1 and 2. Increasing the number of feeding phases in finishing has shown consistent improvements in feed efficiency (Lee et al., 2000; Pomar et al., 2007; Moore and Mullan, 2009), which corresponds with reductions in N and P excretion (Jongbloed and Lenis, 1992; van der Peet-Schwering et al., 1999). The feed efficiency improvement for pigs fed blended diets resulted in net feed savings of $2.59, $4.07, and $4.56 per pig for Exp. 1, 2, and 3, respectively, an average approximate reduction of 4% in overall feed costs over phase-fed pigs. These feed savings resulted in numerical advantages in IOFC in Exp. 2, but due to reduced HCW in curve-fed pigs, greater IOFC did not result in Exp. 1 or 3. As noted by Moore and Mullan (2009), it is also important to consider that although diet blending using the FeedPro system can reduce feed costs, the reported feed costs do not account for the cost of purchasing, installing, and maintenance for the equipment required to implement feed blending.

Mixing ground corn and a complete supplement to provide diets equivalent to standard phase-feeding regimens is an additional avenue to use the feed-blending capabilities of the FeedPro system. In Exp. 1 and 2, corn-supplement blending resulted in poorer feed efficiency compared with blending diets to a Lys curve and reduced ADG compared with standard phase feeding. Feed cost per kilogram of gain for pigs fed the corn-supplement blend was almost as high as in standard pigs in both experiments, but net revenue suffered due to the numerically lighter HCW in the corn-supplement treatment. High feed costs combined with the lowest returns resulted in pigs fed the corn-supplement blend having the poorest IOFC in Exp. 1 and 2. Although diet samples could not be analyzed in Exp. 1, in Exp. 2 the variation in analyzed Lys content compared with formulated Lys levels for the corn-supplement blend was concerning. This variation may explain the poorer growth performance, particularly during the later stages of the growing-finishing period. Because the corn-supplement blend theoretically should have provided a diet equivalent to the standard program, the reason for this variation in Lys content remains unclear. Explanations could include sampling error, incorrect supplement nutrient levels, or inaccuracy of the FeedPro blending capabilities when handling diets differing in form and density. The accuracy of feed blending was determined using diets of similar texture upon installation of the FeedPro system at each facility, but future research evaluating similar blending strategies to verify the blending capability of the system with ingredients of different bulk densities would be prudent. Recent increases in feed ingredient costs within the United States livestock industry may reduce the practicality of 2-ingredient mixing strategies, such as corn-supplement blending, considering that modern diets are now incorporating a larger number of starch and protein sources than traditional corn-soy rations (Plain, 2007).

Evaluation of diet budgeting strategies in Exp. 3 revealed that over-budgeted diets may have restricted growth in the mid- and late-finishing period because of an oversupply of protein. Lenis (1989), Lee et al. (2000), and Garry et al. (2007) have shown that excess amino acids that cannot be used for body protein deposition have to be deaminated and excreted, resulting in deterioration in growth and feed efficiency. Conversely, under-budgeted diets supplied an SID Lys:ME ratio slightly below biological requirements throughout the duration of the experiment. Growth performance for under-budgeted pigs was slightly poorer during phases 1 and 2 (36 to 81 kg), but similar to standard pigs in the late finishing period (81 to 132 kg). Based on well-documented compensatory growth responses seen when feeding adequate protein in later growth periods (Wahlstrom and Libal, 1983), Main et al. (2008) suggested that as long as Lys requirements are met in late finishing, feeding slightly less than the Lys requirement in early finishing period may offer feed cost savings without forfeiting growth performance. Thus, if Lys requirements were accurately estimated, results of Exp. 3 suggest that under-budgeting by 20% can result in similar growth performance responses and potential feed-cost reductions. As additional efforts are made to minimize feed costs in the finishing phase, formulating early finishing diets slightly lower than the physiological needs of the pig may offer an opportunity to lower overall feed costs.

IMPLICATIONS

Feeding diets blended to a Lys curve can effectively reduce overall feed costs but may lead to reductions in growth performance. The reason growth performance in curve-fed pigs was consistently poorer than in phase-fed pigs is unclear, and additional research may elucidate the underlying reasons. Although these experiments have shown the effectiveness of blending 2 base diets on finishing pig growth performance, evaluating the nutrient excretion of finishing pigs fed curve diets compared with phase feeding would be beneficial. Finally, over- and under-feed budgeting did not significantly influence overall growth rate or economic return.

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