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The Effect of Varying Lysine Levels in Starter Diets on Pig Performance and on Subsequent Performance and Carcass Characteristics

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THE EFFECT OF VARYING LYSINE LEVELS IN STARTER DIETS ON PIG PERFORMANCE AND ON SUBSEQUENT PERFORMANCE AND CARCASS CHARACTERISTICS

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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INTRODUCTION

There are ten amino acids that are considered to be essential in diets for growing swine. If the dietary concentration of any essential amino acid is less than the amount required for maximum growth, it is said to be a limiting amino acid. Lysine is the first limiting amino acid in most cereal-based diets for swine. Thus, in cereal-based diets the lysine requirement must be met first if the pig's protein anabolism is to be efficient and maximal.

The most widely used diet in the swine industry today is the corn-soybean meal diet. Corn is deficient in lysine, but soybean meal is a relatively good source of lysine, so soybean meal is added to the corn base to increase the diet's lysine content. Synthetic lysine (L-lysine monohydrochloride) also can be added to corn-soybean meal diets to increase lysine content or added as a replacement for part of the soybean meal. However, the dietary protein level should be reduced a maximum of only 2% or other amino acids may become limiting.

Recent research has indicated that the lysine level recommended by the National Research Council (NRC) may be inadequate for maximum growth and feed efficiency for 10- to 20-kg pigs. This is in agreement with European estimates of the lysine requirement for starter pigs. In fact, many commercial starter diets contain lysine levels closer to European recommendations than that level recommended by the NRC. However, little research has been conducted to determine if the higher lysine levels responsible for improved performance in the starter period are beneficial to performance for the entire growth period (8 to 100 kg) or if higher levels of lysine in starter diets affect carcass characteristics of finished pigs. Therefore, it is important to determine if increasing the lysine content of starter diets is economically beneficial when raising pigs from approximately 8 to 100 kg.

The ultimate objective of this study was to determine the optimum lysine level in swine starter diets (8 to 20 kg) which would result in maximum performance from 8 to 100 kg without adversely affecting carcass characteristics. The parameters used were as follows:

(1) Pig performance as measured by average daily gain, average daily feed intake and feed efficiency during the starter (8 to 20 kg), grower (20 to 35 kg and 20 to 55 kg), finishing (35 to 100 and 55 to 93 kg) and overall (8 to approximately 100 kg) periods.

(2) Quantitative carcass characteristics at 100 kg including carcass length, average backfat, longissimus muscle area and percent muscle.

REVIEW OF LITERATURE

Lysine in Nutrition

In 1914, lysine was first shown to be an essential amino acid for young white rats by Osborne and Mendel. In the first of two studies, gliadin was the sole protein source in the gliadin and gliadin plus lysine (.54%) experimental diets. Zein and edestrin were the protein sources for the basal and lysine supplemented (.54%) basal diets in the second study. Results from both studies were similar. Rats receiving unsupplemented diets only maintained their starting weight, while rats fed lysine supplemented diets exhibited normal growth.

Lysine was proven to be essential for chicks by Almquist and Mecchi (1942). Using diets composed of zein, edestrin and casein, they observed that chicks exhibited the best growth rate when receiving no less than .90% L-lysine in their diet. Other species that have been shown to require lysine are the adult dog (Rose and Rice, 1939), young mouse (Bauer and Berg, 1943) and adult young man (Rose, 1947).

Mertz and others (1949) first proved that lysine was an essential amino acid for weanling pigs. With zein as the sole protein source, these workers formulated a control diet containing 23.5% protein and .029% lysine. Pigs consuming the control diets for 28 d not only ceased to grow but also exhibited rough hair coats, emaciated appearances and apparent inanition. Pigs fed the control diet plus 2% DL-lysine monohydrochloride exhibited both normal growth and appearance. Pigs originally fed the control diet resumed normal growth and deficiency symptoms were alleviated when they were fed lysine supplemented diets.

Lysine Requirement for Starter Pigs

The National Research Council (NRC, 1979) estimated the lysine requirement of 10- to 20-kg pigs to be .79% and protein and metabolizable energy requirements to be 18% and 3,160 kcal, respectively. The lysine level necessary for optimum performance is not constant, however, since lysine requirements are affected by several factors.

In 1948, Grau stated "... the lysine requirement expressed as a percentage of the diet should be qualified in terms of the level of dietary protein." Hutchinson et al. (1956) indicated that dietary lysine requirement was dependent upon dietary protein level.

Brinegar et al. (1950) conducted a study to determine the lysine requirements of weanling pigs at two protein levels. Various levels of L-lysine-HCl were added to the 10.6% protein linseed meal and 22.0% protein sesame meal diets. After a 4-wk trial, the minimum levels of lysine which supported maximum gain and efficiency were .60% and 1.20% for the 10.6% and 22.0% protein diets, respectively. The difference between lysine levels was largely eliminated when the requirements were expressed as a percentage of the dietary protein, 5.7% in the 10.6% protein diet and 5.5% in the 22.0% protein diet.

In 1958, Chance and others studied the protein effect on lysine requirement for weanling pigs. Three levels of protein (10%, 15% and 20%) and lysine (.5%, .7% and .9%) were used in two trials. Treatment differences were only observed in trial 2. The lysine requirement for pigs fed 10 and 15% protein diets appeared to be .7% and increased to .9% for 20% protein diets. McWard et al. (1959) noted similar results feeding sesame seed meal diets to 13.6-kg pigs for 28 d. Six lysine additions in .1% increments were added to 12.8 and 21.7% protein basal diets. At the lowest lysine levels, .33 and .57% for the 12.8 and 21.7% protein diets, respectively, pigs exhibited anorexia, rough hair coat, depressed growth and poor efficiency. Pigs consuming higher levels of lysine were devoid of deficiency symptoms and performance improved as lysine levels increased. Optimum performance was achieved when the 12.8% protein diet contained .71% lysine and the 21.7% protein diet contained .95% lysine. McWard et al. (1959) also suggested that lysine need, when expressed as a percentage of protein, could be determined using the formula $Y = 7.23 - .131X$, where Y is the lysine need and X is the percentage dietary protein.

Baker et al. (1975) conducted a 2 x 6 factorial experiment to determine the lysine requirement of 18-kg pigs at two protein levels. Basal corn-sesame meal diets containing 16 and 12% protein were increased in lysine content from .43 to .91% (.08% increments) by additions of synthetic lysine. Lysine levels required for maximum gains were determined to be .77 and .69% for the 16 and 12% protein diets, respectively.

The aforementioned authors proposed that lysine requirement decreases as protein level decreases. This is in agreement with other work done by Klay (1964) and Lunchick et al. (1978). McWard et al. (1959) suggested a .027% decrease in lysine for every 1% decrease in protein, while Baker et al. (1975) proposed decreasing the lysine level .02% for every 1% decrease in protein. Lunchick et al. (1978) observed similar performance for .02 and .04% lysine reductions per each 1% decrease in protein.

The decrease in lysine requirement at lower protein levels can be explained by two factors. First, more lysine is provided by synthetic lysine in low protein diets than in high protein diets. Since synthetic lysine is much more available than lysine supplied by grain sources, a lesser amount of dietary lysine is needed in low protein diets to provide an equivalent amount of available lysine (Gupta et al., 1957; Netke and Scott, 1970; Klein et al., 1972). Secondly, some researchers have found feed consumption increased as protein level decreased (Klay, 1964; Katz et al., 1973; Baker et al., 1975). Therefore, even though dietary lysine level was lower, absolute daily lysine intake remained unchanged. However, other researchers (Whitelaw et al., 1966; Lunchick et al., 1978; Wyllie and Owen, 1978) observed that protein levels did not affect feed intake.

Catron et al. (1953) showed synthetic lysine can be used to replace part of the soybean meal in swine diets. Although Baker et al. (1975) suggested a maximum 2% lowering of the protein level when replacing soybean meal with synthetic lysine and corn, Wahlstrom and Libal (1974) observed no difference in performance between pigs consuming a 17% protein, corn-soybean meal diet or a lysine-supplemented, 14% protein corn-soybean meal diet. Depending on economics, low protein diets supplemented with L-lysine monohydrochloride can be used to replace higher protein diets.

In 1965, Meade and others studied lysine supplementation of low protein diets. Three-week-old pigs were fed corn-soybean meal diets containing either 16% protein, 16% protein plus .2% L-lysine and .05%

DL-methionine or 18% protein. Lysine and methionine supplementation had no effect on daily gain, but feed efficiency was improved. Also, lysine and methionine additions improved feed efficiency equal to that of the 18% protein diet. Orr et al. (1976) observed similar results feeding 4-wk-old pigs sorghum grain-soybean meal diets. Gains of pigs consuming 16% protein diets supplemented with either .1 or .2% lysine were as rapid and efficient as those of pigs consuming 18% protein diets.

Campbell (1978) conducted a study to determine the response of weanling pigs receiving suboptimal protein diets to supplemental lysine. Wheat-soybean meal diets used were a 20% protein control, a 14.6% protein basal plus lysine additions to provide .54, .72, .90 and 1.08% total lysine and a 16.6% protein basal plus lysine additions providing .72, .90, 1.08 and 1.26% total dietary lysine. In the 5.5- to 20-kg growth period, pigs consuming diets containing 1.08% lysine at either suboptimal protein level had gains and efficiencies similar to pigs receiving the 20% protein diet.

Using corn-soybean meal diets, Katz et al. (1973) found that pigs fed 16% protein diets containing levels of lysine and methionine equivalent to a 19% protein diet performed superior to pigs fed an unsupplemented 16% protein diet. Also, pigs fed amino acid-supplemented, 16% protein diets exhibited gains similar to pigs fed 19% protein diets. Pelura et al. (1980) and Yen and Veum (1982) found no difference in performance between pigs consuming either an 18% protein, corn-soybean meal diet or a lysine-supplemented, 15% protein corn-soybean meal diet.

Protein levels of 20, 18, 16 and 14% were used in a study conducted by Lunchick et al. (1978) to determine the effect of varying lysine levels at different protein levels on the performance of 9.2-kg pigs. Dietary protein was provided by corn and soybean meal. Positive control diets contained 20% protein and 1.08% lysine. Lysine was added to 18, 16 and 14% protein diets to provide dietary lysine levels equal to that of the 20% protein diet minus .02 and .04% lysine per each 1% decrease in protein level. No difference in pig performance was observed between .02 and .04% reductions in lysine level. However, pigs fed 14% protein diets gained slower and less efficiently than pigs consuming higher protein diets. There was no difference in performance between pigs fed 16, 18 or 20% protein diets, but performance was maximized with 16% protein diets containing .92% lysine. In 1973, Allee and others fed four iso-lysine, milo-soybean meal diets containing 12, 14, 16 or 18% protein to 9.7-kg pigs. Pigs fed 12 or 14% protein diets gained slower and were less efficient than pigs consuming 18% protein diets. Gain and efficiency were similar for pigs consuming either 16 or 18% protein diets.

Long et al. (1962) fed corn-soybean meal diets containing .93 and 1.86% lysine at methionine levels of either .32 or .68% to 4.2-kg pigs. Daily gain and feed consumption were reduced at the higher lysine level but improved with methionine addition. This can be explained if 1.86% lysine was in excess of the requirement of the young pig and then methionine became the first limiting amino acid at the higher lysine level. Kornegay (1972) found that, whereas lysine additions of .12 and

.25% to 18.0, 16.4 and 14.5% protein corn-soybean meal diets were beneficial, addition of .4% lysine at any protein level did not improve performance over that of unsupplemented diets. Similarly, in work done by Allee et al. (1973) and Kornegay (1972), lysine additions to high protein diets were not beneficial to performance. This could be due to an amino acid imbalance.

Cole et al. (1967) observed that pigs eat to fulfill their energy needs. It could then be assumed pigs consuming high energy diets would eat less feed daily and would therefore require higher dietary protein levels in order to meet their daily protein needs. However, research results involving calorie:protein and calorie:lysine interrelationships have been inconsistent.

In 1957, Peo and others studied the fat-protein interrelationship in baby pig diets using a 4 x 4 factorial design. Protein levels and fat additions used were 15, 20, 25 and 30% and 0, 2.5, 5 and 10%, respectively. Pigs fed 20% protein diets produced maximum gains and efficiencies. However, there was no protein x fat interaction and fat addition had no effect on gain or efficiency. Lack of a protein x fat interaction was in agreement with work done by Kennington et al. (1958).

Lewis et al. (1981) conducted an experiment to determine the lysine requirement for 5-kg pigs fed diets with and without fat. Fat levels used were 0 and 5% and dietary lysine levels were .95, 1.05, 1.15, 1.25, 1.35 and 1.45%. Pigs fed fat-supplemented diets consumed less feed and were more efficient than pigs fed unsupplemented diets. Lysine additions up to 1.25% resulted in improvements in gain and efficiency.

However, no fat x lysine interaction was found, and there was no indication that fat additions increased lysine requirement. In a similar study, Tribble et al. (1979) added .05 and .10% lysine to sorghum-soybean meal diets containing either 4 or 8% fat. From 28.6 to 101 kg, pig performance was not affected by the calorie:lysine ratio.

Using diets containing 2,926, 3,267 and 3,718 kcal metabolizable energy per kg at six different lysine levels ranging from .54 to 1.14%, Mitchell et al. (1965b) found no energy x lysine interaction on rate of gain but did find an interaction for feed efficiency. From these data, they suggested increasing dietary lysine levels as energy levels were increased.

Anderson and Bowland (1967) investigated the fat-lysine interrelationship in weanling pig diets. Four lysine additions in .2% increments were added to a 14.2% protein basal diet along with fat additions of 0 and 5%. Lysine level appeared to be related to energy content of the diet. Calorie:lysine ratios of 4,000 and 3,500 kcal digestible energy per kg per unit percentage lysine were shown to be necessary for maximum efficiency and gain, respectively. Mitchell et al. (1965b) calculated the lysine requirement to be .23% per 1,000 kcal metabolizable energy and recommended lysine levels of .80 and .98% in diets containing 2,926 and 3,718 kcal per kg, respectively, in order to achieve maximum efficiency.

Lewis et al. (1981) attempted to explain why the calorie x lysine interaction was sometimes absent. Reasons cited were (1) changes in carcass composition may have masked changes in requirements,

(2) parameters used were not sensitive enough to detect changes in lysine requirement and (3) additional fat may have promoted more efficient utilization of lysine.

Lysine Effect on Carcass Characteristics

The ultimate objective of swine production is to produce pork profitably. Dietary lysine has been reported to affect not only rate and efficiency of swine growth but also certain characteristics of the carcass. With packer and consumer emphasis on lean pork, it is economically important that the effect of lysine on carcass characteristics be determined.

Vipperman et al. (1963) studied lysine effect on carcass characteristics of swine. They fed 14.5-kg pigs 16% protein corn-peanut oil meal diets with lysine additions of 0, .3, .6, .9 and 1.2%. Reductions in protein level to 14 and 12% were made at pig weights of 34 and 57 kg, respectively, along with corresponding decreases in dietary lysine levels. Pigs were slaughtered at 84 kg and carcass data obtained. Longissimus muscle area and total lean yield increased when feeding supplemental lysine. The addition of .6% lysine appeared to result in optimum response. Also, chemical analysis of the longissimus muscle showed increases in total protein, moisture and ash with increasing lysine levels and a decrease in intramuscular fat as protein content increased. Cahilly and others (1963) conducted a similar study feeding corn-peanut oil meal diets to 13.6-kg pigs. Identical protein and lysine levels were used with reductions in both made at similar weights. Lean cut yield, longissimus muscle area and carcass backfat thickness increased with lysine supplementations up to .6%, but total fat was unaffected. Protein content of the longissimus muscle was increased, while moisture decreased with lysine additions.

Easter and Baker (1980) examined lysine effect on carcass characteristics at two protein levels. Positive and negative corn-soybean meal diets contained 16, 13 and 12% protein and 14, 11.5 and 11% protein, respectively, with protein changes made at pig weights of 47.2 and 78.4 kg. Lysine was added to the negative control diets to equal total lysine in the high protein diets and in an amount to equal the positive control diets minus .02% lysine for every 1% decrease in protein. Pigs were slaughtered at approximately 93 kg and carcass measurements taken. Cross-sectional area of the longissimus muscle and percent four lean cuts tended to increase as dietary lysine levels increased. Increased longissimus muscle area due to the addition of .4% lysine to a 10% corn-soybean meal diet was observed by Clawson et al. (1963). Jurgens et al. (1967) fed 12 or 16% protein milo-soybean diets to 57-kg pigs to study lysine's effect on carcass characteristics. A lysine addition of .1% was added to both protein levels and carcass data were obtained at 95 kg. Pigs consuming lysine-supplemented diets produced carcasses with lower dressing percentages and larger ham and loin percentages than pigs consuming the basal diets. Baird and McCampbell (1962) found supplementing 12% protein corn-soybean meal diets with .1% lysine tended to result in increased carcass leanness.

Williams et al. (1984) studied lysine requirements for growing-finishing boars and barrows. Carcasses from boars fed lysine-supplemented diets had less backfat and larger longissimus muscle area and ham-loin and lean cut percentages than pigs fed unsupplemented diets. However, only longissimus muscle area increased in barrow carcasses when supplemental lysine was previously fed.

In 1974, Wahlstrom and Libal fed 17 and 14% protein corn-soybean meal diets to pigs to 50 kg and 14 and 11% protein diets to a slaughter weight of 95 kg. Two levels of supplemental lysine (.1 and .2%) and methionine (.2 and .4%) were added to low protein diets. No differences were detected in carcass length, backfat thickness or longissimus muscle area due to lysine supplementation. They recommended, however, that pigs from 13.5 and 17.5 kg to 50 kg require .53% lysine for optimum efficiency and carcass leanness. Brown et al. (1973b) suggested that, for optimum percent protein and ether extract in the longissimus muscle, lysine levels of .60 ± .05% and .55 ± .03% should be used. Also, they recommended .51 ± .03% dietary lysine to obtain optimum percentage of the four lean cuts in swine carcasses.

In 1963, Aldinger and Roberts fed 45-kg pigs corn-soybean meal diets containing 11% protein to test lysine's effect on carcass quality. No differences were detected in backfat thickness, grade, percent lean cuts or carcass length due to .05% lysine supplementation. Lysine addition of .15% to a 15% protein corn-soybean meal diet did not affect backfat thickness, cross-sectional area of the longissimus muscle or percentage of the four lean cuts in a study conducted by Meade et al. (1966a).

Dukelow et al. (1963) fed pigs isolysinic corn-soybean meal diets containing 12, 14 or 16% protein. No differences in carcass characteristics due to protein effect were observed. Meade et al. (1966b) reported that lysine supplementation to 12, 14 and 16% protein corn-soybean meal diets did not affect backfat thickness, cross-sectional area of the longissimus muscle or yield of trimmed ham and loin. Similar observations were made by Blair and others (1969).

Compensatory Performance

Compensatory performance, the ability to overcome the effects of a previously restricted diet when fed a nutritionally adequate diet, has been reported to affect pigs in several ways that might be beneficial to the producer. First, if there is no adverse effect on overall rate and efficiency of growth, starter pigs could be fed lower protein diets which would decrease feed costs. Secondly, a more consumer-acceptable product would be produced if protein or lysine restrictions in the starter period were responsible for leaner carcasses at market weight. It is therefore economically important to determine if pigs can compensate for previous nutritional restrictions.

Whitelaw et al. (1966) fed 210 pigs isolysinic diets containing either 14, 18 or 22% protein from day 21 to day 56. From day 56 to slaughter at 90 kg, all pigs received the same diet. In the starter period, no significant differences in daily gain or efficiency were found. Also, overall performance and carcass characteristics were unaffected by protein treatments. Like results were observed by Wyllie and others (1978). From 7 to 27 kg, pigs were fed 14 or 28% protein diets and then treated identically from 27 to 113 kg. Pigs from each treatment were slaughtered at individual weights of 27, 54, 82 and 113 kg. Performance of pigs from 7 to 27 kg and 27 to 113 kg was not different between treatments. At 27 kg, carcasses from pigs fed 14% protein diets were fatter and contained less lean tissue than pigs consuming 28% protein diets. However, by the time they reached 54 kg, pigs initially fed 14% protein diets compensated and had leaner carcasses than pigs fed 28% protein diets. Pigs fed the low protein diet in the starter period also had leaner carcasses at 82 and 113 kg.

Protein levels of 10, 17, 24 and 31% were fed to pigs from 4.8 to 24 kg by Wyllie and others (1969). All pigs received corn-soybean meal diets containing 16% protein from 24 to 57 kg and 12% protein from 57 to 92 kg. In the starter period, maximum gains resulted from 17% protein diets and efficiency was optimal for 24% protein diets. From 24 to 57 kg, no differences in performance were observed, but feed per unit of gain increased linearly ($P<.01$) with increasing starter protein level from 57 to 92 kg. For the overall period, starter protein levels of 10 and 24% resulted in optimal efficiency and gain. There were no significant differences in carcass characteristics among treatments at 92 kg, but pigs on the low protein regime tended to produce leaner carcasses.

Tjong-A-Hung et al. (1972) fed corn-soybean meal diets containing 16, 20 and 24% protein to pigs from 5.4 to 23.1 kg. Pigs fed 16 or 20% protein diets gained less than pigs fed 24% protein diets and pigs consuming 16% protein diets were less efficient than pigs fed either 20 or 24% protein diets. However, by the time pigs reached slaughter weight (94.1 kg), no differences due to dietary protein level in the starter period were observed for gain, efficiency or carcass leanness. Campbell and Biden (1978) fed 5.5-kg pigs diets containing either 164, 192 or 219 g protein/kg feed to weights of 20 kg. From 20 to 70 kg, pigs were treated alike. In the starter period, pigs fed diets containing 164 g protein/kg feed gained slower and were less efficient than pigs fed higher protein diets. However, from 20 to 45 kg, compensation occurred and by the time pigs reached 70 kg there were no differences in overall performance or carcass quality. These two studies support the statement by Shields and Mahan (1980) that temporary moderate protein restrictions can be placed on pig diets without adversely affecting overall gain and carcass quality.

Gjefsen et al. (1980) studied the effects of different protein levels fed to early weaned pigs. Pigs weaned at 3 wk of age were fed diets containing 15, 20 or 24% protein. From 22 kg to slaughter at 100 kg, pigs were treated alike. In the starter period, daily gains were reduced when feeding the low protein diets, but no differences in performance or carcass characteristics were found for the overall period. Gilster and Wahlstrom (1973) observed that, whereas performance of starter pigs was depressed by feeding low protein diets, the depression was eliminated when pigs were fed adequate protein levels from 45 to 113 kg. Libal and Wahlstrom (1976) fed pigs corn-soybean meal diets containing 12 and 16% protein from 26 to 52 kg. From 52 to 78 kg, pigs were fed 12, 14 or 16% protein diets and 12% protein diets from 78 to 104 kg. In the initial period, rate and efficiency of gain were superior for pigs fed 16% protein diets. When pigs initially fed low protein diets were fed 16% protein diets from 52 to 78 kg, gain and efficiency were optimal. No difference in performance was observed between 78 and 104 kg.

Pierce and Bowland (1972) fed 5-wk-old pigs 20, 17 or 14% protein diets for 6 wk. From 6 wk to market weight, all pigs were treated alike. Inferior performance was exhibited by pigs consuming 14% protein diets for the first 6 wk. For the overall period, however, performance was not affected by starter protein level. No differences in carcass quality were noted except pigs fed the low protein treatment had smaller longissimus muscle areas in one trial. Zimmerman and Khajarern (1973) fed dietary protein levels of 10 and 24% to pigs from 5 to 23 kg. From 23 to 57 kg, pigs received 16% protein diets and 12% protein diets from 57 to 90 kg. Pigs were slaughtered at 23 and 90 kg. In the starter period, pigs fed high protein diets performed better and their carcasses contained more water and protein but less ether extract. No differences in carcass characteristics were found at 90 kg, but 24% protein diets improved gains, while 10% protein diets improved efficiency for the overall period.

Wahlstrom and Libal (1983) studied compensatory effect on growing pigs. Corn-soybean meal diets containing 12, 14 or 16% protein were fed. During the protein-restricted period, gain and efficiency were decreased for low protein diets. Overall performance of pigs fed 14 and 16% protein diets was similar when pigs had an initial weight of 25 kg or more. Lighter pigs did not fully compensate as was the case for pigs fed 12% protein diets.

Pond et al. (1980) studied compensatory response on genetically obese and lean pigs. Four-wk-old pigs were fed either 12 or 18% protein diets for 8 wk and then 18% protein diets to slaughter. Daily gains for the initial and overall periods were higher for pigs consuming 18% protein diets. Obese pigs were less affected than lean pigs and repletion on a high protein diet was not associated with compensatory growth in lean pigs. Hogberg and Zimmerman (1978) conducted a comparable study with strains of fat and lean hogs. Fat-strain hogs made either partial or complete compensation for performance and carcass quality by 100 kg, but lean-strain pigs did not compensate for gain after protein restriction and had smaller cross-sectional areas of longissimus muscle.

Kropf et al. (1959) studied protein level and quality on performance and carcass quality. They found 16 and 12% protein diets supported good gains from weaning to 91 kg as long as each diet contained some high quality protein. Dressing percent and gain were lowest for pigs consuming 16% poor quality protein diets. From this study, it could be inferred that amino acid make-up of the protein is also an important factor in compensatory performance.

MATERIALS AND METHODS

Three experiments involving a total of 272 crossbred weanling pigs were conducted to determine the effects of varying lysine levels in starter diets on pig performance and carcass characteristics. A randomized complete block design was used and two barrows and two gilts were allotted to each pen based on weight and ancestry. From average weaning weights of 7.8 to pen average weights of 20 kg, pigs were fed experimental diets in an environmentally controlled nursery at the South Dakota State University Animal Science Complex. Experimental diets were identical in each respective experiment except for lysine content and met or exceeded NRC (1979) recommendations for all other nutrients (see appendix table 1 for calculated and chemical analyses of starter diets). Supplemental lysine was provided by L-lysine monohydrochloride at the expense of corn. Flooring types used were either rubber-coated, expanded metal or plastic slats. Temperature was initially maintained at 26.7 C and then gradually decreased to 23.3 C as the experiments progressed. Feed and water were offered ad libitum and pig weights, feed additions and feed wastage were recorded weekly.

From 20 kg to the termination of each experiment, pigs were housed in a confinement barn in pens with concrete slatted floors at the South Dakota State University swine research unit. Pen allotment was the same as in the nursery. All pigs received identical diets and water ad libitum. Pig weights and feed intake were recorded every 2 wk. At the termination point in experiments 1 and 3, pigs were slaughtered at the South Dakota State University abattoir and carcass data obtained.

Throughout the three experiments, 16 pigs either died or were removed due to abnormally poor performance. Gains (ADG) were calculated from the last normal weigh day and average daily feed intakes (ADF) and feed efficiencies (F/G) were adjusted based upon maintenance requirement for each pig.

Data were analyzed using a least-squares procedure (SAS, 1979). Variance was divided into linear, quadratic and cubic components. When a treatment effect was found ($P < .05$ or less), a Waller-Duncan K-ratio t test was used to find which treatment means were dissimilar (Steel and Torrie, 1980). Since replicates were random, replication x treatment mean squares were the denominator in F-tests for all individual parameters except carcass characteristics in experiment 3. Residual mean squares were used as the denominator for carcass data in experiment 3 because replicate 6 had no individual in treatment 1. Residual mean squares were used as the denominator when testing treatment effects of feed intake and efficiency. Analysis of variance for all variables in experiments 1, 2 and 3 are presented in appendix tables 2 through 12.

Experiment 1

Ninety-six pigs averaging 7.9 kg were allotted to 24 pens. Each of the six replications had four pigs per treatment. Pigs were fed corn-soybean meal-oat groats diets calculated to contain .75, .85, .95 and 1.05% lysine to a pen average weight of 20 kg. Composition of the basal diet is shown in table 1.

TABLE 1. COMPOSITION OF DIETS (EXPERIMENT 1)

Ingredient	Starter[a] (7.9 to 20 kg)	Grower (20 to 35 kg)	Finishing (35 to 100 kg)
Corn	50.22	80.18	84.10
Oat groats	20.0	--	--
Soybean meal, 44%	14.2	17.0	13.5
Dried whey	10.0	--	--
Yellow grease	2.0	--	--
Dicalcium phosphate	2.2	1.6	1.3
Ground limestone	.65	.70	.70
Trace mineral mix[b]	.05	.05	.05
White salt	.30	.30	.30
Vitamin mix	.03[c]	.03[d]	.03[d]
ASP 250[e]	.25	--	--
Banminth[f]	.10	.10	--
Aureo-50[g]	--	.04	.02

[a] L-lysine monohydrochloride replaced corn to supply diets containing .85, .95 and 1.05% lysine.

[b] Supplied the following in ppm: zinc, 100; iron, 75; manganese, 25; copper, 7.5; iodine, .175; and selenium, .10.

[c] Supplied the following per kg diet: vitamin A, 4,400 IU; vitamin D, 440 IU; niacin, 26.4 mg; pantothenic acid, 19.8 mg; vitamin B_{12}, 19.8 mcg; vitamin E, 16.5 IU; riboflavin, 4.95 mg; and vitamin K, 3.3 mg.

[d] Supplied the following per kg of diet: vitamin A, 3,300 IU; vitamin D, 330 IU; niacin, 17.6 mg; pantothenic acid, 13.2 mg; vitamin B_{12}, 13.2 mcg; vitamin E, 11 IU; riboflavin, 3.3 mg; and vitamin K, 2.2 mg.

[e] Supplied the following per kg of diet: aureomycin, 110 mg; sulfamethazine, 110 mg; and penicillin, 55 mg.

[f] Supplied 106 mg pyrantel tartrate per kg of diet.

[g] Supplied 44 and 22 mg aureomycin per kg of diet in growing and finishing periods, respectively.

From pen average weights of 20 to 35 kg and 35 to 100 kg, all pigs were fed corn-soybean meal diets containing .70 and .61% lysine, respectively. Dietary composition is shown in table 1.

At individual weights of approximately 100 kg, 44 barrows were removed from feed and water for 18 h and slaughtered. Carcass weights were obtained prior to moving the carcasses into the blast cooler. Carcasses were chilled for a minimum of 20 h at 0 to 1.1 C prior to obtaining carcass measurements. Backfat thickness and carcass length were average measurements taken from both sides of the carcass, while 10th rib fat and longissimus muscle area were obtained from the right side only. Since carcasses were skinned, .25 cm was added to each backfat measurement. Carcass measurements and percent lean were obtained by following the procedures outlined by the National Pork Producers Council (1983). A compensating polar planimeter was used to determine area of the longissimus muscle traced on acetate paper.

Experiment 2

Eighty weanling pigs weighing 7.9 kg were allotted to five replications each containing four treatments. Treatments used were corn-soybean meal diets containing either .8, .9, 1.0 or 1.1% lysine. Composition of the basal diet is shown in table 2. When pigs reached a pen average weight of 20 kg, they were fed identical corn-soybean meal diets containing .70% lysine until individual pen weights averaged 35 kg. Dietary composition is shown in table 2. Experiment 2 was terminated at pen average weights of 35 kg due to an outbreak of

TABLE 2. COMPOSITION OF DIETS (EXPERIMENT 2)

Ingredient	Starter[a] (7.9 to 20 kg)	Grower (20 to 35 kg)
Corn	65.71	80.18
Soybean meal, 44%	18.71	17.00
Dried whey	10.00	--
Yellow grease	2.00	--
Dicalcium phosphate	2.20	1.60
Ground limestone	.65	.70
Trace mineral mix[b]	.05	.05
White salt	.30	.30
Vitamin mix	.03[c]	.03[d]
ASP 250[e]	.25	--
Banminth[f]	.10	.10
Aureo-50[g]	--	.04

[a] L-lysine monohydrochloride replaced corn to supply diets containing .9, 1.0 and 1.1% lysine.

[b] Supplied the following in ppm: zinc, 100; iron, 75; manganese, 25; copper, 7.5; iodine, .175; and selenium, .10.

[c] Supplied the following per kg of diet: vitamin A, 4,400 IU; vitamin D, 440 IU; niacin, 26.4 mg; pantothenic acid, 1.98 mg; vitamin B_{12}, 19.8 mcg; vitamin E, 16.5 IU; riboflavin, 4.95 mg; and vitamin K, 3.3 mg.

[d] Supplied the following per kg of diet: vitamin A, 3,300 IU; vitamin D, 330 IU; niacin, 17.6 mg; pantothenic acid, 13.2 mg; vitamin B_{12}, 13.2 mcg; vitamin E, 11 IU; riboflavin, 3.3 mg; and vitamin K, 2.2 mg.

[e] Supplied the following per kg of diet: aureomycin, 110 mg; sulfamethazine, 110 mg; and penicillin, 55 mg.

[f] Supplied 106 mg pyrantel tartrate per kg of diet.

[g] Supplied 44 mg aureomycin per kg of diet.

Haemophilus pleuropneumoniae. The outbreak occurred when pigs weighed approximately 75 kg so data up to 35 kg were unaffected.

Experiment 3

Ninety-six weanling pigs averaging 7.6 kg were allotted to one of four dietary lysine treatments. There were six replications of each treatment and 24 pigs per replication. Lysine levels of the experimental corn-soybean meal diets were .8, .95, 1.10 and 1.25%. Composition of the basal diet is shown in table 3. Diets were changed at average pen weights of 20 and 55 kg and lysine content reduced to .70 and .61%, respectively. Table 3 shows dietary compositions. At individual weights of 93 kg, 13 barrows and(or) gilts from each treatment were slaughtered. Procedures for obtaining carcass data were as specified for experiment 1.

TABLE 3. COMPOSITION OF DIETS (EXPERIMENT 3)

Ingredient	Starter[a] (7.6 to 20 kg)	Grower (20 to 55 kg)	Finishing (55 to 93 kg)
Corn	65.71	78.28	83.60
Soybean meal, 44%	18.71	19.00	14.00
Dried whey	10.00	--	--
Yellow grease	2.00	--	--
Dicalcium phosphate	2.20	1.50	1.30
Ground limestone	.65	.70	.70
Trace mineral mix[b]	.05	.05	.05
White sale	.30	.30	.30
Vitamin mix	.03[c]	.03[d]	.03[d]
ASP 250[e]	.25	--	--
Banminth[f]	.10	.10	--
Aureo-50[g]	—	.04	.02

[a] L-lysine monohydrochloride replaced corn to supply diets containing .95, 1.10 and 1.25% lysine.

[b] Supplied the following in ppm: zinc, 100; iron, 75; manganese, 25; copper, 7.5; iodine, .175; and selenium, .10.

[c] Supplied the following per kg of diet: vitamin A, 4,400 IU; vitamin D, 440 IU; niacin, 26.4 mg; pantothenic acid, 19.8 mg; vitamin B_{12}, 19.8 mcg; vitamin E, 16.5 IU; riboflavin, 4.95 mg; and vitamin K, 3.3 mg.

[d] Supplied the following per kg of diet: vitamin A, 3,300 IU; vitamin D, 330 IU; niacin, 17.6 mg; pantothenic acid, 13.2 mg; vitamin B_{12}, 13.2 mcg; vitamin E, 11 IU; riboflavin, 3.3 mg; and vitamin K, 2.2 mg.

[e] Supplied the following per kg of diet: aureomycin, 110 mg; sulfamethazine, 110 mg; and penicillin, 55 mg.

[f] Supplied 106 mg pyrantel tartrate per kg of diet.

[g] Supplied 44 and 22 mg aureomycin per kg of diet in growing and finishing periods, respectively.

RESULTS

Experiment 1

Performance data of pigs fed starter diets containing .75, .85, .95 and 1.05% lysine are presented in table 4. From pen average weights of 7.9 to 20 kg, daily gains increased linearly ($P<.01$) with increasing levels of lysine. Feed intake was not affected by dietary lysine level during this period. Feed efficiency improved linearly ($P<.01$) from 2.20 for pigs fed diets containing .75% lysine to 1.86 when pigs were fed diets containing 1.05% lysine.

During the period from 20 to 35 kg, pig performance was not significantly different due to starter lysine level, but sex did affect average daily gain ($P<.06$). Gains for barrows and gilts were .60 and .53 kg, respectively.

Although rate of gain did not differ among treatments during the 20- to 35-kg period, gains did differ ($P<.05$) for the combined weight period of 7.9 to 35 kg. Daily gains were .43, .45, .47 and .47 kg for pigs fed starter diets containing .75, .85, .95 and 1.05% lysine, respectively. Feed intake and conversion were not statistically different for the period from 7.9 to 35 kg, but feed conversion tended to be more efficient ($P<.25$) for pigs which had consumed starter diets containing .95 and 1.05% lysine.

Lysine levels in the starter diets did not affect daily gain or feed intake from 35 to 100 kg or 20 to 100 kg. Feed conversion, however, tended to be most efficient in both periods for pigs fed starter diets containing .75% lysine, although the means were not

TABLE 4. LEAST-SQUARES MEANS FOR PERFORMANCE DATA (EXPERIMENT 1)

	Dietary lysine level, 7.9 to 20 kg				
Item	.75	.85	.95	1.05	SE
7.9 to 20 kg					
ADG, kg[a]	.33[b]	.36[bc]	.38[cd]	.39[d]	.011
ADF, kg	.72	.72	.71	.72	.019
F/G[e]	2.20[f]	2.06[g]	1.86[h]	1.85[h]	.034
20 to 35 kg					
ADG, kg	.57	.56	.57	.57	.020
ADF, kg	1.78	1.85	1.70	1.79	.121
F/G	3.19	3.29	2.97	3.15	.184
35 to 100 kg					
ADG, kg	.81	.78	.80	.79	.020
ADF, kg	3.00	3.17	3.11	3.14	.103
F/G	3.76	4.10	4.01	4.00	.119
7.9 to 35 kg					
ADG, kg[i]	.43[b]	.45[bc]	.47[c]	.47[c]	.009
ADF, kg	1.16	1.22	1.16	1.21	.052
F/G	2.77	2.74	2.50	2.57	.107
20 to 100 kg					
ADG, kg	.74	.72	.74	.73	.016
ADF, kg	2.67	2.82	2.70	2.79	.077
F/G	3.65	3.93	3.79	3.83	.098
7.9 to 100 kg					
ADG, kg	.63	.63	.65	.65	.013
ADF, kg	2.14	2.29	2.23	2.30	.063
F/G	3.46	3.67	3.51	3.55	.082

[a] Linear effect (P< .01).
[b,c,d] Means with unlike superscripts differ (P< .05).
[e] Linear effect (P< .001).
[f,g,h] Means with unlike superscripts differ (P< .001).
[i] Linear effect (P< .05).

statistically different. Differences in rate and efficiency of gain due to dietary lysine levels noted from 7.9 to 20 kg were not observed for the overall period from 7.9 to 100 kg. There were, however, differences in daily gain ($P<.01$) due to sex. Gains for barrows and gilts, respectively, were .85 and .73 kg from 35 to 100 kg, .78 and .68 kg from 20 to 100 kg and .68 and .60 kg from 7.9 to 100 kg (see appendix table 13 for sex effect on average daily gain).

Carcass characteristics did not differ due to initial lysine treatments (table 5). Area of longissimus muscle and carcass length ranged from 29.30 cm^2 and 79.80 cm when pigs were fed .75% dietary lysine to 31.25 cm^2 and 80.60 cm for those pigs fed starter diets containing .95% lysine. When pigs were fed starter diets containing 1.05% lysine, the greatest percent muscle and least backfat thickness resulted, while .95% dietary lysine produced carcasses with the lowest percent muscle and greatest backfat thickness.

TABLE 5. LEAST-SQUARES MEANS FOR CARCASS CHARACTERISTICS (EXPERIMENT 1)

Item	Dietary lysine levels, 7.9 to 20 kg				SE
	.75	.85	.95	1.05	
Backfat, cm	3.05	3.13	3.15	3.00	.117
Longissimus muscle, cm^2	29.30	29.33	31.25	29.86	.905
Muscle, %	52.35	52.79	52.33	53.12	.713
Length, cm	79.80	80.05	80.60	80.14	.685

Experiment 2

Performance data of pigs fed various lysine levels (.80, .90, 1.00 and 1.10%) during the starter period are presented in table 6. During the initial period, pigs fed diets containing .90, 1.00 and 1.10% lysine gained faster ($P<.05$) than pigs fed diets containing .80% lysine. Also, pigs fed diets containing .90% lysine consumed more feed ($P<.05$) than pigs fed the three other lysine levels. Feed conversion improved linearly ($P<.01$) as dietary lysine level increased. Feed/gain was 1.95 for pigs fed .80% dietary lysine and 1.72 for those fed diets containing 1.10% lysine.

During the period from 20 to 35 kg, daily gains were similar, but feed intake and efficiency were significantly different ($P<.06$ and $P<.05$, respectively). Feed intakes were 1.69, 1.53, 1.55 and 1.56 kg and feed efficiencies were 3.20, 2.71, 2.92 and 2.82 for pigs initially fed diets containing .80, .90, 1.00 and 1.10% lysine, respectively. Average daily gain and feed intake were not significantly different for the combined 7.9- to 35-kg period. However, from 7.9 to 35 kg, pigs fed the diet containing .80% lysine in the starter period were less efficient ($P<.05$) than pigs fed diets containing .90, 1.00 and 1.10% lysine during the starter period.

TABLE 6. LEAST-SQUARES MEANS FOR PERFORMANCE DATA (EXPERIMENT 2)

	Dietary lysine level, 7.9 to 20 kg				
Item	.80	.90	1.00	1.10	SE
7.9 to 20 kg					
ADG, kg	.35[a]	.40[b]	.39[b]	.40[b]	.010
ADF, kg[f]	.70[a]	.76[b]	.69[a]	.69[a]	.017
F/G[g]	1.95[a]	1.90[ab]	1.78[bc]	1.72[c]	.045
20 to 35 kg					
ADG, kg	.52	.59	.53	.52	.025
ADF, kg[h]	1.69[d]	1.53[e]	1.55[e]	1.56[de]	.039
F/G[f]	3.20[a]	2.71[b]	2.92[ab]	2.82[b]	.098
7.9 to 35 kg					
ADG, kg	.43	.48	.45	.46	.013
ADF, kg	1.15	1.13	1.10	1.12	.016
F/G[g]	2.66[a]	2.35[b]	2.41[b]	2.35[b]	.063

[a,b,c] Means with unlike superscripts differ ($P<.05$).
[d,e] Means with unlike superscripts differ ($P<.06$).
[f] Cubic effect ($P<.05$).
[g] Linear effect ($P<.01$).
[h] Quadratic effect ($P<.06$).

Experiment 3

The effects of dietary lysine levels of .80, .95, 1.10 and 1.25% during the starter period (7.6 to 20 kg) on performance of pigs to slaughter weight (93 kg) are summarized in table 7. Daily gain and feed intake were not significantly different among treatments from 7.6 to 20 kg. Feed efficiency was affected ($P<.05$) however and improved linearly ($P<.01$) with increasing lysine levels.

Daily gains were different ($P<.05$) from 20 to 55 kg. Gains were .72, .72, .66 and .69 kg for pigs fed starter diets containing .80, .95, 1.10 and 1.25% lysine, respectively. Feed intake and

TABLE 7. LEAST-SQUARES MEANS FOR PERFORMANCE DATA (EXPERIMENT 3)

Item	Dietary lysine level, 7.6 to 20 kg				SE
	.80	.95	1.10	1.25	
7.6 to 20 kg					
ADG, kg	.34	.36	.36	.35	.007
ADF, kg	.75	.75	.69	.70	.019
F/G[a]	2.20[b]	2.09[bc]	1.98[c]	1.95[c]	.050
20 to 55 kg					
ADG, kg[d]	.72[b]	.72[b]	.66[c]	.69[bc]	.014
ADF, kg	1.99	1.91	1.87	1.80	.068
F/G	2.88	2.79	2.90	2.63	.105
55 to 93 kg					
ADG, kg	.85	.83	.77	.81	.023
ADF, kg	3.49	3.90	3.36	3.28	.171
F/G[e]	4.10[f]	4.75[g]	4.33[fg]	4.11[f]	.171
7.6 to 55 kg					
ADG, kg	.56	.58	.54	.55	.010
ADF, kg	1.50	1.43	1.41	1.36	.046
F/G	2.69	2.60	2.65	2.46	.069
20 to 93 kg					
ADG, kg[d]	.79[h]	.77[h]	.71[i]	.75[hi]	.011
ADF, kg	2.69	2.79	2.57	2.48	.092
F/G	3.56	3.73	3.63	3.35	.105
7.6 to 93 kg					
ADG, kg[d]	.66[b]	.66[b]	.62[c]	.64[bc]	.010
ADF, kg	2.11	2.21	2.09	2.00	.066
F/G	3.32	3.47	3.38	3.15	.083

[a] Linear effect ($P<.01$).
[b,c] Means with unlike superscripts differ ($P<.05$).
[d] Linear effect ($P<.05$).
[e] Quadratic effect ($P<.05$).
[f,g] Means with unlike superscripts differ ($P<.06$).
[h,i] Means with unlike superscripts differ ($P<.01$).

feed/gain from 20 to 55 kg were not significantly affected (P>.05) by initial lysine treatments. Also, daily gain, feed intake and feed conversion from 7.6 to 55 kg were not significantly different among treatments.

From 55 to 93 kg, feed efficiency was the only parameter that was significantly affected (P<.05) by starter lysine level. Feed efficiencies ranged from 4.10 for pigs fed .80% lysine starter diets to 4.75 for pigs fed .95% lysine starter diets. Feed intake and efficiency were not statistically affected by starter lysine levels for the combined periods of 20 to 93 kg or 7.6 to 93 kg, but feed conversion tended to be most efficient in all periods for pigs fed 1.25% dietary lysine in the starter period. Daily gains for the 20 to 93 kg and 7.6 to 93 kg combined periods decreased linearly (P<.05) as lysine levels increased and were greater for pigs fed starter diets containing .80 and .95% lysine than gains for those fed 1.10% lysine starter diets. Gains for pigs fed 1.25% lysine starter diets were not different from those of pigs fed the other three starter treatments in either the 7.6 to 93 kg or 20 to 93 kg periods.

Barrows gained faster than gilts for the periods from 55 to 93 kg, 20 to 93 kg and 7.6 to 93 kg. Differences at 55 to 93 kg (.86 vs .77 kg) and 20 to 93 kg (.77 vs .73 kg) were significant at the 5% level, while differences for the overall period (.66 vs .64 kg) were significant at the 6% level.

No significant differences in carcass characteristics were observed among treatments (table 8). Backfat thickness ranged from 3.30 cm for the .80% lysine treatment to 3.14 cm for the 1.25% lysine

TABLE 8. LEAST-SQUARES MEANS FOR CARCASS CHARACTERISTICS (EXPERIMENT 3)

Item	Dietary lysine level, 7.6 to 20 kg				
	.80	.95	1.10	1.25	SE
Backfat, cm	3.30	3.19	3.19	3.14	.112
Longissmus muscle, cm^2	26.84	28.97	26.91	28.29	.995
Muscle, %	52.08	53.85	53.01	53.30	.683
Length, cm	79.28	79.18	79.16	79.66	.539

treatment. Maximum values for longissimus muscle area and percent muscle were observed for the .95% lysine treatment, while minimum values were obtained for the .80% lysine treatment. Carcass lengths were 79.28, 79.18, 79.16 and 79.66 cm for the .80, .95, 1.10 and 1.25% lysine levels, respectively.

DISCUSSION

Data from this study suggest that lysine supplementation of a 16% protein, corn-soybean meal diet improves pig performance during the starter period (7.8 to 20 kg). Improvements in daily gain and feed efficiency due to lysine supplementation during the starter period were significant ($P < .05$) in all experiments except for average daily gain in experiment 3. However, in that experiment, there was a trend ($P < .10$) for improvement in gain with supplemental lysine. Drawing from the results of all three experiments, it was concluded that the starter pig's lysine requirement based on daily gain was approximately .90%, while 1.00% lysine was the suggested need when based on feed conversion data.

Improved performance of pigs due to higher lysine levels in starter diets has been observed by many researchers (Lunchick et al., 1978; Katz et al., 1973; Lewis et al., 1981). However, estimates of the lysine requirement for the young pig vary greatly among researchers. Lewis et al. (1981) proposed the starter pig's lysine requirement was between 1.15 and 1.25% when a 19% protein, corn-soybean meal diet was fed, while Brinegar et al. (1950) suggested that lysine levels of .60 and 1.20% met starter pigs' needs when fed 10.6 and 22.0% protein diets, respectively. The variation in estimates can be reduced by expressing lysine requirement as a percentage of dietary protein (Brinegar et al., 1950). The estimates reported herein, .90 and 1.00% lysine when based on gain and efficiency of a 16% protein diet, are equal to 5.6 and 6.3% of the dietary protein, respectively. The estimated need of 5.6% of the dietary protein as lysine in these experiments, based on average daily gain, was similar to lysine values of 5.7 and 5.5% of the protein in diets containing 10.6 and 22.0% protein (Brinegar et al., 1950) and equal to the value (5.6%) determined by Lunchick et al. (1978) when feeding a 16% protein diet. Campbell (1978) suggested that 6.5% of the dietary protein (1.08% lysine in a 16.6% protein diet) was the lysine requirement for young weaned pigs, while Lewis and others (1981) estimated the lysine requirement to be between 6.1 and 6.5% of the protein in a 19% protein diet. The results of the two aforementioned researchers are similar to the value based on feed efficiency reported herein (6.5% of the dietary protein).

A higher lysine requirement for feed conversion than for gain has also been observed by Aldinger and Roberts (1963), Cahilly et al. (1963) and Wahlstrom and Libal (1974). Campbell (1978) and Mitchell et al. (1965a), however, reported no difference in lysine requirement whether based on gain or feed efficiency. Brown et al. (1973a) attempted to explain the differences by suggesting that, after the requirement for gain was met, further additions of lysine enabled other dietary amino acids to be used in protein synthesis instead of being deaminated and used as an energy source.

Compensatory performance, the improvement in performance when fed a nutritionally adequate diet after a previous period of nutrient restriction, did not occur during the grower phase (20 to 35 kg) in experiments 1 and 2. However, compensation did appear to occur in experiment 1 from 35 to 100 kg, since rate and efficiency of gain during the 35- to 100-kg period tended to be superior for pigs previously fed starter diets containing .75% lysine. Also, data from these experiments suggest that, when compensatory performance occurs, it is during the later growth or finishing periods (after 35 kg in experiment 1). Wyllie et al. (1969) observed that compensatory performance for pigs fed protein-restricted diets from 4.8 to 24 kg occurred not in the subsequent period from 24 to 57 kg but rather in the later period from 57 to 92 kg. However, Hogberg and Zimmerman (1978), Campbell and Biden (1978) and Zimmerman and Khajarern (1973) observed that compensatory performance occurred in the subsequent grower period when diets adequate in protein were fed after a protein-restricted starter period.

In experiment 1, pigs fed the low-lysine level diets appeared to completely compensate for the lysine-restricted starter diets during the overall period, since the poorer performance observed from 7.9 to 20 kg for pigs fed .75% lysine starter diets was not present for the overall period from 7.9 to 100 kg. In studies where starter pigs were fed protein-restricted diets from approximately 6 to 24 kg, Zimmerman and Khajarern (1973) and Wyllie and Owen (1978) also observed no differences in performance from weaning to market weight when pigs were fed nutritionally adequate diets following protein restriction.

Feed/gain decreased linearly ($P<.01$) with increasing lysine levels from 7.6 to 20 kg in experiment 3. However, compensation did not appear to occur consistently in subsequent or overall periods. Feed/gain from 55 to 93 kg was greater ($P<.06$) for pigs fed starter diets containing .95% lysine than for pigs fed starter diets containing

.80 or 1.25% lysine. The reason for this effect is unknown, but it was noted that pigs fed starter diets containing .95% lysine had a much higher feed intake from 55 to 93 kg without affecting rate of gain. It seems possible that this may have been due to excessive feed loss which could not be measured in the confinement barn and thus would have resulted in an elevated feed/gain ratio.

Factors which might explain some of the variation in compensatory performance results are weight at which restriction occurred, strain of pig and degree of restriction. Wahlstrom and Libal (1974) reported that early grower pigs fed 12 and 14% protein diets for 4 wk did not perform as well as pigs fed 16% protein diets. When all pigs were then fed 14% protein diets after protein restriction, pigs initially fed 14% diets exhibited overall performance (approximately 26 to 100 kg) similar to that of pigs initially fed 16% protein diets. However, pigs fed 12% protein diets initially did not compensate for their early poor performance. They also observed that pigs initially weighing 18.2, 22.7 and 27.3 kg all gained faster and more efficiently when fed 16% protein diets during an initial 4-wk period when compared to pigs fed 14% protein diets. Pigs weighing 18.2 kg did not compensate for the reduced performance of their first 4-wk period when all pigs were fed 14% protein diets to 100 kg. However, the heavy and medium weight group pigs exhibited faster and more efficient gains during the subsequent period to 100 kg. For the overall period, pigs initially weighing 27.3 kg fully compensated and 22.7 kg pigs nearly compensated for the reduced performance exhibited during the early protein restricted period.

Hogberg and Zimmerman (1978) and Pond et al. (1980) observed that fat-strain pigs more fully compensated for early protein restriction than did lean-strain pigs.

Zimmerman and Khajarern (1973) suggested that the mechanism for compensatory performance involved protein turnover rate, and turnover rate may be influenced by enzymes that catabolize amino acids. Nakano and Ashida (1970) observed that previous feeding of a high-fat or high-carbohydrate diet decreased the concentration of amino acid degrading enzymes. Therefore, the feeding of a low-protein diet in the starter period would result in a lower concentration of catabolic enzymes for amino acids and hence a lower protein turnover rate in the growing phase.

No statistical differences in carcass characteristics at market weight were observed due to initial lysine treatments. In related studies, researchers have found that carcasses from starter pigs fed low-protein diets contained more fat and less protein (Zimmerman and Khajarern, 1973; Campbell and Biden, 1978; Wyllie et al., 1969). The increased fat deposition can be attributed to a decrease in protein synthesis due to low protein levels. When pigs initially fed suboptimal protein levels were then fed adequate protein levels to market weight, no differences in carcass quality were detected. In explaining the lack of differences in carcass quality at market weight, Zimmerman and Khajarern (1973) referred to the normal growth curve which was partitioned into fat and lean gains. They stated that lean mass deposition increases exponentially to about 60 kg, at which point it increases asymptotically and eventually plateaus. Thus, when comparing lean gains of two groups with different lean masses, the lean mass of the smaller group will converge toward that of the heavier group during the asymptotic phase and the amount of lean mass in each group should be identical at market weight. That response could explain the reason that differences in carcass characteristics due to lysine treatment were not observed at market weight.

SUMMARY

Three experiments were conducted to determine the effect of varying lysine levels in starter diets on pig performance to 20 kg and on subsequent performance and carcass characteristics at market weight. Pigs were fed varying lysine levels from approximately 7.8 to 20 kg. From 20 kg to the termination of each respective study, pigs were fed identical diets.

In experiment 1, L-lysine monohydrochloride was added to a 16% protein, corn-oat groats-soybean meal basal diet to provide dietary lysine levels of .75, .85, .95 and 1.05%. From 7.9 to 20 kg, gains increased linearly ($P<.01$) and feed conversion improved linearly ($P<.001$) with increasing lysine levels. No significant differences in performance were observed in subsequent periods or for the overall period from 7.9 to 100 kg. Also, backfat thickness, longissimus muscle area, percent muscle and carcass length at market weight were unaffected by starter lysine level.

L-lysine monohydrochloride was added to a 16% protein, corn-soybean meal basal diet in experiment 2 to provide dietary lysine levels of .80, .90, 1.00 and 1.10%. Gains from 7.9 to 20 kg were greater ($P<.05$) for pigs fed .90, 1.00 and 1.10% lysine diets than for pigs fed the diet containing .80% lysine. During the same period, feed/gain decreased linearly ($P<.01$) with increasing lysine levels. Feed efficiency for the period from 7.9 to 35 kg improved linearly ($P<.01$) with increasing lysine levels.

In experiment 3, lysine was added to a basal diet similar to that in experiment 2 to provide dietary lysine levels of .80, .95, 1.10 and 1.25%. Feed/gain decreased linearly ($P<.01$) from 7.6 to 20 kg with increasing lysine levels. From 20 to 55 kg and 7.6 to 93 kg, gains increased linearly ($P<.05$) with increasing lysine levels in the starter period. Carcass characteristics were not affected in experiment 3 by starter lysine levels.

From the results of these three experiments, it is recommended that producers raising feeder pigs for sale at weights of approximately 20 kg should feed diets containing 1.00% lysine. However, when raising pigs from weaning to market weight, the NRC (1979) recommended lysine level of .79% in starter diets appears to be adequate for overall performance and carcass quality.

LITERATURE CITED

Aldinger, S. M. and C. Y. Roberts. 1963. Effect of lysine on performance and carcass quality of swine. J. Anim. Sci. 22:845 (Abstr.).

Allee, G. L., R. H. Hines and B. A. Koch. 1973. Lysine supplementation of diets for young pigs. J. Anim. Sci. 37:273 (Abstr.).

Almquist, H. J. and E. Mecchi. 1942. Lysine requirement of the chick. Proc. Soc. Exp. Biol. Med. 49:174.

Anderson, G. H. and J. P. Bowland. 1967. Lysine and fat supplementation of weanling pig diets. Can. J. Anim. Sci. 47:47.

Baird, D. M. and H. C. McCampbell. 1962. Influence of lysine, protein and energy levels on growth and carcasses of hogs. J. Anim. Sci. 21:987 (Abstr.).

Baker, D. H., R. S. Katz and R. A. Easter. 1975. Lysine requirement of growing pigs at two levels of dietary protein. J. Anim. Sci. 40:851.

Bauer, C. D. and G. P. Berg. 1943. The amino acids required for growth in mice and the availability of their optical isomers. J. Nutr. 26:51.

Blair, R., J. B. Dent, P. R. English and J. R. Raeburn. 1969. Protein, lysine and feed intake level effects on pig growth. J. Agr. Sci. (Camb.) 73:395.

Brinegar, M. J., H. H. Williams, F. H. Ferris, J. K. Loosli and L. A. Maynard. 1950. Lysine requirement for growth of swine. J. Nutr. 42:129.

Brown, H. D., B. G. Harmon and A. H. Jensen. 1973a. Lysine requirement of the finishing pig for maximum rate of gain and efficiency. J. Anim. Sci. 37:708.

Brown, H. D., B. G. Harmon and A. H. Jensen. 1973b. Lysine requirement of the finishing pig for maximum carcass leanness. J. Anim. Sci. 37:1159.

Cahilly, G. M., Jr., R. F. Miller, R. F. Kelly and C. C. Brooks. 1963. Effect of various levels of dietary lysine on certain blood phenomena, muscle development and muscle-protein biological value of growing swine. J. Anim. Sci. 22:726.

Campbell, R. G. 1978. The response of early weaned pigs to suboptimal protein diets supplemented with synthetic lysine. Anim. Prod. 26:11.

Campbell, R. G. and R. S. Biden. 1978. The effect of protein nutrition between 5.5 and 20 kg live weight on the subsequent performance and carcass quality of pigs. Anim. Prod. 27:223.

Catron, D. V., D. C. Acker, G. C. Ashton, H. M. Maddock and V. C. Speer. 1953. Lysine and/or methionine supplementation of corn and soybean oil meal rations for pigs in drylot. J. Anim. Sci. 12:910.

Chance, R. E., A. F. O. Germann, II, W. M. Beeson and E. T. Mertz. 1958. Effect of protein level on the lysine requirement of weanling pigs. J. Anim. Sci. 17:1161 (Abstr.).

Clawson, A. J., E. R. Barrick and W. W. G. Smart, Jr. 1963. Response of pigs to graded levels of soybean meal and added lysine in ten percent protein rations. J. Anim. Sci. 22:1027.

Cole, D. J. A., J. E. Puckworth and W. H. Holmes. 1967. Factors affecting voluntary feed intake in pigs. Anim. Prod. 9:141.

Dukelow, W. R., R. S. Grant, R. J. Meade and J. H. Goihl. 1963. Influence of protein level and of amino acid supplementation on performance of growing swine and on carcass characteristics. J. Anim. Sci. 22:1119.

Easter, R. A. and D. H. Baker. 1980. Lysine and protein levels in corn-soybean meal diets for growing-finishing swine. J. Anim. Sci. 50:467.

Gilster, K. E. and R. C. Wahlstrom. 1973. Protein levels for swine fed to heavy weights. I. Effects on gain and feed efficiency. J. Anim. Sci. 36:883.

Gjefsen, T., K. E. Gulbrandsen and J. Opstvedt. 1980. Herring type fish meals in diets for early weaned pigs. Acta Agr. Scand. 30:157.

Grau, C. R. 1948. Effect of protein level on the lysine requirement of the chick. J. Nutr. 36:99.

Gupta, J. D., A. M. Dakrowry, A. E. Harper and C. A. Elvehjem. 1957. Biological availability of lysine. J. Nutr. 64:259.

Hogberg, M. G. and D. R. Zimmerman. 1978. Compensatory responses to dietary protein, length of starter period and strain of pig. J. Anim. Sci. 47:893.

Hutchinson, H. D., S. W. Terrill, A. H. Jensen, D. E. Becker and H. W. Norton. 1956. Some factors influencing the lysine requirement of rats and swine. J. Anim. Sci. 15:1236 (Abstr.).

Jurgens, M. H., D. B. Hudman, C. H. Adams and E. R. Peo, Jr. 1967. Influence of a dietary supplement of lysine fed at two levels of protein on growth, feed efficiency and carcass characteristics of swine. J. Anim. Sci. 26:323.

Katz, R. S., D. H. Baker, C. E. Sasse, A. H. Jensen and B. G. Harmon. 1973. Efficacy of supplemental lysine, methionine and rolled oats for weanling pigs fed a low-protein, corn-soybean meal diet. J. Anim. Sci. 37:1165.

Kennington, M. H., T. W. Perry and W. M. Beeson. 1958. Effect of adding animal fat to swine ratios. J. Anim. Sci. 17:1166 (Abstr.).

Klay, R. F. 1964. The lysine requirement for growth of the pig at four protein levels. J. Anim. Sci. 23:881 (Abstr.).

Klein, R. G., W. M. Beeson, T. R. Cline and E. T. Mertz. 1972. Lysine availability of opaque-2 corn for rats. J. Anim. Sci. 35:551.

Kornegay, E. T. 1972. Supplementation of lysine, ammonium polyphosphate and urea in diets for growing-finishing pigs. J. Anim. Sci. 34:55.

Kropf, D. H., R. W. Bray, P. H. Philips and R. H. Grummer. 1959. Effect of protein level and quality in swine rations upon growth and carcass development. J. Anim. Sci. 18:755.

Lewis, A. J., E. R. Peo, Jr., B. D. Moser and T. D. Crenshaw. 1981. Lysine requirement of pigs weighing 5 to 15 kg fed practical diets with and without added fat. J. Anim. Sci. 51:381.

Libal, G. W. and R. C. Wahlstrom. 1976. Compensatory growth of swine following protein insufficiency. J. Anim. Sci. 43:255 (Abstr.).

Long, J. I., D. B. Hudman and E. R. Peo, Jr. 1962. Effect of lysine and/or methionine in baby pig rations. J. Anim. Sci. 21:1004 (Abstr.).

Lunchick, C., A. J. Clawson, W. D. Armstrong and A. C. Linnerud. 1978. Protein level, lysine level and source interaction in young pigs. J. Anim. Sci. 47:176.

McWard, G. W., D. E. Becker, H. W. Norton, S. W. Terrill and A. H. Jensen. 1959. The lysine requirement of weanling swine at two levels of dietary protein. J. Anim. Sci. 18:1059.

Meade, R. J., W. R. Dukelow and R. S. Grant. 1966a. Influence of percent oats in the diet, lysine and methionine supplementation and of pelleting on rate and efficiency of gain of growing pigs and on carcass characteristics. J. Anim. Sci. 25:58.

Meade, R. J., W. R. Dukelow and R. S. Grant. 1966b. Lysine and methionine additions to corn-soybean meal diets for growing swine: effects on rate and efficiency of gain and carcass characteristics. J. Anim. Sci. 25:78.

Meade, R. J., J. T. Lyppo, M. E. Tumbleson, J. H. Goihl and Helmut Von Der Mehden. 1965. Effects of protein source and level and lysine and methionine supplementation on rate and efficiency of gain of pigs weaned at an early age. J. Anim. Sci. 24:626.

Mertz, E. T., D. C. Shelton and W. M. Beeson. 1949. The amino acid requirements of swine, lysine. J. Anim. Sci. 8:524.

Mitchell, J. R., Jr., D. E. Becker, A. H. Jensen, H. W. Norton and B. G. Harmon. 1965a. Lysine need of swine at two stages of development. J. Anim. Sci. 24:409.

Mitchell, J. R., Jr., D. E. Becker, A. H. Jensen, H. W. Norton and B. G. Harmon. 1965b. Caloric density of the diet and the lysine need of growing swine. J. Anim. Sci. 24:977.

Nakano, K. and K. Ashida. 1970. Effect of dietary carbohydrate and fat on amino acid-degrading enzymes in relation to their protein-sparing action. J. Nutr. 100:208.

Netke, S. P. and H. M. Scott. 1970. Estimates on the availability of amino acids in soybean oil meal as determined by chick growth assay: methodology as applied to lysine. J. Nutr. 100:281.

NPPC. 1983. Procedures to Evaluate Market Hogs. National Pork Producers Council, Des Moines, Iowa.

NRC. 1979. Nutrient Requirements of Domestic Animals, No. 2. Nutrient Requirements of Swine. Eighth Revised Ed. National Academy of Sciences-National Research Council, Washington, DC.

Orr, D. E., Jr., L. F. Tribble and A. M. Lennon. 1976. Added lysine in sorghum-based young pig diets. J. Anim. Sci. 43:257 (Abstr.).

Osborne, T. B. and L. B. Mendel. 1914. Amino acids in nutrition and growth. J. Biol. Chem. 17:325.

Pelura, J., III, J. L. Krider, T. R. Cline, C. Reisert and L. B. Underwood. 1980. Virginiamycin, protein and lysine responses of young swine. J. Anim. Sci. 50:767.

Peo, E. R., Jr., G. C. Ashton, V. C. Speer and D. V. Catron. 1957. Protein and fat requirements of baby pigs. J. Anim. Sci. 16:885.

Pierce, A. B. and J. P. Bowland. 1972. Protein and amino acid levels and sequence in swine diets: Effects on gain, feed conversion and carcass characteristics. Can. J. Anim. Sci. 52:531.

Pond, W. G., J. T. Yen and R. N. Lindvall. 1980. Early protein deficiency: Effects on later growth and carcass composition of lean or obese swine. J. Nutr. 110:2506.

Rose, W. C. 1947. The role of amino acids in human nutrition. Proc. Amer. Phil. Soc. 91:112.

Rose, W. C. and E. E. Rice. 1939. The significance of amino acids in canine nutrition. Science 90:186.

SAS. 1979. SAS User's Guide. Statistical Analysis System Institute, Inc., Gary, NC.

Shields, R. G., Jr. and D. C. Mahan. 1980. Effect of protein sequences on performance and carcass characteristics of growing-finishing swine. J. Anim. Sci. 51:1340.

Steel, R. G. D. and D. H. Torrie. 1980. Principles and Procedures of Statistics (2nd Ed.). McGraw-Hill Book Co., New York.

Tjong-A-Hung, A. R., L. E. Hanson, J. W. Rust and R. J. Meade. 1972. Effect of protein level sequence and sex on rate and efficiency of gain of growing swine and on carcass characteristics, including composition of lean tissue. J. Anim. Sci. 35:760.

Tribble, L. F., Shannon H. Ingram, C. T. Gaskins and C. B. Ramsey. 1979. Evaluation of added fat and lysine to sorghum-soybean meal for swine. J. Anim. Sci. 48:541.

Vipperman, P. E., Jr., C. C. Brooks, R. F. Kelly, P. P. Graham and H. R. Thomas. 1963. Effect of dietary lysine level on muscle size and composition in swine. J. Anim. Sci. 22:674.

Wahlstrom, R. C. and G. W. Libal. 1974. Gain, feed efficiency and carcass characteristics of swine fed supplemental lysine and methionine in corn-soybean meal diets during the growing and finishing periods. J. Anim. Sci. 38:1261.

Wahlstrom, R. C. and G. W. Libal. 1983. Compensatory responses of swine following protein sufficiency in grower diets. J. Anim. Sci. 56:118.

Whitelaw, A. W. W., F. W. H. Elsley, A. S. Jones and A. W. Boyne. 1966. The effect of protein level in creep feed on growth rate and body composition of suckling pigs. J. Agr. Sci. (Camb.) 66:203.

Williams, W. D., G. L. Cromwell, T. S. Stahly and J. R. Overfield. 1984. The lysine requirement of the growing boar versus barrow. J. Anim. Sci. 58:657.

Wyllie, D. and J. B. Owen. 1978. Dietary protein content and the subsequent body composition and food intake of pigs. J. Agr. Sci. (Camb.) 90:69.

Wyllie, D., V. C. Speer, R. C. Ewan and V. H. Hays. 1969. Effects of starter protein level on performance and body composition of pigs. J. Anim. Sci. 29:433.

Yen, J. T. and T. L. Veum. 1982. Effects of lysine, tryptophan and/or carbadox additions to low protein corn-soybean meal diets for young pigs. J. Anim. Sci. 55:1099.

Zimmerman, D. R. and S. Khajarern. 1973. Starter protein nutrition and compensatory responses in swine. J. Anim. Sci. 36:189.

APPENDIX

TABLE 1. ANALYSIS OF STARTER DIETS

Diet	Calculated Lysine	Chemical[a] Lysine	Chemical[a] Protein
		Experiment 1	
1	.75	.76	16.7
2	.85	.96	17.1
3	.95	1.02	16.9
4	1.05	1.05	16.4
		Experiment 2	
1	.80	.74	--
2	.90	.83	--
3	1.00	.99	--
4	1.10	1.08	--
		Experiment 3	
1	.80	.85	16.2
2	.95	.85	15.6
3	1.10	1.05	15.7
4	1.25	1.23	15.4

[a] As fed basis.

TABLE 2. ANALYSIS OF VARIANCE FOR AVERAGE DAILY GAIN (EXPERIMENT 1)

Source	df	Mean squares 7.9- 20 kg	20- 35 kg	7.9- 35 kg	df	Mean squares 35- 100 kg	20- 100 kg	7.9- 100 kg
Total	92				91			
Replication (R)	5	.010	.035	.005	5	.076[a]	.038	.009
Treatment (T)	3	.065[a]	.001	.038[a]	3	.024	.009	.016
Linear	1	.191[b]	.001	.112[a]	1	.014	.001	.031
Quadratic	1	.004	.000	.003	1	.008	.003	.000
Cubic	1	.001	.000	.002	1	.050	.022	.017
R x T	15	.013	.046	.009	15	.042[c]	.029	.018
Sex (S)	1	.001	.507[c]	.114	1	1.500[b]	1.191[b]	.650[b]
R x S	5	.026	.080	.033	5	.089[b]	.063[a]	.033
T x S	3	.007	.096	.037	3	.018	.028	.018
R x T x S	15	.019	.038	.022	15	.017	.014	.009
Residual	45	.024	.036	.024	44	.023	.019	.015

[a] P< .05.
[b] P< .01.
[c] P< .06.

TABLE 3. ANALYSIS OF VARIANCE FOR AVERAGE DAILY FEED INTAKE (EXPERIMENT 1)

Source	df	Mean squares 7.9- 20 kg	20- 35 kg	7.9- 35 kg	35- 100 kg	20- 100 kg	7.9- 100 kg
Total	23						
Replication (R)	5	.017	.447	.046	.549	.496	.264
Treatment (T)	3	.002	.112	.025	.162	.140	.158
Linear	1	.003	.020	.012	.182	.074	.234
Quadratic	1	.001	.001	.000	.143	.031	.047
Cubic	1	.002	.315	.063	.161	.316	.192
Residual	15	.010	.429	.078	.312	.173	.110

TABLE 4. ANALYSIS OF VARIANCE FOR FEED CONVERSION (EXPERIMENT 1)

Source	df	Mean squares 7.9-20 kg	20-35 kg	7.9-35 kg	35-100 kg	20-100 kg	7.9-100 kg
Total	23						
Replication (R)	5	.018	.119	.030	.225	.169[a]	.125[a]
Treatment (T)	3	.171[b]	.110	.103	.128	.086	.047
Linear 1		.471[b]	.066	.208	.125	.050	.005
Quadratic 1		.025	.008	.018	.186	.089	.039
Cubic 1		.015	.255	.084	.075	.119	.098
Residual	15	.007	.203	.068	.085	.058	.040

[a] P< .05.
[b] P< .01.

TABLE 5. ANALYSIS OF VARIANCE FOR CARCASS CHARACTERISTICS (EXPERIMENT 1)

Source	df	Mean squares Backfat	Longissimus muscle area	Percent muscle	df	Mean squares Length
Total	43				42	
Replication (R)	5	.025	1.074	3.350	5	1.354
Treatment (T)	3	.009	.204	1.593	3	.179
Linear 1		.002	.171	1.842		.194
Quadratic 1		.022	.125	.314		.199
Cubic 1		.000	.317	2.258		.129
R x T	15	.023	.216	5.592	15	.801
Residual	20	.029	.504	4.182	19	.890

TABLE 6. ANALYSIS OF VARIANCE FOR AVERAGE DAILY GAIN (EXPERIMENT 2)

Source	df	Mean squares 7.9-20 kg	df	Mean squares 20-35 kg	Mean squares 7.9-35 kg
Total	79		76		
Replication (R)	4	.079	4	.134	.053
Treatment (T)	3	.041[a]	3	.103	.038
Linear	1	.067		.007	.017
Quadratic	1	.032		.156	.048
Cubic	1	.028		.155	.052
R x T	12	.009	12	.057	.015
Sex (S)	1	.003	1	.205	.077
R x S	4	.023	4	.051	.022
T x S	3	.008	3	.037	.009
R x T x S	12	.015	12	.024	.015
Residual	39	.037	37	.064	.042

[a] P<.05.

TABLE 7. ANALYSIS OF VARIANCE FOR AVERAGE DAILY FEED INTAKE AND FEED CONVERSION (EXPERIMENT 2)

		Mean squares					
		Avg daily feed intake			Feed conversion		
Source	df	7.9-20 kg	20-35 kg	7.9-35 kg	7.9-20 kg	20-35 kg	7.9-35 kg
Total	19						
Replication (R)	4	.053[a]	.109	.034[c]	.019	.136	.034
Treatment (T)	3	.025[b]	.125[c]	.011	.057[b]	.225[b]	.112[b]
Linear	1	.011	.159	.020	.167[a]	.213	.189[a]
Quadratic	1	.020	.167[c]	.009	.000	.196	.086
Cubic	1	.044[b]	.050	.005	.004	.264[b]	.060
Residual	12	.007	.038	.006	.010	.048	.020

[a] P<.01.
[b] P<.05.
[c] P<.06.

TABLE 8. ANALYSIS OF VARIANCE FOR AVERAGE DAILY GAIN TO 55 KG (EXPERIMENT 3)

Source		df	Mean squares 7.6-20 kg	df	Mean squares 20-55 kg	Mean squares 7.6-55 kg
Total		91		87		
Replication (R)		5	.005	5	.074	.022
Treatment (T)		3	.013	3	.089[a]	.026
Linear	1		.012		.140[a]	.019
Quadratic	1		.027		.033	.004
Cubic	1		.000		.102	.059
R x T		15	.005	15	.020	.011
Sex (S)		1	.026	1	.000	.006
R x S		5	.025	5	.007	.015
T x S		3	.020	3	.017	.016
R x T x S		15	.022	15	.051	.031
Residual		44	.024	40	.031	.021

[a] P<.05.

TABLE 9. ANALYSIS OF VARIANCE FOR AVERAGE DAILY GAIN TO 93 KG (EXPERIMENT 3)

Source		df	Mean squares 55-93 kg	Mean squares 20-93 kg	Mean squares 7.6-93 kg
Total		85			
Replication (R)		5	.058	.022	.013
Treatment (T)		3	.121	.108[a]	.043[b]
Linear	1		.184	.159[b]	.071[b]
Quadratic	1		.093	.075	.009
Cubic	1		.087	.090	.051
R x T		15	.053	.012	.010
Sex (S)		1	.659[b]	.132[b]	.039[c]
R x S		5	.067	.014	.006
T x S		3	.114	.014	.011
R x T x S		15	.068	.038	.025
Residual		38	.061	.026	.017

[a] P<.01.
[b] P<.05.
[c] P<.06.

TABLE 10. ANALYSIS OF VARIANCE FOR AVERAGE DAILY FEED INTAKE (EXPERIMENT 3)

Source		df	Mean squares 7.6–20 kg	20–55 kg	7.6–55 kg	55–93 kg	20–93 kg	7.6–93 kg
Total		24						
Replication (R)		5	.002	.434[a]	.127	.589	.432	.286
Treatment (T)		3	.032	.171	.098	2.187	.545	.217
Linear	1		.072[a]	.508	.282[a]	1.997	1.075	.319
Quadratic	1		.000	.001	.002	1.760	.252	.242
Cubic	1		.025	.005	.010	2.803	.308	.089
Residual		15	.011	.136	.061	.858	.248	.126

[a] $P < .05$.

TABLE 11. ANALYSIS OF VARIANCE FOR FEED CONVERSION (EXPERIMENT 3)

Source		df	Mean squares 7.6–20 kg	20–55 kg	7.6–55 kg	55–93 kg	20–93 kg	7.6–93 kg
Total		23						
Replication (R)		5	.006	.056	.131	.218	.050	.035
Treatment (T)		3	.081[a]	.091	.061	.559[b]	.157	.109
Linear	1		.198[c]	.122	.126[a]	.045	.157	.109
Quadratic	1		.029	.054	.015	1.148[a]	.308[a]	.215[a]
Cubic	1		.015	.099	.041	.485	.004	.003
Residual		15	.015	.067	.028	.175	.063	.041

[a] $P < .05$.
[b] $P < .06$.
[c] $P < .01$.

TABLE 12. ANALYSIS OF VARIANCE FOR CARCASS CHARACTERISTICS (EXPERIMENT 3)

		Mean squares			
Source	df	Backfat	Longissimus muscle area	Percent muscle	Length
Total	51				
Treatment (T)	3	.008	.329	7.116	.103
Linear 1		.020	.078	4.983	.122
Quadratic 1		.002	.042	6.806	.172
Cubic 1		.002	.834	8.424	.020
Sex (S)	1	.044	.008	1.221	.631
T x S	3	.033	.786	6.460	.564
Residual	44	.025	.309	6.601	.585

TABLE 13. SEX EFFECT ON AVERAGE DAILY GAIN

	Least-squares means (kg)		
Period	Barrows	Gilts	SE
	Experiment 1		
20 to 35 kg[a]	.60	.53	.019
35 to 100 kg[b]	.85	.73	.020
20 to 100 kg[b]	.78	.68	.017
7.9 to 100 kg[b]	.68	.60	.012
	Experiment 3		
55 to 93 kg[c]	.86	.77	.018
20 to 93 kg[c]	.77	.73	.008
7.6 to 93 kg[a]	.66	.64	.006

[a] Means differ ($P<.06$).
[b] Means differ ($P<.01$).
[c] Means differ ($P<.05$).