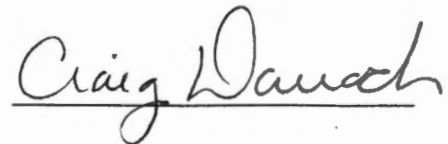


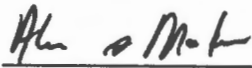
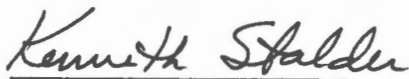
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I am submitting herewith a thesis written by Russell Farrell Gilliam entitled "The Effects of Using High Oil Corn Based Diets on the Performance of Growing Pigs." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Animal Science.

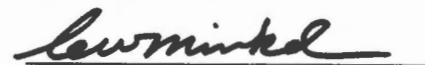


Craig Darroch, Major Professor

We have read this thesis
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Accepted for the Council:



Associate Vice Chancellor and
Dean of the Graduate School

**THE EFFECTS OF USING HIGH OIL CORN BASED DIETS ON
THE PERFORMANCE OF GROWING PIGS**

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Russell Farrell Gilliam
May 2000

AG-VET-MED.

Thesis

2000

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DEDICATION

This thesis is dedicated to my deceased maternal grandfather
Mr. Mahlon Rose,
who never saw me attain the success
that he taught me to achieve when I was a small child.

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There are many individuals to whom I am forever indebted to for my unforgettable and rewarding experiences at the University of Tennessee. I would like to express my deepest appreciation to my major professor, Dr. Craig Darroch for his unlimited help and support throughout my graduate career, his friendship will always be remembered. Dr. Alan Mathew served on my committee and as my academic advisor as a graduate student. He always had the time for professional advice, which was invaluable during my time as a student. I would also like to express my thanks to Dr. Ken Stalder for serving on my graduate committee, he took time out his busy schedule to ultrasound pigs and interpret the measurements for my project. His humor and advice was always beneficial. Dr. Frank Masincupp served on my committee and made a conscious effort to mold me into a seasoned card player. To Dr. Kelly Robbins, for helping move pigs and providing the knowledge and patience to make my metabolism study a success.

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ABSTRACT

To remain competitive in today's swine industry, producers must utilize every tool available to efficiently raise pigs to market. Nursery feeds are the most expensive feeds used by swine producers, and decreasing nursery feed costs and maintaining or improving pig growth performance in this phase of production would allow producers to increase profits.

The two experiments in this thesis research project focused on: one, the effects of using high oil corn (HOC) in a nursery phase feeding program; and two, the relative nutrient availability in HOC, damaged HOC, and commercial corn. Results from these experiments provide information that producers can use to formulate lower cost nursery diets that promote efficient growth in young pigs.

In the first study, 558 crossbred pigs ($n = 293$; Trial 1, $n = 265$ Trial 2) were weaned, segregated by sex, and weight into small, medium and heavy groups, and allotted to 12 nursery pens. Pigs received one of two dietary treatments; (1) a commercial transitional phase I diet for 7 days; a corn-based phase II diet for 14 days, and a phase III diet (NCIII) for 7 days; (2) a HOC-based phase II diet for 21 days and the NCIII diet for 7 days. Average daily gain (ADG), average daily feed intake (ADFI) and feed to gain (F/G) ratios were measured weekly during the nursery period. Pigs were transferred to a grow/finish barn on day 28, and bodyweight (BW) and ultrasound measurements were taken for back fat (BF) and loin eye area (LEA) at the 10th and last ribs four times prior to market. ADG of nursery pigs on the three-phase diet was greater than pigs fed the HOC two-phase diet at day 21 ($P = .0034$) and 28 ($P = .0128$). ADG for heavy pigs was greater

($P = .0001$) than that of medium and light weight pigs, and no treatment x weight group interactions were observed ($P = .2043$). Pigs fed the three-phase diet had greater G/F ratios than pigs fed the HOC two-phase diet at day 21 ($P = .0137$) and 28 ($P = .0134$). LEA of pigs fed the three-phase diet was greater than that of pigs fed the HOC two-phase diet when measured on day 28 at the 10th ($P = .0565$) and last rib ($P = .0370$). There were no effects of treatment on BF. Even though pigs were fed alike in the grow/finish period, ADG of pigs fed the three-phase nursery diet was greater ($P = .0106$) than that of pigs fed the HOC two-phase nursery diet. Based on loin eye area and backfat measurements, throughout the grow/finish period there was a tendency ($P = .0728$) for pigs fed the three-phase nursery diet to be leaner than pigs fed the HOC two-phase nursery diet. However, the average daily lean gain between treatments was not different throughout the experiment ($P = .8611$). The results suggest that removal of the transitional phase I diet and the substitution of HOC for corn in a phase II diet fed to nursery pigs did not support maximal BW and lean gains in the nursery and subsequent grow/finish periods.

In the second study, the objective of the trial was to determine the relative nutritive values of damaged high oil corn (DHOC), undamaged high oil corn (HOC), and normal yellow corn (NC). Two groups of 12 crossbred barrows, with an average initial weight of 32.1 kg, were placed in stainless steel metabolism crates in a RCBD to determine energy and protein digestibilities of HOC, DHOC, and NC. In each 10-d feeding period (5-d adaptation, 5-d collection), pigs were fed the test grain as the only source of protein and energy in the diet. Vitamins and minerals were supplied to meet NRC (1998) requirements. Damaged HOC had lower ($P < .0001$) 1000 kernel weights,

(238.1 g; n = 5) when compared to HOC (355.4 g) and NC (272.0 g). This was related to differences in the quality of each corn type. Compared to HOC, damaged HOC had fewer intact kernels (50.8% vs 77.0%, $P < .0001$), more damaged whole kernels (15.9% vs 5.0%, $P < .0001$), more fragmented kernels (32.3% vs 17.6%, $P < .0001$) and more chaff (0.9% vs 0.4%, $P = .0028$). NC had the greatest percentage of intact kernels (87.9%), and the lowest percentages of damaged whole kernels (1.5%) and fragmented kernels (10.2%). NC and HOC had similar levels of chaff and fines. Despite differences in quality, HOC and DHOC had higher GE values (3866 kcal/kg and 4081 kcal/kg, respectively) than NC, which averaged 3562 kcal/kg. HOC had the highest level of crude protein (9.1%), DHOC was intermediate (8.9%) and NC had the lowest crude protein level (7.6%) ($P = .0001$). The coefficient for crude protein digestibility was not different for the treatments ($P = .1145$). Test corn digestible crude protein was different ($P = .0001$), DHOC and HOC were greater than NC, (8.1, 8.1 and 6.8 respectively). Final pig live body weights, adjusted for initial BW were not different among treatments ($P = .8692$), but pigs in the second replication were heavier ($P = .0168$) than those in the first replication. The metabolizable energy values were different for the treatments ($P = .0174$), 3367.1 ± 89.96 , 3330.6 ± 89.68 , 3002.4 ± 89.77 for DHOC, HOC and NC, respectively. The ME:DE ratios which averaged .975 were not different ($P = .9952$), among treatments. The results of this experiment suggest that damage to HOC did not significantly lower protein quality and availability, or have a large impact on digestible energy levels of HOC. HOC even when damaged may be used as a replacement for commercial corn in diets for growing pigs.

High oil corn in place of NC in a phase II nursery diet did not support optimum growth for nursery pigs when used in place of a transitional phase I diet in a nursery phase feeding program. However, formulation of a phase II diet containing HOC and some higher quality ingredients found in a transitional diet could lead to a diet intermediate in cost compared to a transition diet that would provide nursery pigs with the nutrients to optimize performance.

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1. INTRODUCTION

The need for swine producers to improve pig production has resulted in earlier weaning ages for pigs (Ravidran and Kornegay, 1993). As a result of an earlier weaning age, young pigs are impacted more by nutritional and environmental stressors. At weaning, the change in diet from milk based products to animal and plant based products often leads to digestive disturbances and reduced growth performance, which is referred to as post-weaning lag (Ravidran and Kornegay, 1993). The post-weaning lag period will typically occur during the first week after weaning and may last up to two weeks, depending on the severity of conditions. The lag period has not been studied extensively enough to attribute it to one specific area of development or dietary composition, but it has been attributed to sudden changes in ingredient quality and a shift from liquid to solid diets at weaning. In most instances, the gastrointestinal tract of the early-weaned pig has not matured sufficiently to digest and absorb nutrients in lower quality plant feedstuffs like corn and soybeans. However, the losses associated with the impairment of growth rates due to weaning stress can continue into the grow-finish phase and result in losses that are not attributed to weaning. Attempts to shorten or eliminate the post weaning lag period have led to the development of expensive, highly digestible transitional diets based on animal products.

During the post weaning lag period, nursery pig death loss is estimated to be 2.5 million of the 98 million pigs produced in the U.S. each year (USDA, 1992). Death losses in the nursery represent a monetary value of 80 million dollars per year, assuming a cost of \$25 per weaned pig and a potential for \$10 profit per finished pig per year (Rawls,

1993). On well-managed farms, high priced, high quality transitional diets are routinely fed to early-weaned pigs in an attempt to minimize mortality in the nursery.

Producers are now interested in ways to reduce costs of production associated with the feeding of transitional diets. At weaning, the introduction of plant feedstuffs into the diet of young pigs helps stimulate gut development. Value-added plant feedstuffs have been developed, marketed, and have the potential to reduce some of the higher priced animal feedstuffs in transitional diets without affecting growth performance of weaned pigs. Compared to traditional plant feedstuffs, improved plant varieties such as high oil corn are higher in nutritional quality and may be absorbed more efficiently in the young pig, reducing the post weaning lag period. Therefore, the following experiments focus on evaluation of HOC as an ingredient in nursery diets for weaned pigs.

2. LITERATURE REVIEW

The U.S. is by far the world's largest producer of corn, and nationally corn production has surpassed the combined total of all other major grains (Weber, 1978). Prior to 1976, approximately 88% of corn grown in the U.S. was used in livestock feed (Han et al., 1987), but today only 55% of the corn crop finds its way into livestock feeds (Lambert et al., 1998). Global trading and new uses for corn in human and industrial applications have contributed to the shift in corn usage in the U.S. This increased competition for corn has affected the price and availability of corn in livestock feeds. As producers adjust to these changes, they are now looking at alternative energy feedstuffs in pig diets. New value-added plant feedstuffs such as high oil corn (HOC) may provide several cost effective opportunities for the swine producer.

2.1 HIGH OIL CORN CHEMICAL COMPOSITION

High oil corn is a value added, energy dense feed ingredient with more oil and improved protein quality when compared to normal yellow corn. The average chemical composition of dry, conventional yellow corn is 80% carbohydrate, 8.6% crude protein (CP), 4.5% oil, 3.5% fiber, and 2% minerals (NRC, 1998). The protein content of high oil corn is typically higher than normal corn, which decreases the requirement for other protein sources, commonly soybean meal, in swine diets. It has been shown that as the protein content in high oil corn increases, the oil increases as well (Dudley-Cash, 1996). The introduction of high oil corn into nursery diets allows the producer to increase energy and protein content with less supplemental ingredients. Studies with some of the first HOC varieties (Hogan et al., 1955), showed that as CP increased in the kernel, the level

of lysine as a percentage of CP usually decreased along with protein quality. This was not the case for HOC varieties developed and tested later by Han et al., (1987). In this study, both lysine and protein quality increased as oil levels increased. Lambert et al., (1998), also found higher lysine levels in HOC. In general, HOC varieties have more germ than traditional corn, and the lysine:protein ratio in the germ is higher than in most other parts of the seed (Dudley-Cash, 1996). Approximately 90 to 95% of the oil in the corn kernel is located in the germ. Selection for increased oil concentration in the kernel has resulted in an increase in germ size, with an increase in oil concentration in the germ and a reduction in the size of the endosperm (Lambert et al., 1998).

2.2 GENETIC DEVELOPMENT OF HIGH OIL CORN

The breeding of corn for high and low oil contents was first initiated at the University of Illinois in 1896 (Han et al., 1987). In 1981, after numerous breedings of mass selection, the Illinois high oil strain emerged with 19% oil (Weber, 1978). Proper breeding and selection techniques have produced HOC varieties with yields comparable to conventional corn varieties, but which contain 6-8% oil (Creech and Alexander, 1978; Han et al., 1987). There are now over 70 different strains of HOC, with various levels of oil and grain yields (Han et al., 1987).

The Top Cross method from Dupont of producing HOC consists of pollinating corn plants from a cytoplasmic male-sterile single cross hybrid with pollen from high oil male-fertile hybrid corn plants. When fields are planted using a mixture of approximately 92 to 94% male-sterile hybrid corn seed and 6 to 8% male-fertile HOC seed, pollinated corn plants will produce kernels with an oil level of 60 to 80 g kg⁻¹ (Lambert et al.,

1998). Pioneer recently developed varieties that are true hybrids unlike the single cross hybrids produced by the Top Cross method. Pioneer hybrids are not currently available, but are expected to have advantages when they reach market (Dudley-Cash, 1996).

2.3 ANIMAL FEEDING TRIALS

The use of high oil corn has received increased attention as swine producers strive to become more efficient. However, there is little information on the inclusion of high oil corn (HOC) in diets for young pigs in the nursery. High oil corn could potentially alleviate difficulties associated with: mixing, storage, handling and automated delivery of fat supplemented diets (Chiba et al., 1985).

2.3.1 High oil corn use in nursery diets

There are few studies that focus on the utilization of high oil corn in nursery diets. Adams and Jensen (1987), reported no differences in average daily gain when compared to normal corn, but noted lower feed intakes and higher gain to feed ratios for pigs weaned at 28 days of age and fed high oil corn for 28 days. Spurlock et al (1997), also noted the same effects on feed intake and gain:feed. Bergstrom et al., (1996), fed high oil corn and noticed improved gain:feed for pigs fed high oil corn when compared to normal corn. There were no differences noted for average daily gain, so they are in agreement with the results of Adams and Jensen, (1987). However, a second experiment was conducted and average daily gain and gain:feed were impaired from day 4-14 when high oil corn was fed and compared to normal corn and normal corn plus soy oil. Adams and Jensen (1987), weaned pigs at 10 kg and fed them for 105 d, but did not detect any changes in average daily gain, average daily feed intake, gain:feed, backfat depth, and

loin eye area. DeCamp et al. (1998) reported decreased performance of pigs when fed high oil corn compared to pigs fed normal corn and weaned at 28 days of age. It was noted that pigs fed high oil corn performed better at later stages of development and this was attributed to the pigs' ability to digest fat later in life. Pigs fed high oil corn had a higher feed intake from days 0-14 and 0-25 post weaning. Serum urea nitrogen for high oil corn and high oil corn supplemented with amino acids was noted to be higher than normal corn, and normal corn plus oil and synthetic amino acids, which would suggest high oil corn is not utilized as efficiently as normal corn by the young pig.

2.3.2 High oil corn in grow-finish trials

Carroll and co-workers, (1999) fed diets containing high oil corn and high oleic, high oil corn, and noted differences in growth performance, and pork quality. High oleic, high oil corn increased feed consumption during the grower and finisher phases. Yellow corn supplemented with choice white grease decreased consumption and improved feed efficiency in both the grower and finisher phases of production. ADG was not affected by inclusion of high oil corn in grower and finisher pig diets (Adams and Jensen, 1987; Bowers et al., 1999a), but these researchers also observed an increase in feed efficiency. However, incremental improvements in feed efficiency did not reach the typical 2% level noted for each 1% addition of supplemental dietary fat (Bowers et al., 1999a). In contrast, Carroll et al., (1999), reported a decrease in feed efficiency when high oil corn was fed to market hogs. Morris et al. (1999) noted that animal performance was similar for average daily gain, and gain:feed; and that carcasses had similar values for dressing percentage, lean yield, color score, marbling core, and percent drip loss.

Carcass traits do not seem to be greatly affected by dietary treatment with high oil corn when compared to normal yellow corn (Adams and Jensen, 1987; Bowers et al., 1999a; Morris et al., 1999). Carroll et al., (1999) recorded higher carcass pH and Bowers et al., (1999a) noticed that some HOC fed pig carcasses had less backfat.

2.3.3 High oil corn use in sow diets

Bowers et al. (1999b), noted the effects of HOC on sow production during lactation, based on body weight, feed intake, backfat depth, and weaning performance of the pigs. Adams and Jensen (1987) fed HOC to sows in gestation and throughout lactation and observed changes in reproduction and growth performance. Litter size was not different among sows fed diets based on high oil corn, normal corn, or normal corn plus fat (Adams and Jensen, 1987; Bowers et al., 1999b), but average piglet weights from sows fed high oil corn diets were greater (Adams and Jensen, 1987). This is beneficial to producers because several trials have shown that pigs with heavier birth weights grow more efficiently in the grower and finisher stages of production. Sows fed diets with supplemental fat or HOC had higher daily energy intakes and this resulted in greater litter weight gains over the entire lactation period when compared to sows fed normal corn. ADFI increased for high oil corn and normal corn plus fat fed sows for the first week of lactation (Bowers et al., 1999b), but was decreased in trials by Adams and Jensen (1987). Sows fed high oil corn gained more weight in gestation (Adams and Jensen, 1987) and lost more body weight in lactation when compared to sows fed normal corn plus fat (Bowers et al., 1999b). After production data was split to separate high producing sows (those that weaned 10 or more pigs per litter) from average sows, litter weight gains

throughout the trial were higher in sows with increased energy intakes. When Adams and Jensen (1987) measured milk composition, they noted an increase in fat content in colostrum, but did not detect any differences in DM, ash, or crude protein. When milk was tested on day three of lactation, DM and fat tended to be slightly higher, and crude protein lower, for milk from sows that received a high oil corn diet compared to normal corn fed sows.

2.3.4 High oil corn in poultry diets

The inclusion of HOC into broiler diets improved gain:feed in broilers by as much as 14%, and has increased feed conversion when incorporated into laying hen diets (Han et al., 1987), but did not enhance the growth rate of broiler chicks. Han et al., (1987), reported feed efficiency was highly correlated to oil content of the corn. Under normal feeding conditions, it is necessary to supplement corn-soybean meal based broiler diets with 4-8% fat to provide enough dietary energy to support maximum growth rates. Han et al. (1987) achieved maximal growth rates in broilers by feeding diets based on high oil corn alone.

Laying hens given high oil corn had a higher egg:feed ratio and greater body weight gain than hens fed diets containing normal yellow corn (Han et al., 1987). These responses were attributed to the higher fat and energy ratios in HOC based diets compared to diets based on yellow corn. The trials were conducted in the summer months, and it has been shown that fat supplementation in laying hen diets often improves performance when the environmental temperature is high (Valencia et al. 1980).

2.3.5 High oil corn use in dairy rations

Previous studies that focused on feeding high oil corn as a grain, and as a silage to dairy cattle have reported variable effects on performance. High oil corn has been shown to improve feed efficiency of dairy cattle (Lambert et al, 1998). Atwell et al. (1988), observed a decreased dry matter (DM) digestibility, when HOC was substituted for normal corn in diets. As silage, high oil corn varieties have lower neutral detergent fiber (NDF) and ether extract (EE) digestibilities, when compared to typical corn silage, and this reduced total diet digestibility in Atwell's study. LaCount et al., (1995) and Elliot (1993) reported that there were no differences in dry matter intake (DMI) between lactating cows fed high oil or normal corn varieties. Replacement of normal corn grain with high oil corn resulted in an increased acetate:propionate ratio in studies conducted by Elliot et al.(1993) and Atwell et al.(1988) on dairy cattle. Cows that experience intake inhibition due to high starch diets will typically have low acetate:propionate ratios. Elliot et al. (1993), stated that an increase in the starch content of the diet increases the incidence of intake inhibition due to a higher percentage of VFA being produced in the rumen, which is commonly referred to as acidosis. In high oil corn, some of the starch portion of the grain is replaced by oil and may be beneficial in reducing the incidence of intake inhibition by reducing the rate of microbial fermentation. This would reduce the rate of VFA production and prevent the drop in pH that is associated with the feeding of high starch feeds. Atwell et al. (1988), attributed the increased feed intake in his trials with high oil varieties to the reduction in the incidence of ketosis in cows in early lactation, which is in agreement with Elliot et al. (1993).

Ketosis is seen in lactating dairy cattle, which are regularly in a negative energy balance. In this state, cows breakdown fat to ketone bodies, and the resulting increase in circulating ketones lowers blood pH. There have been reports that as many as 50% of high producing cows experience signs of subclinical ketosis during early lactation (Atwell et al., 1988), which results in a lower DMI (Baird et al., 1982). Studies have also shown a trend for increased milk yield when cattle were fed high oil corn grain compared to normal corn grain in early lactation, but not when measured throughout an entire lactation. This effect was not observed when normal corn silage was replaced by high oil corn silage (LaCount et al., 1995).

2.4 FAT AND OIL DIGESTIBILITY

Studies have shown that dietary fat is a more efficient source of energy than dietary carbohydrate or protein (Donato and Hegsted, 1985). As fat enters the body of non-ruminants it is first attacked by lipases, which are present in gastric, bile and pancreatic secretions. Lipases will hydrolyze the ester bonds of triglycerides, leaving glycerol backbones, and di and mono-acylglycerides. Glycerol will quickly be absorbed in the small intestine by passive diffusion. The mono-acylglycerides that are left are emulsified by bile salts. These bile salts, which are hydrophilic in nature, allow the hydrophobic glycerides to form a micelle. The micelle is a fat droplet with a hydrophobic interior and a hydrophilic exterior that is absorbed by the enterocytes of the intestinal wall via passive diffusion. After diffusion of the droplet through the intestinal wall, the micelles dissociate or break apart, and the fatty acids and monoacylglycerides are reesterified to triacylglycerides. The triacylglycerides are then combined with cholesterol,

phospholipids, and protein to form chylomicrons. Chylomicrons enter the lymph system through lacteals and eventually enter the general circulation where they are distributed to peripheral tissues and organs such as the liver (Mathew, 1998).

Rendered animal fat is efficiently utilized by pigs, because it has a fatty acid profile that closely resembles the pattern seen in body tissues and the digestive and absorptive processes are relatively simple. Compared to fat, carbohydrate and protein digestion and absorption in pigs is complex and involves more enzyme activity. In the newly weaned pig, enzyme activity is limited due to insufficient gut development and this can reduce nutrient utilization, particularly of protein and carbohydrate. Because HOC derives a greater percentage of energy from fat, it may be of more importance nutritionally than conventional corn in diets for the newly weaned pig (Han et al., 1987).

Fat typically contains 2.25 times more energy as the same amount of dietary carbohydrate. The use of fat in diets has been examined extensively for a number of years and has been shown to reduce average daily feed intake (ADFI), increase gain:feed (G/F), and average daily gain (ADG). Increasing the digestible energy level of swine diets through fat or oil addition has reduced, improved, and had no effect on performance of pigs (Adams and Jensen, 1984,1987; Howard et al., 1990; Brumm and Peo, 1994).

Adams and Jensen (1987), suggested that an extensive formation of micelles containing saturated fatty acids immediately post-weaning may have contributed to the growth lag at weaning in many studies with young pigs fed supplemental fat (Lawrence and Maxwell, 1983; Cera et al, 1988, 1990). The digestibility of fat (Frobish et al., 1969; Eusebio et al., 1965; Ewan, 1970) and protein (Howard et al., 1990; Cera et al., 1988) increases with age

post weaning and parallels an increased digestive enzyme activity (Cera et al., 1988).

Hartman et al., (1961) observed that both pancreatic lipase and rate of weight gain increase with time after weaning. The reduced rate of gain after weaning may also be affected by the stress of weaning and weaning weight. Pigs with greater weaning weights have been shown to adapt to a weaning environment quicker than those weaned at lower weights. Heavier pigs may have a more developed gastrointestinal tract. As weaning weight increases there is a reduction in the length of the post weaning growth lag (Howard et al., 1990).

Increasing the caloric density of animal diets will typically reduces average daily feed intake (Miller, Ullrey and Lewis, 1991) and increases protein accretion in pigs that are less than 50 kg (Edwards and Campbell, 1993). Howard et al., (1990), reported that piglet (5 to 15 kg) performance at weaning was suppressed when feed intake was reduced through fat supplementation. Piglets did not increase their rate of gain and required more feed per unit of gain. This contradicts the results of Howard et al., (1990) and Eusebio, (1965), who both showed an increased rate of gain and increased G/F when fat was added to the diet of growing pigs (15 to 40 kg). One explanation of the observed differences in performance may relate to differences in the type and quality of supplemental fat used in the studies. The use of coconut oil, which contains more medium length fatty acids, in a diet for lightweight (5.8 kg) weaned pigs led to increased performance, but when fed to pigs in a heavyweight (8.1 kg) group there were no improvements in pig performance (Cera et al., 1988). Coconut oil may produce smaller micelles, which move through the intestinal mucosa of the young pig more easily than fats with higher molecular weights.

Smaller molecular weight fats are typically more digestible, but older animals will sometimes gain at a faster rate when fed higher molecular weight fats. This could support results of Frobish et al., (1970), who reported that lard was similar in composition to sow's milk, which is efficiently utilized by the young pig.

In addition to increasing digestible energy and providing essential fatty acids, the addition of fat in swine diets reduces dust levels in swine barns (Chiba et al., 1985), and this may improve the health status of pigs and workers in swine facilities (Chiba et al., 1985). Odor is reduced as well when fat is added to feed, by binding odor molecules to the fat particles.

Although weanling pig diets will typically contain 3-10% supplemental fat, results of research are conflicting (Cera et al., 1988), which could be related to type of fat fed. Some researchers have reported that lard was more digestible than corn and soybean oil (Frobish et al., 1970), while others have reported a higher digestibility of corn oil-supplemented diets, than for tallow-supplemented diets (Lawrence and Maxwell, 1983). Fat digestibility in weanling swine has been evaluated for short periods at various times post-weaning (Cera et al., 1988). Fat digestibility increases as age increases in swine (Cera et al., 1988). Some have observed no change in digestibility with increasing age (Braud and Newport, 1973; Cera et al., 1988). The increase in fat digestibility with increasing age is most likely related to increased gut development. Cera et al., (1988), reported that digestibility of tallow and lard as fat sources in young pigs increased at a greater rate than corn oil (17% vs. 10%, respectively) from 1-3 weeks post weaning, but all sources appeared to reach a plateau by three weeks post weaning, and fat digestibility

increased at a slower rate between 3 and 4 weeks post weaning (Cera et al., 1988). This may be attributed to the animal's ability to more effectively emulsify, digest, and absorb saturated and unsaturated fats with age (Cera et al., 1988).

2.5 ENERGY SYSTEMS TO EVALUATE SWINE DIETS

The cost of feeding represents greater than 50% of the cost associated with the production of swine and energy feedstuffs represent the largest fraction of feed (Noblet and Perez, 1993). The ability to estimate the economic and nutritional value of a particular feed is of importance to producers, to prevent overfeeding of costly nutrients that increase overall production costs (Noblet and Henry, 1993). Dietary energy in pig feeds can be partitioned into forms that become more available for production and these include: gross energy (GE), digestible energy (DE), metabolizable energy (ME), and net energy (NE). There are a number of factors that may influence the relative energy values of a particular feed or feedstuff, such as feedstuff physical and chemical characteristics, animal characteristics that relate to age, sex and production stage, and environmental factors related to temperature, humidity and air movement and quality. A number of researchers have proposed prediction equations (Just et al., 1984; Morgan et al., 1987; Ewan, 1989), that estimate the DE, ME, and NE values of mixed diets. A comparison of these equations is difficult because they do not all use the same predictors. In addition, many prediction equations were developed from studies that used different diets, pigs and environmental conditions and were based on different performance criteria (BW, feeding level, age, etc) (Noblet and Perez, 1993). There remains a lot of controversy in the swine industry on the appropriate type of energy system to use in diet formulation. In theory,

NE is the best estimate of the pig's actual energy requirement for productive purposes that include: reproduction, milk production, and lean growth. The "quality" of each value lies in its' ability to predict the performance of the animal and the energy value of feed and raw materials with some degree of accuracy (Noblet and Henry, 1993).

2.5.1 Gross energy

The gross energy value of a diet or feedstuff may be obtained by bomb calorimetry. Gross energy is an accurate measurement for the total energy in a feedstuff or mixed diet, but it is not an accurate determinant of the energy available to a pig for maintenance and production.

2.5.2 Digestible energy

The DE content of a diet or feedstuff may be obtained by placing animals into metabolism cages and measuring energy intake and fecal energy lost in a specified period of time. Digestible energy is calculated by subtraction of fecal energy from energy intake and final digestibility coefficients are expressed as percentages. This method, which can involve total collection of feces or use of an indicator, is widely accepted in the industry.

Feedstuff and diet DE levels and digestibility coefficients can also be estimated from chemical analysis and regression equations developed from digestion trials described previously (Noblet and Perez, 1993). This method assumes no interaction of the ingredients and digestibility coefficients are constant. Digestion trials are costly and time consuming, and prediction equations based on chemical analyses are now widely used to predict DE in pig diets. However, this method does not have all chemical equations for all ingredients and at times is based solely on assumptions.

From a practical point of view, DE values of compound feeds are mostly based on tabular values of individual feed ingredients, estimated from equations and only rarely determined directly in a metabolism study. There are often differences associated with the measured DE values and tabular values for ingredients, which indicates that the later were estimated in the presence of highly digestible feedstuffs (Noblet and Henry, 1993). The most accurate measurement of a particular compound feed is undoubtedly the measured value, however it is impossible and costly to determine the measured value for all diets.

The apparent DE value of feed (kcal/kg DM) is determined by subtracting the energy excreted in the feces from the total gross energy value. The ratio ($\times 100$) is sometimes referred to as the coefficient of digestibility energy, and varies between 70 and 90% for most pig diets and between 0 and 100% for raw ingredients. The majority of variability in energy digestibility coefficients is related to the level of dietary fiber. The inclusion of fiber will also reduce the apparent fecal digestibility of crude protein, fat, and some other nutrients (Noblet and Shi, 1993).

A variety of chemical methods are available to assess the type of fiber in livestock diets and feedstuffs. The Weende technique is used to measure crude fiber (CF) by determining the amount of lignin and cellulose content. Van Soest and Wine (1967) developed a method for the determination of neutral detergent fiber (NDF), which includes: lignin, cellulose, and a number of hemicelluloses, but ignores non-soluble polysaccharides (NSP). Acid detergent fiber (ADF), is used to measure cellulose and lignin and is closely related to the CF value of feedstuffs and mixed diets (Southgate et al., 1978; Carre and Brillouet, 1989).

Coefficients of digestible energy of feeds are affected by other factors, not associated with the diet. Digestible energy coefficients will decrease if feed intake is increased at any stage of growth (Everts et al., 1986). When sows and growing pigs are compared at relatively the same energy intake level, the digestible energy coefficients are not that different (Everts et al, 1986), but if compared at normal ad libitum intake levels, they are obviously different (Etienne, 1987; Fernandez et al., 1986). Compared to growing pigs, sows have the ability to digest and absorb ingredients more efficiently. These differences are largely attributed to transit time and hindgut digestive capacity (Noblet and Shi, 1993).

2.5.3 Metabolizable Energy

Metabolizable energy is the amount of energy retained and deposited as body tissues. Metabolizable energy (ME) is the gross energy minus fecal energy, urinary energy, and gaseous energy. The metabolizable energy value of a diet can be lowered by feeding diets high in protein, or diets with poor protein quality. ME values of diets are also lower when fed to pigs with extremely rapid lean gains. Noblet and Perez (1993) reported the ME value to decrease by .7 and .8 kcal, with each additional gram of crude protein or digestible crude protein (DCP), respectively above nitrogen balance. In other words, the catabolism of protein in excess of the amount required for growth, is associated with a loss of energy. ME may also be calculated from regression equations based on the chemical composition of feedstuffs in the same way that DE is calculated (Noblet et al., 1989).

2.5.4 Net Energy

Net energy is the ME value minus the heat increment (HI) associated with metabolism of energy and the cost of ingestion and digestion. Animals in a negative energy balance use ME as a way to prevent body losses. When the energy level is in excess of the maintenance requirement, the excess energy can be used for growth and reproduction. Therefore, feeds differing in ME, will have NE values associated with their final utilization (Noblet et al., 1994).

Net Energy values for growing pigs are calculated as the sum of fasting heat production (FHP) and retained energy (Noblet et al., 1989). As a result, animals that efficiently deposit protein have higher NE values for a specific feed than an animal with a lower rate of protein deposition. The previous statement would imply that genetic variation has some relevance to NE. Net energy levels are also related to the pig's environment, and are maximized when the pig is housed in its' thermoneutral zone. The HI of digestion contributes to maintaining body temperature when the pig is housed in an environment below the lower temperature limit of the thermoneutral zone (Noblet and Henry, 1993) and decreased feed intake when it is above the upper limit of the thermoneutral zone. Therefore NE is greatly dependent on the nature of the activity that is taking place. The value for NE will vary according to: maintenance, growth, lactation, relative rates of body tissue (protein, fat and bone) gain, level of FHP, feeding level, and climatic conditions (Noblet et al., 1985, 1989; Noblet and Henry, 1993).

Some of the NE values in the literature are calculated from ME values for maintenance and growth (Just, 1982) and for fattening (Noblet et al., 1989) by assuming similar efficiencies for maintenance and energy retention. NE values are highly correlated to the dietary DE and ME. The ability to predict the NE value of a particular feed increases if the prediction equations include information on dietary chemical characteristics. By using stepwise regression, Noblet et al. (1994) and Noblet and Perez (1993), identified the following dietary chemicals: ether extract, starch, crude protein, and crude fiber or neutral detergent fiber which when used in prediction equations along with DE or ME values, improved the estimates of NE. These equations seem to provide accurate predictions of NE of a feed, but are unable to be used for prediction of NE values of individual feed ingredients in a mixed diet (Noblet and Henry, 1993).

In order to propose a NE system, it is necessary to perform energy balance studies under conditions in which the variations in heat production between diets are attributed to their chemical and nutritional characteristics. The NE of a diet is the sum of fasting heat production (FHP) and retained energy, so constants for maintenance, protein gain, and fat deposition must be controlled for all measured diets (Noblet et al., 1994). Controlling environmental temperature allows thermoregulatory heat production to be kept to a minimum (Noblet and Henry, 1993). Having said this, the best way to avoid prejudice due to feeding level, composition of gain, or the estimate of FHP is to carry out measurements on pigs that have the same genetic potential and body weight in controlled environmental conditions; and that are receiving approximately the same amount of dietary energy.

2.5.5 Metabolizable energy: digestible energy ratio

In pigs, the relative loss of energy in the gaseous form increases with age, as the ability to digest lower quality feedstuffs increases. Noblet et al., (1989) determined the gas production from 41 different diets and found that methane levels increased with increasing fiber digestibility. The increase was related to greater volatile fatty acid (VFA) production in the older animals, from hindgut microbial fermentation.

The amount of urinary energy is highly variable and there is a strong correlation to the amount of nitrogen in urine. The amount of nitrogen in urine is related to the amount of protein in the diet, metabolic activity, ratio of maintenance for growth, and ratio for fat:protein accretion in growth. The ME:DE ratios for normal yellow dent corn grain, beef tallow, soybean oil, and choice white grease are .97, .96, .96, .96, respectively. In fact, the ME:DE ratios of most feedstuffs used in swine rations are similar.

2.5.6 Comparison of energy systems

The relative values of ME or DE will vary in the NE system with chemical composition. NE is reduced as fiber and protein are increased, and NE is increased when energy is provided as fat or starch. The energy value of protein and fiber are overestimated, and the energy value of fat and starch are underestimated when expressed on a DE basis (Noblet and Henry, 1993). The NE value of a feed is accepted as the best estimate of the “true” energy available for productive purposes.

Variation in energy digestibility coefficients occurs when feeding level and/or physiological state change. Animal and dietary factors can change the digestibility of

ingredients and diets. By increasing the level of feed intake, the NE value of a feed is decreased. DE, ME, and NE values can be predicted with a degree of accuracy when the chemical composition is the only source available, however these values are solely dependent on the accuracy of the analyses. The fiber fraction of a diet is a major factor affecting nutrient utilization and more emphasis should be placed on the quality of dietary fiber for prediction of digestibility.

The use of accurate energy values for feeding of animals is essential in research; however, rapid and accurate prediction methods for feed are essential for the feed industry. The objective of a study by Noblet and Perez (1993) was to define these values so an accurate prediction could be made. The values used in tables (NRC, 1998) are a reasonable estimate for use by the animal feed industry and are accepted for estimates of the feeding value of ingredients. The values that are reported in the tables are estimates and change at different inclusion levels and stages of production, so they are not the “true” value for all situations. It is difficult to determine accurately, the energy value of an individual feedstuff, because no one feedstuff contains all the nutrients needed to optimize growth or production in an animal. The preferred way of assessing feed quality should be the NE system. Noblet et al. (1989) proposed a system, which considers more information on the chemical characteristics, and seems to predict the NE values of both diets and ingredients.

2.6 ENERGY:PROTEIN RATIO

When pigs are given increasing amounts of protein, of the same quality and a set amount of energy, protein deposition increases linearly until a maximum rate is reached.

Any further increase in the protein level will not increase protein deposition, until the energy level is increased and a new maximum level of protein deposition will result. Protein deposition is unaffected by energy intake when protein is limiting, and is driven by energy intake when dietary protein supply is at or above the requirement (Edwards and Campbell, 1993).

Whether protein accretion responds linearly to the intake limit of an animal or reaches a plateau at some other level of feeding, performance traits may be significantly affected. Composition of gain, rate of gain, protein requirements, and feed conversion are all affected by the amount of feed consumed by the animal (Edwards and Campbell, 1993). Energy intake is a major determinant of protein accretion, and assuming the protein:energy ratio is correct, changes in the energy intake of the animal will always affect the pigs tissue demand for protein.

The relationship between energy intake and protein deposition is affected by factors such as sex and genotype. The amount of dietary protein required to support maximum body protein accretion in pigs of a known age, sex or genotype is affected by amino acid availability and balance, as well as the energy level of feeding (Edwards and Campbell, 1993). Information is required on all factors affecting protein deposition so that these factors can be integrated into a feeding program to promote maximum body weight gain and protein accretion.

Energy and protein digestibility are limited by the pigs' genetic ability to deposit protein and grow efficiently. A change in diet nutrient composition cannot overcome a genetic limitation for protein deposition and an inferior growth rate. There is a need for

researchers to focus more on the biological basis for nutritional systems, in order to develop a more sound understanding of the factors affecting protein deposition. A full understanding of the concepts associated with protein accretion and growth in pigs will enable nutritionists to provide the producer with valuable information to promote lean and efficient growth in pigs.

3. EXPERIMENT 1. THE EFFECT OF SUBSTITUTING HIGH OIL CORN FOR NORMAL CORN IN NURSERY PIG DIETS.

3.1 ABSTRACT

The objective of this study was to determine the effects of using high oil corn (HOC) in a nursery phase feeding program and monitoring growth performance to market. Two groups of crossbred pigs (n = 293 trial 1; n = 265 trial 2) were weaned, segregated by sex and weight into small, medium and heavy groups, and allotted to 12 nursery pens. Pigs received one of two dietary treatments which included; (1) a transitional phase I diet for 7 days; a corn-based phase II diet for 14 days and a phase III diet (NCIII) for 7 days; (2) a HOC-based phase II diet for 21 days and the NCIII diet for 7 days. BW, ADFI and F/G ratios were measured weekly during the nursery period. Pigs were transferred to a grow/finish barn on day 28 post-weaning, and BW and ultrasound measurements were taken for back fat (BF) and loin eye area (LEA) at the 10th and last ribs four times prior to market. ADG of nursery pigs on the three-phase NC diet was greater than pigs fed the HOC two-phase diet at day 21 post-weaning (P = .0034) and 28 post-weaning (P = .0128). ADG for heavy pigs was greater (P = .0001) than that of medium and light-weight pigs, and no treatment x weight group interactions were observed (P = .2043). Pigs fed the three-phase diet had greater G/F ratios than pigs fed the HOC two-phase diet at day 21 (P = .0137) and 28 (P = .0134). LEA for pigs fed the three-phase diet was greater than pigs fed the HOC two-phase diet when measured on day 28 at the 10th (P = .0565) and last rib (P = .0370). There were no effects of treatment on BF. Even though pigs were fed alike in the grow/finish period, ADG of pigs fed the three-

phase nursery diet was greater ($P = .0106$) than that of pigs fed the HOC two-phase nursery diet. Throughout the grow/finish period there were no differences for average lean gain per day ($P = .8611$) or percent lean of carcasses ($P = .2865$) for treatment. The results suggest that removal of the transitional phase I diet and the substitution of HOC for corn in a phase II diet fed to nursery pigs did not support maximal BW and lean gains in the nursery. Even though pigs fed the three phase diet in the nursery had similar rates of lean gain in the grow/finish period when compared to pigs fed the two phase HOC diet, their efficiency of lean gain to market was superior.

3.2 INTRODUCTION

The need for swine producers to improve pig production has resulted in earlier weaning ages for pigs (Ravidran and Kornegay, 1993). At weaning, the change in diet from milk based products to animal and plant based products often leads to digestive disturbances and reduced growth performance, which is referred to as post weaning lag (Ravidran and Kornegay, 1993). The post weaning lag period will typically occur during the first week after weaning and may last up to two weeks depending on the severity of conditions. Attempts to shorten or eliminate the post weaning lag period have led to the development of expensive, highly digestible transitional diets based on animal feedstuffs.

Producers are now interested in ways to reduce costs of production associated with the feeding of transitional diets. Recently, value-added plant feedstuffs have been developed, marketed, and have the potential to reduce some of the higher priced animal feedstuffs in transitional diets without affecting growth performance of weaned pigs. Compared to traditional plant feedstuffs, improved plant varieties such as high oil corn

(HOC) are higher in nutritional quality and may be absorbed more efficiently in the young pig, reducing the post weaning lag period. Therefore, the objective of the following experiment evaluated HOC as an ingredient in nursery diets for weaned pigs.

3.3 MATERIALS AND METHODS

3.3.1 Animal management

Pigs (n = 558), 293 in trial replicate 1 and 265 in trial replicate 2, were weaned at 28 (± 3) days of age, segregated by sex and weight group and placed into 12 nursery pens by small ($5.4 \pm .083$ kg), medium ($7.2 \pm .082$ kg), and heavy ($9.4 \pm .082$ kg) groups into a nursery site at the Ames Plantation. Pigs were assigned to one of two dietary treatments: T1) ad-libitum access to a commercial pelleted transition diet based on yellow corn for 7 days (phase I), a ground phase II diet based on yellow corn for 14 days, ground nursery phase III diet based on yellow corn for 7 days. T2) ad-libitum access to a ground high oil corn based phase II nursery diet for 21 days, then the same phase III diet as T1 for 7 days (Table 1). Pigs were provided ad-libitum access to water via a nipple waterer. Animals and feed were weighed using an electronic scale (O'Haus Model I-10) and weights recorded to the nearest one-tenth pound at days 7, 14, 21, 28 days post weaning. Feed and animal weights were used to calculate, average daily gain (ADG), average daily feed intake (ADFI) and gain to feed (G/F) ratio. At day 14, five pigs were randomly selected and a button ear tag was placed in the left ear, for identification of pigs that were to be ultrasonically evaluated prior to removal from the nursery, and at the time of diet change in a three-phase grow-finish feeding program. On d-14 post-weaning, a 2-ml blood sample was drawn from four of the pigs receiving an ear tag using a 18 G x 1.5 in. needle

(Becton Dickinson and Co., Rutherford, NJ) and 10-ml Vacutainer (Becton Dickinson and Co., Rutherford, NJ) containing Sodium Heparin or EDTA (two pigs for each type) via vena cava puncture in the supine position. Blood was placed on ice until taken to the laboratory for centrifugation. After centrifugation, plasma was separated from whole blood and analyzed for plasma urea nitrogen. On d-28 post-weaning, animals were moved into a fully slatted grow-finish facility. Pigs were weighed to determine average daily gain at time of each diet change in the grow-finish facility. Loin eye area and backfat ultrasound measurements were used to estimate lean and fat gain.

3.3.2 Feed analysis

Prior to diet formulation a 454-g sample of each feed ingredient was randomly obtained to determine energy, protein, and amino acid content. After grinding and mixing of diets, one-pound samples were obtained to determine energy and protein content of the mixed diets. All diets to be fed during the trial were ground and mixed using a Gehl Mix-All 125 mixer in one-ton batches.

Gross energy of all samples was determined using a Parr 1241 oxygen bomb adiabatic bomb calorimeter (Parr Instrument Company, Moline, IL). One-milligram samples were dried at 60° C and placed into crucibles. After samples were weighed, they were placed into an oxygen bomb with 30 atmospheres of oxygen. All samples were run in triplicate and gross energy determination averaged for the samples. Crude protein (Nx6.25) content of the feed used in experiment 1 was determined using standard Kjeldahl procedure (AOAC, 1995).

3.3.3 Ultrasound measurements

Estimates of lean gain and fat accretion rates were made from loin muscle area and back fat measurements taken at the 10th and last ribs using real-time ultrasonography (Aloka 500V with a 3.5 MHz probe, Corometrics Medical Systems, Wallingford, CT). All ultrasonic scans were performed and interpreted by the same technician to eliminate measurement variation due to technician. The 5th rib was estimated by locating the point of the shoulder, and the last rib was determined by palpation. Determination of the 10th rib was approximated as the point slightly caudal to the midpoint between the palpated last rib and the estimated 5th rib. After location, the points were marked using a livestock marker. After scanning, images were recorded using a Beta style, video cassette recorder. Images were interpreted using software image analysis software (Animal Ultrasound Services, Ithaca, NY and backfat depth and loin muscle area determined. The equation used to predict daily lean gain was $((7.6 + (.308 * \text{weight at trial completion}) - (16.44 * 10^{\text{th}} \text{ rib backfat}) + (4.693 * 10^{\text{th}} \text{ rib loin muscle area}) - (.418 * \text{weight at trial initiation}))$. The equation used to predict carcass percentage lean was $((3.950 + (.308 * \text{live weight in pounds}) - (16.440 * 10^{\text{th}} \text{ rib fat depth in inches}) + (4.693 * 10^{\text{th}} \text{ rib LMA in inches squared}) / \text{live weight} / 74 * 100)$ (NSIF, 1997).

3.3.4 Statistical Design

The statistical model consisted of a randomized complete block design in a 2x3x2 factorial arrangement using repeated measures analysis with the pen as the experimental unit. In two trials, pigs were separated by sex and blocked by weight into small, medium and large groups and then assigned to one of 12 nursery pens. There were six pens per

treatment and two pens per weight group. The data were analyzed for body weight, average daily gain, gain:feed, average daily feed intake, average daily lean gain, 10th and last rib fat and loin muscle area, and predicted percentage lean for the carcasses. Data were analyzed using PROC MIXED procedure of SAS (SAS, 1997) with trial replication as a random effect. Fixed effects in the models were treatment, sex, and weight group. Variation associated with trial replication was not significant, so data from each growth trial were pooled for analysis. Blood urea nitrogen (BUN) was analyzed for anti-coagulant type (EDTA or Heparin). Variation among tube type was not significant, so data among type were pooled and analyzed using the PROC MIXED procedure with body weight at d 14 post-weaning as a covariate. Where appropriate, variable means were compared using pdmix procedures of SAS (1997).

3.4 RESULTS

Nursery pigs that consumed the three-phase normal corn-based diets were heavier at d 21 post-weaning ($P = .0171$) (Figure 1), but not at market ($P = .5886$) when compared to pigs that consumed the two-phase high oil corn-based nursery diets. There were no differences in BW observed between barrows and gilts at d 21 post-weaning ($P = .3752$), but barrows were heavier than gilts prior to market ($P = .0539$). There were expected differences in BW among weight groups ($P = .0001$) at d 21 post-weaning and prior to market ($P = .0005$), but there were no group x treatment interactions ($P = .9940$) at d 21 post-weaning. Prior to market, a group x treatment interaction was observed, with high oil corn heavy pigs being larger than the normal corn pigs ($P = .0009$) (Table 2).

Average daily gains of nursery pigs (Table 2) receiving normal corn-based diets were greater than those of high oil corn-based diets at d 21 ($P = .0034$) and at market ($P = .0128$). Pigs in the heavy weight group had a greater average daily gain than pigs in the medium or small weight groups at d 21 ($P = .0046$) and at market ($P = .0027$).

There were no differences between treatments in average daily feed intake of pigs at the end of the phase-II diet period, d 21 ($P = .1252$) or at any other time in the nursery phase of the study. The gain:feed ratio was higher for animals consuming NC diets at d 7 post-weaning ($P = .0194$) (Figure 2), but no interactions were significant for group x sex ($P = .4816$), treatment x sex ($P = .4905$), treatment x group ($P = .6415$). At d 21 post-weaning, pigs that consumed normal corn-based nursery diets had higher gain:feed ratios than those on high oil corn ($P = .0137$). There were no differences for gain:feed among sex ($P = .4163$) and there was no treatment x sex interaction ($P = .6454$), but there was a sex x group trend observed with medium gilts and small barrows tending to have higher gain:feed than the remainder of the sex x group combinations ($P = .0912$).

There were no differences observed among the treatments for last or 10th rib backfat ($P = .3866$ and $P = .5398$, respectively) 28 days after weaning. Gilts had less backfat at the 10th rib than barrows ($P = .0001$, 22.3 mm and 26.1 mm, respectively) but not at the last rib ($P = .2244$). There were no interaction of sex x treatment observed for 10th rib ($P = .5493$) or the last rib backfat ($P = .2416$). Prior to market, small weight grouped pigs fed the high oil corn-based nursery diets tended to have less backfat than small weight grouped pigs fed normal corn-based diets ($P = .1027$). However, there were no differences observed for backfat when body weight was used as a covariate for 10th rib

backfat ($P = .2692$), 10th rib loin muscle area ($P = .4338$), or loin muscle area at the last rib ($P = .3994$). Backfat measurements were still greater for the heavy group pigs when body weight was used as a covariate at the last rib ($P = .0001$). Compared to barrows, gilts had greater loin muscle area at the 10th rib ($P = .0464$), and showed a trend to have greater loin muscle area at the last rib at marketing ($P = .1056$). There were no differences for average daily lean gain ($P = .8611$), $.53 \pm .01$ lbs/day for NC and $.52 \pm .01$ lbs/day for HOC. The estimated percent lean for carcasses were not different ($P = .2865$), $53.3 \pm .4$ for NC and $52.7 \pm .4$ for HOC.

Blood urea nitrogen (BUN) was not correlated to BW at d 14 post-weaning ($P = .1619$). After covariant analysis, there were no main effects of dietary treatment ($P = .4164$), sex ($P = .2665$) or weight group ($P = .2421$) on serum or plasma urea nitrogen values, but there was a treatment x group interaction. The interaction was likely due to the animals from the heavy weight group, in both treatments, having much higher BUN values than the small weight group for the HOC and medium group for NC treatments ($P = .0195$) (Table 4).

After analyzing these data for economic importance, feeding high oil corn was still more cost effective even with noted differences in performance throughout the nursery and to market. Normal corn fed (105.4 ± 2.0 kg) pigs were .9 kilograms heavier than high oil corn fed (104.5 ± 2.1 kg) pigs when they reached market, and this only contributed to a cost savings of \$.12 per day/animal for the normal corn fed pigs. The death loss of animals for the two treatments was 6.0 for high oil corn pigs and 2.2% for normal corn pigs from weaning to market. The three-phase normal corn fed pigs cost

\$6.02 and the two-phase high oil corn fed pigs cost \$4.58 per pig for feed costs to maintain through the nursery stage. This amounted to a savings of \$1.44 per pig removed from the nursery site for high oil corn pigs. Since these animals were fed alike in the grow-finish barn and there was no accurate way to determine the consumption of feed and efficiency of gain, it was assumed that the pigs consumed approximately the same amount of feed and deposited protein at a similar rate since the differences in carcass lean percentages were not significant. Taking these assumptions into consideration, there was a difference of \$443.50 in feed cost in favor of high oil corn. The higher death loss associated with the high oil corn fed pigs amounted to \$110 loss in income compared to normal corn fed market animals, assuming a \$10 profit potential for each marketed animal. After subtracting the \$110 profit margin for the increased pigs to market for normal corn from the \$443.50 savings from the feeding of high oil corn, there was still \$335.50 generated from the feeding of high oil corn. This amounts to a \$1.27 more profit per animal marketed when high oil corn is fed in the same conditions in which this experiment was conducted.

3.5 DISCUSSION

Initially in this experiment we wanted to determine if a relatively low cost phase two, nursery diet based on high oil corn could replace a more expensive commercial transitional (phase one) diet without adversely affecting pig performance. The commercial transitional diet contained high quality animal-based protein sources typically seen in young pig diets.

The results of this study have shown that when an HOC based diet was used to

replace a transitional phase I diet, average daily gain and gain:feed were negatively affected. Average daily feed intake was not affected by treatment diets in this study. However, DeCamp et al., (1998) observed increased feed intake for high oil corn compared to normal corn, and attributed the increase to greater palatability of high oil corn. The lack of food in the intestine of weanling pigs during the first few days after weaning leads to alterations in intestinal morphology (Cera et al. 1988; Kelly et al., 1991; Spurlock et al, 1995; Pluske et al., 1996). There is clear evidence of feed intake affecting weanling pig performance (McCracken et al., 1999), which may lead to atrophy of the mucosa. According to McCracken et al. (1999), increased feed intake leads to an increase in enzyme activity. Feed intake has been shown by some researchers to have an effect on the feed conversion ratio; and on further development of the pig, which may be the reason for the HOC pigs being smaller at the end of the trial. However, this was not the case in our study, which may be the reason high oil corn fed pigs recovered from the growth lag early in the nursery period.

Average daily gain was depressed when high oil corn was fed, this in agreement with previous experiments that utilized corn oil (Lawrence and Maxwell, 1983; Han et al., 1987), and disagrees with DeCamp et al. (1998), who noted no differences in average daily gain or in body weight in one experiment but noted differences in a similar experiment. McCracken et al. (1999), suggests that intestinal morphology after weaning is related to two hypotheses: dietary immune response possibly related to soy-protein and lack of luminal stimulation due to reduced feed intake, both of which affect gain in the growing pig. However, we did notice that normal corn fed pigs gained at a faster rate than

those fed high oil corn based diets. An explanation of the difference in average daily gain could lie within the difference in protein quality of the NC diet. The NC diet contained expensive but highly digestible animal protein sources that are more easily used by the young pig than plant sources. It would appear by the result of our blood urea nitrogen values that the protein quality was closely related (Cai et al., 1995) since the values were not different, but DeCamp et al., (1998) saw differences in the serum urea nitrogen values at day 14 and attributed them to better utilization of high oil corn by growing pigs. There may be other interactions occurring that caused the NC fed pigs to gain at a faster rate than those on the HOC treatment that were unable to be measured in our study. The energy and protein values for the transitional diet were higher than the values measured for the phase two high oil corn diet. More and higher quality protein and a better energy:protein ratio in the transitional diet could partially explain the increased performance of the pigs fed the NC three phase diet.

The gain:feed ratios were greater for normal corn fed pigs than those of the high oil corn fed pigs. The reduction in growth and G/F may be largely related to the results obtained by Han et al., (1987). Younger pigs do not digest carbohydrate and protein as well as fat, due to less enzyme activity and gut development. This statement could be contradicted when the results of Bergstrom et al., (1996) are considered. There were no differences in average daily gain or gain:feed when comparing high oil corn to normal corn and normal corn plus fat or soy oil. Bergstrom et al., (1996) conducted a second experiment and noted average daily gain was improved when normal corn was fed from day 4-14. Enzymatic development in the young pig is a function of diet (McCracken et al.

1999) and weaning (Jensen et al.,1997). Adams and Jensen (1987), using 16 kg pigs, reported that fat, in high oil corn was effectively utilized by the young pig. The pigs in our study were smaller, and probably had less developed digestive tracts than those used by Adams and Jensen (1987), and would not be able to utilize nutrients as efficiently. The difference in protein quality would likely result in the larger body size of the NC pigs. Some of the proteins in the NC transitional diet were of animal origin and would be utilized more efficiently. Fats in the animal products would also contain a fatty acid profile more closely related to the needs of the pig and as a result be more efficiently used by the pig.

Ultrasonography is accepted as a predictor of live animal and carcass characteristics (Smith et al., 1992). Animals in our study had few carcass measurements that were different using ultrasonography. Gilts in our study were leaner than the barrows; which was expected since gilts grow slower than barrows. The pigs in the smaller weight group had less backfat, which may have been attributed to the animals being smaller in body weight. These animals may have been at a different state of maturity than the larger pigs, which could explain the difference. Since this was the only difference that may have affected carcass quality, one would expect that HOC fed animals would have had carcasses that were as marketable as the NC fed pigs. There were no differences noted for average daily lean gain, and this implies that, throughout the experiment, the high oil corn fed pigs performed as well as those fed normal corn. The nursery results observed may have been overcome during the finisher phase. The predicted percentage lean for the carcasses was not different and implies that the effects

of the decreased growth during the nursery phase did not promote the animal to alter the fat:muscle ratio during the finisher phase. However, it is likely that pigs fed the three-phase diet deposited muscle more efficiently.

Swine producers are constantly seeking a more efficient way to produce pigs to market weight. In this study, high oil corn increased the profit of marketed pigs by simply eliminating the transition diet. The high oil corn fed animals only required one extra day of feed to reach a market weight of 104.5 kg. In doing this, the swine producer would have generated an extra \$1.27 per pig marketed without sacrificing meat quality.

3.6 IMPLICATIONS

The use of high oil corn in the nursery phase of production did not maximize growth performance in our study. A phase two, HOC-based diet cannot simply replace a transitional diet based on higher quality animal ingredients. It is likely that young pigs need some of the nutrients provided in the transitional diet to support maximal growth and feed efficiency in the nursery. Further work is needed to formulate HOC-based, phase one diets for nursery pigs. However, based on economics, a producer may generate more profit by using HOC in place of higher priced animal ingredients in transitional nursery diets.

4. EXPERIMENT 2. A COMPARISON OF NUTRIENT AVAILABILITY IN HIGH OIL CORN, DAMAGED HIGH OIL CORN, AND NORMAL YELLOW CORN FED TO YOUNG PIGS.

4.1 ABSTRACT

The objective of this experiment was to determine nutrient availability in high oil corn (HOC), damaged high oil corn (DHOC) and normal corn (NC). Two groups of 12 crossbred barrows, average initial weight of 32.2 kg, were used in two 10-d feeding trials to evaluate the response of pigs when the test corn was the only source of protein and energy in the diet. Vitamins and minerals were supplied to meet NRC (1998) requirements. Gross energy values for DHOC, HOC, and NC were 4081.43, 3866.87, and 3562.07 cal/g, respectively. Crude protein percentage values for DHOC, HOC, and NC were 8.9, 9.1, and 7.6 as fed, respectively. There were no differences for ending body weight when beginning body weight was used as a covariate in the model for data analysis ($P = .8692$). The trial replication effect was different ($P = .0028$) and was due to animals being heavier in the second replication. The test corn digestible crude protein values were different ($P = .0001$), with HOC ($8.11 \pm .07$) and DHOC ($8.09 \pm .07$) having more digestible crude protein than NC ($6.75 \pm .07$). Damaged high oil corn had a higher ME value than undamaged high oil corn and normal corn ($P = .0174$). Digestible energy was higher in damaged and undamaged high oil corn compared to normal corn ($P = .0083$). ME:DE ratios were not different and averaged 97.5% ($P = .9789$) for all treatments. Treatment fecal or urine dry matter content were not different ($P = .1399$, $P =$

.3698), respectively for the three treatments. The results of this experiment suggest that corn damage did not significantly reduce the digestibility of nutrients in high oil corn when compared to undamaged high oil corn and normal corn.

4.2 INTRODUCTION

The effect of damage on grain crops can amount to a devastating loss to cash grain producers each year. Most reports on damage to corn relate to disease resistance (Scott and White, 1985), or yield and value when marketed (Coggin and Dively, 1980), but few relate to the feeding value of damaged corn. Damage to normal yellow corn has been shown to alter the amino acid and protein content of the grain (Scott and White, 1985). The effect of feeding damaged high oil corn on pig performance has not been evaluated to date. The objective of the following study was to determine the differences in levels and digestibilities of nutrients, and energy in undamaged high oil corn, damaged high oil corn and normal yellow corn.

4.3 MATERIALS AND METHODS

4.3.1 Project Management

Damaged HOC used in this study was from corn harvested in 1997, and intact HOC was from corn harvested in 1998 at the Martin Experiment Station, Martin, TN and the normal corn used in this study was from corn harvested in 1998 at the Ames Plantation Experiment Station, Grand Junction, TN. Before mixing the diets, 454 g samples were taken at random for all ingredients mixed in the diet for determination of protein and gross energy. Test diets were mixed and ground using a hammer mill (Gehl Mix-All 125) and a 9/64th in. screen at Ames Plantation and then transferred to Knoxville.

Pigs used in the study were handled in accordance with the guidelines set by the Institutional Animal Care and Use Committee of The University of Tennessee, Knoxville.

The digestibility study was conducted at the Cherokee Animal Facility of The University of Tennessee at Knoxville Experiment Station. Two groups of 12 crossbred barrows, average initial weight 32.2 kg were used in two replicated trials with 12 stainless steel metabolism crates. In each replicate, each test corn diet was assigned randomly to four of the twelve pigs. Diets were formulated so that the test grain was the only source of protein and energy in the diet (Table 4). Vitamins and minerals were supplied in the diet to meet or exceed current NRC (1998) requirements. Pigs were housed individually in .83-m x .71-m stainless steel metabolism cages in an environmentally controlled room and fed twice daily (0600 and 1800) for 5-d to adjust to diets and metabolism cages. During the adjustment and collection periods, pigs received a daily DM intake of 4.3% of initial BW. Feed was presented to the pigs as a wet mash to promote feed consumption and reduce wastage. Between meals, pigs were allowed ad libitum access to water in their feed bowls. The 5-d adjustment period was followed by a 5-d total collection of feces and urine. Ferric oxide was used as an indigestible marker to signal initiation and termination of collection. Feces was collected twice daily, weighed and pooled within each pen and frozen (-18°C) for chemical analysis. Urine, from individual pigs was collected daily, weighed and added to a collection container, containing 10 ml concentrated H_2SO_4 . At the end of each day, urine was strained through glass wool, the volume measured, and then a 30% sample taken and frozen (-18°C) for chemical analysis.

4.3.2 Chemical Analysis

One-thousand kernel weights were determined by counting 250 corn kernels of each type and weighing to the nearest 1/100th gram and multiplying by four. The weights of whole kernels, damaged kernels, whole damaged kernels, fragmented kernels, chaff and fines were determined by separating each variable to be measured and weighing to the nearest 1/100th gram. Each variable measured was weighed in 5 replicates. Fecal samples were thawed, mixed and a 20% subsample taken and dried 65 °C. The samples were weighed and ground in a Wiley mill through a 1-mm screen. Urine samples were thawed and dried at 60 °C for 72 h and immediately removed and weighed for DM determination. Samples were then placed in plastic containers until they were analyzed for gross energy. Crude protein (N x6.25) analyses of feed, feces and urine were determined using semi-automated Kjeldahl procedure (AOAC, 1990), and gross energy by adiabatic bomb calorimetry (Parr Instrument Company, Moline, IL).

4.3.3 Statistical Analysis

Twenty-four pigs were used in a metabolism study that was replicated twice. In each replication (block), 12 pigs housed individually in stainless steel metabolism crates were randomly assigned to one of three treatment diets (4 pigs/diet). The experimental unit in this study was the pig (total of 8 pigs/treatment). Data were analyzed using the General Linear Models Procedure of SAS (1997) using a completely randomized block design. Replication was included in the model as a random effect. Treatment was a fixed effect in the model, that was analyzed for gross energy, metabolizable energy, digestible

energy, digestibility coefficients, and ME:DE ratios. Protein variables analyzed were digestible crude protein, and coefficient of protein digestibility. Mean separation of energy and protein variables was performed using the lsmeans procedure where appropriate.

4.4 RESULTS

Damaged HOC had lower ($P < .0001$) 1000 kernel weights, 238.1 g (± 3.32 ; $n = 5$) when compared to HOC (355.4 g) and NC (272.0 g). This was related to differences in the quality of each corn type. Compared to HOC, damaged HOC had fewer intact kernels (50.8% vs 77.0%, $P < .0001$), more damaged whole kernels (15.9% vs 5.0%, $P < .0001$), more fragmented kernels (32.3% vs 17.6%, $P < .0001$) and more chaff (0.9% vs 0.4%, $P = .0028$). NC had the greatest percentage of intact kernels (87.9%), and the lowest percentages of damaged whole kernels (1.5%) and fragmented kernels (10.2%). NC and HOC had similar levels of chaff and fines.

After feeding the test corn diets for 10 days, final pig live body weights, adjusted for initial BW were not different among treatments ($P = .8692$), but pigs in the second replication were heavier ($P = .0168$) than those in the first replication.

Despite differences in visual quality, HOC and DHOC had higher GE values (3866 kcal/kg and 4081 kcal/kg, respectively) than NC, which averaged 3562 kcal/kg. Digestible energy differed among treatments ($P = .0083$) and averaged 3418.6, 3456.4 and 3075.4 (± 150.0 , 190.2, 316.4, respectively) kcal DE/kg diet for HOC, DHOC and NC, respectively (Table 5). The coefficients of digestible energy were not different for

the diets ($P = .5204$) and averaged 73.1 , 76.4 and 74.6 ± 1.96 , for DHOC, HOC and NC, respectively. Coefficients of metabolizable energy were not different ($P = .5836$) and averaged 71.3 , 74.4 and 72.8 ± 2.09 for DHOC, HOC and NC, respectively.

Metabolizable energy was different for the treatments ($P = .0174$), with DHOC and HOC being greater than NC (Table 5). These differences were not seen when beginning weight was used as a covariate ($P = .8387$). The ME:DE ratios of the test corns were not different ($P = .9789$), and averaged $.97 \pm .005$.

Crude protein percentage values for DHOC, HOC, and NC were 8.9 , 9.1 , and 7.6 , respectively. The coefficients for protein digestibility were not different ($P = .1145$). The coefficient for protein digestibility was highest ($87.5 \pm .82 \%$) for HOC. DHOC had a lower coefficient for protein digestibility ($85.3 \pm .82 \%$). The apparent fecal digestible protein level of NC ($6.75 \pm .07$) was lower than those of HOC ($8.11 \pm .07$) and DHOC ($8.09 \pm .07$) (Table 6).

4.5 DISCUSSION

The high oil corn tested in this experiment was only slightly affected by damage. The normal corn used in this study was subjected to drought conditions, which could account for the lower energy and protein levels compared to tabulated values in the literature. However, the undamaged high oil corn was superior for all variables tested in our experiment. The damaged high oil corn, which was the same as the high oil corn that was not damaged, did prove to still be a valuable source of energy and protein. The digestible and metabolizable energy values for the high oil corn varieties were not different from each other, and were higher than the values for the normal corn tested. The

digestible energy value for the damaged high oil corn was higher than the undamaged high oil corn, which was unexpected. This result may be similar to findings of Scott and White (1985), who noted that there were more available amino acids in corn when damage occurred during the milk stage of production. However, most of the damage in our study occurred during storage. The ME:DE ratios of the corns tested were not different. In relation to the amount of nutrients available in the corns we tested, there were no differences in their relative digestibilities.

4.6 IMPLICATIONS

The findings of this experiment suggest that when damage occurs, high oil corn can still be a valuable source of energy and protein for growing pigs. The producer needs to obtain a nutrient analysis before making decisions on the feeding value of the damaged corn. In our experiment, damage did not impair the feeding value of the high oil corn to a great degree and could have been used as a feed ingredient in swine diets.

5. OVERALL SUMMARY OF THESIS RESEARCH

The results presented in both of these studies provide a baseline for future research with high oil corn. The results obtained in the first experiment indicate that the newly weaned pig benefits from high quality nutrients in transitional diets and that HOC cannot simply replace animal-based ingredients. Data has shown that as pigs become older, their ability to digest plant-based products increases. Following weaning, pigs are subjected to a number of stressful situations that are related to the diet, and the pig's environment. These stressors, in combination with a decreased ability to digest plant products, may have resulted in the decreased performance in the present study. However, based on an economic analysis, substituting HOC for higher priced, animal ingredients found in the transitional diet, did result in higher profit margins per market pig. A second study was conducted to measure the digestibility of energy and protein in high oil corn, and damaged high oil corn, then compare those values to normal corn. The results showed that high oil corn was a valuable source of energy and protein for growing pigs. Damage to high oil corn had little, if any, impact on the digestibility of energy and protein. These results suggest that producers can use damaged high oil corn as a source of nutrients for growing pigs. The use of high oil corn for replacement of the normal corn used in the present study would allow the swine producers to provide pigs higher energy and protein in diets fed to their pigs.

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APPENDICES

Appendix 1 **Tables for experiments**

Table 1. Comparison of diets (as-fed basis) fed to pigs following weaning to evaluate the effect of high oil corn compared to normal corn in experiment 1.

	Normal Corn Treatment			High Oil Corn Treatment	
Ingredient %	Transition ^a	Phase II	Phase III	Phase II	Phase III
High Oil Corn		-	-	50.3	-
Normal Corn		50.3	51.7	-	51.7
SBM (48% CP)		26.2	24.3	26.2	24.3
Starter Mix ^b		20.0	20.0	20.0	20.0
Lincomix 10 ^c		1.0	-	1.0	-
Mecadox ^d		-	1.0	-	1.0
Rendered Animal Fat		2.5	3.0	2.5	3.0
Chemical Analysis					
Crude Protein (Nx6.25)%	21.6	20.50	19.67	21.20	19.67
Ether Extract %	6.5	5.66	6.19	6.90	6.19
Lysine %	1.6	1.25	1.20	1.17	1.20

^a Ingredients proprietary (supplied as complete pelleted feed, TN Co-op PW 6-13).

^b Supplied as vitamin and mineral premix from TN Co-op, ingredient composition proprietary.

^c Lincomycin hydrochloride added to provide 10 mg/lb.

^d Carbadox added to supply 25 g/ton.

Table 2. Average daily gain (ADG) least squares means (grams/day) for treatment x group interaction of nursery pigs fed a three-phase normal corn diet or a two-phase diet containing high oil corn.

Day on Test ^a	Weight Group	3-Phase Commercial NC Diet ^f	2-Phase HOC Diet	SEM
0-7 ^b	Small	254.5	92.6	±40.86
	Medium	215.2	62.2	±40.76
	Heavy	326.8	163.5	±40.78
7-14 ^c	Small	155.2	159.8	±36.57
	Medium	120.3	159.6	±36.47
	Heavy	218.0	251.1	±36.46
14-21 ^d	Small	304.5	286.4	±32.94
	Medium	388.7	305.3	±32.74
	Heavy	443.4	352.5	±32.79
21-28 ^e	Small	428.8 ^{bc}	368.6 ^{cd}	±32.60
	Medium	445.6 ^b	352.8 ^d	±32.19
	Heavy	425.0 ^{bc}	511.2 ^a	±32.19
0-21 ^f	Small	238.6	179.5	±25.39
	Medium	242.7	175.8	±25.31
	Heavy	328.6	253.1	±25.33

^a Lsmeans with different letters are different from each other (P < .05).

^b Treatment*group interaction (P = .9624).

^c Treatment*group interaction (P = .3856).

^d Treatment*group interaction (P = .0829).

^e Treatment*group interaction (P = .0001).

^f Treatment*group interaction (P = .9338).

Table 3. Least squares means of blood urea nitrogen (BUN) values at day 14 for treatment x weight group interaction ($P = .0195$) from pigs fed a three-phase normal corn (NC) or two-phase high oil corn (HOC) nursery diet at weaning.

Group ^b	Treatment ^a		SEM
	Three-phase ^c NC diet	Two-phase ^c HOC diet	
Small	9.40	7.65	±.85
Medium	7.26	9.29	±.76
Heavy	9.20	10.30	±.88

^a Ls means with different superscripts are different ($P < .05$).

^b Weight group of pigs fed high oil corn or normal corn diets.

^c BUN is reported for pooled serum and plasma samples in mg/dl.

Table 4. Comparison of diets (as-fed basis) fed to 32-kilogram pigs for comparisons of digestibility of high oil corn (HOC), damaged high oil corn (DHOC), and normal corn (NC) in experiment 2.

Item %	HOC ^a	DHOC ^b	NC ^c
NC	-	-	95.97
DHOC	-	95.97	-
HOC	95.97	-	-
Dicalcium phosphate	2.40	2.40	2.40
Limestone	.50	.50	.50
Salt	.25	.25	.25
Vitamin Premix ^d	.50	.50	.50
Trace mineral premix ^e	.10	.10	.10
Selenium ^f	.15	.15	.15
Mecadox ^g	.13	.13	.13

^a High oil corn grown at the University of Tennessee at Martin, undamaged.

^b High oil corn grown at the University of Tennessee at Martin, damaged.

^c Normal corn grown at the Ames Plantation, Grand Junction, Tennessee.

^d Provided the following per kg of diet: vitamin A, 12,211 IU; Vitamin D₃, 1,214 IU; vitamin E, 46 IU; menadione sodium bisulfite, 9 mg; vitamin B₁₂, 62 µg; riboflavin, 12 mg; d-pantothenic acid, 45 mg; niacin, 70 mg.

^e Provided the following per kg of diet: Zn, 200 mg; Fe, 10 mg; Mn, 50 mg; Cu, 10 mg; I, 1.5 µg.

^f Provided 300 µg of Se per kilogram of diet.

^g Provided 250 g per ton of feed.

Table 5. Least squares means values for gross (GE), digestible (DE) and metabolizable (ME) energy levels, digestibility coefficients and ME:DE ratios of high oil corn (HOC), damaged high oil corn (DHOC), and normal corn (NC) fed to 32-kilogram pigs in experiment 2.

	Corn Type ^a			SEM
	DHOC	HOC	NC	
Value				
GE(kcal/kg)	4725 ^a	4477 ^b	4124 ^c	
Coefficient of DE % ^b	73.2 ^a	76.3 ^a	74.5 ^a	±1.96
DE(kcal/kg) ^c	3456.4 ^a	3418.6 ^a	3075.4 ^b	±84.2
Coefficient of ME % ^d	71.4 ^a	74.4 ^a	72.7 ^a	±2.1
ME(kcal/kg) ^e	3367.1 ^a	3330.6 ^a	3002.4 ^b	±89.9
ME:DE ratio ^f	.975 ^a	.975 ^a	.975 ^a	±.005

^a Lsmeans values with different superscripts are significantly different (P<.05).

^b Treatment effect (P = .5204).

^c Treatment effect (P = .0083).

^d Treatment effect (P = .5836).

^e Treatment effect (P = .0174).

^f Treatment effect (P = .9952).

Table 6. Total and apparent digestible crude protein levels, and protein digestibility coefficients for damaged high oil corn (DHOC), undamaged high oil corn (HOC) and normal corn (NC) fed to 32-kilogram pigs in experiment 2.

	DHOC ^a	HOC ^a	NC ^a	SEM
Crude Protein ^b				
Digestibility	85.3 ^a	87.5 ^a	85.2 ^a	±.8
Coefficient %				
Test Corn ^c				
Crude Protein	9.5 ^a	9.3 ^b	7.9 ^c	-
%				
Test Corn ^d				
Digestible	8.09 ^a	8.11 ^a	6.75 ^b	±.07
Crude Protein				
%				

^a Lsmeans values with different superscripts are different (P<.05).

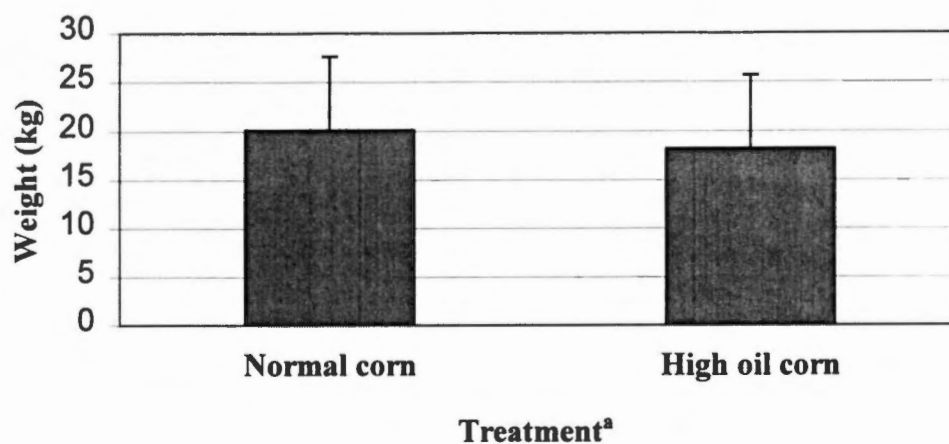
^b Treatment effect (P = .1145).

^c Treatment effect (P = .0001).

^d Treatment effect (P = .0001).

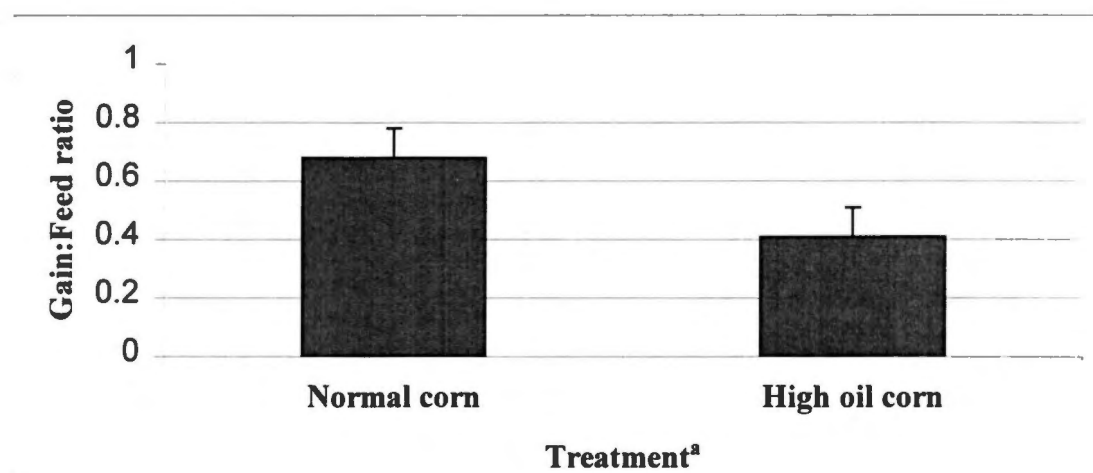
Appendix 2
Figures for experiments

Figure 1. Body weight at day 21 for pigs fed a normal corn or high oil corn diet after weaning.



^aTreatment effect ($P = .0001$).

Figure 2. Gain:Feed ratio at day 21 post-weaning for pigs fed a three-phase normal corn or a two-phase high oil corn diet after weaning.



^a Treatment effect ($P = .0134$).

VITA

Russell Farrell Gilliam was born June 5, 1974, and is the son of James Farrell and Marie Rose Gilliam. He received his elementary and secondary education in Columbia, Tennessee, graduating from Columbia Central High School in May of 1992. He then entered the University of Tennessee at Martin in August of 1992, majoring in Animal Science. Russell graduated from the University of Tennessee at Martin, with a Bachelor of Science in Agriculture in December of 1996. He was then employed by The Ames Plantation in Grand Junction, Tennessee where he worked in the beef and swine units until August of 1998. He entered the University of Tennessee at Knoxville in August of 1998, to begin his graduate degree. After completing the coursework for his degree he returned to the Ames Plantation to continue working in the swine unit. Russell received his Master of Science with a major in Animal Science in August 2000.

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