Section 4
Meat Quality

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Executive Summary- Meat Quality
Soy/Swine Nutrition Program Year 1

- Three studies were done that compared major protein sources to soybean meal, and examined the effects of adjusting lysine levels on meat quality. Growth, carcass traits, and pork quality and sensory data were measured.

- The protein source trials had pigs fed to slaughter weight with diets that replaced a standard corn-soybean meal with diets using another protein source: crystalline amino acids, dry extruded soybeans, canola meal, peanut meal, sunflower meal, cottonseed meal, peas, meat and bone meal or poultry by-product meal.

- Pigs fed the amino acid diet had decreased growth performance and carcass muscling, and in increased carcass fat content. A similar, but not as severe response was seen in pigs fed the animal source protein.

- The other plant source proteins were not better than soybean meal, but some were similar, namely the dry extruded soybeans diet. However, these pigs had pork quality sensory data indicative of the higher level of fat in these diets.

- The lysine feeding trials fed diets deficient in lysine to late finishing stage pigs to determine the effects on carcass fat levels and eating quality of the pork. Trials varied how long the lysine deficient diet was used.

- In general, the results were mixed when the varying times of feeding the lysine deficient diet are compared. In one study though, pigs fed a diet with lower lysine levels (4.8 g/kg) for five weeks increased intramuscular fat, but there was a slower growth rate during this period.

- The lysine deficient diets were further studied under thermo-neutral and hot conditions. Diets with 4.6 g/kg (deficient) or 6.4 g/kg (normal) lysine were fed 5 or 7 weeks under one of the two environments. Again, the lysine deficient diet improved intramuscular fat content, under either condition.

- Dietary lysine content did not affect feed intake or average daily gain, but the lysine-deficient diet pigs had a poorer gain:feed ratio. High environmental temperature decreased feed intake and average daily gain, but improved the gain:feed ratio.

Characterization of the Effect of Soybean Meal in Swine Diets, Relative to Other Oilseed Proteins on Pork Quality (Color, Water-Holding Capacity, Palatability, and Fat Quality)

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It is known that taste and sensory characteristics of meat can be influenced by diet. Yet virtually nothing has been done to define the effects of protein supplement.

Under this objective, comparisons of the major protein sources (eg. fish meal, peas, wheat, canola, etc.) in diets will characterize any advantages that soy may have in meat quality. In addition, the evaluation of potential effects of carbohydrates (digestible and indigestible sources) in soybean meal on meat quality will give the industry information that will suggest processing and/or genetics modifications. Information about nutritional manipulation of intramuscular qualities can have a significant impact on the swine industry. Improve acceptability and palatability of pork can increase pork consumption both domestically and abroad, leading to increases in overall pork production, and ultimately in the use of soybean meal in the diet.

Under this objective, three studies have been completed in the first year of the study as follows:

Study l. Effects of Soybeans in Swine Diets on Pork Quality

Study 2. The influence of dietary lysine level and time of feeding on the intramuscular fat content of pork loin.

Study 3. Effect of dietary lysine level and environmental temperature during the finishing phase on the intramuscular fat content of pork.

Study 1. Effects of Soybeans in Swine Diets on Pork Quality

Summary

Crossbred gilts (n=200) and barrows (n=200) were allotted to 10 dietary treatments. One-half of the pigs were at Louisiana State University and the other half at the University of Illinois. Pigs were fed a corn soybean meal diet or diets containing corn and various other protein sources that included: crystalline amino acids, dry extruded soybeans, canola meal, peanut meal, sunflower meal, cottonseed meal, peas, meat and bone meal, or poultry by-product meal. The

diets were formulated to contain 105% true ileal digestible lysine requirement according to age and gender, and all other amino acids met or exceeded their requirement. The diets were also formulated on an equal lysine:metabolizable energy basis. Pigs were fed the diets through the grower-finisher phases and killed at approximately 114 kg. Growth, carcass traits, and pork quality and sensory data were taken at the end of the experiment. Pigs fed the corn soybean meal diet were compared to pigs fed the diet with amino acids, peas, dry extruded soybeans, animal source proteins (meat and bone meal and poultry by-product meal), or plant source proteins (dry extruded soybeans, canola, peanut, and sunflower meals). All pigs fed the cottonseed meal died of gossypol poisoning. In general, pigs fed the amino acid diet had a decreased growth performance and carcass muscling, and an increased carcass fat content. In addition, the pork quality data in these pigs seemed to reflect an increased carcass fatness. These data suggest that the amino acid diet was deficient in one or more amino acids or in total nitrogen for the synthesis of nonessential amino acids. The response in pigs fed the animal source proteins was similar to that of pigs fed the amino acid diet, although the negative effects were not as severe. All the plant source proteins were compared to the corn soybean meal diet. On average, the other plant sources were not better than soybean meal as a protein source, but some were similar to soybean meal. The dry extruded soybeans resulted in growth performance, carcass traits, and pork quality traits that were similar (but not equal) to pigs fed the corn soybean meal diet. However, these pigs had pork quality sensory data indicative of the higher level of fat in these diets. In summary, soybean meal is an excellent quality supplemental protein source for pigs, and none of the protein sources evaluated resulted in better overall growth performance, carcass traits, or pork quality - when these protein sources were the sole source of supplemental protein in the diet.

Problem Addressed

Soybean meal is the major protein source traditionally used in swine diets. However, there is a range of other protein meal supplements that compete with soybean meal on a world basis. These include canola (or rapeseed), coconut, cottonseed, bean, flax, lupin, sunflower, pea, peanut, safflower, and sesame meals. The decision on which protein source to include in swine diets is largely based on availability and cost. However, other considerations are becoming of increasing importance when choosing feed ingredients, including any potential effect on meat quality.

Interest in meat quality is relatively recent and is driven by the need to supply the consumer with a consistent, high quality product at an affordable price. There is an increasing realization that unless consumer demands for quality are met, pork consumption will decline and the demand for soybean meal will also be reduced. There are a number of quality issues that are of significant economic importance to the industry. Researchers at the University of Illinois and Colorado State University carried out a quality audit of the pork chain in the US, which showed that inadequate color and poor water holding capacity were two major quality concerns identified by all sectors of the pork chain, including packers, processors, and purveyors (Cannon et al., 1995). Similar problems have been identified in most other countries. In addition, the eating quality of pork is the ultimate criterion that consumers use to judge quality, and there is concern that the palatability attributes of modern lean genotypes may be deteriorating.

Because meat quality in general, and pork quality in particular, has only recently become an issue, relatively little research has been carried out to investigate the impact of production factors, including nutrition, on quality attributes. As such, there has been no systematic evaluation of the impact, if any, of protein meal supplements on the color, water holding capacity, and palatability of pork.

There is evidence that certain oilseed meals and full-fat oilseeds can have an effect on pork quality. Hansen et al. (1979), cited by Rundgren (1983), reported that pigs fed partially defatted low glucosinolate rapeseed produced meat with impaired taste and structure. These authors also noted that pigs that were changed onto a rapeseed-free diet at 40 kg liveweight had normal meat quality at slaughter. In contrast, Dransfield et al. (1995) compared pigs fed diets containing either low glucosinolate rapeseed meal or soybean meal and found that meat from pigs fed on rapeseed meal had more heme pigment and was slightly darker and redder in color than that from pigs fed soybean meal. However, differences between pigs fed rapeseed or soybean meal for other quality attributes were small.

A number of studies have evaluated the impact of feeding soybean oil or full-fat soybeans to pigs on fat quality. Vegetable oils contain a relatively high concentration of unsaturated fatty acids which are deposited directly into the fat of the pig resulting in a softer fat which can cause problems with bacon slicing and reduce yields. In addition, unsaturated fats are more susceptible to oxidation than saturated fats and lipid oxidation may increase the incidence of fat rancidity and unpleasant odors or flavors, ultimately leading to a decrease in shelf life.

Pontif et al. (1987) showed that feeding increasing levels of raw full-fat soybeans to finishing swine for 53 or 56 days prior to slaughter resulted in a linear increase in iodine value of the fat (from 61.6 to 68.9 for diets containing 0 and 19.7% of raw soybeans, respectively). The iodine value is an index of unsaturation of fat, with higher values indicating a greater proportion of unsaturated fatty acids. Leszcynski et al. (1992) fed diets containing 0, 10 or 20% extruded full-fat soybeans for 3 or 6 weeks before slaughter and showed a small increase in lipid oxidation of bacon and longissimus muscle with increasing levels of full-fat soybeans and the length of feeding prior to slaughter. However, the sensory characteristics of longissimus samples were similar across treatments. Given that full-fat soybeans and soy oil are used in commercial swine diets in certain situations, there is a need to establish their impact on quality attributes.

In summary, there is a dearth of information in the literature on the impact on pork quality of oilseeds and oilseed meals in general, and soybeans and soybean meal in particular. The broad objective of this proposal was to evaluate the effect of soybeans, relative to other protein sources used globally, in swine diets on growth performance and pork quality. The study was carried out as a collaborative project with the University of Illinois and Louisiana State University. The two institutions will use pigs of different genetic backgrounds, which will allow the effect of protein source to be tested in different genetic lines.

Approach Used

Gilts (n = 200) and barrows (n = 200) from the Louisiana State University Agricultural Center (crossbred gilts) and the University of Illinois (PIC commercial hybrids) were used. Their average initial and final weights were 30.1 (LSU, 28.3 kg; UI, 31.8) and 114.1 kg (LSU, 115.2 kg; UI, 113.0), respectively. The pigs were allotted to 10 dietary treatments (four replications of barrows and four replications of gilts with five pigs per replicate) on the basis of weight in a completely randomized design at each university. Two replications of barrows and two replications of gilts were each used at the University of Illinois and at Louisiana State University.

The 10 dietary treatments were: 1) corn-soybean meal control (CSBM), 2) crystalline amino acids (AA), 3) dry extruded soybean meal (DESB), 4) canola meal, 5) peanut meal, 6) sunflower meal, 7) cottonseed meal, 8) peas, 9) meat and bone meal, and 10) poultry by-product meal. Each protein source served as the sole source of supplemental protein in the diets. Diet formulations were based on an analysis of soybean meal, DESB, canola meal, peanut meal, sunflower meal, cottonseed meal, peas, meat and bone meal, and poultry meal (Tables 1 to 5). The amino acid composition of the protein products was determined after acid hydrolysis, whereas total sulfur amino acid content was determined after performic acid oxidation followed by acid hydrolysis. Tryptophan content was determined after alkaline hydrolysis (AOAC Method 15:982.30 E(a,b,c); Thomas P. Mawhinney, University of Missouri, Columbia). The mineral composition of the protein sources was determined by Inductively Coupled Plasma Emission Spectroscopy after digestion in nitric acid and peroxide.

Diets were formulated to contain 105% of the NRC (1998) requirement for true ileal digestible lysine according to each growth phase and sex. The diets used in the grower phase were formulated to 0.87% lysine for both gilts and barrows (Table 1). The early finisher phase gilt and barrow diets were formulated to 0.75 % and .65% lysine, respectively (325 g lean gain per day; Tables 2 and 3). The late finisher phase gilt and barrow diets were formulated to 0.58% and .50% lysine, respectively (325 g lean gain per day; Tables 4 and 5). All other amino acids were formulated to meet or exceed the requirements of NRC (1998). An equal lysine:metabolizable energy (%:mg/kg) ratio was used in all diets according to phase and sex. The ratio used in the grower phase was 0.30 for gilts and barrows. The ratio used in the early finisher phase was 0.25 for gilts and 0.22 for barrows, and the ratio used in the late finisher phase was 0.19 for gilts and 0.16 for barrows. The diets were formulated to contain 0.70% Ca and 0.60% P in the grower phase, 0.60% Ca and 0.55% P in the early finisher phase, and 0.55% Ca and 0.50% P in the late finisher phase. Treatment diets and water were provided on an ad libitum basis throughout the experiment.

At LSU during the grower phase, pigs were housed in a total confinement in 1.2 x 2.4 m pens and aluminum slotted floors. The pigs were later moved to an open-sided finishing barn with 1.5 x 3.0 m pens with totally slatted concrete floors. At UI, pigs were housed in a total confinement in 2.0 x 2.4 m pens with half solid and half concrete slats throughout the grower and finisher phases.

Carcass Evaluation

At the termination of the experiment, two or three pigs per pen were transported to each university's Meats Laboratory for slaughter. Pigs were killed by exsanguination following electrical stunning. Hot carcass weight was collected. Carcass measurements were taken from the left side of the carcass after a 20-h chill at 2^{o}C. The carcass measurements included longissimus muscle area, first-rib backfat thickness, last lumbar vertebra backfat thickness, carcass length, muscle score, and pork quality scores.

Longissimus muscle area was determined by tracing the longissimus muscle surface area at the 10^{th} rib. Tenth rib backfat thickness was determined by measuring the fat thickness at the 10^{th} rib, three-quarters of the lateral length of the longissimus muscle, perpendicular to the outer skin surface. Average backfat was determined by averaging the backfat thickness at the first and last rib and last lumbar vertebra. Percentage muscling was determined with the equation described by the NPPC (1991), which uses a 5% estimation for intramuscular fat and compensates for unequal body weights. The equation used was: {[(7.231 + (.437 x hot carcass weight) – 18.746 x tenth rib fat) + (3.877 x longissimus muscle area) / hot carcass weight] x 100}. The following equation was used to calculate kilograms of total lean: {[7.231 + (.437 x hot carcass weight) – (18.746 x tenth rib fat) + (3.877 x longissimus muscle area)] / 2.204622622}.

Muscle scores ranged from 1 being light muscled to 3 being heavy muscled. The pork quality scores (color, marbling, and firmness/wetness) were determined according to the guidelines of the NPPC (1991). Objective color (using L*, a* and b* values to evaluate lightness, redness and yellowness, respectively) was determined by a Minolta Chromameter CR-300 (Minolta Camera Co., Japan, illuminant D65 and 0^{o}) at the University of Illinois and a Minolta spectrophotometer (Model CM-508d, Minolta Corporation, Ramsey, NJ) at Louisiana State University.

Drip loss was determined by the suspension method. The 1.27 cm chops were taken from the 10^{th} rib, weighed, and suspended in a plastic bag. At 24 to 36 h, the samples were weighed and drip loss was determined by the equation {[(initial weight of chop – final weight of chop)/initial weight of chop] x 100}.

A 12.7 cm loin section was taken above the 10^{th} rib. The sections were vacuum-packed, aged for 7 d, frozen, and then shipped to the University of Illinois. The samples were thawed, cooked to an internal temperature of 70 C, and a sensory panel evaluation was conducted. The sensory evaluation was based on tenderness, juiciness, pork flavor intensity (PFI), and off flavor intensity (OFI). Tenderness was measured with 0 being extremely tough and 15 being extremely tender. For juiciness, 0 was extremely dry and 15 was extremely juicy. Pork flavor intensity and OFI were measured with 0 being extremely intense and 15 being none. Shear force (Instron Universal Testing Machine, Canton, MA), cook loss, moisture, and intramuscular fat also were determined on this sample. The moisture and intramuscular fat contents were determined using standard techniques (Novakovski, 1989).

The fat plate was removed from the sensory panel loin sample. The skin was then removed to access the second fat layer. This fat layer was sampled, vacuum-packed, frozen, and then sent to the University of Illinois for determination of fat firmness (Instron Universal Testing Machine, Canton, MA) and thickness (calipers).

A 2.54 cm loin section was taken at the last rib 18 to 36 h postmortem. These samples were blended, placed in plastic bags, frozen, and shipped to the University of Illinois for determination of 24-h pH by the iodoacetate method. The pH was determined with a 5 g sample homogenized at speed 3 (Brinkman Homogenizer Model PT 10/35, Brinkman Instrument CO., Westbury, NY) with 20 mL iodoacetate. The pH was measured with a Orion model 720a pH meter (Orion Research, Boston, MA) fitted with a Ross sure flow 81-72 electrode calibrated with 3 pH buffers (pH 4.0, 7.0, and 10.0).

Statistical Analysis

Data were analyzed by analysis of variance procedures (Steel and Torrie, 1980) appropriate for a randomized complete block design using the GLM procedures of SAS. For all data, the statistical model included location, sex, and treatment. There were no meaningful location × treatment or sex × treatment interactions. Treatment differences were separated by single degree of freedom comparisons. The control diet containing soybean meal was compared with the diet containing DESB, amino acids, peas, the diets containing all plant sources of protein (DESB, canola, peanut, and sunflower meals), and the diets containing all animal sources of protein(meat and bone meal and poultry by-product meal). The pen of pigs was the experimental unit for all data.

Results and Discussion

Pigs fed diets containing cottonseed meal all died or became moribund within 4 to 6 wk after initiation of the experiment. The cause of death was gossypol poisoning. Data from pigs fed these diets are not included in this report.

The effect of protein sources on growth performance, carcass traits, and pork quality are presented in Tables 7 to 9. Each of these tables provides an indication of any significant ($P < 0.10$) contrasts in the data. Tables 10 to 12 provide the specific probability of significance for each or the variables for each of the contrasts.

Daily gain for the entire growth period was reduced ($P < 0.10$)in pigs fed the AA diet and in those fed the plant and animal sources of protein compared with pigs fed the CSBM diet (Table 7). Growth of pigs fed the diet with peas or DESB was not different from those fed the CSBM diet. Feed intake was reduced in pigs fed the DESB, AA, and animal protein sources compared with pigs fed the CSBM diet. Efficiency of feed utilization was higher in pigs fed the DESB and lower in pigs fed the AA diet relative to those fed the CSBM diet. Growth performance for the grower and early and late finisher periods is shown in Table 7. Generally, growth performance was more negatively affected during the early periods of growth than during the late finisher period. This response would be expected, because amino acid needs for protein accretion are higher in younger pigs than in older pigs.

The effect of soybean meal and the other protein sources on carcass characteristics is shown in Table 8. Carcass length and dressing percentage were not affected by diet. Loin muscle area, percentage muscle and kilograms of lean were reduced and 10^{th} rib and average backfat thickness were increased in pigs fed the AA diet relative to those fed the CSBM diet. Similarly, 10^{th} rib and average backfat thickness were increased and percentage muscling was decreased in pigs fed the animal source proteins. Pigs fed DESB had a higher average backfat thickness than pigs fed the CSBM diet. Pigs fed peas had reduced kilograms of lean and percentage of muscling and an increased 10th rib fat.

The results of the growth and carcass traits data indicate that the AA diet was deficient in one or more amino acids, or possible in total nitrogen for the synthesis of the nonessential amino acids. This is depicted in a reduced growth performance and carcass muscling and an increased carcass fat. The animal source proteins and peas responded in a manner similar to the AA diet, although the negative effects were not as severe. Again, this suggests that these diets may be deficient in one or more amino acids. The plant sources, although not equal to SBM, were not as detrimental to growth and carcass traits as the AA or animal source proteins.

The pork quality data are presented in Table 9. Pigs fed the AA diet had an increased fat thickness, intramuscular fat, and 24-h pH but a reduced muscle score, shear force, and moisture content of the longissimus muscle. Drip loss also tended to be lower in pigs fed the AA diet. Muscle score was lower in pigs fed all diets relative to the those fed the CSBM. Pork flavor intensity was higher and off flavor intensity lower in pigs fed the DESB than in pigs fed the CSBM diet. Intramuscular fat was higher and percentage moisture lower in the longissimus muscle in pigs fed the animal source protein diets.

The pork quality data seem to mimic the growth and carcass trait data in that most of the effects indicate amino acid (or protein) deficiency. The pigs fed the AA diet had a reduced muscle score and moisture content of the muscle but an increased fat thickness, intramuscular fat; all effects indicative of an amino acid deficiency. A similar effect, although not to the same degree, was observed with the animal source proteins. The exception in the pork quality data to the amino acid deficiency concept may be in pigs fed the DESB. Pork from these pigs had a greater pork flavor intensity and less of an off flavor intensity. This response is probably due to the higher level of soy oil (or total fat) in these diets than in any of the other diets.

In summary, pigs fed diets consisting of corn and soybean meal had growth performance, carcass traits, and pork quality equal to or better than pigs fed the other plant or animal source proteins as the sole source of supplemental protein in the diet. Some of the individual plant sources were overall similar to soybean meal, but none had consistent responses greater than soybean meal.

Future Directions

The proposed future research will continue to focus on establishing the impacts, both positive and negative, of soybeans and soybean meals on pork quality, defined in the broadest terms. In addition, it is proposed that research will be carried out to clearly define the pork quality requirements of packers, retailers, and consumers in order that strategies to improve quality can be targeted more accurately. Finally, the potential to manipulate the quality of pork using soybeans and soybean oil will be investigated.

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Table 1. Grower diet composition for barrows and gilts

	SBM	AA	DESB	Canola	Peanut	Sunflower	Cottonseed	Pea	Meat/Bone	Poultry
Corn	64.26	92.58	54.71	48.58	47.08	38.19	57.77	28.52	88.08	82.35
Protein source	31.98	-	41.68	48.84	49.35	58.70	38.78	67.16	8.13	15.01
Monocalcium PO_4	1.07	1.62	1.00	-	0.82	-	-	1.20	0.25	0.03
Limestone	1.16	1.13	1.08	1.02	0.83	1.30	1.50	1.22	-	-
Salt	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Sodium bentonite	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Vitamins[a]	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
Minerals[b]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Selenium premix[c]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
L-Lysine•HCL	-	0.99	-	0.03	0.37	0.28	0.37	-	0.78	0.56
L-Threonine	-	0.38	-	-	-	-	0.03	0.10	0.28	0.16
L-Valine	-	0.33	-	-	-	-	-	0.03	0.21	0.08
DL- Methionine	-	0.26	-	-	-	-	-	0.17	0.20	0.09
L-Histidine	-	0.15	-	-	-	-	-	-	0.07	0.01
L-Tryptophan	-	0.13	-	-	0.02	-	0.02	0.07	0.11	0.10
L-Arginine	-	0.10	-	-	-	-	-	-	-	-
L-Isoleucine	-	0.30	-	-	-	-	-	-	0.21	0.08
L-Phenylalanine		0.38	-	-	-	-	-	-	0.21	-
L-Leucine		0.12	-	-	-	-	-	-	-	-
CP, %	20.52	9.346	19.21	21.45	28.50	28.20	21.24	17.91	12.73	13.84
TSAA, %	0.599	0.548	0.603	0.825	0.556	0.858	0.571	0.542	0.552	0.562
Lys,[d] %	0.995	0.961	1.035	0.896	0.975	0.884	0.872	0.950	0.969	0.985
Trp, %	0.202	0.173	0.194	0.181	0.175	0.178	0.157	0.171	0.174	0.177
Thr, %	0.701	0.603	0.707	0.727	0.621	0.492	0.547	0.596	0.607	0.618
ME, kcal/kg[e]	3279	3166	3409	2951	3212	2912	2874	3131	3192	3246
Lys:ME[f]	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30

[a]Vitamin premix provided the following per kilogram of diet: vitamin A, 8,267 IU; vitamin D2 2,480 IU; vitamin E, 66 IU; menadionine (as minadionine pyrimidinol bisulfite complex) 6.2 mg; riboflavin, 10 mg; Ca d-pantothenic acid, 37 mg; niacin, 66 mg; vitamin B12, 45 :g; d-biotin, 331 :g; folic acid, 2.5 mg; pyridoxine, 3.31 mg; thiamine, 3.31 mg; vitamin C, 83 :g.

[b] Trace mineral premix provided the following per kilogram of diet: Zn, 127 mg; Fe, 127 mg; Mn, 20 mg; Cu, 12.7 mg; I, 0.80 mg, as xinc sulfate, ferrous sulfate, manganese sulfate, copper sulfate, ethylenediamine dihydriodide respectively with calcium carbonate as the carrier.

[c] Provided 0.3 mg Se per kilogram of diet.

[d] Amino acid values are calculated based on actual analysis of the protein sources and NRC (1998) values for corn. They are on a true ileal digestibility basis with digestibility coefficients from NRC (1998).

[e] ME values were calculated using NRC (1998).

[f] ME in kcal/kg and lysine in %.

Table 2. Early finisher barrow diet composition

	SBM	AA	DESB	Canola	Peanut	Sunflower	Cottonseed	Pea	Meat/Bone	Poultry
Corn	75.91	94.60	70.15	63.59	68.60	53.66	70.97	52.28	90.50	85.26
Protein source	20.56	-	26.42	33.74	27.85	43.41	25.74	43.94	6.97	12.85
Monocalcium PO_4	1.01	1.36	0.97	0.25	0.91	0.17	0.29	1.09	0.18	0.01
Limestone	0.99	0.97	0.93	0.89	0.80	1.09	1.21	1.03	-	-
Salt	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Sodium bentonite	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Vitamins[a]	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
Minerals[b]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Selenium premix[c]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
L-Lysine•HCL	-	0.64	-	-	0.29	0.14	0.25	-	0.46	0.27
L-Threonine	-	0.23	-	-	-	-	-	0.04	0.13	0.03
L-Valine	-	0.15	-	-	-	-	-	-	0.04	-
DL-Methionine	-	0.11	-	-	-	-	-	0.05	0.05	-
L-Histidine	-	0.05	-	-	-	-	-	-	-	-
L-Tryptophan	-	0.08	-	-	0.02	-	0.01	0.04	0.06	0.05
L-Arginine	-	-	-	-	-	-	-	-	-	-
L-Isoleucine	-	0.16	-	-	-	-	-	-	0.08	-
L-Phenylalanine	-	0.12								
CP, %	16.07	8.815	15.12	17.29	19.66	22.90	16.79	14.45	11.71	12.71
TSAA, %	0.492	0.405	0.492	0.663	0.444	0.713	0.48	0.400	0.406	0.448
Lys,[d] %	0.709	0.697	0.727	0.660	0.700	0.651	0.651	0.689	0.700	0.707
Trp, %	0.147	0.124	0.141	0.140	0.124	0.144	0.116	0.122	0.124	0.125
Thr, %	0.534	0.449	0.533	0.574	0.452	0.598	0.420	0.444	0.451	0.456
ME, kcal/kg[e]	3291	3236	3374	3066	3250	3023	3023	3199	3250	3284
Lys:ME[f]	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22

[a]Vitamin premix provided the following per kilogram of diet: vitamin A, 8,267 IU; vitamin D2 2,480 IU; vitamin E, 66 IU; menadionine (as minadionine pyrimidinol bisulfite complex) 6.2 mg; riboflavin, 10 mg; Ca d-pantothenic acid, 37 mg; niacin, 66 mg; vitamin B12, 45 :g; d-biotin, 331 :g; folic acid, 2.5 mg; pyridoxine, 3.31 mg; thiamine, 3.31 mg; vitamin C, 83 :g.

[b] Trace mineral premix provided the following per kilogram of diet: Zn, 127 mg; Fe, 127 mg; Mn, 20 mg; Cu, 12.7 mg; I, 0.80 mg, as xinc sulfate, ferrous sulfate, manganese sulfate, copper sulfate, ethylenediamine dihydriodide respectively with calcium carbonate as the carrier.

[c] Provided 0.3 mg Se per kilogram of diet.

[d] Amino acid values are calculated based on actual analysis of the protein sources and NRC (1998) values for corn. They are on a true ileal digestibility basis with digestibility coefficients from NRC (1998).

[e] ME values were calculated using NRC (1998).

[f] ME in kcal/kg and lysine in %.

Table 3. Early finisher gilt diet composition

	SBM	AA	DESB	Canola	Peanut	Sunflower	Cottonseed	Pea	Meat/Bone	Poultry
Corn	71.11	93.97	63.79	55.45	58.90	47.51	64.10	42.19	89.90	84.96
Protein source	25.44	-	32.88	41.08	37.74	49.64	32.79	53.96	6.95	12.82
Monocalcium PO_4	0.93	1.37	0.88	0.07	0.76	-	-	1.03	0.20	0.01
Limestone	0.99	0.97	0.92	0.87	0.74	1.11	1.28	1.04	-	-
Salt	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Sodium bentonite	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Vitamins[a]	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
Minerals[b]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Selenium premix[c]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Lysine•HCL	-	0.79	-	-	0.31	0.21	0.28	-	0.61	0.42
L-Threonine	-	0.30	-	-	-	-	0.01	0.07	0.21	0.11
L-Valine	-	0.23	-	-	-	-	-	-	0.13	0.01
DL Methionine	-	0.19	-	-	-	-	-	0.12	0.13	0.04
L-Histidine	-	0.10	-	-	-	-	-	-	0.03	-
L-Tryptophan	-	0.10	-	-	0.02	-	0.01	0.06	0.09	0.07
L-Arginine	-	-	-	-	-	-	-	-	-	-
L-Isoleucine	-	0.22	-	-	-	-	-	-	0.14	0.03
L-Phenylalanine	-	0.23							0.08	
L-Leucine										
CP, %	17.98	9.093	16.87	19.32	23.73	25.08	19.18	15.98	11.96	12.92
TSAA, %	0.538	0.480	0.54	0.742	0.496	0.773	0.530	0.474	0.482	0.489
Lys,[d] %	0.832	0.812	0.858	0.762	0.818	0.753	0.745	0.802	0.816	0.826
Trp, %	0.170	0.149	0.163	0.16	0.150	0.158	0.136	0.147	0.149	0.151
Thre, %	0.606	0.526	0.607	0.649	0.530	0.650	0.483	0.520	0.528	0.535
ME, kcal/kg[e]	3292	3214	3395	3017	3239	2983	2951	3175	3229	3272
Lys:ME[f]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25

[a]Vitamin premix provided the following per kilogram of diet: vitamin A, 8,267 IU; vitamin D2 2,480 IU; vitamin E, 66 IU; menadionine (as minadionine pyrimidinol bisulfite complex) 6.2 mg; riboflavin, 10 mg; Ca d-pantothenic acid, 37 mg; niacin, 66 mg; vitamin B12, 45 :g; d-biotin, 331 :g; folic acid, 2.5 mg; pyridoxine, 3.31 mg; thiamine, 3.31 mg; vitamin C, 83 :g.

[b] Trace mineral premix provided the following per kilogram of diet: Zn, 127 mg; Fe, 127 mg; Mn, 20 mg; Cu, 12.7 mg; I, 0.80 mg, as xinc sulfate, ferrous sulfate, manganese sulfate, copper sulfate, ethylenediamine dihydriodide respectively with calcium carbonate as the carrier.

[c] Provided 0.3 mg Se per kilogram of diet.

[d] Amino acid values are calculated based on actual analysis of the protein sources and NRC (1998) values for corn. They are on a true ileal digestibility basis with digestibility coefficients from NRC (1998).

[e] ME values were calculated using NRC (1998).

[f] ME in kcal/kg and lysine in %.

Table 4. Late finisher barrow diet composition

	SBM	AA	DESB	Canola	Peanut	Sunflower	Cottonseed	Pea	Meat/Bone	Poultry
Corn	83.29	95.70	79.70	74.77	81.59	72.77	82.41	67.70	91.54	87.67
Protein source	13.35	-	17.00	22.45	14.92	24.10	14.26	28.84	6.59	10.52
Monocalcium PO_4	0.88	1.11	0.86	0.37	0.87	0.45	0.52	0.93	-	-
Limestone	0.95	0.94	0.91	0.88	0.84	1.00	1.07	0.97	0.02	0.14
Salt	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Sodium bentonite	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Vitamins[a]	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
Minerals[b]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Selenium premix[c]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Lysine•HCL	-	0.42	-	-	0.23	0.15	0.21	-	0.25	0.11
L-Threonine	-	0.12	-	-	-	-	-	-	0.03	-
L-Valine	-	0.04	-	-	-	-	-	-	-	-
DL Methionine	-	0.02	-	-	-	-	-	-	-	-
L-Histidine	-	-	-	-	-	-	-	-	-	-
L-Tryptophan	-	0.05	-	-	0.02	-	0.01	0.03	0.04	0.03
L-Arginine	-	-	-	-	-	-	-	-	-	-
L-Isoleucine	-	0.07	-	-	-	-	-	-	-	
L-Phenylalanine	-									
CP, %	13.25	8.485	12.60	14.20	14.33	16.35	12.95	12.22	11.28	11.76
TSAA, %	0.425	0.317	0.424	0.542	0.377	0.529	0.399	0.331	0.353	0.422
Lys,[d] %	0.528	0.524	0.537	0.504	0.524	0.504	0.504	0.519	0.525	0.528
Trp, %	0.112	0.098	0.108	0.109	0.098	0.101	0.095	0.097	0.098	0.099
Thre, %	0.428	0.349	0.426	0.460	0.350	0.435	0.336	0.347	0.350	0.394
ME, kcal/kg[e]	3300	3274	3353	3150	3275	3148	3148	3241	3278	3299
Lys:ME[f]	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16

[a]Vitamin premix provided the following per kilogram of diet: vitamin A, 8,267 IU; vitamin D2 2,480 IU; vitamin E, 66 IU; menadionine (as minadionine pyrimidinol bisulfite complex) 6.2 mg; riboflavin, 10 mg; Ca d-pantothenic acid, 37 mg; niacin, 66 mg; vitamin B12, 45 :g; d-biotin, 331 :g; folic acid, 2.5 mg; pyridoxine, 3.31 mg; thiamine, 3.31 mg; vitamin C, 83 :g.

[b] Trace mineral premix provided the following per kilogram of diet: Zn, 127 mg; Fe, 127 mg; Mn, 20 mg; Cu, 12.7 mg; I, 0.80 mg, as xinc sulfate, ferrous sulfate, manganese sulfate, copper sulfate, ethylenediamine dihydriodide respectively with calcium carbonate as the carrier.

[c] Provided 0.3 mg Se per kilogram of diet.

[d] Amino acid values are calculated based on actual analysis of the protein sources and NRC (1998) values for com. They are on a true ileal digestibility basis with digestibility coefficients from NRC (1998).

[e] ME values were calculated using NRC (1998).

[f] ME in kcal/kg and lysine in %.

Table 5. Late finisher gilt diet composition

	SBM	AA	DESB	Canola	Peanut	Sunflower	Cottonseed	Pea	Meat/Bone	Poultry
Corn	79.72	95.31	75.06	69.22	73.85	61.21	75.52	60.06	91.27	87.51
Protein source	16.97	-	21.71	28.20	22.82	35.97	21.36	36.46	6.61	10.54
Monocalcium PO_4	0.83	1.11	0.79	0.18	0.74	0.13	0.22	0.89	-	-
Limestone	0.95	0.93	0.91	0.87	0.80	1.04	1.14	0.98	0.02	0.14
Salt	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Sodium bentonite	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Vitamins[a]	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
Minerals[b]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Selenium premix[c]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Lysine•HCL	-	0.53	-	-	0.24	0.12	0.22	-	0.36	0.22
L-Threonine	-	0.19	-	-	-	-	-	0.03	0.10	0.02
L-Valine	-	0.10	-	-	-	-	-	-	-	-
DL Methionine	-	0.07	-	-	-	-	-	0.02	0.02	-
L-Histidine	-	0.01	-	-	-	-	-	-	-	-
L-Tryptophan	-	0.06	-	-	0.02	-	0.01	0.03	0.05	0.04
L-Arginine	-	-	-	-	-	-	-	-	-	
L-Isoleucine	-	0.12	-	-	-	-	-	-	0.04	-
L-Phenylalanine		0.04								
CP, %	14.68	8.66	13.87	15.78	17.58	20.38	15.32	13.36	11.44	11.89
TSAA, %	0.459	0.366	0.459	0.604	0.418	0.643	0.45	0.362	0.367	0.422
Lys,[d] %	0.619	0.612	0.632	0.584	0.613	0.578	0.578	0.605	0.613	0.618
Trp, %	0.130	0.111	0.124	0.125	0.111	0.128	0.105	0.110	0.112	0.112
Thre, %	0.482	0.411	0.480	0.519	0.412	0.535	0.389	0.407	0.413	0.416
ME, kcal/kg[e]	3300	3260	3368	3112	3266	3078	3078	3224	3269	3294
Lys:ME[f]	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19

[a]Vitamin premix provided the following per kilogram of diet: vitamin A, 8,267 IU; vitamin D2 2,480 IU; vitamin E, 66 IU; menadionine (as minadionine pyrimidinol bisulfite complex) 6.2 mg; riboflavin, 10 mg; Ca d-pantothenic acid, 37 mg; niacin, 66 mg; vitamin B12, 45 :g; d-biotin, 331 :g; folic acid, 2.5 mg; pyridoxine, 3.31 mg; thiamine, 3.31 mg; vitamin C, 83 :g.

[b] Trace mineral premix provided the following per kilogram of diet: Zn, 127 mg; Fe, 127 mg; Mn, 20 mg; Cu, 12.7 mg; I, 0.80 mg, as xinc sulfate, ferrous sulfate, manganese sulfate, copper sulfate, ethylenediamine dihydriodide respectively with calcium carbonate as the carrier.

[c] Provided 0.3 mg Se per kilogram of diet.

[d] Amino acid values are calculated based on actual analysis of the protein sources and NRC (1998) values for corn. They are on a true ileal digestibility basis with digestibility coefficients from NRC (1998).

[e] ME values were calculated using NRC (1998).

[f] ME in kcal/kg and lysine in %.

Table 6. Amino acid and mineral composition (%) of the protein sources

	Corn[a]	SBM	DESB	Canola	Peanut	Sunflower	Cottonseed	Pea	Meat/Bone	Poultry
Arg	0.37	3.63	2.95	2.23	4.78	2.81	4.84	1.66	3.92	4.09
His	0.23	1.25	1.04	0.98	0.85	0.80	1.15	0.47	1.06	1.11
Ile	0.28	2.12	1.82	1.49	1.27	1.19	1.36	0.87	1.57	2.10
Leu	0.99	3.76	3.18	2.97	2.51	2.11	2.56	1.49	3.41	4.11
Lys	0.26	3.01	2.58	2.02	1.36	1.20	1.87	1.51	2.80	3.16
TSAA	0.36	1.40	1.26	1.63	0.95	1.46	1.39	0.52	1.42	1.91
Phe + Tyr	0.64	4.17	3.52	2.68	3.34	2.29	3.43	1.59	3.08	3.96
Thr	0.29	1.96	1.66	1.64	1.14	1.28	1.43	0.77	1.89	2.27
Trp	0.06	0.59	0.49	0.42	0.35	0.37	0.44	0.16	0.31	0.36
Val	0.39	2.14	1.81	1.84	1.51	1.40	1.78	0.91	2.23	2.71
Ca	0.03	0.25	0.30	0.61	0.50	0.33	0.29	0.07	7.82	4.47
P	0.28	0.61	0.57	0.95	0.60	0.84	1.13	0.40	3.70	2.42

[a] Amino acid values were taken from the NRC (1998).

Table 7. Effect of protein sources on growth performance.

	$P < 0.10^{a-e}$	SBM	AA	DESB	Canola	Peanut	Sunflower	Peas	Meat/bone	Poultry
Grower										
ADG, kg/d	a,d,e	0.81	0.56	0.78	0.61	0.75	0.62	0.78	0.70	0.69
ADF, kg/d	c	1.89	1.82	1.81	1.92	1.83	2.11	2.12	1.85	1.85
G:F	a,c,d,e	0.43	0.31	0.43	0.32	0.41	0.30	0.37	0.38	0.37
Early finisher										
ADG, kg/d	a	0.93	0.77	0.96	0.84	0.91	0.86	0.88	0.90	0.88
ADF, kg/d	e	2.95	2.69	2.64	3.06	2.85	3.17	2.93	2.60	2.61
G:F	a,b	0.32	0.29	0.37	0.28	0.32	0.27	0.30	0.35	0.34
Late finisher										
ADG, kg/d	e	0.84	0.85	0.79	0.86	0.86	0.81	0.81	0.74	0.75
ADF, kg/d	NS	3.25	3.06	2.91	3.35	3.14	3.69	3.02	2.96	2.80
G:F	NS	0.26	0.28	0.27	0.27	0.27	0.22	0.27	0.25	0.27
Overall										
ADG, kg/d	a,d,e	0.85	0.70	0.83	0.74	0.82	0.76	0.82	0.75	0.77
ADF, kg/d	a,b,e	2.76	2.45	2.47	2.62	2.60	2.96	2.68	2.47	2.41
G:F	a,b	0.31	0.28	0.34	0.29	0.32	0.26	0.30	0.30	0.32

[a] SBM vs amino acids.
[b] SBM vs dry extruded soybeans.
[c] SBM vs peas.
[d] SBM vs plant (dry extruded soybeans, canola, peanut, and sunflower).
[e] SBM vs animal (meat and bone meal, and poultry by-product meal).

Table 8. Effect of protein sources on carcass characteristics

	$P < 0.10$[a-e]	SBM	AA	DESB	Canola	Peanut	Sunflower	Peas	Meat/bone	Poultry
Loin muscle area, cm^2	a	43.29	31.87	42.20	41.79	41.63	42.20	41.55	40.47	43.74
10th rib ¾backfat, cm	a,c,e	1.87	2.67	2.05	1.98	1.99	1.94	2.10	2.15	2.06
Average backfat, cm	a,b,d,e	2.60	3.01	2.89	2.81	2.76	2.55	2.78	2.87	2.83
Carcass length, cm	NS	84.18	84.53	84.12	83.02	84.20	84.22	84.01	83.75	83.60
Dressing percentage, %	NS	74.69	73.60	75.23	74.74	75.33	73.86	75.09	75.30	75.51
Percentage muscling, %[f]	a,c,e	53.93	47.06	52.89	53.15	52.93	53.53	52.51	51.98	53.32
Kilograms of lean, kg	a,c	46.52	40.26	45.90	45.76	45.98	45.61	45.17	45.16	46.46

[a] SBM vs amino acids.
[b] SBM vs dry extruded soybeans.
[c] SBM vs peas.
[d] SBM vs plant (dry extruded soybeans, canola, peanut, and sunflower).
[e] SBM vs animal (meat and bone meal, and poultry by-product meal).
[f] Calculated using the equation described by NPPC (1991), which uses a 5% estimation for intramuscular fat and compensates for unequal body weights

Table 9. Effect of protein sources on pork quality

	P < .10[a-e]	SBM	AA	DESB	Canola	Peanut	Sunflower	Peas	Meat/bone	Poultry
NPPC Pork Quality[f]										
Color	d	2.43	2.25	2.23	1.93	1.95	2.19	2.40	2.51	2.52
Firmness/wetness	NS	2.34	2.56	2.12	2.22	2.01	2.22	2.51	2.36	2.60
Marbling	a	1.63	2.66	1.72	1.55	1.61	1.50	1.87	2.01	1.75
Muscle score	a,b,c,d,e	2.31	2.00	2.15	2.25	2.08	2.24	2.08	2.11	2.24
Minolta Color Score[g]										
L*	NS	51.32	52.79	52.02	53.63	53.91	52.49	51.27	51.73	50.55
a*	NS	5.97	5.83	5.94	4.49	5.96	4.53	5.80	6.79	6.06
b*	NS	4.96	5.80	5.02	5.19	6.21	5.07	4.86	5.32	4.88
45-min pH[h]	NS	6.30	6.13	6.28	6.18	6.10	6.21	6.36	6.39	6.31
24-h pH[i]	a	5.43	5.52	5.44	5.43	5.38	5.43	5.43	5.40	5.44
Sensory panel[j]										
Tenderness	NS	7.54	8.41	7.19	7.41	7.25	6.60	7.46	8.06	8.31
Juiciness	NS	7.02	7.00	6.31	6.25	6.98	5.66	5.98	7.45	7.00
Pork flavor intensity	b	6.28	6.34	7.42	6.70	6.67	6.72	6.52	6.29	6.29
Off flavor intensity	b	13.53	13.64	11.79	13.35	13.10	13.16	13.54	13.45	13.55
Drip loss, %	NS	5.22	3.61	5.14	5.29	6.59	5.62	4.20	4.82	4.02
Cook loss, %	NS	25.04	24.55	26.88	23.99	26.05	25.51	24.73	24.74	24.93
Instron fat firmness	NS	56.35	47.59	55.04	55.35	54.32	55.53	52.91	53.37	56.97
Fat thickness	a,c	1.06	1.38	1.00	1.05	1.08	1.10	1.32	1.19	1.04
Intramuscular fat	a,e	1.91	4.39	1.93	1.86	2.02	1.71	2.26	2.60	2.74
Shear force	NS	4.29	4.14	4.53	4.33	4.43	4.94	4.41	4.13	4.26
Moisture	a,c,e	75.22	73.54	75.24	75.24	75.39	75.07	74.70	74.92	74.65

[a] SBM vs amino acids.
[b] SBM vs dry extruded soybeans.
[c] SBM vs peas.
[d] SBM vs plant (dry extruded soybeans, canola, peanut, and sunflower).
[e] SBM vs animal (meat and bone meal, and poultry by-product meal).
[f] NPPC scores were taken at the 10th rib interface.
[g] A loin section was taken at the 10th rib, bloomed for 20-40 minutes and color scores (L* a b; Minolta color meter) were measured.
[h] The pH measurements were taken in the longissimus muscle above the last rib.
[i] The pH measurements were taken by iodoacetate method at the University of Illinois.
[j] A 12.7 cm loin section was taken, bloomed for 24 h, and sent to the University of Illinois for sensory panel evaluation.

Table 10. Effect of protein sources on growth performance

	SBM vs AA	SBM vs DESB	SBM vs Peas	SBM vs Plant[a]	SBM vs Animal[b]	SEM
Grower						
ADG, kg/d	0.01	NS	NS	0.01	0.01	0.03
ADF, kg/d	NS	NS	0.01	NS	NS	0.06
G:F	0.01	NS	0.01	0.01	0.01	0.01
Early Finisher						
ADG, kg/d	0.01	NS	NS	NS	NS	0.04
ADF, kg/d	NS	0.12	NS	NS	0.05	0.14
G:F	0.09	0.02	NS	NS	NS	0.01
Late Finisher						
ADG, kg/d	NS	NS	NS	NS	0.09	0.04
ADF, kg/d	NS	NS	NS	NS	0.12	0.19
G:F	NS	NS	NS	NS	NS	0.01
Overall						
ADG, kg/d	0.01	NS	NS	0.04	0.01	0.03
ADF, kg/d	0.02	0.02	NS	NS	0.01	0.09
G:F	0.05	0.05	NS	NS	NS	0.01

[a] SBM vs plant (dry extruded soybeans, canola, peanut, and sunflower).
[b] SBM vs animal (meat and bone meal, and poultry by-product meal).

Table 11. Effect of protein sources on carcass characteristics

	SBM vs AA	SBM vs DESB	SBM vs Peas	SBM vs Plant[a]	SBM vs Animal[b]	SEM
Loin muscle area, cm^2	0.01	NS	NS	NS	NS	0.99
10th rib ¾backfat, cm	0.01	NS	0.09	NS	0.05	0.10
Average backfat, cm	0.01	0.01	0.11	0.09	0.01	0.08
Carcass length, cm	NS	NS	NS	NS	NS	0.58
Dressing percentage, %	0.10	NS	NS	NS	NS	0.40
Percentage muscling, %	0.01	NS	0.09	NS	0.08	0.57
Kilograms of lean, kg	0.01	NS	0.05	NS	NS	0.47

[a] SBM vs plant (dry extruded soybeans, canola, peanut, and sunflower).
[b] SBM vs animal (meat and bone meal, and poultry by-product meal).

Table 12. Effect of protein sources on pork quality

	SBM vs AA	SBM vs DESB	SBM vs Peas	SBM vs Plant[a]	SBM vs Animal[b]	SEM
NPPC Pork Quality						
Color	NS	NS	NS	0.02	NS	0.13
Firmness/wetness	NS	NS	NS	NS	NS	0.17
Marbling	0.01	NS	NS	NS	0.12	0.13
Muscle score	0.01	0.07	0.02	0.07	0.09	0.06
Minolta Color Score						
L*	NS	NS	NS	NS	NS	1.15
a*	NS	NS	NS	NS	NS	0.49
b*	NS	NS	NS	NS	NS	0.34
ph						
45-min pH	NS	NS	NS	NS	NS	0.07
24-h pH	0.09	NS	NS	NS	NS	0.03
Sensory Panel						
Tenderness	NS	NS	NS	NS	NS	0.46
Juiciness	NS	NS	NS	NS	NS	0.54
Pork flavor intensity	NS	0.04	NS	NS	NS	0.37
Off flavor intensity	NS	0.02	NS	NS	NS	0.48
Drip loss, %	0.12	NS	NS	NS	NS	0.63
Cook loss, %	NS	NS	NS	NS	NS	1.04
Instron fat firmness	0.12	NS	NS	NS	NS	3.47
Fat thickness	0.04	NS	0.05	NS	NS	0.09
Intramuscular fat	0.01	NS	NS	NS	0.01	0.24
Shear force	NS	NS	NS	NS	NS	0.22
Moisture	0.01	NS	0.07	NS	0.08	0.19

[a] SBM vs plant (dry extruded soybeans, canola, peanut, and sunflower).
[b] SBM vs animal (meat and bone meal, and poultry by-product meal).

Study 2. The Influence of Dietary Lysine Level and Time of Feeding on the Intramuscular Fat Content of Pork Loin.

Summary

Three studies were carried out over 1-, 3-, and 5-wk periods, respectively, to determine the effect of dietary lysine deficiency on the intramuscular fat content of the *longissimus dorsi*. Seventy-two hybrid gilts (24 per study) were individually housed and fed one of four dietary lysine levels (4.0 v. 4.8 v. 5.6 v. 6.4 g lysine per kg). Live weights at the start and end were 107.9 (SD 2.20) and 114.5 (SD 2.44) kg, 97.0 (SD 1.91) and 114.9 (SD 2.37) kg, and 67.3 (SD 2.05) and 94.7 (SD 2.19) kg for the 1-, 3-, and 5-wk studies, respectively. Pigs were given ad libitum access to diets that were formulated to supply the same level of crude protein (100 g/kg) and energy (14.75 MJ DE/ kg). Feeding lysine-deficient diets for periods of one or three weeks had little effect on growth performance, carcass characteristics or intramuscular fat levels.

In the 5-wk study, pigs fed diets containing 4.8 g/kg lysine had higher intramuscular fat levels than those fed 6.4 g/kg lysine. However, pigs given access to diets with 4.0 g/kg lysine grew slower than those on the other diets and showed no significant change in *longissimus dorsi* intramuscular fat levels compared to those fed to the lysine requirement (6.4 g/kg). This suggests that a 5-wk period of feeding lysine-deficient diets is required to produce an increase in intramuscular fat and that there is an optimum dietary lysine level to maximize the response in intramuscular fat, which in the present study was at 4.8 g/kg or approximately 75% of the estimated requirement.

Problem Addressed

The substantial decline in carcass fat levels that has occurred in pigs resulting from genetic selection and improved nutritional programs has been accompanied by a reduction in the amount of intramuscular fat, or marbling. The relationship between intramuscular fat and pork eating quality is not clearly established. There are reports that tenderness and juiciness improves with increasing intramuscular fat (Meat and Livestock Commission, 1992; Castell *et al.*, 1994) and of a threshold level for marbling for good eating quality (Bejerholm and Barton-Gade, 1986; DeVol *et al.*, 1988). The most commonly adopted approach to increasing the marbling fat content of pork is the use of breeds with high intramuscular fat levels, particularly the Duroc, and there is evidence of an advantage for this breed for both marbling fat and eating quality (Ellis *et al.*, 1996). Another approach that would also allow increased, and perhaps targeted levels, of intramuscular fat to be produced is by manipulating the nutrition of the pig. There are a number of reports of substantial increases in intramuscular fat levels resulting from the feeding of protein-deficient diets throughout the growing and finishing periods (Castell *et al.*, 1994; Kerr *et al.*, 1995; Goerl *et al.*, 1995; Blanchard, 1995). However, these studies also reported higher carcass fat levels and lower feed efficiencies from the use of protein deficient diets, and such an approach to increasing levels of intramuscular fat is likely to be uneconomic in most situations. However, fat deposition rates increase with the weight of the animal and Cisneros *et al.* (1996) reported significant increases in fat content of the *longissimus dorsi* as a result of feeding an amino acid-deficient diet during the last 3 and 5 wks of the finishing period. The objectives of the studies reported in this paper were to determine the optimum level of lysine deficiency and minimum time of feeding of lysine deficient diets to maximise the increase in intramuscular fat content of the longissimus.

Approach Used

The impact of feeding lysine deficient diets on intramuscular fat was investigated in three studies that were carried out for periods of time before slaughter of 1, 3, or 5 wks, respectively. Fixed-time rather than fixed-weight studies were used because this is the likely approach that would be used in practice. Within each study, four dietary treatments were used involving different levels of lysine (4.0 v. 4.8 v. 5.6 v. 6.4 g per kg) at the same crude protein content (Table 1). The diet with the highest lysine level was formulated to meet the requirements of the genotype used in this study previously determined at the University of Illinois (Hahn and Baker, 1995; Hahn *et al.*, 1995). A basal diet containing 100g crude protein per kg was formulated using maize, soya-bean meal, soya-bean oil and mineral and vitamin supplements. This basal diet was supplemented with synthetic amino acids (L-lysine, L-threonine, DL-methionine, and L-tryptophan), glutamic acid and/or starch to achieve the required nutrient composition (Table 1).

Seventy-two gilts from a commercial hybrid line were used, with 24 animals in each study. The live weights at the start were 107.9 (SD 2.20), 97.0 (SD 1.91) and 67.3 (SD 2.05) kg for the one-, three- and five-week studies, respectively. Within each study, gilts were formed into outcome groups of four animals, on the basis of live weight and litter of origin. Animals were randomly allocated from within an outcome group to one of the four dietary treatments. The study was carried out in two identical controlled environment buildings at the Swine Research Center of the University of Illinois. Animals were individually housed and fed, and the temperature in the buildings was set at 18^oC throughout the study. Pens (dimensions 2m x 1.5m) were equipped with a nipple drinker and a single-space, ad libitum feed hopper. Pigs had continuous access to feed and water. Fresh diet was added to the feeder on a daily basis, with refusals being collected and weighed on a weekly basis. Animals were weighed at the start of the study and once per week thereafter, and the three studies ended after 7-, 21- or 35-d respectively.

Animals were transported to the University of Illinois Meat Science Laboratory on the afternoon of the day they completed the test period and were slaughtered the following morning after a period in lairage of approximately 18 h. Animals from the three feeding periods and the four dietary lysine level treatments were transported and slaughtered at the same time. Pigs had access to water but not food during lairage. Slaughter and carcass dressing were carried out using standard procedures. The head, kidneys and flare fat were removed and the carcass was split down the mid-line. A hot carcass weight (kg) was taken approximately l-h post mortem at which time carcasses were placed in a chiller (at 4^0C) where they were held overnight.

At 24-h post mortem, carcass measurements were taken on the left side of the carcass with a metal ruler as follows: carcass length (cm, measured from the cranial tip of the symphysis pubis to the cranial edge of the first rib adjacent to the thoracic vertebra); mid-line fat depths opposite the first rib, last rib and last lumbar vertebra (mm); fat depth over the centre of the *longissimus dorsi* muscle at the 10^{th} rib (mm); and *longissimus dorsi* area at the 10^{th} rib (cm^2). *Longissimus dorsi* muscle color, firmness, and marbling were subjectively evaluated on the cut surface of the muscle at the 10^{th} rib using five-point scales (NPPC, 1991; 1 = pale, soft and devoid of marbling to 5 = dark, firm, and moderately abundant or greater marbling, respectively). All subjective evaluations were carried out blind by the same experienced assessor for all animals. Muscle samples for chemical analysis were obtained from the *longissimus dorsi* immediately posterior to the tenth rib and opposite the junction of the 3rd/4th lumbar vertebra. A 2-cm thick section of muscle was taken and trimmed of external fat, epimysium and connective tissue prior to homogenizing. Proximate analysis for fat and moisture content were conducted in duplicate on the homogenized muscle samples using the procedures described by Novakofski *et al.* (1989). Moisture content was determined using oven drying to constant weight (110^{o}C for 24 to 48h) and fat determinations were carried out using extraction with an azaeotropic mixture of warm chloroform and methanol (4:l).

For each study, statistical analysis was carried out using the General Linear Models procedures of SAS (1988) appropriate for randomized complete-block design with the main effects included in the model being dietary lysine level and week of slaughter. The LSD procedure of Carmen and Walker (1985) was used to evaluate differences among dietary treatment means.

Results and Discussion

The effects of dietary lysine level on growth performance are summarized in Table 2. Pigs on the 5-wk study were lighter at the start and end of the test period than those on the other studies. For the 1- and 3-wk study periods, there was no effect of lysine level on feed intake, daily gain, or gain:feed ratio. For the 5-wk study, pigs on the lowest lysine level grew more slowly ($P<0.00l$) than those on the other treatments (Table 2). Gain:feed ratio was highest for pigs fed the 6.4 g/kg lysine diet, lowest for those fed the 4.0 g/kg lysine diet, and intermediate for the other diets.

The slaughter and carcass characteristics of pigs on the different lysine levels are summarized in Table 3. Within each study, differences between dietary treatments were limited and inconsistent. In the 1-wk study, the only dietary treatment effect was for tenth rib backfat thickness which was higher for pigs on the 6.4 g/kg lysine diet than for the other treatments. For the 3-wk study, pigs on the lowest lysine level had less first rib fat than the other treatments, and in the 5-wk study pigs fed the diet containing 5.6 g/kg lysine had larger loin eye areas than those fed lower levels of lysine.

There were no significant differences among lysine levels for meat quality for the 1- and 3-wk studies (Table 4); however, in the 5-wk study *longissimus dorsi* pH at 24h was lower for pigs fed the higher lysine level compared to those fed the diet containing 4.8 g/kg, with the other diets being intermediate in this respect. Intramuscular fat levels showed no consistent response to reduced lysine levels in the 1- and 3-wk studies (Table 4). On the other hand, *longissimus dorsi* fat content was higher for pigs fed the diet containing 4.8 g/kg lysine compared to the other dietary lysine levels.

The objective of these studies was to establish the optimum combination of dietary lysine deficiency and time of feeding to increase the intramuscular fat content of the loin muscle. The results reported here suggest that a feeding period of approximately 5-wks is required to produce any increase in marbling. There was no suggestion of a response in intramuscular fat from feeding lysine-deficient diets for 1 or 3-wks. Cisneros *et al.* (1996) also investigated the impact of feeding a lysine-deficient diet (approximately 70% of estimated requirement) on marbling and found that feeding periods of 3 or 5 wks produced similar increases in the intramuscular fat content of the *longissimus dorsi*. However, these authors also showed that the fat content of the *semimembranosus* was higher after a feeding period for the lysine-deficient diets of 5-wks compared to 3-wks.

There was a difference in the weights of the pigs on the three studies and this confounds any direct comparisons of the impact of time on feed on intramuscular fat levels. However, lean growth rates and, therefore, lysine requirements, are generally declining as pigs approach 100 kg live weight and the relative response in intramuscular fat levels to dietary lysine deficiency should increase with live weight. The fact that there was no response in intramuscular fat in the 1- and 3-wk studies, where slaughter weights averaged approximately 115 kg, suggests that these periods may also be too short in duration to produce a response at lighter weights, or, conversely, that a 5-wk feeding period would produce a positive response at heavier weights.

For the 5-wk feeding period, there was only one level of lysine that produced an increase in intramuscular fat, which was 4.8 g/kg, or approximately 75% of the estimated lysine requirement. Analyzed lysine levels were higher than formulated levels for all four diets and, thus, the diet that maximized intramuscular fat levels contained 5.1 g/kg lysine, or approximately 80% of the requirement. The lack of response in intramuscular fat for the diet containing 5.6 g/kg lysine compared to those fed to requirements probably reflects the similar lysine intakes for these treatments (Table 2). Feeding the diet with the lowest lysine level produced similar levels of intramuscular fat to the animals that were fed the diets with the two highest lysine levels. This result is surprising given that Cisneros *et al.* (1996) showed a substantial increase in intramuscular fat for pigs fed at approximately 70% of the lysine requirement and that similar responses in intramuscular fat have been found in two other studies carried out at this center where diets containing 4.8 and 6.4 g/kg lysine have been fed for a five-week period prior to slaughter (Bidner et al., 1999; Witte et al., 1999). However, in the present study pigs on the lowest lysine level exhibited a significant reduction in growth rate compared to animals fed the other lysine levels. Hahn *et al.* (1995), in a study carried out at this center, also showed reduced growth rates for pigs fed diets with reduced lysine levels (between 64 and 74% of requirement). In contrast, there was no effect of lysine level on growth performance in the study of Cisneros *et al.* (1996) that was carried out in the same facility as the current study and with pigs from the same genetic line. This suggests that the response in intramuscular fat to feeding lysine-deficient diets will depend, at least in part, on the growth performance of the animals on the reduced lysine diets. In addition, this variability between studies in the magnitude of the response in intramuscular fat to lysine-deficient diets suggests that such an approach is unlikely to be successful in targeting specific levels of marbling in practice.

The lysine level that generated the maximum response in intramuscular fat (4.8 g/kg) also produced a reduction in feed efficiency and was associated with a trend towards increased carcass fat levels. These results are in line with the many other studies that have investigated the influence of dietary lysine level on growth and carcass characteristics (Castell *et al.*, 1994; Loughmiller *et al.*, 1998) and the current study illustrates that using such an approach to increase marbling will increase production costs and is likely to reduce overall carcass value.

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Table 1. Composition of diets (as fed basis)

	Lysine level (g/kg)			
Ingredients (g/kg)	4.0	4.8	5.6	6.4
Basal diet[a]	993.65	993.65	993.65	993.65
Starch	0	1.0	2.0	3.0
L-Lysine	0	0.57	1.31	2.08
L-Tryptophan	0	0	0.12	0.26
L-Threonine	0	0	0.45	1.01
Glutamic acid	6.35	4.78	2.47	0
Analysis (g/kg)				
Crude protein[b]	100.0	102.5	99.4	99.4
Total lysine[b]	4.3	5.1	6.1	6.5
Total threonine[c]	3.9	3.9	4.3	4.9
Total tryptophen[c]	0.94	0.94	1.06	1.20
Digestible energy (MJ/kg)[c]	14.75	14.77	14.78	14.80
Calcium[c]	5.5	5.5	5.5	5.5
Phosphorus[c]	4.6	4.6	4.6	4.6

[a]Basal diet included (g/kg): maize, 885.85; soya-bean meal, 62.8; soya-bean oil, 20.6; dicalcium phosphate, 10.5; limestone, 8.2; micromineral premix, 3.6; vitamin premix, 2.1. Each kilogram of micromineral premix contained: Se, 85.7 mg; I, 100 mg; Cu, 2.3 g; Mn, 5.7g; Fe, 25.7 g; NaCl, 855g. Each kilogram of vitamin premix contained the following: vitamin A 3,300,00 IU, vitamin D_3 330,000 IU, vitamin E 44,000 IU, vitamin K 2.2g, vitamin B_{12} 27.9 mg, riboflavin 4.4 gg; d-pantothenic acid 12.2 g; choline chloride 165g and roughage products to l kg.

[b] Analyzed

[c] Calculated.

Table 2. Growth performance of pigs fed with graded levels of lysine for one, three or five weeks before slaughtering

	Lysine level g/kg					
Study period/ Trait	4.0	4.8	5.6	6.4	SEM	Significance [1]
One week:						
Weight at start, kg	106.6	105.3	108.2	116.6	1.97	NS
Weight at end, kg	112.8	111.5	114.7	119	2.44	NS
Average daily gain, g	888	873	923	1062	160	NS
Average daily feed intake, g	3.44	3.23	3.29.	3.89	0.535	NS
Average daily lysine intake, g	13.6	15.9	2.19	23.6	2.89	NS
Gain:feed	0.26	0.27	0.28	0.27	0.074	NS
Three week:						
Weight at start, kg	97.7	98.6	96.4	95.2	1.48	NS
Weight at end, kg	114.4	114.8	115.1	115.4	2.29	NS
Average daily gain, g	792	769	891	963	58	NS
Average daily feed intake, g	3.12	3.12	3.32	3.22	0.192	NS
Average daily lysine intake, g	13.3[a]	15.9[a]	19.9[b]	21.1[b]	1.13	***
Gain:feed	0.25	0.25	0.27	0.30	0.021	NS
Five week:						
Weight at start, kg	67.2	67.0	68.0	67.4	1.71	NS
Weight at end, kg	89.1[a]	96.9[b]	97.0[b]	96.7[b]	1.97	*
Average daily gain, g	625[a]	853[b]	826[b]	834[b]	29	***
Average daily feed intake, g	2.80	3.02	2.94	2.62	0.130	NS
Average daily lysine intake, g	11.9[a]	15.4[b]	18.0[b]	17.1[bc]	0.630	***
Gain:feed	0.23[a]	0.28[b]	0.28[b]	0.32[c]	0.011	***

[a, b, c,] Means within the same row with different superscripts differ ($P<0.05$). [1] NS, *, *** = not statistically significant, $P<0.05$, $P<0.001$, respectively.

Table 3. Carcass characteristics of pigs fed with graded levels of lysine for one, three or five weeks before slaughter

Study Period/Trait	Lysine level, g/kg					
	4.0	4.8	5.6	6.4	SEM	Significance[1]
One week:						
Slaughter weight, kg	109.6	108.3	111.7	115.5	2.00	NS
Hot carcass weight, kg	81.1	79.5	82.5	85.4	1.70	NS
Killing out proportions, g/kg	739	734	739	739	4.6	NS
Carcass length, cm	82.6	82.7	83.7	85.3	0.83	NS
Midline fat depths, mm						
First rib	33.4	33.9	34.3	36.8	2.36	NS
Last rib	23.3	26.0	20.7	22.6	1.98	NS
Last lumbar	20.5	23.0	20.5	24.6	1.77	NS
Tenth rib fat depth, mm	18.4[a]	17.1[a]	17.4[a]	24.1[b]	1.69	NS
Loin eye area, cm^2	37.1	35.4	36.8	34.2	1.44*	NS
Three week:						
Slaughter weight, kg	110.6	111.5	111.4	112.1	2.22	NS
Hot carcass weight, kg	82.5	82.4	82.6	83.0	1.69	NS
Killing out proportions, g/kg	747	739	741	740	3.4	NS
Carcass length, cm	84.2	83.1	81.9	84.1	0.83	NS
Midline fat depths, mm						
First rib	29.6[a]	36.4[b]	36.5[b]	35.6[b]	1.77*	NS
Last rib	22.0	21.6	21.2	19.5	1.53	NS
Last lumbar	21.2	16.1	18.2	18.2	1.44	NS
Tenth rib fat depth, mm	18.2	16.9	17.4	16.9	1.44	NS
Loin eye area, cm^2	37.3	40.3	38.7	39.2	1.56	NS
Five week:						
Slaughter weight, kg	87.1	93.3	94.5	93.6	2.49	NS
Hot carcass weight, kg	63.3	68.2	70.5	69.7	2.05	NS
Killing out proportions, g/kg	727	731	745	744	6.9	NS
Carcass length, cm	79.6	80.4	79.2	79.4	0.82	NS
Midline fat depths, mm						
First rib	33.4	36.4	34.7	32.0	1.55	NS
Last rib	18.2	18.0	21.0	17.8	1.14	NS
Last lumbar	16.1	15.9	17.4	16.0	1.23	NS
Tenth rib fat depth, mm	17.4	16.9	15.7	14.2	1.13	NS
Loin eye area, cm^2	28.0[a]	30.5[a]	34.0[b]	33.4[ab]	1.02	**

[a, b, c] Means within the same row with different superscripts differ (P<0.05).
[1] NS, *, ** = not statistically significant, P<0.05, P<0.01, respectively.

Table 4. Meat quality of longissimus from pigs fed with graded levels of lysine for one, three or five weeks before slaughter.

Study Period/Trait	Lysine level, g/kg					
	4.0	4.8	5.6	6.4	SEM	Significance[1]
One week:						
24 hour pH	5.45	5.44	5.40	5.37	0.037	NS
Drip loss, %	8.53	8.46	8.16	8.12	0.880	NS
Hunter color: L	52.39	54.49	53.19	55.03	1.382	NS
a	6.51	6.48	6.34	6.67	0.215	NS
b	16.82	16.84	16.51	17.56	0.336	NS
Subjective:						
Color	2.50	2.50	2.50	2.33	0.220	NS
Marbling	2.67	2.33	2.33	2.33	0.211	NS
Firmness	2.67	2.33	2.50	2.33	0.214	NS
Longissimus dorsi fat content, g/kg:						
Tenth rib	32.2	31.6	31.5	29.0	2.68	NS
Third/fourth lumbar	41.2	31.4	34.4	33.7	5.67	NS
Three week:						
24 hour pH	5.44	5.47	5.47	5.45	0.030	NS
Drip loss, %	6.06	5.58	7.02	6.48	1.059	NS
Hunter color: L	52.67	51.15	53.96	52.18	1.122	NS
a	7.49	7.34	7.18	7.45	0.358	NS
b	17.09	16.84	16.83	16.90	0.321	NS
Subjective:						
Color	2.82	2.83	2.33	2.67	0.190	NS
Marbling	2.33	2.50	2.00	2.17	0.175	NS
Firmness	2.67	2.50	2.33	2.50	0.217	NS
Longissimus dorsi fat content, g/kg:						
Tenth rib	30.8	28.1	28.2	30.5	2.45	NS
Third/fourth lumbar	47.3	32.1	45.0	46.9	4.53	NS
Five week:						
24 hour pH	5.46[ab]	5.51[a]	5.43[ab]	5.39[b]	0.028	*
Drip loss, %	5.43	4.37	6.04	6.79	0.805	NS
Hunter color: L	52.47	54.73	54.73	53.54	1.003	NS
a	8.43	7.82	7.88	8.49	0.295	NS
b	17.02	16.89	16.75	16.89	0.320	NS
Subjective:						
Color	2.67	2.67	2.67	2.80	0.205	NS
Marbling	2.67	2.83	2.83	2.60	0.192	NS
Firmness	2.67	3.00	2.83	2.20	0.209	NS
Longissimus dorsi fat content, g/kg:						
Tenth rib	33.4[ab]	39.7[b]	34.6[ab]	28.2[a]	2.22	**
Third/fourth lumbar	34.6[a]	50.6[b]	33.4[a]	28.3[a]	4.29	**

[a, b] Means within the same row with different superscripts differ (P<0.05).

[1] NS, *, ** = not statistically significant, P<0.05, P<0.01, respectively.

Study 3. Effect of Dietary Lysine Level and Environmental Temperature During the Finishing Phase on the Intramuscular Fat Content of Pork

Summary

This study was designed to investigate the effects of dietary lysine level on the intramuscular fat content of the longissimus in finishing pigs reared at two environmental temperatures. Seventy-two hybrid gilts were individually penned and given ad libitum access to either a diet formulated to meet their lysine requirement (6.4 g/kg lysine) or a lysine-deficient diet (4.8 g/kg). Pigs were held at one of two environmental temperatures [thermoneutral (18^{o}C) or hot (32^{o}C)]. The study was carried out between approximately 90 to 126 kg live weight with pigs in the thermoneutral and hot environments being on test for five and seven wk, respectively. There were no interactions between dietary lysine level and environmental temperature. Dietary lysine content did not influence feed intake or average daily gain; however, pigs on the lysine-deficient diet had a poorer gain:feed ratio than those fed to requirement ($P < .01$). High environmental temperature decreased feed intake ($P < .001$) and average daily gain ($P < .01$) but improved gain:feed ratio ($P < .01$). Backfat at the 10th rib was increased and loin eye area and estimated percent lean in the carcass were decreased for pigs on the lysine-deficient diet. The higher environmental temperature resulted in an increase in carcass length but had no effect on other carcass measurements or intramuscular fat. Feeding the lysine-deficient diet resulted in an increase of .55 percentage units in longissimus intramuscular fat content ($P < .01$); however, there was no difference in subjective marbling scores between the diets. Warner-Bratzler shear force values were not affected by dietary lysine level or environmental temperature. Results from this study suggest that feeding of lysine-deficient diets at the end of the finishing period can increase intramuscular fat deposition under thermoneutral and hot conditions.

Problem Addressed

The carcass lean content of pigs has increased dramatically over recent years and has resulted in a corresponding reduction in intramuscular fat. Several studies have suggested a favorable relationship between intramuscular fat and the juiciness and tenderness of pork (Hodgson et al., 1991; Castell et al., 1994), and other research has suggested that a minimum, threshold level of intramuscular fat is needed to maximize tenderness (Bejerholm and Barton-Gade, 1986; DeVol et al., 1988). One approach to increasing intramuscular fat in lean lines of pigs has been to include breeds with high marbling levels, particularly the Duroc, in crossbreeding programs (Ellis et al., 1996). Another potential approach to increasing intramuscular fat within a breed or line is via nutrition. Numerous studies have shown that intramuscular fat content is increased by feeding protein-deficient diets throughout the growing and finishing phases (Castell et al., 1994; Kerr et al., 1995). However, these studies also reported decreased feed efficiency and carcass lean content as a result of feeding protein-deficient diets. Cisneros et al. (1996) showed that the intramuscular fat content of pork can be increased by feeding lysine-deficient diets during the last five weeks of the finishing phase.

The increase in intramuscular fat from feeding lysine-deficient diets results from an increase in the amount of energy available for fat deposition. High environmental temperatures generally reduce feed and energy intake (Lopez et al., 1991; Becker et al., 1992) which could limit the response in intramuscular fat from feeding lysine-deficient diets. This study was conducted to investigate the interaction between dietary lysine level and environmental temperature in terms of the intramuscular fat content of the longissimus muscle.

Approach Used

The study was conducted as a completely randomized design in a 2 x 2 factorial arrangement, with two dietary lysine levels and two environmental temperatures. Diets were formulated based on corn and soybean meal to contain the same protein level and either 4.8 or 6.4 g/kg lysine, using the nutrient levels in feedstuffs provided by NRC (1988). The higher level was the estimated requirement for pigs of the genotype used in the study based on previous research at this center (Hahn and Baker, 1995; Hahn et al., 1995) and the lower lysine content was the level that gave the maximum response in intramuscular fat in the study of Cisneros (unpublished data). A basal diet was formulated using corn, soybean meal, soybean oil, and mineral and vitamin supplements (Table 1). The basal diet was supplemented with synthetic lysine, tryptophan, and threonine, glutamic acid, and starch to give the required lysine level at the same crude protein content (Table 1).

The study was carried out in two identical environmentally controlled buildings. Two environmental temperatures were compared, with one of the buildings maintained at thermoneutrality (18^{o}C) and the other building held at a high temperature (32^{o}C). Barn temperatures were maintained at a constant temperature throughout the study using a combination of heaters and fan ventilation in each building. Temperature and humidity were recorded constantly using pre-calibrated hygrothermographs (Oakton, Model 37250-00, Japan and Belfort Instrument Company, Baltimore, MD) placed in the central alleyway of each building at pig height (25 cm above the floor). Average recorded temperatures for the thermoneutral and hot barns were 18.3^{o}C (SE .426) and 32.7^{o}C (SE .437), respectively.

Seventy-two gilts, that were the progeny of PIC 326 sires mated to C15 dams, with an average initial weight of approximately 85 kg were allotted to treatment on the basis of live weight and litter of origin, such that full- or half-sibs were represented in each of the four treatment subclasses. Following allocation, pigs were allowed a 7-day period for acclimation before the start of the experimental period. Animals were housed in individual pens (1.5 m x 2.0 m) and had ad libitum access to feed and water from a feed hopper and nipple water drinker, respectively. The feeding period was from approximately 90 to 126 kg live weight and lasted five and seven wk for the thermoneutral and hot environments, respectively. All pigs and feeders were weighed individually each week during the feeding period. Feed was added to the feeders as required with the weight being recorded.

Animals were transported (240 km) to a commercial abattoir on the afternoon they completed the test period and were slaughtered the following morning after a period in lairage of approximately 14 h. A hot carcass weight was recorded approximately 1 h after slaughter. At 24-h postmortem, carcass measurements were collected from the left side of the carcass as follows: carcass length (cm, measured from the cranial tip of the aitch bone to the cranial edge of the first rib adjacent to the thoracic vertebra); mid-line fat depths opposite the first rib, last rib and last lumbar vertebra (mm); fat depth measured 3/4 of the distance across the longissimus muscle at the 10th rib (mm), and longissimus muscle area at the 10th rib (cm^2). Carcass lean content was estimated, based on 10th rib backfat and loin eye area, using the equation provided by NPPC (1991). Longissimus muscle color, firmness, and marbling were evaluated on the cut surface of the muscle at the 10th rib using five-point scales (1 = pale, soft and devoid of marbling to 5 = dark, firm, and moderately abundant or greater marbling, respectively; NPPC, 1991). All subjective and objective carcass scores were collected by the same trained evaluator.

The bone-in loin was removed from the left side of each carcass and transported to the Meat Science Laboratory at the University of Illinois for further evaluation. The ultimate pH of the longissimus muscle was determined at approximately 30-h postmortem. A 5-g sample was removed at the level of the last rib and homogenized in 25 ml of distilled water. Measurements were taken using an Orion model 720a pH meter fitted with a Ross Sure flow 81-72 electrode (Orion Research, Boston, MA). Objective color (L*, a*, and b*) was measured using a Hunter MiniScan XE (Hunter Associates Laboratory, Reston, VA).

Two chops (2.5 cm thick) were cut from the longissimus muscle immediately posterior to the last rib. One chop was used for Warner-Bratzler shear force determination and was vacuum packaged, aged for 7 d at 4^{o}C, and frozen (-20^{o}C) prior to analysis. Chops were thawed, weighed, and cooked to a final internal temperature of 70^{o}C on a Farberware Open Hearth grill (Model 455N, Walter Kidde, Bronx, NY). Temperatures were monitored using copper-constantan thermocouple wires (Type T, Omega Engineering, Stamford, CT) with a Barnant scanning thermocouple thermometer (Model 692-8000, Barnant Co., Barrington, IL). Chops were allowed to cool (25^{o}C) and a minimum of four 1.3 cm cores were removed parallel to the muscle fibers from each chop. Shearing was accomplished with an Instron model 1122 Universal Testing Machine (Instron, Canton, MA) fitted with a Warner-Bratzler Shear attachment. The full-scale load was set at 10 kg and the chart drive and cross head speeds were 200 mm/min. Shear force values for individual cores were averaged for each sample.

The chop for proximate analysis was trimmed of connective tissue and external fat prior to homogenizing (Shortcut Food Processor, Black and Decker, Shelton, CT). Proximate analysis procedures for fat and moisture content were conducted in duplicate on the homogenized sample using procedures described by Novakofski et al. (1989). Moisture content was determined using oven drying to a constant weight (110^{o} C for 24 to 48 h), and fat determination was carried out using extraction with an azaetropic mixture of warm chloroform and methanol (4:1).

Statistical analyses were conducted using the General Linear Models procedures of SAS (1995) with the model accounting for the effects of dietary lysine content, environmental temperature and dietary lysine x environmental temperature interaction. Means for traits where treatments were different ($P < .05$) were compared using the PDIFF option of SAS (1995).

Results and Discussion

There were no significant lysine level x environmental temperature interactions for any of the growth, carcass, or meat quality variables, suggesting that any effect of dietary lysine level was independent of environmental temperature. The effects of lysine level and environmental temperature on growth performance are presented in Table 2. Feed intake and average daily gain were not affected by dietary lysine content, however, gain:feed ratio was improved for pigs on the high-lysine diet. Similar results were found by Cisneros (unpublished data) for pigs fed diets with the same lysine levels as used in this study for a five-week period at the end of the finishing phase.

High environmental temperature decreased daily feed intake (by 860 g) and average daily gain (by 188 g), which is in agreement with numerous other studies (Becker et al., 1992; Katsumata et al., 1996; Lopez et al., 1991; Stahly et al., 1979). Gain:feed ratio was improved with the higher environmental temperature, which is in contrast with Becker et al. (1992), Lopez et al. (1991), and Stahly et al. (1979) who observed no effect of high temperatures on this trait.

The effects of dietary lysine content and environmental temperature on slaughter and carcass characteristics are presented in Table 3. The lower lysine diet increased subcutaneous fat at the 10th rib (+2.6 mm) and decreased loin eye area (-2.2 cm^2). Estimated carcass lean percentage was lower (-1.4 percentage units) for the low-lysine diet which is consistent with other studies that have fed lysine-deficient diets during the growing and finishing phases (Castell et al., 1994; Loughmiller et al., 1998). Inadequate dietary lysine limits protein synthesis and increases the amount of energy available for fat deposition. Other carcass traits and subjective color, firmness, and marbling scores were not affected by dietary lysine content (Table 3).

Environmental temperature had minimal effects on carcass measurements (Table 3) which is consistent with results reported by Becker et al. (1992), Lopez et al. (1991), and Stahly et al. (1979). High environmental temperatures resulted in a small increase in the length of the carcass. Increases in carcass length for pigs reared under hot compared to thermoneutral conditions have been reported by others (Stahly and Cromwell, 1979; Becker et al., 1992).

The effects of dietary lysine content and environmental temperature on meat quality traits are summarized in Table 4. Hunter L* values were higher for pigs reared under thermoneutral conditions, indicating paler muscle color for this treatment. However, there was no effect of environmental temperature on any of the other quality measurements (Table 4) which suggests little effect of rearing finishing pigs under hot conditions on fresh meat quality.

Environmental temperature had no affect on the intramuscular fat content of the longissimus muscle, which is in agreement with Lefaucheur et al. (1991). However, feeding lysine-deficient diets during finishing significantly increased the intramuscular fat level in the longissimus muscle which is consistent with other studies at this center (Cisneros et al., 1996). This is in contrast to the lack of an effect of dietary lysine level on subjective marbling scores reported in Table 3. However, marbling scores were numerically higher for the lysine-deficient diet. In addition, the response in intramuscular fat to dietary-lysine deficiency during finishing was lower than reported in previous studies at this center. For example, Cisneros et al. (1996) showed an increase in longissimus muscle intramuscular fat content of approximately 1.8 percentage units from feeding lysine-deficient diets (4.0 compared to 5.6 g lysine per kg diet) for three or five wk before slaughter. In addition, Cisneros (unpublished data), using the same genetic line as in the present study, showed an increase in intramuscular fat of 1.1 percentage units for pigs fed diets with 4.8 compared 6.4 g/kg lysine in the last five wk of the finishing period. The diets used in the present study were formulated to contain 4.8 and 6.4 g/kg lysine; however, analyzed values were higher at 5.7 and 6.9 g/kg lysine, respectively. The increase in intramuscular fat content from feeding the reduced lysine diet observed in the present study of .55 percentage units is similar to that shown by Cisneros (unpublished data) of .64 percentage units from feeding diets with similar lysine levels, namely 5.6 compared to 6.4 g/kg lysine, respectively. However, this response in intramuscular fat did not produce any effect on Warner-Bratzler shear force which is in contrast to the studies of Hodgson et al. (1991) and DeVol et al. (1988) that both reported higher levels of intramuscular fat resulted in a significant decrease in shear force and improvement in sensory panel scores. One possible explanation for the discrepancy in these results is that the intramuscular fat content of control animals in the present study was still above the minimum threshold value for optimum eating quality proposed by DeVol et al. (1988) of 2.5 to 3.0%. In addition, there was no statistically significant increase in subjective marbling and the increase in intramuscular fat content was relatively modest.

In summary, the use of lysine deficient diets at the end of finishing is a potential approach to increasing intramuscular fat levels in pigs. However, the lack of response in shear force suggests that this approach may be of limited utility in improving tenderness in pigs with a relatively high level of marbling. Further research is needed to investigate the potential of such an approach in leaner genotypes with inherently low levels of intramuscular fat. The lack of interaction between dietary lysine level and environmental temperature suggests that feeding lysine deficient diets in late finishing is likely to be effective in increasing marbling in pork under the hot conditions experienced in many situations during the summer.

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

	Lysine level (g/kg)	
	4.8	6.4
Ingredients, g/kg		
Basal diet[a]	993.65	993.65
Starch	.57	2.08
L-lysine	1.0	3.0
L-Tryptophan	0	.26
L-Threonine	0	1.01
Glutamic acid	4.78	0
Composition, g/kg		
Crude protein[b]	103.5	104.3
Total lysine[b]	5.7	6.9
Total threonine[c]	3.9	4.9
Calcium[c]	5.5	5.5
Phosphorus[c]	4.6	4.6
Metabolizable energy (kcal/kg)[c]	3395	3400

[a]Basal diet included (g/kg): corn, 885.85; soybean meal, 62.8; soybean oil, 20.6; dicalcium phosphate, 10.5; limestone, 8.2; micromineral premix, 3.6; vitamin premix, 2.1. Each kilogram of micromineral mix contained the following: Se, 85.7 mg; I, 100 mg; Cu, 2.3 g; Mn, 5.7 g; Fe, 25.7; Zn, 28.6; NaCl, 855 g. Each kilogram of vitamin premix contained the following: vitamin A, 3,300,000 IU; vitamin D3, 330,000 IU; vitamin E, 44,000 IU; vitamin K, 2.2 g; vitamin B_{12}, 17.9 mg; riboflavin, 4.4 mg; d-pantothenic acid, 12.2 g; choline chloride, 165 g; and roughage products to 1 kg.
[b]Analyzed
[c]Calculated

Table 2. Effects of dietary lysine level and environmental temperature during the finishing phase on growth performance.

	Lysine level, g/kg		Environmental temperature, °C		
	4.8	6.4	18	32	SEM
Start weight, kg	89.6	89.8	91.3	89.3	1.16
Slaughter weight, kg	125.4	127.2	125.1	127.5	2.10
Days on test	42	42	35	49	
Av.daily feed intake, kg	3.20	3.02	3.55^{a}	2.69^{b}	.10
Av.daily gain, kg	.853	.890	$.967^{a}$	$.779^{b}$	.04
Gain:feed	$.267^{b}$	$.295^{a}$	$.272^{b}$	$.290^{a}$	.09

SEM=standard error of the mean

[a,b] Within a row, means lacking a common superscript letter differ (P<.05).

Table 3. Effects of dietary lysine level and environmental temperature during the finishing phase on carcass characteristics.

	Lysine level, g/kg		Environmental temperature, °C		
	4.8	6.4	18	32	SEM
Hot carcass weight, kg	89.53	91.66	89.44	91.75	1.59
Dressing percentage	71.36	72.08	71.50	71.95	.37
Carcass length, cm	84.25	84.05	83.34[b]	84.94[a]	.60
lst rib fat, cm	4.32	4.17	4.29	4.17	.11
10th rib fat, cm	2.11[a]	1.85[b]	1.98	1.98	.11
Last rib fat, cm	2.39	2.26	2.36	2.29	.08
Last lumbar fat, cm	2.13	2.03	2.11	2.06	.09
Loin eye area, cm^2	36.71[b]	38.90[a]	37.68	37.94	.72
Carcass lean percentage[1]	50.77[b]	52.21[a]	51.57	51.43	.53
Color[2]	2.38	2.29	2.32	2.34	.14
Firmness[3]	2.32	2.23	2.26	2.29	.15
Marbling[4]	2.09	1.71	1.94	1.86	.19

SEM=standard error of the mean
[a,b] Within a row, means lacking a common superscript letter differ ($P<.05$).
[1] Estimated from NPPC (1991) equation.
[2] Subjective color, 1=pale to 5=dark.
[3] Subjective firmness, 1=soft to 5=dark.
[4] Subjective marbling, 1=devoid to 5=moderately abundant or greater.

Table 4. Effects of dietary lysine level and environmental temperature during the finishing phase on meat quality traits measured on the longissimus muscle.

	Lysine level, g/kg		Environmental temperature, °C		
	4.8	6.4	18	32	SEM
Ultimate pH	5.47	5.42	5.43	5.46	.02
Drip loss, %	4.66	4.96	4.47	5.15	.41
Hunter color:					
L*	55.91	55.64	56.71[a]	54.87[b]	.90
a*	6.81	7.20	6.92	7.09	.21
b*	16.44	16.75	16.76	16.43	.28
Intramuscular fat, %	3.48[a]	2.93[b]	3.25	3.15	.22
Cooking loss, %	27.92	26.67	27.82	26.76	1.02
Shear force, kg	3.24	3.42	3.23	3.43	.15

SEM = standard error of the mean
[a,b]Within a row, means lacking a common superscript letter differ (P<.05).