INTERACTION OF DIETARY PROTEIN, FIBER, AND ENERGY ON GROWTH PERFORMANCE IN FINISHING BARROWS

by

PAUL MARTIN CLINE

(Under the Direction of Michael Azain)

ABSTRACT

The objective of these studies was to determine the performance response to changes in dietary fat, protein, and fiber content in finishing barrows. Previous work has shown that increases in dietary energy density result in decreased feed intake. Experiment 1 was conducted in a 3 x 3 factorial arrangement, with main effects of crude protein (12, 16, 20%, lysine: 0.60, 0.80, 1.00%) and added Fat (1, 6, 11%). There was a main effect of dietary protein on gain ($P < 0.03$). Average daily gain increased as dietary protein increased from 12. There were main effects of dietary fat on caloric intake ($P < 0.01$) and efficiency ($P < 0.01$). Experiment 2 was conducted in 2 trials of 25 individually penned pigs each (1 pig/pen, total 50 pigs). In each trial barrows (initial wt=85.3kg) were blocked by weight and assigned one of five experimental diets (0.50, 0.55, 0.60, 0.65, and 0.70 % lysine) with a constant lysine: ME ratio (1.833). The lowest diet, 0.50% lysine did not meet NRC requirements however all other diets met NRC requirements. There was main effect of dietary lysine on final body weight, gain, intake, feed efficiency, caloric intake, and lysine intake. All parameters measured increased linearly as %lysine was increased in the diet. Experiment 2 showed that even at a constant lysine: ME ratio swine performance characteristics can vary.

INDEX WORDS: Fat, Fiber, Protein, Calorie:Protein Ratio, Caloric requirement, Finishing Barrows

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PAUL MARTIN CLINE

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PAUL MARTIN CLINE

Approved:

Major Professor: Michael Azain

Committee: Mark Freotschel
Gene Pesti

Electronic Version Approved:

Maureen Grasso
Dean of Graduate School
The University of Georgia
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Chapter 1

Introduction

Purpose of the study

Attaining the best growth rate with optimal carcass characteristics are what pork produces strive to achieve throughout a pigs life. This becomes especially important during the finisher phase when protein accretion rates slow and lipid deposition rates increase. To optimize swine growth, many studies have adjusted the calorie to protein ratio. In order to understand why calorie to protein ratio is important, it is best to understand why protein and energy are important to swine growth.

The correct calorie to protein ratio is necessary for optimal growth during a pig's life. Feeding a nutrient dense feed with an optimal ratio of energy to protein can minimize waste and have the best feed efficiency. Pigs eat to meet their energy requirement. A pig that eats a diet high in energy will stop eating before the protein requirement has been met and will become protein deficient. Pigs on this type of diet tend to grow slower and deposit more fat (Campbell et al., 1984; Cooke et al., 1972; Smith et al., 1999b). Adding fat to a finishing swine diet has been shown to increase ADG, feed efficiency, body weight, and decrease feed intake (Kerr et al., 2003; La Llata et al., 2007a, b; Smith et al., 1999b; Szabo et al., 2001). Reducing CP in the diet is another way to cut costs for swine producers. Reducing crude protein (CP) below NRC recommendations will decrease protein deposition and average daily gain. However, these can be offset by the addition of synthetic amino acids. Many studies have shown that pigs fed low CP with amino acid supplemented diets can lead to greater fat deposition. This could be explained by more dietary energy being available for lipogenesis due to less energy needed to digest the protein in the diet (Kerr et al., 1995; Kerr et al., 2003; Le Bellego et al., 2001).

Many studies have studied optimal calorie to protein ratio by limit feeding. These studies showed pigs limit fed had different carcass characteristics at varying diet nutrient densities. Diets that where nutrient dense tended to increase growth and increase back fat. This was because the amount of energy needed to meet energy requirement would easily been met and the pig would have excess energy in the diet. This extra energy was stored as fat. The diets that were nutrient deficient resulted in reduced growth but also had less back fat when pig reached market weight. This was only true when pigs were limit fed because they were not able to eat to meet their energy requirement (Cooke et al., 1972; Lodge et al., 1972). When the pigs were fed the same nutrient dense diets at ad libitum level, the nutrient dense diets would obtain same carcass characteristics, however the nutrient deficient diets had less of a negative effect on pig growth. The pigs on nutrient deficient diets would eat more to meet their energy requirement or eat till their gut was filled. These pigs would be able to overcome some of the negative effects seen at limit fed by consuming more feed (Brumm and Miller, 1996; Smith et al., 1999b).

The objectives of these experiments were to determine the intake responses and carcass characteristics to changes in nutrient density and changes in the ratio of dietary energy to protein in finishing pig diets. Also, to determine if the genetics of modern pigs have changed nutrient requirements compared to studies using older genetic pigs.

Literature Review

<u>Protein</u>

Adequate protein in a swine diet was extremely important for optimal growth. However, the protein in itself is not what is important but the amino acids that make up the protein (Baker and Speer, 1983). During growth some amino acids are needed in larger amounts than other amino acids. When one amino acid becomes limiting in the diet the pig will grow slower. The amino acid lysine is accepted to be the first limiting in most swine diets (NRC., 1998). A pig's growth can still be slowed if the requirement for lysine has been met but another amino acid is limiting. However, just the having all amino acids above requirement may not be enough for optimal growth. The protein content of the diet must be balanced between essential amino acids and non-essential amino acids to allow for optimal growth. A diet that contains this type of protein is referred to as an Ideal Protein (Lewis and Southern, 2001).

Requirements for all amino acids must be met for optimal growth (NRC., 1998). This brings back the concept of adequate protein in the diet. Generally, protein in the diet comes from multiple feed stuffs. Most feedstuffs contain different concentrations of amino acids. When protein concentration in the diet is fed in generous proportion, producers do not need to be concerned with limiting amino acids restricting growth. Limiting amino acids are a concern when producers reduce total protein concentration of the diet in an effort to reduce feed costs. It has been well documented that diets deficient in protein cause pigs to grow slower and fatter (Whang et al., 2003). This was caused by not enough amino acids available to be absorbed by the gut to be lean tissue and the extra energy that would have been used to deposit lean was deposited as fat tissue.

Throughout a pigs life, amino acid requirements change. Growing pigs and sows producing milk have a higher amino acid requirement than older slower growing pigs or sows not producing milk (Lewis and Southern, 2001). Pigs 1 to 5 kg cannot synthesize enough proline to meet their growth requirement. However, proline is not a limiting amino acid for pigs larger than 5 kg. Pigs less than 50 kg can be limited by the amount of arginine, but older pigs do not have a large requirement of arginine. Therefore, arginine is not limiting growth of pigs larger than 50 kg. Lysine is the first limiting amino acid in most feed stuffs and is generally accepted to be the first limiting amino acid throughout entire swine life (Lewis and Southern, 2001). The changing amino acid requirements throughout swine life have been addressed in the 1998 NRC. The 1998 NRC developed a computer model to allow nutritionists to estimate the amount of amino acids needed for optimal growth at any age or sex of swine. The following addresses experiments performed that allowed the NRC to make estimated computer model of amino acid requirements for swine life.

Cooke et al. (1972) showed that by adjusting percent protein from 15.5, 17.4, 20.2, 25.3, and 27.3% in the diet, while maintaining a constant amino acid balance between all diets, increased average daily gain until the protein requirement was met in growing pigs (23 to 59 kg). They also found that as protein increased in the diet, the carcass percent lean increased and the carcass percent fat decreased. This suggests that the energy in the diet went to protein synthesis as more amino acids became available.

In another study by Tyler et al. (1983) they found that increasing protein from 14 to 24% in growing-finishing boars (25 to 99 kg) caused an increase percent lean muscle and had no effect on backfat. They also found that as protein increased, feed efficiency improved until 18% crude protein. At 18% crude protein feed efficiency declined back to 16% crude protein levels. The pig needed to eat less to meet the energy and protein requirement, so less feed was needed to grow at the same rate. However, when protein was added at very high levels, the extra protein was used as energy and feed efficiency declines as protein was not an efficient source of energy.

Protein deposition maybe related to energy density of the diet when crude protein is not limiting in the diet. Campbell et al. (1984) showed that when growing-finishing pigs (25 to 90 kg) were fed diets in excess protein, the rate of protein deposition was directly related to the amount of energy in the diet (Figure 2.1). They found that pigs fed digestible energy (DE) at 3.5 x maintenance had a protein deposition 13.7% better than pigs fed DE at 2.5 x maintenance. These results suggest that at higher energy levels the protein requirement may increase. At the lower energy level with low protein the pigs grew slower and deposited more fat. As protein was increased in the lower energy diet the pigs grew faster with more protein deposition and less fat deposition. When the high energy diet was fed the pigs overall had more protein deposition and less fat deposition than the low energy diet. Also, as protein increased in the high energy diet the pigs deposited more protein and less fat. These results demonstrate that there was an interaction between amount of energy in the diet and amount of protein in the diet and a pig will stop depositing protein when the maximum deposition rate has been reached.

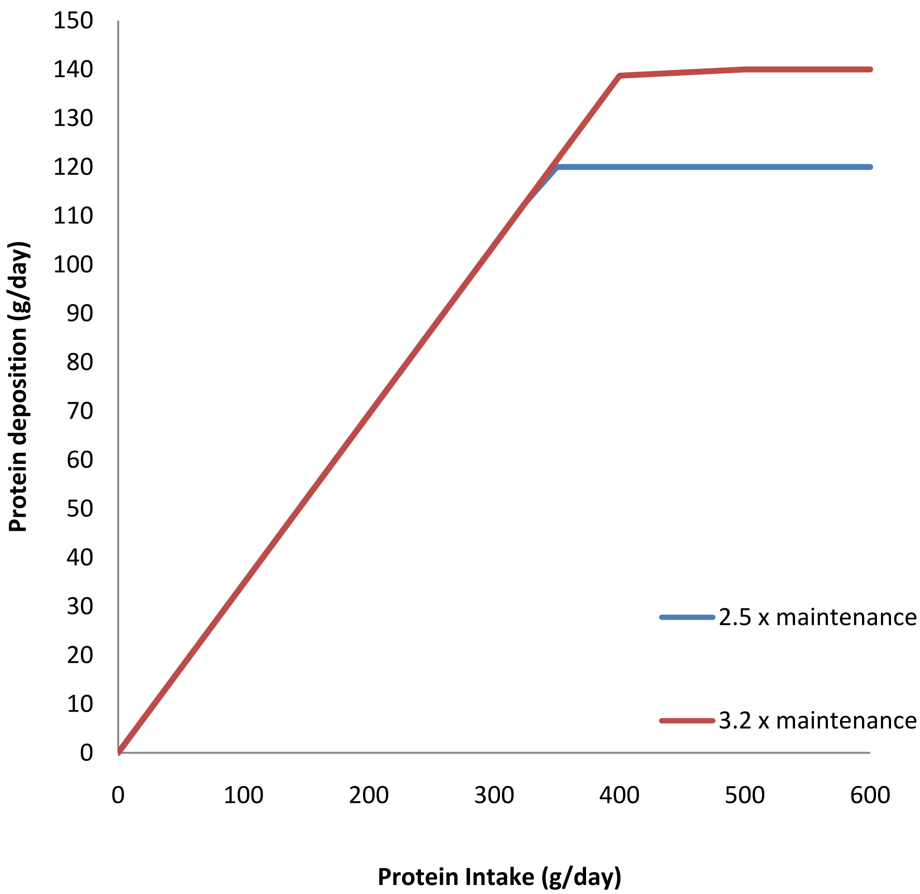

Figure 1.1 - P**rotein deposition is related to the amount of energy intake when protein requirement is met by the diet**[a]

[a]Campbell et al. (1984)

After a period of being fed a diet deficient in energy and protein, pigs typically have a period of compensatory gain where there was increased protein and lipid deposition (Bikker et al., 1996a; Pond and Mersmann, 1990). Whang et al (2003) showed that during the compensatory period the pigs requirement for protein was increased compared to pigs of the same weight that were not feed restricted. They found that when growing pigs were fed a 9% CP diet and 3.50 Mcal/kg it took them 10 days longer to grow from 20 to 30 kg compared to pigs on an 18% CP diet and 3.50 Mcal/kg. This shows that energy was not the only limiting growth factor in growing pigs. When a pig was only protein deprived they grew fatter and slower. After a period of protein deprivation when protein became available, pigs were more efficient in digesting and using that protein. However, both lipid and protein deposition rates are increased but protein accretion is mainly restricted to organ growth and not lean muscle (Bikker et al., 1996a). This suggested that compensatory growth after a time of deprivation depended on whether protein was deficient or if protein and energy were both deficient. Consequently, if the pigs were only deprived of protein and not energy, during the corresponding compensatory period they would increase protein accretion in lean muscle. When the diet was deficient in protein and energy the pig increased growth during the compensatory period to make up for energy and protein loss but the pig stored more energy as fat and increased protein accretion in the organs.

Another factor that can affect the amount of protein consumed is how much space per pig is available. Feed intake is decreased when pigs are not given optimal space (Brumm, 1993; Gehlbach et al., 1966; Randolph et al., 1981). Brumm and Miller (1996) tried to added excess protein in the diet to overcome the decreased intake. However, the addition of protein showed no positive effects to overcrowding. This suggested that protein addition in the diet was independent of the decreased growth.

Over feeding protein is another issue that can have negative effects on performance. Chen et al. (1999) fed finishing pigs 100% above NRC CP recommendation. They found as protein increased over maintenance feed intake decreased, gain decreased and feed efficiency remained the same. However, backfat decreased as protein increased. This could be because pigs overall ate less energy, so less energy was available to be stored as fat. Another reason that pigs performance did not improve as excess protein was added was that high amount of protein may increase maintenance energy needs in the liver, kidneys, GI tract and pancreas because the organs must work harder at digesting, storing and excreting large amounts of protein. This also leads to larger organ size which does not benefit the consumer. Finally, excess protein in the diet is an environmental problem, because the excess protein is degraded and excreted as urea.

Minimizing nitrogen excretion is important to the swine industry for environmental reasons. One way of achieving this is by reducing crude protein in the diet. As previously stated, protein deficient diets can be detrimental to growing-finishing pig performance. Synthetic amino acids can be added to protein deficient diets to increase crude protein without increasing protein rich feed stuffs (Le Bellego et al., 2001). Addition of synthetic amino acids to a low crude protein diet has shown to produce normal pig growth and decrease nitrogen excretion. For every 1 percent decrease in crude protein there is a 10 percent decrease in nitrogen excretion. One negative effect of feeding supplemented diets is that pigs tend to deposit more fat. This could be due to less energy lost in the digestive tract in the form of heat which was used to digest the protein and this energy becomes available to the body to be stored as excess energy or fat.

Kerr et al. (1995) fed diets to growing-finishing pigs that contained crude protein content 4 percent below NRC recommendations (Table 2.1) and supplemented with synthetic lysine, tryptophan, and threonine. They found no differences between the adequate fed pigs and the supplemented fed in their lean muscle area and quality of meat but did find that supplemented pigs had a larger 10th rib fat and larger backfat.

Table 1.1 - Nutrient Requirements of Growing-Finishing Swine[a]

	Growing Swine (50-80 kg)	Finishing Swine (80-120 kg)
ME content of diet, kcal/kg	3,265	3,265
Estimated ME intake, kcal/day	8,410	10,030
Crude protein, %	15.5	13.2
Amino acids, %		
Arginine	0.27	0.19
Histidine	0.24	0.19
Isoleucine	0.42	0.33
Leucine	0.71	0.54
Lysine	0.75	0.60
Methionine	0.20	0.16
Methionine + Cystine	0.44	0.35
Phenylalanine + Tyrosine	0.70	0.55
Threonine	0.51	0.41
Tryptophan	0.14	0.11
Valine	0.52	0.40
Fat (Linoleic acid), %	0.10	0.10
Minerals, %		
Calcium	0.50	0.45
Phosphorus	0.45	0.40
Potassium	0.19	0.17
Sodium	0.10	0.10
Chloride	0.08	0.08
Magnesium	0.04	0.04
Minerals, mg/kg		
Copper	3.50	3.00
Iodine	0.14	0.14
Iron	50.00	50.00
Manganese	2.00	2.00
Selenium	0.15	0.15
Zinc	50.00	50.00
Vitamins, IU/kg		
A	1,300	1,300
D	150	150
E	11	11
Vitamins, mg/kg		
Thiamin	1.00	1.00
Riboflavin	2.00	2.00
Pantothenic Acid	7.00	7.00
Niacin	7.00	7.00
Pyridoxine	1.00	1.00
Folic Acid	0.30	0.30

[a]NRC. 1998. Nutrient requirements of swine, Natl. Acad. Press, Washington, D

Energy

Energy is important in life because energy is used or stored in metabolic processes. Energy is found in all feed stuffs and is given a value of kilocalories (kcal). The total amount of energy in a feed stuff can be determined by bomb calorimetry and is called the gross energy (GE) (NRC., 1998). The GE minus the energy found in fecal is the digestible energy (DE) (Morgan and Whittemore, 1982). DE minus the energy lost in urine and gas is called metabolizable energy (ME) (ARC, 1981). Net Energy (NE) is the most precise way to measure available energy to the pig (Noblet et al., 1994). NE is ME minus heat increment (HI). HI is the amount of heat lost while feed is being digested and heat lost during metabolic activity in the animal. The overall energy flow is shown below in figure 2.2.

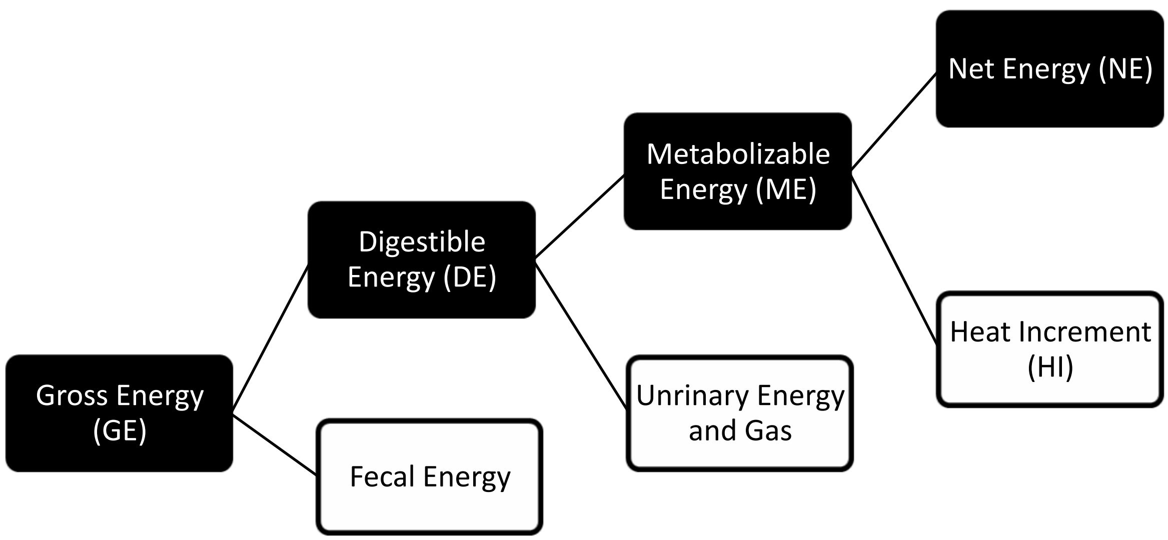

Figure 1.2 Energy Utilization by Pigs

In a typical diet, energy can come from multiple sources. Carbohydrates are the main source in common diets (NRC., 1998). Protein can be used as an energy source when in excess in the body (Campbell et al., 1984). Lipids can be used specifically to increase energy in the diet (Allee, 1984). However, there are multiple reasons why fat might be added to a swine diet.

Fat can change carcass characteristics like increasing intramuscular lipid deposition (Cromwell et al., 1978). The addition of fat can make a diet more palatable (Campbell and Taverner, 1986). Dietary fat is also a source of essential fatty acids and fat soluble vitamins that are necessary to optimal growth (NRC., 1998). The addition of fat to the diet can be used as an energy source in the diet. Fat added to the diet tends to increase voluntary energy intake in hot environments (Stahly and Cromwell, 1979). This allows the pigs to grow normally during a period of heat stress. In thermo neutral environments the addition of fat will decrease intake while the pigs eat the same amount of calories (Seerley et al., 1978). They also showed that during this time other nutrients tend to be slightly more digestible or more available for the pig to use. The type of fat also determines how beneficial the fat is to the pig. Saturated fats form fewer micelles and are not as efficiently digested as unsaturated fats (Bayley and Lewis, 1965).

Campbell et al. (1986) found that the addition of fat to growing swine diet increased growth rate with no detrimental effect on the carcass. Feed efficiency increased linearly as fat was added in the diet. This is because the pigs consumed less feed but grew faster compared to a diet with no added fat. The theory that pigs will eat till they meet their caloric requirement has generally been accepted and could be a possible explanation why feed efficiency increases with fat in the diet (Stahly, 1984).

Smith et al. (1999b) found in barrows from 44.5 to 104.3 kg that the addition of fat (white choice grease) form 0, 1.5, 3.0, 4.5, and 6.0% did not affect ADG but increased feed efficiency. Feed increased linearly as fat was added to the diet from .33 to .36 F:G.

The concentration of blood urea nitrogen (BUN) is indicative of the energy and protein status of the pig. When BUN is high, protein is broken down to be excreted because the body has excess protein or growth is being limited either due to not meeting an amino acid requirement or not enough energy in the diet and protein must be used as a source of energy (Coma et al., 1995). Azain et al. (1991) showed blood urea nitrogen (BUN) decreased by 33% as 10% fat was added to the diet of growing-finishing pigs. This is a desired effect because less nitrogen is lost to the environment. Plasma glucose increased 18% and there was a trend for free fatty acids to increase when fat was added to the diet.

Adding fat during parts of swine life could be one way to maximize feed efficiency without any detrimental effects. Pigs fed 6% fat from 25 to 95 kg then given a no added fat diet from 95 to 115 kg had much less backfat than pigs fed a typical low fat diet from 25 to 115 kg. Pigs fed 6% supplemented fat from 25 to 115 kg tended to gain more fat but overall they had better feed efficiency and average daily gain and consequently could be marketed faster (De la Llata et al., 2001).

The effects of a change in the environment on pig performance have been well studied and documented. In an early study by Heitman and Hughes (1949), they found as the environment got warmer pigs increased their body temperature and respiration rate and feed intake decreased. The pigs subsequently grew slower. In cold environments pigs body temperature and respiration rate decreases. Feed intake increased in very cold environment but average daily gain decreased and feed efficiency was not as good.

Stahly and Cromwell (1979) showed that in hot environments pigs reduce their feed intake as a possible way to reduce heat production in the gastro intestinal tract. They found that growing swine will reduce their feed intake by 17% at 35°C versus 22.5°C. However, in cold environments pigs will eat more to maximize heat production in the gastro intestinal tract as well as obtaining extra energy to stay warm. They found that growing swine will increase their feed consumption by 16% at 10°C versus 22.5°C. They also found that in the hot environment (35°C) when the diet is supplemented with 5% fat the swine increased ADG by 7% versus a diet with no added fat. However, the 5% added fat did not bring ADG to the levels of swine in the 22.5°C environment. The addition of fat to swine diets in 10°C environments did not affect ADG or feed intake compared to diet with no added fat. The results are shown in Table 2.2 below.

Table 1.2 Effect of Environmental Temperature and Dietary Fat Supplementation on Performance and Energy Utilization in Growing Swine

Temperature, °C	**10**		**22.5**		**35**		
Fat, %	**0**	**5**	**0**	**5**	**0**	**5**	**C.V.**
Daily Gain, kg/day	.784	.759	.785	.803	.573	.616	10.8
Daily Feed, kg/day	2.28	2.05	1.95	1.84	1.61	1.49	8.0
Feed:Gain	2.95	2.71	2.48	2.29	2.80	2.45	8.9
ME intake							
Daily ME Intake, Mcal	7.36	7.06	6.29	6.35	5.19	5.14	8.0
ME/Gain, Mcal/kg	9.35	9.30	8.01	7.90	9.04	8.43	8.8

Stahly and Cromwell (1979)

One way swine producers can help alleviate heat stress in hot environments is to supplement the diets with fat. When fat is increased in the diet the total amount of feed consumed is decreased therefore decreasing the heat increment of the feed stuffs. The lower heat increment may allow the pigs to grow normally (Seerley et al., 1978; Southern et al., 1989; Spencer et al., 2005).

In cold environments researchers have suggested that decreasing the energy in the diet by adding fiber maybe beneficial by increasing heat production in the gastro intestinal tract. Fiber is known to increase heat increment of the diet. Studies using Alfalfa meal, Bermuda grass, or both have been done to study effects of added fiber on pig performance. These studies have failed to show to suggested improvement in ADG or increased feed efficiency (Coffey et al., 1982; Seerley et al., 1978; Southern et al., 1989; Stahly and Cromwell, 1979).

Fat deposited by the pig is highly influenced by the type of fat that is fed. A diet containing high amounts of unsaturated fat would be more digestible, but would also make the pigs fat soft (Cromwell et al., 1978). Soft fat is undesirable and will make the carcass less valuable. Supplementing diets with saturated fat such as tallow would be deposited as firmer fat but at a cost. Unsaturated fat can be found in abundance from old restaurant grease. One way to use the unsaturated fat is to saturate it using chemical hydrogenation. There are a couple of problems with this approach. One is if the fat is over hydrogenated it raises the melting point past that of a pigs body temperature. When a fat doesn't melt when ingested, then it becomes virtually indigestible. Another problem is that chemically hydrogenated fat has been shown to decrease feed intake and average daily gain. However, getting the correct unsaturated to saturated ratio can make the pigs fat firmer and not result in decreased pig performance (Gatlin et al., 2005).

Fiber

Fiber was added to swine diets in the 1930s and 1940s to decrease the energy density of the diet. The genetics of swine then predisposed them to deposit more fat because fat was valuable. In the 1930s and 40s the consumer wanted a leaner pig and the only way for a producer to reduce fat deposition was to decrease energy intake. A producer would decrease energy intake by either, limit feeding or decrease the energy density of the diet. Limit feeding required producers to hand feed the pigs which took more time. Fiber was added to the diet to decrease energy concentration of the diet which allowed producers to continue to feed ad libitum (Merkel et al., 1958a, b).

The amount of fiber in the diet did not affect amount of lean muscle growth in a pig (Merkel et al., 1958b). Fiber is an effective tool to reduce energy density. When energy in the diet is held constant with different inclusions of fiber, up to 11%, the pig carcass characteristics remain unchanged (Baird et al., 1970). As fiber increased in the diet, the pig had a less efficient gain to feed ratio and a lower average daily gain. Fiber does not contribute nutritionally to the diet, but acts as a digestive tract filler (Kass et al., 1980a; Kass et al., 1980b; Varel et al., 1984).

As corn prices have increased recently, producers have begun to increase amounts of alternative ingredients, some that are high in fiber. Distillers dried grains (DDGS) is a common ingredient today that is higher in fiber than tradition feed stuffs. Swine have the ability to digest part of the fiber of DDGS in their large intestine with the help of cellulytic bacteria (Varel, 1987). Cellulytic bacteria produce enzymes that are capable of breaking some of the bonds found in fiber. Veral et al. (1984) studied the effect of a high fiber diet on pigs weighing 30 kg for 70 days. They fed two diets: one with low fiber (contained no alfalfa meal); one with high fiber (contained 35% alfalfa meal). The pigs fed high fiber gained 17.3% less overall but consumed the same amount of feed. However, the high fiber diet increased cellulase activity by 48% compared to low fiber diet. This suggests that pigs have the ability to adapt to some increase of fiber in their diet by changing the microbes in their gut and producing more cellulase.

Anguita et al. (2006) fed three diets varying in fiber to pigs weighing 49 kg for 14 days. The pigs were terminal ileum and ileocecal junction cannulated and the study was done in-vitro and in-vivo to determine the digestibility and flow of fiber. The three diets fed were; low fiber (8%), medium fiber (16%), and high fiber (24%). Increasing fiber in the diet caused an increased flow of digesta through the gut. As fiber increased in the diet, short chain fatty acid production in the ileum was increased. Pigs on the medium and high fiber diets digested 19% and 29% less energy in the foregut respectively and 46% and 54% more energy in the hindgut respectively. However, as fiber in the diets increased less of the digested energy in the hindgut is absorbed by the pig and lost to feces or micro organisms. This study has shown pigs can digest up to 24% fiber, but they lose increasing amount energy in the hindgut as fiber increases in the diet. Therefore, feeding fiber in large amounts to pigs may not be efficient or productive.

Another way producers have increased digestibility of fiber is by adding fiber degrading enzymes to the feed. One enzyme that been used in the past is cellulase. Cellulase breaks down cellulose into glucose molecules that are absorbed by the small intestine. Efforts to genetically select pigs that have higher cellulytic bacteria in their large intestine have not improved feed efficiency (Pond, 1987).

Kass et al. (1980a) showed that as fiber increased in the diet backfat decreased and overall gain decreased. The high fiber diets supplied up to 14% of maintenance energy by converting fiber to VFA in the large intestine. Pigs that had a high fiber did not have as efficient digestibility of protein and other nutrients. This was probably due to an increased passage rate that was caused by the high fiber (Anguita et al., 2006). The digesta did not have enough time in the digestive tract to be digested. The viscosity of the digesta was also increased which leads to increased bulk fill and enzymes are less effective.

In another study, when pigs were fed diets with high levels of fiber their gut micro flora increased cellulase production. The type of bacteria found in the large intestine changed to be more like the profile found in the ruminant. This allowed the pigs to digest more of the fiber (Varel, 1987; Varel et al., 1984).

Protein and Fat interaction

In older studies, the effect of varying protein and energy level in the diets feed to swine was studied by limit feeding (Campbell et al., 1984; Cooke et al., 1972; Cromwell et al., 1978; Greeley et al., 1964a). Limit feeding is not a practice commonly done today. In these studies, the pigs gained more weight as protein and energy in the diet increased. Most of the gained weight was gained as backfat when protein levels were not correctly adjusted to meet amino acid requirements (Greeley et al., 1964a; Greeley et al., 1964b). In another limit feed study by Cook et al. (1972) growing pigs were fed at a theoretical optimum ratio of energy to protein where growth characteristics are maximized. As nutrient density in the diet increased, ADG increased until 18% CP and at high CP levels remained constant. A diet with 18% CP and 3.50 Mcal/kg was the most efficient diet to allow the growing pigs to be the leanest and deposit the least fat. A follow up study by Lodge et al. (1972) used 17 to 21.5% CP with three varying energy densities to find the most efficient energy concentration. The diets that were the least nutrient dense gave the pigs the best carcass characteristics. The authors summed up the results best, "Energy increment increased growth rate but not, apparently, deposition of lean tissue, so indicated that dietary energy and dietary protein were acting independently and that an optimal ratio which allows fullest utilization of each for lean growth at carrying levels of intake may not be attainable." However, these studies do not truly study the effect of protein to energy ratio because when limit fed the same amount of feed from each diet, the diets with higher CP and DE provided more energy to the pigs compared to the less nutrient dense feeds. The pigs fed a nutrient dense feed should have been fed a lower amount to keep the caloric intake the same among all treatments if the true effect of CP to energy in the diet was to be studied.

Contrary to the previous research (Carr et al., 1977), the amount of energy consumed by growing pigs has been shown to determine the amount of protein deposition when there are no other nutrients limiting growth (Figure 2.1). When growing pigs were fed 2.5 times maintenance, protein deposition was 125 grams per day. When growing pigs were fed 3.2 times maintenance protein deposition was 141 grams per day. However, even though protein deposition was desired, fat deposition increased from 140 gram per day to 250 gram per day when fed the high energy diet. The increase in lipid deposition that occurs with the increase in protein deposition, suggest that increasing energy density of the diet may not always be warranted (Campbell et al., 1984).

There are many problems when trying to apply studies when pigs were limit fed with today production methods. Since these pigs were not allowed to eat ad libitum, they overall consumed less energy and protein. Therefore, the energy that was consumed went first to the maintenance needs of the animal, then to lean muscle growth, and finally the remaining energy would be stored as fat. When pigs are allowed to eat ad libitum they eat more of the same diet and consequently consume more energy. This extra energy would then go to lipid deposition as all the other needs had been met (NRC., 1998).

Many studies have been done studying the effect of nutrient density of diets when the pigs were fed ad libitum. When pigs are allowed voluntary feed intake, they will eat till they meet their energy requirement (NRC, 1998). There are different factors producers must consider in this type of feeding system: the amount of energy, the concentration of amino acids in the diet, the effect of fiber on feed intake, the nutrient ratios are also important. The specific nutrient ratio of amino acids to energy or lysine to digestible energy (lys:DE) ratio has been a major focus on all ages of growing pigs (NRC., 1998).

Chiba et al. (1991a, b) showed that in 20 to 50 kg pigs, the amino acid concentration in the diet needs to be adjusted to the amount of energy in the diet. As DE increased in the diet from 3.00 Mcal/kg to 4.00 Mcal/kg the pig's feed intake decreased to maintain a nearly constant total energy intake. When feed intake decreased, the pigs gained more fat if amino acids were not increased. In high DE diets, with adjusted amino acid concentration the pigs had better feed efficiency compared to a low DE diet. Digestibility of protein tended to increase as DE increased in the diet. However, in the nutrient dense diets, the pigs gained more backfat. This could be due to more energy available to the pig in a nutrient dense diet and this excess energy was stored as fat. In swine from 20 to 50 kg, protein deposition increased linearly as Lys:DE ratio increased.

Similar studies across all weight ranges concluded that the amino acid concentration in the diet needs to be adjusted to the amount of energy in the diet to obtain optimal growth with the best carcass characteristics (Apple et al., 2004; Bikker et al., 1995; Bikker et al., 1996a; Bikker et al., 1996b; Chen et al., 1999; Chiba et al., 1991a, b; de Greef et al., 1994; De la Llata et al., 2001; La Llata et al., 2007b; Mohn et al., 2000; NRC., 1998; Smith et al., 1999a; Smith et al., 1999b). They also concluded that when amino acids were limiting in the diet the performance and carcass characteristics were negatively affected.

After multiple studies have showed that there is an interaction between the energy concentration of the diet and the amino acid concentration the next step was to determine the optimal lysine the energy ratio.

In young pigs from 10 to 25 kg, there could be a greater need to optimize the ratio because these pigs grow rapidly. Younger pigs need more energy and protein in their diets to obtain maximum growth (NRC., 1998). When 10 kg pigs were fed a ratio of 3 g lysine to 1 Mcal of energy per kg of feed with a ME of 3.25 Mcal per kg of feed they grew the slowest and deposited more fat than the most dense diet, 4.35 g lysine per 1 Mcal of energy per kd of feed with a ME of 4.35 Mcal per kg of feed (Smith et al., 1999a). When the lys:DE stayed constant and energy was increased to 3.51 Mcal per kg there was a 8% increase in backfat depth with no improvement on lean gain. When the pigs were fed increasing Lys:DE diets, their lean gain increased and back fat decreased. As ME of the diets increased with the ratio of Lys:DE, the pigs growth improved. This showed that in pigs from 10 to 25 kg, increased protein in the diet can produce leaner pigs while the addition of energy can increased growth as fat. The addition of both at the correct ratio can optimize growth and carcass characteristics. At a Lys:DE ratio at 3.9 g per 1 Mcal per kg of feed and the ME at 3.38 Mcal per kg of feed, obtained the leanest growth and minimum fat deposition. This diet would be the optimal diet for 10 to 25 kg pigs. Diets higher in lysine increased nitrogen loss and diets higher in energy only increased backfat. The NRC (1998) recommends a diet for 10 to 25 kg pigs of 4.7 g lysine per 1 Mcal per kg of feed and the ME at 3.265 Mcal per kg of feed. Smith et al. (1999a) found that NRC (1998) recommends feeding higher levels of lysine and lower levels of energy for optimal growth than what they had found.

Chiba et al. (1991a) found the optimal lysine to DE ratio of growing pigs from 20 to 50 kg. Diets above a Lys:DE ratio of 3.0 g lysine to 1 Mcal the protein deposition plateau and fat deposition continued to increase. This shows that when diets are fed at a 3.0 g lysine to 1 Mcal DE, the pigs optimized performance by gaining the leanest muscle and the least fat deposition.

Lysine to D.E. ratio was studied in finishing pigs (80 to 110 kg) by Apple et al. (2004). The researchers found that as energy density in the diet increased, the protein concentration had to be increased. When energy was increased without the addition of protein, the pigs increased fat deposition. On the lowest Lys:DE ratio diet (1.7 g to 1 Mcal per kg of feed) the pigs were the fattest and grew the slowest. The pigs on 3.1 g lysine to 1 Mcal per kg of feed grew the leanest while depositing the least amount of fat. The reason pigs on the lowest ratio diet did not grow as well was that amino acids were limiting for growth and the extra energy in the diet was then going to fat deposition.

The effects of adjusting the Lys:DE ratio on growing-finishing pigs (25 to 110 kg) in a commercial environment was studied by La Llata et al. (2007b). These researchers showed pigs in a commercial environment responded to changes in Lys:DE ratio same as pigs in controlled environments. When pigs were fed diets 1.12 g lysine to 1 Mcal per kg with a ME of 3.31Mcal per kg of feed the pigs grew slower and gained the most fat. As the Lys:D.E. increased to 1.69 g per Mcal with a ME of 3.58 Mcal per kg of feed, the pigs gained lean muscle linearly. Diets fed above 1.69 g lysine to 1 Mcal gained more lean at a slower rate and increased their nitrogen excretion. Therefore, feeding a diet at 1.69 g lysine to 1 Mcal and ME with 3.58 Mcal per kg of diet is the optimal diet for grower-finisher swine.

Synthetic amino acids have been used to supplement diets deficient in protein. The use of synthetic amino acids in the diet makes swine have a lower ADG (Gomez et al., 2002). These diets should contain a slightly higher Lys:DE ratio to offset the slower gain. Synthetic amino acids are believed to reduce maintenance energy since less protein catabolism is done in the gut. Consequently, the pig needs to have a higher concentration of amino acids in the diet compared to a non-synthetic diet at the same energy density. There are benefits from using synthetic amino acids such as a 40% decrease in nitrogen excretion and reduction of urinary loss. Using synthetic amino acids can also decrease the total cost of the diet (Smith et al., 1999b).

The use of synthetic amino acids in a growing finishing diet during times of heat stress helps reduce the heat increment of the diet (Kerr et al., 2003). This allows the pigs to consume more feed during heat stress. Grower-finisher pigs (25-110 kg) can be fed diets with CP as low as 12% with supplemented amino acids without any adverse affects. However, when the energy content of the diet was increased 10% with 1.9% tallow, the back fat depth was increased by 10%. When synthetic amino acids are used in a swine diet, the Lys:DE ratio must be adjusted to maintain the optimal growth.

Summary

The increasing costs of feed have forced swine producers place more attention to feeding their herd as efficient as possible. Feeding at the optimal protein to calorie ratio can be a good way of optimizing feed efficiency for the herd. Calorie to protein ratio could become more important as other feeds start to be used as a replacement for corn and soybean meal due to high costs. Being able to feed the new feeds at levels that do not negatively impact the growth and carcass characteristics will become an issue for producers. By demonstrating that feeding a diet at different nutrient densities, but maintaining a constant protein to calorie ratio, produces similar growth and carcass characteristics could help formulate diets with alternative feed stuffs. The new diets will be made to achieve the optimal protein to calorie ratio and the growth performance and carcass characteristics will be similar to that seen with traditional corn, soybean meal diets.

There are potential environmental benefits to feeding at optimal ratio, due to the expected decrease in urea excretion (Le Bellego et al., 2001). Urea from swine farms can produce environmental problems when leaked into streams.

Most importantly, when operating a swine the main goal is to maximize profits. Feeding at an optimal ratio allows producers to control backfat thickness and growth the herd. This allows producers to make their herd as efficient as possible, allowing them to save money. Also, by feeding at optimal lysine to ME ratio allows producers to increase efficiency of their herd growth, which intern decreases feed consumption. Since feed is a major cost to a production herd, by decreasing the amount of feed needed for a hog to reach market weight a producer can save money.

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CHAPTER 2

INTERACTION OF DIETARY PROTEIN AND ENERGY ON GROWTH PERFORMANCE AND CARCASS CHARACTERISTICS IN FINISHING BARROWS

Cline, P.M., R. Dove and M. J. Azain. To be submitted to *Journal of Animal Science*

Abstract

The objective of these studies was to determine the performance response to changes in dietary fat, protein, and fiber content in finishing barrows. Previous work has shown that increases in dietary energy density result in decreased feed intake. Experiment 1 was conducted in 3 trials of 18 pens each (4 pigs/pen, total n=216). Within each trial, barrows (PIC C42 x 280, initial wt. = 84 kg) were blocked by weight and assigned to one of 9 experimental diets in a 3 x 3 factorial arrangement, with main effects of crude protein (12, 16, 20%, lysine: 0.60, 0.80, 1.00%) and added Fat (1, 6, 11%). The lowest protein diet with 1% added fat, met the NRC recommendations for pigs in this weight range. Body weight, intake and efficiency were determined initially and on d 14 and 28. There were no significant interactions of dietary protein and fat. There was a main effect of dietary protein on gain ($P < 0.03$). Average daily gain increased as dietary protein increased from 12 (1.08 kg/d) to 16% CP (1.16 kg/d), but no further increase was observed at 20% CP (1.16 kg/d). There were no effects of protein level on feed or caloric intake or on gain:feed ratio ($P > 0.10$). There was no main effect of dietary fat on gain ($P > 0.05$). There were main effects of dietary fat on caloric intake ($P< 0.01$) and efficiency ($P < 0.01$). Gain was not different in pigs fed 1 (1.10 kg/d), 6% added fat (1.12 kg/d) or 11% fat (1.15 kg/d). Daily caloric intake was increased as dietary fat level increased from 1 to 11% (10.5, 10.8 and 11.8 Mcal/d). Gain:feed ratio improved linearly with fat addition (0.34, 0.36 and 0.38). Serum urea, determined at the end of the feeding period, increased as dietary protein increased ($P < 0.01$), but was not affected by dietary fat. Experiment 2 was conducted in 2 trials of 25 individually penned pigs each (1 pig/pen, total 50 pigs). In each trial barrows (initial wt=85.3kg) were blocked by weight and assigned one of five experimental diets (0.50, 0.55, 0.60, 0.65, and

0.70 % lysine) with a constant lysine: ME ratio (1.833). The lowest diet, 0.50% lysine did not meet NRC requirements however all other diets met NRC requirements. There was main effect of dietary lysine on final body weight, gain, intake, feed efficiency, caloric intake, and lysine intake. All parameters measured increased linearly as %lysine was increased in the diet. Experiment 2 showed that even at a constant lysine: ME ratio swine performance characteristics can vary.

Introduction

Optimizing lean growth and reducing lipid deposition by adjusting nutrient density of the diet can be done by swine producers to increase efficiency of the farm. Changing the amino acid concentration to match the ideal acid pattern has been show to decrease lipid deposition and increase lean growth (Campbell et al., 1984; Cooke et al., 1972; Kerr et al., 1995; Tyler et al., 1983). Over feeding protein caused unwanted affect by decreasing feed efficiency, decreasing gain and increasing nitrogen excretion (Chen et al., 1999). Adding synthetic amino acids in a protein deficient diet improved swine growth and decreased nitrogen excretion by 10% for every 1% crude protein that was supplemented from synthetic amino acids (Le Bellego et al., 2001).

The addition of fat to swine diet is another way producers can improve feed efficiency. Campbell et al. (1986) showed that with the addition of 10% fat, feed efficiency improved by 21%. Feed intake decreased by 10% with no changes in carcass characteristics. Others have shown that the addition of 6% fat to the diet increased ADG and Gain:Feed but also increased backfat on the carcass (de Greef et al., 1994; De la Llata et al., 2001).

The conflicting responses to the addition of fat in the diet suggest that when fat was added to the diet there was a relationship between energy and protein concentration of the diet. The addition of fat and protein together has shown improved pig performance seen by the addition of protein and fat separate, while the lipid deposition decreases (Chiba et al., 1991a, b; Kerr et al., 2003). Since lysine is typically the first-limiting amino acid in swine diets, it is common to express the amount of protein and fat in the diet as the lysine:energy ratio. Increasing the lysine:energy ratio has shown improved ADG and increased gain:feed. La Llata et al. (2007a, b) showed when growing-finishing swine were fed a diet 1.12 g lysine to 1 Mcal per kg of feed the pigs grew slow and gained weight as backfat. As the Lys:D.E. increased to 1.69 g / Mcal the pigs gained lean muscle linearly. Diets fed above 1.69 g lysine to Mcal gained more lean very slowly and increased their nitrogen excretion. Therefore, feeding a diet at 1.69 g lysine to 1 Mcal per kg of diet is the optimal diet for grower-finisher swine. The correct calorie to protein ratio is necessary for optimal growth and best efficiency for producers. When feeding at an optimal ratio a nutrient dense feed can minimize waste and have the best efficiency rate (Smith et al., 1999a).

The objective of experiment 1 was to determine the performance responses to changes in fat and protein content in finishing barrows. We also wanted to find at which lysine:energy ratio the barrows had the best performance. The objective of experiment 2 was to determine performance responses of finishing barrows fed a diet at a constant lysine: energy ratio but with different nutrient densities.

Material and Methods

General

Experimental protocols were approved by the University of Georgia Institutional Care and Use Committee. All nutrient levels met or exceeded NRC (1998) recommendations except for diet 1 in experiment 2. Feed and water were available ad libitum for all pigs during the entire experiment. Nitrogen content of the diet was analyzed using an Nitrogen analyzer (LECO FP-528, LECO Corp., St. Joseph, MI). A bomb calorimeter was used to determine Gross Energy of the diets (Parr 1261 Instrument Co., Moline, IL). To determine crude fat in the diet, A Labconco Goldfisch Fat Extractor (Labconco, Kansas City, MO) was used following the ether extraction AOAC 920.39 official procedure (AOAC 200).

Experiment 1

The experiment was conducted at the University of Georgia Swine center in three replicates using pigs from consecutive farrowing groups. A total of 216 Barrows were used with an initial body weight of 83.8 (±2.3) Kg. Pigs used in this study were from the University of Georgia herd with similar genetic background (PIC C42x280). The diets were given to two pens of four pigs each, done in three continuous replicates from July to November 2007. The diets listed in Table 1 were as follows: 1) low protein/ low fat (LPLF) (12% CP, 0.60% lysine, 1% fat) 2) low protein/ med fat (LPMF) (12% CP, .60% lysine, 6% fat), 3) low protein/ high fat (LPHF) (12% CP, 0.60% lysine, 11% fat), 4) med protein/ low fat (MPLF) (16% CP, 0.80% lysine, 1% fat), 5) med protein/ med fat (MPMF) (16% CP, 0.80% lysine, 6% fat), 6) med protein/ high fat

(MPHF) (16% CP, 0.80 lysine, 11% fat), 7) high protein/ low fat (HPLF) (20% CP, 1.03% lysine, 1% fat), 8) high protein/ med fat (HPMF) (20% CP, 1.03% lysine, 6% fat), and 9) high protein/ high fat (HPHF) (20% protein, 1.03% lysine, 11% fat). The experiment was conducted in a 3 x 3 factorial design to determine the intake responses to changes in dietary energy (1, 5 and 11% fat) and protein (12, 16, and 20% CP). All animals were allotted and placed on LPLF diet one week prior to the start of the experiment so all pigs started from the same diet. Animals were allotted such that average pen weight and weight range were similar in each pen. Dimension in all pens (1.83 m x 4.27 m) were identical. Body weights were determined on days 0, 14, and 28. On days 0, 14, and 28 ultra sound was performed and feeders were emptied to measure feed consumption. At day 28 blood samples were drawn from 2 average weight pigs per pen (determined by d21 weights). These blood samples were used to analyze serum urea nitrogen (SUN). The blood was centrifuged (1,200 x g at 4°C for 20 min) and blood serum was extracted and frozen for later analysis. A commercial kit was used to measure end point SUN concentration indirectly by coupled enzyme reactions involving urease and glutamate dehydrogenase (Sigma BUN End point assay; Sigma Diagnostics, Inc., St. Louis, MO.)

Experiment 2

The experiment was conducted in the Large Animal Research Unit at the University of Georgia two replicates using pigs from consecutive farrowing groups. A total of 54 Barrows were used with an initial body weight of 83.8 (±2.3) Kg. One barrow died during the study and consequently statistics were adjusted. Pigs used in this study were from the University of Georgia herd with similar genetic background (PIC C42x280). The diets were given to five pens of one pig each, done in two continuous replicates from January to March 2008. The diets listed in Table 3.6 were as follows: 1) 0.50% lysine 2) 0.55% lysine 3) 0.60% lysine 4) 0.65% lysine and 5) 0.70% lysine. All diets were formulated to meet a constant lysine: ME ratio of 1.833. All animals were allotted and placed on .60% lysine diet one week prior to the start of the experiment to normalize growth of all pigs. Animals were allotted such that each pig weight and weight range was similar. Dimensions of all pens (1.83 m x 4.27 m) were identical. Body weights were measured on days 0, 14, and 28 BW were measured. At days 0, 14, and 28 ultra sound was performed and feeders were emptied to measure feed consumption. At day 28, blood samples were drawn from each pig. These blood samples were used to analyze serum urea nitrogen (SUN). The blood was centrifuged (1,200 x g at 4°C for 20 min) and blood serum was extracted and frozen for later analysis. A commercial kit was used to measure end point SUN concentration indirectly by coupled enzyme reactions involving urease and glutamate dehydrogenase (Sigma BUN End point assay; Sigma Diagnostics, Inc., St. Louis, MO.)

Fecal samples were collected during weighing on day 21 and day 28. Samples were oven dried at 49°C, finely ground, and placed in -80°C freezer until analysis. Summary of procedure for determining concentration of TiO_2, wet-ash digestion of sample (Njaa, 1961), followed by addition of H2O2 as described by Titgemeyer et al. (2001) to produce an orange/yellow color that was subsequently read at 410 nm using a UV/Vis Spectrophotometer (UV160U, Shimadzu Corp., Colombia, MD). Total serum T3 and T4 were determined by RIA using commercially available kits (ICN Biochemicals, Costa Mesa, CA).

Statistical Analysis

All statistics were performed using General Linear Models procedure (PROC GLM) of SAS (SAS Institute, Inc., Cary, NC). Experiment 1 was analyzed as a 3x3 factorial with fat and protein as factors. Experiment 2 was a randomized block design with 5 treatments. The experimental unit in experiment 1 was pen and in experiment 2 was pig. Least squares means, probabilities of differences and standard errors of the means were obtained to evaluate differences among treatment means. Differences were considered significant at $p<0.05$, also was assumed a trend at $p<0.10$.

Results

Experiment 1

There were no protein x fat interactions on any parameters measured ($P>0.10$) (Table 3.2). Trial interactions ($P<0.05$) were observed for average daily intake (ADFI) for days 0-14 and days 0-28, caloric intake for days 0-14, lysine intake days 0-14 and days 0-28, and for serum urea nitrogen (SUN) on day 28. Trial x protein interactions ($P<0.05$) observed was caloric intake for days 0-14. Trial x fat interactions ($P<0.05$) observed were ADFI for days 0-28, SUN on day 28, caloric intake for days 0-14, 14-28, and 0-28, and LYS for days 0-14, 14-28, and 0-28.

Initial body weights were similar across all treatments (Table 3.2). Increasing dietary protein from 16 to 20% resulted in heavier body weights for day 14 ($P<0.05$). Increasing dietary protein from 12 to 16% resulted in heavier body weights for day 28 ($P<0.05$). Average daily gain (ADG) increased from 12 to 16% protein for days 0-14 and 0-28 ($P<0.05$). On days 14-28

ADG plateaus on 16% protein at 1.19 kg/day (P<0.05). SUN increased from 4.34 mg/dL (12% protein) to 8.59 mg/dL (20% protein) on day 28 (P<0.05) (Table 3.4). Lysine intake increased as protein increased in the diet (12 to 20%) for days 0-14, 14-28, and 0-28 (P<0.05). Change in dietary protein did not have an effect on ADFI, feed efficiency and caloric intake (P>0.05).

Feed efficiency increased 8.3% as dietary fat increased from 1 to 6% for days 14-28 and increased 5.6% for days 0-28 (P<0.05) (Table 3.2). Caloric intake increased from 9.85 Mcal/day to 11.32 Mcal/day for 1 to 11% added fat for days 0-14 (P<0.05). Caloric intake increased from 6 to 11% added fat for days 14-28, and 0-28 (P<0.05) (Table 3.4). Lysine intake decreased from 27.9 g/day to 26.3 g/day from 1 to 6% added fat (P<0.05).

Table 2.5 shows the breakdown of cost in dollar per kg of gain. The results show that as protein increased from 12 to 20% the cost per kg of gain also increased for all days measured (P<0.05). As dietary fat was added to the diet from 1 to 11% the cost per kg of gain also increased for all days measured (P<0.05).

Experiment 2

There were no trial interactions so all data was compiled together. The final body weight for pigs on 0.50 % lysine diet was 7% less than pigs on 0.65% lysine diet (P<.01). Overall, final body weights were heavier for diets containing 0.55% to 0.70% lysine compared to 0.50% lysine diets. (P<.05) (Table 3.7). ADG was lowest for 0.50% lysine and was highest at 0.65% lysine for days 0-14 and 0-28 (P<.05). ADFI was lowest for 0.70% lysine for all days measured

(P<.05). There were no difference in intake for the remaining diets (P<.05). Feed efficiency significantly increased from .50 to .65% lysine diets (P<.05). There was no difference between 0.65 and 0.70% lysine diets (P>.05). Caloric intake was not different from 0.55 to 0.70% lysine diets while for the 0.50% lysine diet had a significantly reduced caloric intake (P<.05). Lysine intake was greatest for 0.65% lysine diet and was lowest for 0.50% lysine diet. SUN was lowest for 0.50% lysine diet and the remaining diets were not significant different (P<.05). There was no difference in backfat or loineye area among diets for and days measured (P>.05)(Table3.10).

Table 3.5 shows the fecal concentration and digestibility of nutrients using titanium as the marker. The fecal energy increased from 0.50 to 0.70% lysine diets (P<.05). The concentration of fecal protein was lowest for .50 and .55% lysine diets and highest for 0.60 to 0.70% lysine diets (P<.05). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were highest for 0.50 and 0.55% lysine diets and lowest for 0.60 to 0.70% lysine diets (P<.05). Fecal concentration of hemicellulose remained unchanged for all diets (P>.05).

Digestibilities of nutrients were measure by percent digested out of total ingested. Calories from 0.70% lysine diet were the most digestible at 83.5%. Calories from the 0.50% lysine diet were the least digestible at 54.4% (P<.05). Protein was 79.9% digestible at 0.70% lysine diet and 45.9% digestible at 0.50% lysine diet (P<.05). NDF and hemicellulose were the least digestible in 0.50 and 0.55% lysine diets. ADF digestibility was not different between the diets (P>.05).

Insulin levels show in Table 3.6 were not different between the different diets (P>.05). T_3 was highest for 0.70% lysine diet at 178.46 mg/dL and was not significantly different between 0.50 to 0.65% lysine diets (P<.05). T_4 was not different for any of the diets (P>.05).

Discussion

Experiment 1

Adjusting fat and protein levels of finishing swine diets did affect performance. The results of this experiment showed an increased in final body weight and ADG for pigs fed increasing amounts of protein until protein in the diet was excessive. Other research has also shown that as protein increased in the diet, pigs had better ADG and increased final body weight (Chen et al., 1999; Cromwell et al., 1993; Kerr et al., 2003; Quiniou et al., 1995; Szabo et al., 2001). The pigs fed 20% CP diet did not have significantly different ADG than pigs fed 16% CP diet. These results show pigs fed 16% CP maximized their ability to utilize the protein in the diet. Other research has shown that pigs fed excess protein decrease ADG (Chen et al., 1999). This can be attributed to the body not being able to make enough enzymes to break down all protein ingested. Also, the breakdown of protein and synthesis of lean muscle requires energy. When excess amounts of protein are fed in the diet, there may not be enough available energy in the diet to maximize growth. This research showed that a decrease in ADG and final body weight was not seen when pigs where fed 20% crude protein.

Lysine intake increased as protein increased in the diet. This was expected, swine consume a constant amount of feed therefore if concentration of protein is higher they will consume more lysine in the same amount of feed. In the NRC (1998) the optimal growth was seen when pigs were fed 19.7 g per day. Pigs on the 12% crude protein diet consumed 17.7 g of lysine per day while the pigs on 16 and 20% consumed 23.9 and 31.1 g per day respectively. These results support the NRC that 19.7 g lysine per day is optimal. Pigs reached their highest ADG and final body weight at 16% crude protein. This shows that the optimal lysine intake should between 17.7 and 23.9 g lysine per day for this experiment.

SUN increased as protein increased in the diet. When protein is fed in excess amounts the pig must dispose of the extra protein as urea (Cameron et al., 2003). Urea then increases in the blood as a result. The excretion of urea does come at a cost to the pig. Chen et al (1999) proposed that urea synthesis can decrease available energy in the body. Therefore, less fat deposition and lean muscle growth can occur. The current experiment did not see detrimental growth at high levels of protein, however there was no growth advantage of feeding 20% CP diet over the 16% CP diet.

The inclusion of fat in the diet only effected feed efficiency. Feed efficiency increased by 5.6% from 1 to 6% added fat and increased again by 5.3% from 6 to 11% added fat. These results support previous research that better digestion and absorption of nutrients from the feed when fat was added to the diet (Campbell and Taverner, 1986; De la Llata et al., 2001; Stahly, 1984). However, for ADFI, caloric intake, and lysine intake a fat x trial interaction was seen ($P<0.05$) (Figure 3.2). For trial 1 and 2 the temperature average high heat index was between 35.0 to 39.4°C. Trial 3 the average high heat index was 21.1°C. The average low temperature was 21.2, 22.3, and 9°C for trial 1, 2, and 3 respectively. The average high temperature was 32.4, 36.3, and 21.5°C for trial 1, 2, and 3 respectively. Since this experiment was split between a hot and cold season the fat effects could have been negated due to the temperature effects on feed intake. The addition of fat to diets during heat stress allows pigs to consume more feed as compared to diets with no added fat (NRC., 1998; Seerley et al., 1978; Southern et al., 1989; Spencer et al., 2005). The addition of fat to diet in normal temperature reduces feed intake and increase feed efficiency (Southern et al., 1989; Spencer et al., 2005; Stahly, 1984). Figure 3.1 shows feed intake for each trial. In the first two trials the addition of fat had no effect on amount of feed consumed. In the third trial the addition of fat allowed feed intake to decrease. These results support the previous statements because during the first two trials the temperature was causing heat stress on the pigs. In this type of environment the addition of fat allows the pigs to consume more feed. The third trial the pigs were in a thermo neutral environment where the addition of fat will cause a decrease in feed intake (Seerley et al., 1978). For those reasons, this experiment had a fat x trial interaction. Caloric intake increased with the addition of fat to the diet in trial 1 and 2. This contradicts Southern et al. where they added 0, 5, and 10% fat and the swine did not change their caloric intake. The results of the current research could be influence by the trial x fat interaction which could be why the pigs did not eat the same amount of energy. During the first two trials, the pigs not consuming high fat diets could have been heat stressed not able to consume as much feed. As the fat was added in the diets the pigs still consumed the same amount of feed but the feed was more energy dense. Lysine intake was also different between trials. During trial 1 and 2 the amount of feed consumed was constant between all diets. During trial 3, the pigs consuming no fat added diets consumed more feed. Ultimately these pigs consumed more lysine. A trial x fat interaction for lysine intake was seen because of these differences.

An optimal Lysine:ME ratio could not be determined from this study (Table 3.3). This experiment did find that as lysine:ME increased ADG also increased. Consequently, this shows that feeding pigs at a higher lysine:ME ratio could be profitable for producers. Smith et al. (1999a; 1999b) and De la Llata et al. (2001) showed that in low energy diets, high lysine:ME ratio, growing pigs decreased backfat. In finishing pigs they found that as lysine:ME decreased intake decreased and feed efficiency increased. This contradicts the current research that suggests pigs maintain a constant intake however, as previous discussed could be due to trial x fat interaction. These results suggest that growth is limited by the amount of energy in the diet. This result is also supported by Chen et al. (1999) and Szabo et al. (2001).

Table 3.5 shows the cost of feeding each diet in terms of dollar per kg of gain. The least cost diet to feed was the 12% protein and 1% fat diet. For producers the least cost way to feed their farm would be to feed low added fat with low protein. To produce market size hogs could take a couple of extra days as ADG is not as high. Overall, the lowest diet per kg of gain would be no fat and low protein.

Experiment 2

The objective of the second study was to determine if the nutrient density of the diet would affect pig performance at a constant lysine:ME ratio. The first study found pig performance was significantly changed when lysine:ME ratio was adjusted (Table 3.3). This study shows that even when pigs are fed at a constant lysine: ME ratio, their performance can vary depending on the nutrient density of the diet. To make a diet that was low nutrient dense, fiber (Solka Floc) was added to dilute out the nutrients. To increase the nutrient density of the diet, fat and soybean meal was added to increase the energy and protein concentration and the fiber was removed. The 0.60% lysine diet is a reference diet for this experiment because it did not have added fat or fiber. The pigs on the least dense diets did not grow as well as the other diets. These pigs could have been reaching appoint of gut fill (Kass et al., 1980a). These pigs were not able to consume enough feed to obtain optimal growth. Varel et al (1984) found feeding 35% alfalfa meal decreased ADG by 17.4%. They also found that pigs on high fiber diets had larger gastro intestinal tracts and consequently larger gut fill at slaughter. In the current study, feeding 16.2% Solka Floc decreased ADG by 18.6%. Pigs on this diet consumed 17.9 g lysine per day. Optimal growth for finishing swine is 19.7 g lysine per day (NRC., 1998). This supports pigs on 16.2% Solka Floc could not consume enough feed for optimal growth. The final body weight for these pigs was not significantly different than pigs fed 0.60% lysine (control, no added Solka Floc or fat) diet. However, the duration of the study may not have been long enough to truly observe growth differences between fiber diets and 0.60% lysine diet. Feeding Solka Floc at 8.1% decreased ADG by 4.2% but this was not statistically significant. Pond (1987) suggests that swine fed fiber over a period of time produce more cellulytic bacteria in the gut which increased digestibility of the feed. In the current study ADG for 16.2% Solka Floc during the first 14 days was .86 kg per day and for the last 14 days was 1.06 kg per day. For the pigs on 8.1% Solka Floc ADG was 1.01 kg per day for the first 14 days and 1.25 kg per day for the last 14 days. Pigs fed 0.60% lysine diet gained 1.18 kg per day. This supports Pond that swine have the ability to adapt to some increase in fiber in their diet.

The pigs on the nutrient dense feed grew as well as the .60% lysine diet. However, the nutrient dense fed pigs were 11.2% more efficient than 0.60% lysine fed pigs. Pigs on 0.65% lysine diet consumed 0.06 kg per day less but was not statistically significant (P>0.05). Pigs fed 0.65% lysine diet tended to have a larger final body weight by 2%, but this was also not statistically significant (P>0.05). ADG was not statistically different for added fat diets compared to 0.60% lysine diets for the first 14 or last 14 days (P>0.05). However, intake was decreased for 0.70% lysine diet compared to 0.60% lysine diet by 14% for days 0-14, 14-28, and 0-28 (P<0.05). This suggests, that pigs on 0.70% lysine diets were more efficient since their final body weights were the same as 0.60% lysine diet. Campbell et al. (1984, 1986) and Smith et al. (1999b) found that diets supplemented with up to 10% fat decreased intake with no adverse effects on gain. They also found the composition of the carcass was not affected by the addition of fat. In the current study, there was no affect of diet on ultra sound estimates of backfat and loineye area. However, this was expected as the lysine:ME ratio did not change between diets. This shows that by keeping lysine:ME ratio constant a producer could be able to add new feed ingredients as they become cheaper than corn and soybean meal without detrimental effects on the carcass.

The digestibilities of the diets were highly influenced by the addition of fiber and fat. The pigs fed 16.2% Solka Floc had the least digestible diet. Kass et al. (1980b) found that feeding up to 60% alfalfa decreased digestibility. They concluded that the decreased digestibility was due to increased passage rate. In the current study, passage rate was not recorded and that conclusion could not be drawn. The addition of fat in the diets (0.65 and 0.70% lysine) had no effect on nutrient digestibility (P>0.05). A review by Stahly (1984) suggests that fat in the diet increases digestibility of the diet. He proposes that fat is digested more efficiently which promotes more energy being available to the pig since less heat is being produced in fermentation and nutrient metabolism. However, he also suggests that the extra energy available to the pig gets deposited as lipid and not lean muscle gain. In the current study the digestibility of nutrients in the fat diets were not significantly different from .60% lysine diet. However, there was a strong linear increase of digestibility as fat increased in the diet. This was probably due to the decrease of digestibility of the diet as fiber increased in the diet.

Insulin was not significantly different between diets, but trended to increase as energy density of the diets increased. T_4 was not significantly different between diets. However, this contradicts previous research by Dauney et al. (1983) that found T_4 was high affected by energy status of a 10 kg pig. They found that as energy in the diet increased, T_4 increased also. In the current study, T_3 significantly increased as energy density of the diet increased ($P<0.05$). This is opposite of what Dauney et al. had seen. However, they suggest that they did not feed high density diets long enough to see T_4 effect and concluded that T_4 will be elevated only if the animal has a maintained positive energy status. From this study, one can conclude that the elevated T_4 could be an indication of a high metabolic status in the pigs which was a result from high energy density feeds.

According to NRC (1998) a diet containing at least .60% lysine at 3.27 Mcal/g or a lysine: ME ratio of 1.833 is where a boar deposits the most lean. This study found that using NRC recommendations of a lysine: ME ratio at 1.833, swine performance and efficiency can still be variable depending on the density of the diet. Therefore just feeding a diet at recommended lysine: ME ratio is not specific enough to maximize feed efficiency. The finishing swine in this study had the most efficient gain at a diet containing .65% lysine with 3,547 Mcal DE. Further research needs to be conducted testing the optimal nutrient density using NRC recommendations of weaning and growing swine.

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Table 2.1 Composition of Diets (as-fed basis) Experiment 1

	Dietary Treatments								
Item	LPLF	LPMF	LPHF	MPLF	MPMF	MPHF	HPLF	HPMF	HPHF
Ingredient, %									
Corn	877.89	81.72	75.56	77.88	71.72	65.56	67.92	61.79	55.66
Soybean Meal 48%	8.46	9.64	10.81	18.72	19388	21.04	28.85	29.95	31.06
Poultry Fat	1.00	6.00	11.00	1.00	6.00	11.00	1.00	6.00	11.00
Limestone	1.02	0.98	0.95	1.05	1.02	0.98	1.09	1.06	1.02
Dical. Phos.	0.81	0.6	0.92	0.62	0.67	0.73	0.443	0.49	0.54
Common Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin Premix	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Mineral Premix	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
DL-Methionine	---	---	---	0.02	0.03	0.03	0.06	0.06	0.07
L-Lysine HCl	0.16	0.14	0.11	0.06	0.03	0.01	---	---	---
Calculated analysis									
Crude Protein, %	12.0	12.00	12.00	16.00	16.00	16.00	20.00	20.00	20.00
ME, g/Mcal	3270	3510	3750	3280	3520	3760	3290	3530	3770
Ether Extract, %	3.76	8.58	13.40	3.53	8.35	13.17	3.31	8.13	12.95
Lysine, %	0.60	0.60	0.60	0.80	0.80	0.80	1.03	1.03	1.03
TSAA, %	0.42	0.42	0.42	0.56	0.56	0.56	0.70	0.70	0.70
Threonine, %	0.42	0.42	0.42	0.58	0.58	0.58	0.74	0.74	0.74
Tryptophan, %	0.12	0.12	0.12	0.18	0.19	0.19	0.25	0.25	0.26
Lysine : ME	1.83	1.71	1.60	2.44	2.27	2.13	3.13	2.92	2.73
Digestible Lysine, %	0.49	0.49	0.49	0.66	0.65	0.66	0.85	0.87	0.88
Chemical analysis									
Crude Protein, %	11.45	12.07	11.82	15.66	15.23	16.76	19.77	19.72	21.26
Ether Extract, %	3.39	7.06	11.97	4.34	5.56	10.90	3.20	7.70	12.89

Table 2.2 Effects of Dietary Protein and Fat on Performance Traits in Experiment 1

	Protein, %				Fat, %				P-values					
	12	16	20	*se*	1	6	11	*se*	Protein	Fat	Protein x Fat	Trial	Trial x Protein	Trial x Fat
Body Weight, kg														
Day 0	83.90	83.50	84.10	0.42	83.30	83.70	84.40	0.42	0.60	0.15	0.15	.022	0.79	0.29
Day 14	98.70^{x}	99.60^{x}	100.50^{y}	0.44	98.80	99.50	101.30	0.44	0.03	0.10	0.50	0.40	0.25	0.82
Day 28	114.10^{x}	116.30^{y}	116.30^{y}	0.63	114.70	115.30	116.80	0.65	0.03	0.09	0.15	0.49	0.28	0.70
Gain, kg/day														
Days 0-14	1.07^{x}	1.13^{xy}	1.19^{y}	0.03	1.08	1.12	1.18	0.03	0.03	0.10	0.50	0.40	0.25	0.50
Days 14-28	1.10^{x}	1.19^{y}	1.13^{xy}	0.02	1.13	1.12	1.17	0.02	0.05	0.32	0.09	0.91	0.60	0.81
Days 0-28	1.08^{x}	1.16^{y}	1.16^{y}	0.02	1.10	1.12	1.18	0.03	0.03	0.09	0.15	0.49	0.28	0.70
Intake, kg/day														
Days 0-14	2.95	2.99	3.02	0.05	3.00	2.95	3.01	0.05	0.68	0.70	0.71	0.01	0.06	0.06
Days 14-28	3.21	3.40	3.28	0.07	3.43	3.23	3.24	0.07	0.13	0.07	0.40	0.80	0.75	0.06
Days 0-28	3.07	3.20	3.15	0.05	3.21	3.09	3.12	0.05	0.26	0.19	0.41	0.04	0.22	0.04
Feed Efficiency, G:F														
Days 0-14	0.36	0.38	0.40	0.02	0.36	0.38	0.39	0.01	0.09	0.12	0.81	0.16	0.71	0.76
Days 14-28	0.35	0.35	0.35	0.01	0.33^{x}	0.36^{xy}	0.38^{y}	0.01	0.86	0.02	0.47	0.61	0.92	0.17
Days 0-28	0.35	0.36	0.37	0.01	0.34^{x}	0.36^{xy}	0.38^{y}	0.01	0.18	0.01	0.44	0.27	0.86	0.30

^{x,y}Within a column, means with a different superscript letter differ ($P<0.05$)

Table 2.3 Effects of Protein and Fat on Finishing Pig Performance in Experiment 1

Fat, %	Protein, %	Lysine/ME g/Mcal	Body Weight	Average Daily Gain	Feed Intake	Feed Efficiency
1	12	1.83	112.20	1.01	3.09	0.33
	16	2.44	117.39	1.20	3.42	0.35
	20	3.13	114.47	1.09	3.21	0.34
6	12	1.71	114.21	1.09	3.05	0.36
	16	2.27	115.23	1.12	3.11	0.36
	20	2.92	116.31	1.16	3.13	0.37
11	12	1.60	115.98	1.14	3.10	0.37
	16	2.13	116.18	1.16	3.11	0.37
	20	2.73	118.28	1.23	3.07	0.40
	Fat, %	1	114.70	1.10	3.21	0.34^{x}
		6	115.30	1.12	3.09	0.36^{x}
		11	116.80	1.18	3.12	0.38^{y}
		P-value	0.09	0.09	0.19	0.01
	Protein, %	12	114.10^{x}	1.08^{x}	3.08	0.35
		16	116.30^{y}	1.16^{y}	3.20	0.36
		20	116.30^{y}	1.16^{y}	3.15	0.37
		P-value	0.03	0.03	0.26	0.18
	Interaction	P-value	0.15	0.15	0.41	0.44

^{x,y}Within a column, means with a different superscript letter differ ($P<0.05$)

Table 2.4 Effect of Dietary Protein and Fat on Serum Urea Nitrogen and Caloric and Lysine Intake on Finishing Barrows on Experiment 1

	Protein, %				Fat, %				P-values					
	12	16	20	*se*	1	6	11	*se*	Protein	Fat	Protein x Fat	Trial	Trial x Protein	Trial x Fat
Serum Urea Nitrogen, mg/dL														
Day 28	4.34[x]	5.50[y]	8.59[z]	0.51	7.06	5.97	5.41	0.51	0.01	0.10	0.74	0.01	0.17	0.01
Caloric Intake Mcal/Day														
Days 0-14	10.38	10.53	10.64	0.17	9.85[x]	10.40[y]	11.32[z]	0.17	0.56	0.01	0.66	0.01	0.04	0.04
Days 14-28	11.07	11.94	11.55	0.24	11.22[x]	11.17[x]	12.18[y]	0.24	0.06	0.01	0.42	0.98	0.96	0.04
Days 0-28	10.73	11.24	11.10	0.17	10.53[x]	10.79[x]	11.75[y]	0.17	0.12	0.01	0.36	.07	0.44	0.01
Lysine Intake g/Day														
Days 0-14	17.7[x]	23.9[y]	31.1[z]	0.4	24.4	24.0	24.3	0.4	0.01	0.75	0.74	0.01	0.10	0.03
Days 14-28	19.2[x]	27.2[y]	33.8[z]	0.5	27.9[x]	26.3[y]	26.2[y]	0.5	0.01	0.03	0.26	0.83	0.79	0.03
Days 0-28	18.5[x]	25.6[y]	32.4[z]	0.4	26.1	25.1	25.2	0.4	0.01	0.12	0.29	0.03	0.25	0.01

[x,y,z]Within a column, means with a different superscript letter differ ($P<0.05$)

Table 2.5 Dietary Protein and Fat Effect on Cost, Dollar/kg of Gain on Experiment 1

	Protein, %				Fat, %				P-values					
	12	16	20	*se*	1	6	11	*se*	Protein	Fat	Protein x Fat	Trial	Trial x Protein	Trial x Fat
Cost, Dollar / kg gain														
Days 0-14	0.82^{x}	0.88^{y}	0.94^{z}	0.01	0.81^{x}	0.87^{y}	0.96^{z}	0.01	0.01	0.01	0.71	0.01	0.05	0.04
Days 14-28	0.89^{x}	1.00^{y}	1.03^{y}	0.02	0.93^{x}	0.95^{x}	1.04^{y}	0.02	0.01	0.01	0.42	0.77	0.76	0.03
Days 0-28	0.86^{x}	0.94^{y}	0.99^{z}	.01	0.87^{x}	0.91^{y}	1.00^{z}	0.01	0.01	0.01	0.42	0.06	0.20	0.02

^{x,y,z}Within a column, means with a different superscript letter differ (P<0.05

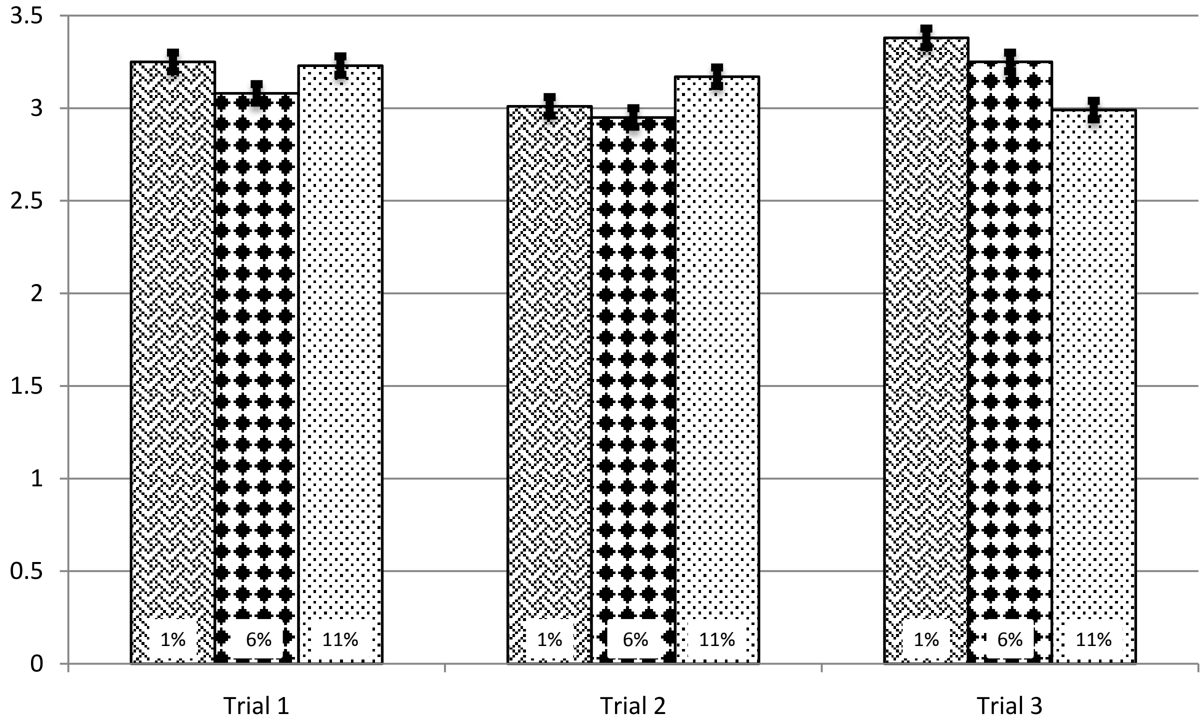

Figure 2.1 Fat x Trial Interaction Effect on Feed Intake, kg/day on Experiment 1

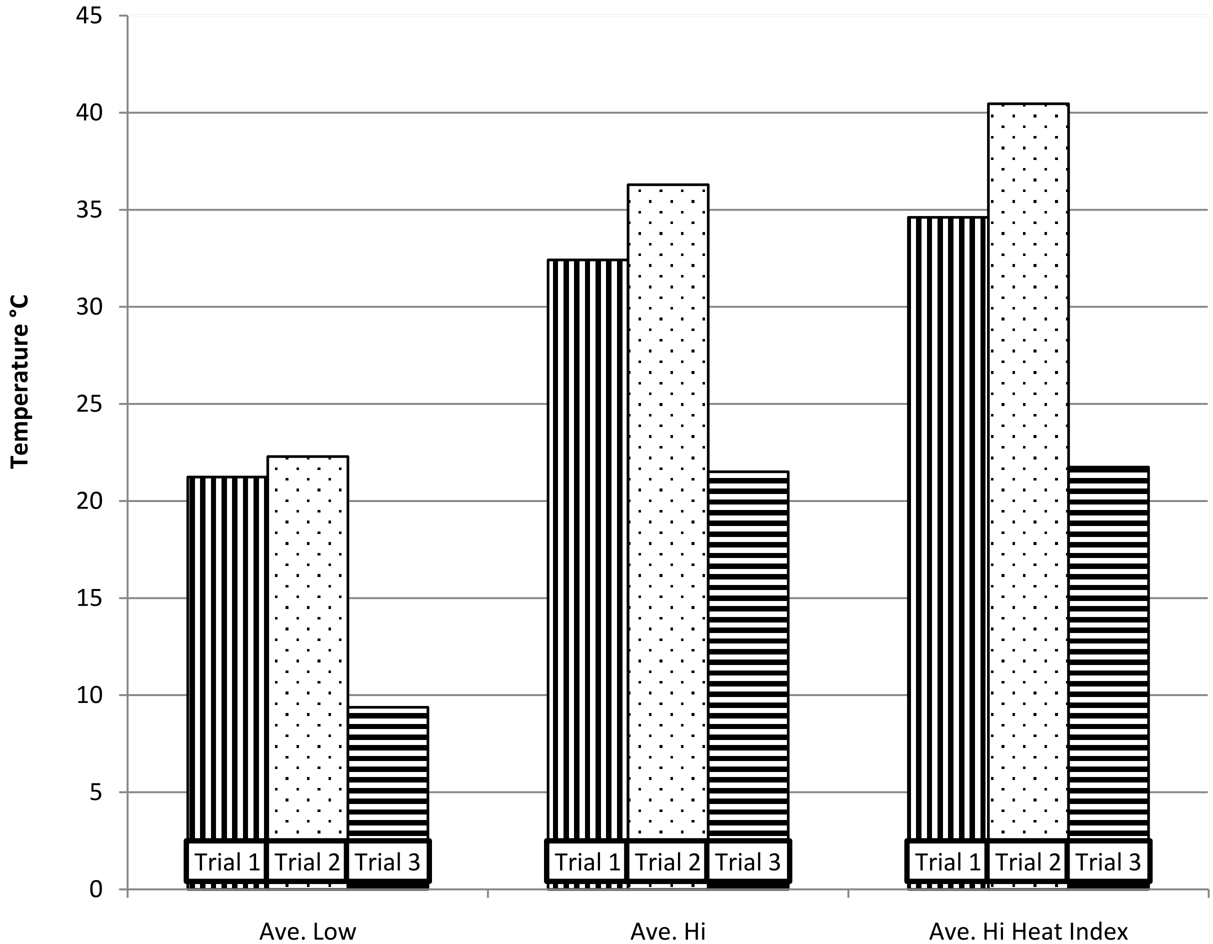

Figure 2.2 Average Temperature During Experiment 1

Table 2.6 Composition of Diets (as-fed basis) Experiment 2

Item	Diets % lysine / ME (as-fed basis)				
	0.50 2.73	0.55 3.00	0.60 3.27	0.65 3.55	0.70 3.82
Ingredient, %					
Corn	70.66	77.73	84.79	76.82	68.83
Soybean Meal 48%	10.69	11.75	12.82	15.21	17.60
Poultry Fat	0.00	0.00	0.00	5.60	11.20
Solka Floc	16.21	8.11	0.00	0.00	0.00
Limestone	0.87	0.89	0.89	0.89	0.87
Dical. Phos.	0.82	0.77	0.73	0.73	0.74
Common Salt	0.35	0.35	0.35	0.35	0.35
Vitamin Premix	0.15	0.15	0.15	0.15	0.15
Mineral Premix	0.15	0.15	0.15	0.15	0.15
Titanium oxide	0.10	0.10	0.10	0.10	0.10
Calculated analysis					
Crude Protein, %	11.33	12.56	13.68	14.14	14.59
ME, g/Mcal	2.73	3.00	3.27	3.55	3.82
Ether Extract, %	2.79	3.07	3.35	8.67	14.00
Lysine, %	0.50	0.55	0.60	0.65	0.70
TSAA, %	0.40	0.44	0.48	0.49	0.49
Threonine, %	0.40	0.45	0.49	0.51	0.53
Tryptophan, %	0.12	0.13	0.15	0.16	0.17
Lysine : ME	1.83	1.83	1.83	1.83	1.83
Digestible Lysine, %	0.40	0.44	0.47	0.52	0.58
Dig. Lysine : ME	1.47	1.47	1.44	1.46	1.52
Chemical analysis					
Crude Protein, %	11.48	12.47	14.18	14.89	15.78
Ether Extract, %	2.25	2.13	2.78	7.43	12.93
ADF, %	24.44	17.83	11.61	13.33	13.36
NDF, %	13.20	8.50	3.00	2.70	2.90

Table 2.7 Performance Characteristics of Growing-Finishing pigs from Effect of Varying Protein Concentrations at a Constant Lysine to Calorie Ratio on Experiment 2

	Dietary Treatments (% Lysine/ME)							
	0.50 2.73	0.55 3.00	0.60 3.27	0.65 3.55	0.70 3.82	SEM	L	Q
Body Weight, kg								
Day 0	85.32	85.28	84.96	84.55	85.32	0.46	.63	.39
Day 14	97.41^{w}	99.47^{wx}	100.83^{xy}	102.33^{yz}	101.78^{xz}	0.84	.01	.12
Day 28	112.22^{w}	116.98^{x}	118.12^{x}	120.65^{x}	116.62^{x}	1.46	.01	.01
Gain, kg/day								
Days 0-14	.86^{w}	1.01^{wy}	1.13^{xy}	1.27^{x}	1.18^{xy}	0.06	.01	.04
Days 14-28	1.06	1.25	1.23	1.31	1.06	0.08	.81	.01
Days 0-28	.96^{w}	1.13^{x}	1.18^{xy}	1.29^{y}	1.12^{wx}	0.05	.01	.01
Intake, kg/day								
Days 0-14	3.30^{wx}	3.56^{w}	3.61^{w}	3.50^{w}	3.12^{x}	0.11	.24	.01
Days 14-28	3.88^{w}	3.97^{w}	3.69^{w}	3.68^{w}	3.17^{x}	0.14	.01	.09
Days 0-28	3.59^{w}	3.77^{w}	3.65^{w}	3.59^{w}	3.15^{x}	0.11	.01	.01
Feed efficiency, Gain:Feed								
Days 0-14	.26^{w}	.29^{wx}	.31^{x}	.36^{y}	.37^{y}	0.01	.01	.91
Days 14-28	.27^{w}	.32^{wx}	.34^{x}	.36^{x}	.33^{x}	0.02	.01	.03
Days 0-28	.27^{w}	.30^{y}	.32^{yx}	.36^{x}	.35^{x}	0.01	.01	.10
Caloric Intake, Mcal/day								
Days 0-14	8.98^{w}	10.69^{x}	11.81^{y}	12.42^{y}	11.93^{y}	0.35	.01	.01
Days 14-28	10.57^{w}	11.92^{wx}	12.07^{x}	13.07^{x}	12.12^{x}	0.46	.01	.04
Days 0-28	9.77^{w}	11.31^{y}	11.94^{yx}	12.74^{x}	12.02^{yx}	0.34	.01	.01
Lysine Intake, g/day								
Days 0-14	16.46^{w}	19.60^{x}	21.64^{y}	22.76^{y}	21.85^{y}	0.65	.01	.01
Days 14-28	19.37^{w}	21.85^{wx}	22.13^{x}	23.95^{x}	22.20^{x}	0.85	.01	.04
Days 0-28	17.92^{w}	20.72^{x}	21.88^{xy}	23.35^{y}	22.03^{xy}	0.63	.01	.01
Serum Urea Nitrogen mg/dL								
Day 28	15.83^{w}	20.71^{x}	19.68^{x}	17.84^{x}	20.21^{x}	1.11	.11	.18

^{w,x,y,z}Within a column, means with a different superscript letter differ (P<0.05)

Table 2.8 Fecal Concentration and Digestibility of Nutrients on Experiment 2

	Dietary Treatments (% Lysine/ME)					SEM	L	Q
	0.50 2.73	0.55 3.00	0.60 3.27	0.65 3.55	0.70 3.82			
Fecal Concentration								
Calories, Mcal/g	4277.0[w]	4222.0[w]	4486.0[x]	4513.0[x]	4688.0[x]	44.0	.01	.18
Protein, %	15.3[w]	16.9[w]	21.1[x]	21.4[x]	20.4[x]	0.5	.01	.01
NDF, %	48.5[w]	48.7[w]	37.8[x]	35.6[x]	35.6[x]	1.5	.01	.14
ADF, %	24.7[w]	21.9[w]	11.5[x]	11.4[x]	11.2[x]	1.1	.01	.01
Hemicellulose	23.9	26.7	26.3	24.2	24.3	0.9	.58	.05
Digestibility, %								
Calories	54.4[w]	74.9[x]	78.3[xy]	78.6[xy]	83.5[y]	2.2	.01	.01
Protein	45.9[w]	72.0[xy]	71.6[y]	71.1[y]	79.9[y]	2.8	.01	.01
NDF	16.4[w]	34.7[wx]	40.9[xy]	53.5[y]	56.3[y]	6.5	.01	.32
ADF	21.3	37.4	24.4	13.1	43.3	9.2	.51	.39
Hemicellulose	11.4[w]	31.2[x]	46.2[xy]	62.3[y]	60.5[y]	6.3	.01	.09

[w,x,y,z]Within a column, means with a different superscript letter differ ($P<0.05$)

Table 2.9 Insulin T_3 and T_4 levels of Growing-Finishing Swine from Effect of Varying Protein Concentrations at a Constant Lysine to Calorie Ratio on Experiment 2

	Dietary Treatments (% Lysine)							
	0.50	0.55	0.60	0.65	0.70	SEM	L	Q
	2.73	3.00	3.27	3.55	3.82			
Insulin, μU/ml	172.88	152.24	207.18	206.16	192.50	18.09	.10	.62
T_3, μg/ml	2.17^{wx}	1.96^{w}	2.21^{wx}	2.51^{wy}	2.77^{y}	0.15	.01	.11
T_4 μg/dl	54.32	57.92	64.62	58.57	67.32	4.63	.09	.90

^{w,x,y,z}Within a column, means with a different superscript letter differ (P<0.05)

Table 2.10 Ultra-sound Measurements on Growing-Finishing Swine Due to Varying Protein Concentrations at a Constant Lysine to Calorie Ratio on Experiment 2

	Dietary Treatments (% Lysine)							
	0.50 2.73	0.55 3.00	0.60 3.27	0.65 3.55	0.70 3.82	SEM	L	Q
Backfat, cm								
Day 0[a]	0.77	0.77	0.77	0.77	0.77	0	.99	.99
Day 14	0.82	0.85	0.92	0.98	0.96	.04	.01	.56
Day 28	0.93	1.01	1.01	1.07	1.04	.04	.06	.31
Net gain 0-28	0.16	0.24	0.24	0.30	0.27	.04	.06	.31
Loineye Area, cm^2								
Day 0[a]	4.10	4.10	4.10	4.10	4.10	0	.99	.99
Day 14	4.56	4.72	4.81	4.45	4.62	.14	.71	.40
Day 28	5.00	5.10	5.44	5.16	5.07	.14	.67	.07
Net gain 0-28	0.86	0.96	1.30	1.02	0.93	.14	.67	.07

[w,x,y,z]Within a column, means with a different superscript letter differ (P<0.05)
[a]Values were co-varied for analysis