

NET ENERGY CONTENT OF SOYBEAN MEAL AND GLYCEROL FOR
GROWING AND FINISHING PIGS

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FOR GROWING AND FINISHING PIGS

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ABSTRACT

Three experiments were conducted to determine the net energy (NE) content of commercial soybean meal (C-SBM), low-oligosaccharide soybean meal (LO-SBM), and glycerol in growing and finishing pigs. An additional experiment was conducted to determine the effects of feeding ractopamine and various energy levels to finishing swine. In Exp. 1, the operational net energy for maintenance requirement (ONE_m) of growing and finishing pigs was determined. The experiment was completed at the University of Missouri (MO), the University of Illinois (UIUC), and the Prairie Swine Centre (PSC). The ONE_m was greater ($P < 0.01$) for finishing pigs (219, 123, and 270 kcal/kg $BW^{0.6} \cdot d^{-1}$ at UIUC, MO, and PSC) than for growing pigs (128, 115, and 78 kcal/kg $BW^{0.6} \cdot d^{-1}$ at UIUC, MO, and PSC). The ONE_m were different ($P \leq 0.05$) among locations. The interaction between the stage of growth and location for ONE_m was significant ($P < 0.01$). In conclusion, the and ONE_m for finishing pigs are greater than for growing pigs. Experiment location influences the ONE_m . The experiment location interacts with stage of growth on ONE_m , which suggests that different values for ONE_m should be used for calculating the NE of diets and ingredients measured in different stage of growth and experiment locations.

In Exp. 2, the NE content of C-SBM and LO-SBM were determined. The NE of C-SBM and LO-SBM were determined to not be different from each other at 1,634 and

1,990 kcal/kg ($P < 0.175$), respectively, in growing pigs and 2,150 and 2,554 kcal/kg ($P < 0.313$), respectively, in finishing pigs. The stage of growth (growing vs. finishing) did not affect the NE of C-SBM at 1,634 vs. 2,150 kcal/kg ($P < 0.147$) or LO-SBM at 1,990 vs. 2,554 kcal/kg ($P < 0.095$).

In Exp. 3 the digestible, metabolizable, NE content of glycerol was determined to be 3,898, 3,854, and 2,740 kcal/kg, respectively, for growing pigs and 3,771, 3,747, and 3,461 kcal/kg, respectively, for finishing pigs. The digestible, metabolizable, NE content of glycerol did not differ ($P < 0.90$) between the phases of growth.

In Exp. 4, the effects feeding ractopamine with various levels of dietary energy were investigated. There were no interactive effects ($P > 0.05$) of ractopamine and energy level. The feeding of 7.4 ppm ractopamine improved ($P < 0.05$) ADG, F:G, carcass weights, loin eye area, and loin pH. The feeding of reduced energy diets resulted in reduced ADG with the lowest energy level and increased F:G at both reduced energy levels. The feeding of the lowest energy level resulted in reduced carcass weight, backfat, and loin pH. Due to no interaction between ractopamine and energy level being present, it can be concluded that a ractopamine response will be observed regardless of the dietary energy level.

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Chapter I

REVIEW OF LITERATURE

INTRODUCTION

Within the US swine industry, dietary energy has typically been expressed as digestible (DE) or metabolizable (ME) energy. As with the utilization of standardized ileal digestibility, interest is growing in regards to the application of the net energy (NE) system in diet formulation. The NE system is a more refined energy system than that of DE and ME in that it takes into account all metabolism energy expenditures and results in a more refined amount of energy that is available for maintenance or production within the animal.

Within Europe, the use of NE systems is widely accepted. These systems include the French INRA, the Dutch CVB, and the Danish Potential Physiological Energy (PPE) systems. The INRA and CVB systems are based off of digestibility studies and subsequent regression equation that were developed by Noblet et al. (1994). The PPE system is based off of the potential energy value for ATP production when digestible nutrients are completely oxidized in animals (Boisen, 2003).

While these energy systems are widely accepted throughout Europe, North American swine nutritionists have little faith in them. This lack of faith is due mainly to over/under estimations of feedstuffs and the experimental conditions in which the values

were obtained. Therefore, it is of importance that an energy system is developed in which North American nutritionists have confidence in. In order to do this, the energy system must take into account animal factors such as nutrient utilization and must be developed in experimental conditions that replicate commercial conditions as closely as possible.

UTILIZATION OF ENERGY BY PIGS

The typical energy flow schematic for swine includes gross energy (GE), DE, ME, and NE (Figure 1.1). The GE of a diet or ingredient is typically obtained via bomb calorimeter and includes the maximum amount of energy that is available to the animal and is dependent upon the proportions of carbohydrate, fat, protein, minerals, and water present in the sample (Ewan, 2001). The standard contribution of energy for carbohydrate, protein, and fat are 3.7 to 4.2, 5.6, and 9.4 kcal/kg, respectively (NRC, 1998). Therefore, the protein and fat content of the diet are the greatest contributors of energy content.

Digestible energy is the amount of energy remaining after fecal energy is subtracted from GE, with this being the energy available for utilization within the animal (Ewan, 2001). While DE represents the energy available for digestion, it over estimates the energy content of protein and fibrous feedstuffs and under estimates the energy content of fat and starch sources (Noblet, 1998).

Metabolizable energy is the amount of energy remaining after urinary energy is subtracted from DE and is the amount of energy available to the animal for metabolic processes. Additionally, gaseous energy from within the digestive tract represents a small

portion of the difference between DE and ME and is typically ignored in the calculations. As with DE, ME over estimates the energy content of protein and fibrous feedstuffs and under estimates the energy content of fat and starch sources (Noblet, 1998). Within both DE and ME systems, the over estimation of protein and fibrous feedstuffs is in relation to the fact that ingestion of these feedstuffs results in varying levels of heat production (Noblet et al., 1994), with this expenditure not being taken into account calculation of NE.

Net energy is the amount of energy remaining after heat increment (HI) is subtracted from ME. The HI is heat that is produced by the digestion, metabolism, and fermentation of nutrients within the gastrointestinal tract. Net energy more closely represents the “true energy” that is available to the animal and can be split into NE for maintenance (NEm) and NE for production (NEp). The NEm is energy that is utilized to maintain life and body heat and NEp represents excess energy above NEm that is utilized for production purposes such as milk synthesis, lean or fat accretion, or fetal development (Ewan, 2001).

NET ENERGY SYSTEMS

There are currently three NE systems that are utilized in Europe. These include the French INRA, the Dutch CVB, and the Danish PPE (potential physiological energy) systems. The INRA and CVB systems were developed utilizing indirect calorimetry and nutrient digestibility studies and the subsequent development of prediction equations. The PPE system utilizes *in vitro* nutrient digestibility values and the oxidation of nutrients used for ATP synthesis. While these systems are widely accepted throughout Europe,

North American nutritionists are reluctant to accept these systems due to the over/under estimation of the energy values of common feedstuffs and the fact that little of the previous work with these systems has been performed under true production conditions with *ad libitum* feed intake nor with current genetic lines.

The French NE system

The Institut National de la Recherche Agronomique (INRA) NE system is based off of indirect calorimetry and digestibility studies that were conducted by Noblet et al. (1994). Within these studies, 45 kg boars were fed 61 diets that represented a wide range of feedstuffs. High ME intake (550 kcal of ME/kg BW^{0.6}) and low ME intake (330 kcal of ME/ BW^{0.6}) diets were fed during the data collection period, with energy digestibility, energy losses, and heat production being measured. Heat production was measured by the indirect calorimetry method. The average fasting heat production of growing pigs (179 kcal/kg BW^{0.6}) was determined by extrapolating energy retention to zero ME intake using a linear regression equation. The NE values of each diet were then calculated as the sum of fasting heat production and energy retention in pigs fed at a high ME intake. Eleven regression equations based on the concentrations of digestible nutrients and dietary nutrients were proposed for predicting NE values in mixed diets and feed ingredients (Noblet et al., 1994, Sauvant et al., 2004). Of these eleven equations, three are typically utilized:

$$NE = 2.892*DCP + 8.365*DEE + 3.418*ST + 2.844*SU + 2.055*Dresidue$$

$$NE = 0.703*DE + 1.58*EE + 0.47*ST - 0.97*CP - 0.98*CF$$

$$NE = 0.730*ME + 1.31*EE + 0.37*ST - 0.67*CP - 0.97*CF$$

where:

CP = crude protein

DCP = digestible CP

EE = ether extract

DEE = digestible EE

ST = starch

SU = sugar

Dresidue = digestible organic matter – DCP – DEE – ST – SU

DE = digestible energy

CF = crude fiber

ME = metabolizable energy

The Dutch NE system

The Central Bureau Livestock Feeding (CVB) method for determination of NE is was developed by the modification of one of the INRA NE equations. The main differences between the two energy systems is analytical procedures that were utilized to measure carbohydrates and lipids. In the CVB system, starch is measured via enzymatic digestion and sugar is measured via the enzymatic digestible fraction and the fermentable fraction. Additionally, lipids are measured via acid hydrolysis.

$$NE = 2.796*DCP + 8.542*DEE_{acid} + 3.380*ST_{ame} + 3.047*SU_e + 2.328*FCH$$

where:

DCP = digestible CP

DEEacid = digestible ether extract using acid hydrolysis

STame = enzymatic digestible fraction of the starch fraction, analyzed according to the amyloglucoside method

SUe = enzymatic degradable fraction of the total sugar fraction

FCH = fermentable carbohydrate fraction, being starch (amyloglucoside method) + fermentable SU + DNSP

DNSP = digestible OM – digestible CP – digestible ether extract using acid Hydrolysis – starch (amyloglucoside method) – 0.95*SU

0.95 = correction factor for disaccharides for ingredients

The Danish NE system

The Potential Physiological Energy (PPE) system was developed by Boisen (2007). This energy system is based off of the potential energy value for ATP production when digestible nutrients are completely oxidized in animals (Boisen, 2003). The PPE system utilizes *in vitro* digestibility estimates of crude protein, amino acids, organic matter, lipids, and carbohydrates, tabular digestible nutrient concentrations, ingredient SID amino acid values, and enzyme indigestible ileal dry matter in the calculation to determine PPE. The PPE system does not take into account the intended metabolic utilization of various nutrients which allows for the PPE of various ingredients to be additive within the complete diet and is independent of animal factors (Boisen, 2007). Additionally, the PPE system is not influenced by experimental, environmental, or animal factors, resulting in a more refined, consistent energy value (Boisen, 2007).

MAINTENANCE ENERGY REQUIREMENT

Maintenance energy requirement can be expressed as either the ME requirement for maintenance (ME_m) or as the NE requirement for maintenance (NE_m, NRC, 1998). Both ME_m and NE_m are typically expressed in terms of metabolic body weight as an exponential function (aBW^b , NRC, 1998). The use of an exponential function is based upon the proportionality between fasting heat production and metabolic body weight, with the exponent maintaining proportionality between body weight and the maintenance requirement (Kleiber, 1975, Chwalibog, 1991). Traditionally, the exponent of 0.75 has been utilized to express the metabolic body weight of animals (NRC, 1998). However, exponents ranging from 0.42 (Noblet et al., 1994) to 0.67 (Heusner, 1982) have been suggested as being a more appropriate exponent. This is due to the fact that when an exponent of 0.75 is used, ME_m decreases with increasing body weight (Chwalibog, 1991). This discrepancy is presumably due to changes in body composition and the ratio of visceral weight to body weight during the growth of the animal (Noblet et al., 1991). With this in mind, an exponent of 0.60 has been suggested to be more appropriate to predict the maintenance requirement of growing pigs (Brown, 1982; Noblet et al., 1994; van Milgen et al., 1998).

Two main methods are utilized to determine the maintenance requirement of pigs. In one method, the requirement is estimated when pigs are fasted or fed a restricted energy intake in order to reach a level of zero energy retention (Chwalibog, 1991). However, with differences in energy metabolism in fasted or limit fed pigs and pigs that are allowed free access to feed, this method can prove to be unrepresentative

(Baldwin, 1995). Another method of determining maintenance requirement involves the feeding of graded levels of energy intake. In this procedure, the maintenance requirement is estimated by the regression of energy retention on energy intake (Figure 1.2). This regression results in MEM being represented by the x-intercept and NEM being represented by the y-intercept (de Goey and Ewan, 1975; Ewan, 2001). For purposes throughout the rest of this thesis, NEM will be referred to as the operational NE requirement for maintenance (ONEM). When utilizing 0.60 as the exponent to determine metabolic body weight, ONEM estimates range from 117 kcal/kg (de Lange et al., 2006) to 179 kcal/kg (Noblet et al., 1994).

Based upon the variation in published maintenance energy requirements, it is obvious that many factors can influence requirement estimations within pigs. These factors can include both environmental and physiological, as well as the methods in which the estimates were calculated.

Environmental temperature can be one of the largest factors that influence energy requirements. It has been observed that when temperatures are above thermoneutral levels (23° C, Stahly and Cromwell, 1979), maintenance energy requirements are affected very little (Black, 1995; Giles et al., 1998). This is due to a low energy cost for the act of panting to dissipate heat and reduced feed intakes will result in decreased metabolic rates. On the other hand, when temperatures are lower than the thermoneutral range, maintenance energy requirements are increased 3 to 4% for every 1° C reduction in temperature (Noblet et al., 1985; Close, 1996).

Another factor that contributes to variation in energy requirements is the size of the gastrointestinal tract and visceral organs. It has been suggested that heat production

from metabolically active organs can contribute up to 30% of the animal's basal heat production (Baldwin and Bywater, 1984). Additionally, the gastrointestinal tract and visceral organs can have four times the influence on fasting heat production than muscle and fat tissues (Tess et al., 1984; Noblet et al., 1999). Differences in housing conditions, gender, genetics, nutrition, feeding strategy, and stage of growth can also contribute to variations in energy requirements (Noblet et al., 1999).

The method utilized to determine energy requirements can also contribute to the variation. Typically, indirect calorimetry is utilized to determine fasting heat production. Within indirect calorimetry, the length of the fasting period, previous diets, and physical activity can influence the measurements (de Lange et al., 2006; Emmans, 1999).

Additionally, the overall animal environment in which these measurements are obtained do not represent production systems in which the values are to be applied.

The comparative slaughter method is also utilized to measure energy requirements (Adeola, 2001). Within this method, a representative initial slaughter group is harvested in order to predict initial body composition of the test subjects. An important factor with this method is that the initial slaughter group must be a representative sub-sample of the animal population that is to be utilized within the study. With comparative slaughter studies, the length of feeding is typically longer and animal numbers per treatment are typically greater in order to minimize variations in body composition values (Boisen and Verstegen, 2000). Comparative slaughter studies are considered to be more representative of commercial feeding systems than indirect calorimetry studies (Reynolds, 2000).

ENERGY CONTENT OF SOYBEAN MEAL

Soybean products, in particular soybean meal (SBM), have traditionally been utilized in swine diets as a source of highly available amino acids, with 8.6 million tons utilized in swine diets in 2007 (Soy Stats, 2008). While containing high levels of lysine, threonine, tryptophan, isoleucine, and other amino acids, SBM is an excellent complement to other ingredients that may be deficient in these amino acids. While being utilized primarily as an amino acid source, SBM also becomes an important energy source.

On a gross (4,132 vs. 3,869 kcal/kg; Sauvant et al., 2004) and digestible (3,685 vs. 3,525 kcal/kg; NRC, 1998) basis, SBM contains more energy than corn. However, when expressed on a metabolizable (3,420 vs. 3,380 kcal/kg; NRC, 1998) or net (2,395 vs. 2,020 kcal/kg; NRC, 1998) basis, corn contains more energy than SBM. This inefficiency of energy utilization does not appear to be due to problems in the digestion of the protein fraction of the meal, but rather to the poor digestion of the carbohydrate portion of the meal (Sebastian et al., 1999).

Oligosaccharides are saccharide polymers containing a small number of simple sugars that are linked together by α -1,6-galactosidic linkages (Liener, 2000). In regards to monogastric nutrition, raffinose and stachyose are the oligosaccharides of concern when SBM is utilized in diets due to their poor digestibility and utilization (Coon et al., 1990; Liener, 2000; Sebastian et al., 2000). This poor utilization is caused by monogastrics lacking the enzyme α -galactosidase, the enzyme that is necessary for the hydrolysis of the α -1,6-galactosidic linkages of raffinose and stachyose to produce readily absorbable

sugars (Liener, 2000). As a result of this enzyme not being present, these oligosaccharides pass into the lower gastrointestinal tract and are fermented by the microbial population (Liener, 2000; van Kempen et al., 2006).

This increase in fermentation results in increases of carbon dioxide, hydrogen, and methane production (Liener, 2000). Additionally, the increase in gas production yields increases in flatulence, nausea, diarrhea, and acidity of the lower gastrointestinal tract (Coon et al., 1990; Liener, 2000; van Kempen et al., 2006). These digestive abnormalities, alone or in unison, can lead to reductions in nutrient digestibilities do to reduced digesta contact with the absorptive properties within the digestive tract.

Over the past two decades, SBM varieties have been produced that lack the genes responsible for galactinol, raffinose, stachyose, and myo-I, 1P synthase production (Figure 1.3, Sebastian et al., 2000). The absence of these genes leads to reductions in galactinol, raffinose, and stachyose content and an increase in sucrose content (Sebastian et al., 2000). In addition to reductions in oligosaccharide content, these new SBM varieties also contain reduced amounts of phytic acid due to the inhibition of the myo-I, 1P synthase gene.

Studies utilizing low-oligosaccharide SBM have been conducted in both poultry and swine with positive results in terms of nutrient utilization. Coon et al. (1990) fed roosters SBM in which the raffinose and stachyose content was reduced via alcohol extraction. The removal of the oligosaccharides resulted in increased digesta time and tended to increase digesta pH. Additionally, true metabolizable energy was increased from 2,794 to 3,368 kcal/kg when the oligosaccharides were removed from the SBM. When the SBM was extracted in the study by Coon et al. (1990), sucrose content was

reduced as well. Therefore, the difference in energy content of the SBM types could have been even greater due to the fact that sucrose alone contains 3,635 kcal/kg of ME (NRC, 1998).

In swine, Smiricky et al. (2002) fed 35 kg pigs complex diets with and without a source of oligosaccharides (soy solubles). The inclusion of oligosaccharides in the diet reduced dry matter digestibility along with the digestibility of the majority of the amino acids. The most prolific reductions in amino acid digestibility included lysine, methionine, and threonine being reduced by 7.1, 3.1, and 4.9 percentage units, respectively.

Due to reductions in phytic acid content of the low-oligosaccharide SBM, phosphorus bioavailability was increased from 34 to 81% in broiler chicks and from 31 to 60% in growing pigs when low-oligosaccharide SBM was compared to commercial SBM (Spencer et al., 2000). This increase in phosphorus bioavailability can lead to the use of less inorganic phosphorus within the diets while reducing phosphorus excretion.

ENERGY CONTENT OF GLYCEROL

In addition to the utilization of ethanol co-product utilization, there are opportunities within the swine industry to utilize co-products from other alternative energy sources. One such co-product is glycerol. Glycerol is the main co-product resulting from the production of bio-diesel from new or used vegetable oils and animal fats (Kerr et al., 2007; NBB, 2009). Glycerol is utilized in many industrial practices ranging from a flavor additive in chewing tobacco to a moisturizing agent in lipsticks. In

2008, an estimated 2.7 billion liters of biodiesel were refined, yielding 210 million kg of glycerol (NBB, 2009).

In regards to animal nutrition, it would appear as though glycerol could be utilized as a potential energy source. When glycerol is consumed, it is absorbed in the small intestine at high rates due to its low molecular weight and its ability to passively diffuse (Lin, 1977; Guyton, 1991). Upon absorption, glycerol is converted to glucose or oxidized for energy production by glycolysis and the citric acid cycle (Robergs and Griffin, 1998). Gluconeogenesis is limited by the availability of glycerol (Cryer and Bartley, 1973; Baba et al., 1995), therefore it would seem plausible that glucose production could be increased if a free form of glycerol is fed in the diet.

Research conducted in the mid-1990's indicated that the inclusion of glycerol in swine diets did not negatively impact growth performance, carcass characteristics, or meat quality (Kijora, 1995; Mourot et al., 1994). More recently, work in our lab (Hinson et al., 2008) has indicated that glycerol could replace 6% of the corn in nursery pig diets while maintaining similar growth performance. Additionally, Groesbeck et al. (2008) illustrated that 3 and 6% inclusion of glycerol in nursery pig diets numerically increased performance values over that of the control diets with 0% glycerol. In grow-finish pigs, Lammers et al. (2008b) indicated that up to 10% glycerol can be included in the diet without impacting growth performance, carcass characteristics, or meat quality. Additionally, Stevens et al. (2008) illustrated that up to 10% glycerol inclusion in the diet can improve ADG and ADFI. However, backfat depths were increased and loin quality scores were decreased (Stevens et al., 2008).

In terms of energy content, little research has been conducted with glycerol. It has been reported that the GE of glycerol is 3,625 kcal/kg (Lammers et al., 2008a), with in house analysis of glycerol resulting in a GE value of 3,596 kcal/kg. Work by Lammers et al. (2008a) determined the DE and ME of glycerol to be 3,344 and 3,207 kcal/kg, respectively. The inclusion rate of glycerol and the size of the pig did not affect the energy values that were obtained. While little work has been done to determine the DE and ME values of glycerol, no work has been completed to determine the NE content.

While it appears as though glycerol can successfully be added to swine diets, there are precautions that need to be taken. Glycerol can have elevated levels of both sodium chloride and methanol. Salt levels in the diet can be adjusted to accommodate the inclusion of glycerol is sodium chloride values are high. In the case of methanol, FDA limits the methanol content of a total mixed ration at 150 ppm. Therefore, methanol content of glycerol should be determined prior to feeding to ensure that excessive amounts are not fed. Additionally, the physical properties of glycerol may limit inclusion rates in certain production systems due to the possibility of feed flowability issues within feeders and feed bins.

RACTOPAMINE HYDROCHLORIDE (PAYLEAN®)

It is well known that the feeding of Paylean increases the partitioning of energy from lipid accretion to protein accretion through reducing lipogenesis and increasing lipolysis in adipose tissue and increasing protein synthesis in muscle tissue (Adeola et al., 1990 and Williams et al., 1994). Since its approval in 1999, Paylean has consistently

provided a 10% improvement in ADG and feed efficiency, 1% increase in yield, and 0.5% in lean (Jones et al., 2000; Weber et al., 2006; Crome et al., 1996; Armstrong et al., 2004; Carr et al., 2005). These large improvements in performance criteria have led to Paylean being extensively utilized within the swine industry as a means of producing more kilograms of pork in a more timely and efficient manner.

Upon its approval, Paylean was typically included in the diet at 11 to 22 ppm for up to 35 days under the pretense that more is better. However, within the last few years, it has been realized that inclusion rates from 5 to 10 ppm at shorter durations (14 to 28 days) are the most economically advantageous (Armstrong et al., 2004). Other Paylean feeding programs that have been shown to be advantageous are step-up programs in which lower inclusion rates of Paylean are fed for a certain time period followed by higher concentrations for a certain time period (i.e. 5 ppm for 2 weeks followed by 10 ppm for two weeks).

Diminishing returns in regards to increased dose and duration is attributed to the fact that a down regulation or desensitization of the β -adrenergic receptors that are involved in the mechanism of action occurs with ractopamine hydrochloride (Moody et al., 2000).

DIETARY ENERGY LEVEL

Dietary energy is one of the most costly ingredients in swine diets, with these costs fluctuating greatly in the last few years. Therefore, dietary energy should play an important part of diet formulation.

It is well known that swine will consume feed at rates that meet their energy needs. As dietary energy levels are increased, feed consumption will be reduced and when dietary energy levels are reduced, feed consumption will increase to meet the animals energy needs (Steerley and Evans, 1983). However, when the energy density of a diet is increased, it is imperative to adjust amino acid levels within the diet to maintain similar calorie:amino acid ratios. This increase in amino acid concentrations within the diet is to ensure that amino acid intake on a g/d basis is adequate with the increased energy content and subsequent reduction in feed intake (Azain, 2001).

In a review by Petigrew and Moser (1991), the addition of fat in nursery diets (5 to 20 kg) improved feed efficiency when calorie:amino acid ratios were held constant. However, when calorie:amino acid ratios were not held constant, there was only a slight reduction in ADG and this reduction was not observed when the ratio was held constant. In grow-finish pigs, increased energy density resulted in improved gain, feed efficiency, reduced feed intake, and increased carcass fat. These effects were observed when the calorie:amino acid ratio was and was not maintained at a constant ratio. Decreased feed intake with increased energy density is more consistent in grow-finish pigs than in nursery pigs. This suggests that other factors such as gut fill influence feed intake in nursery pigs more than energy density (Azain, 2001).

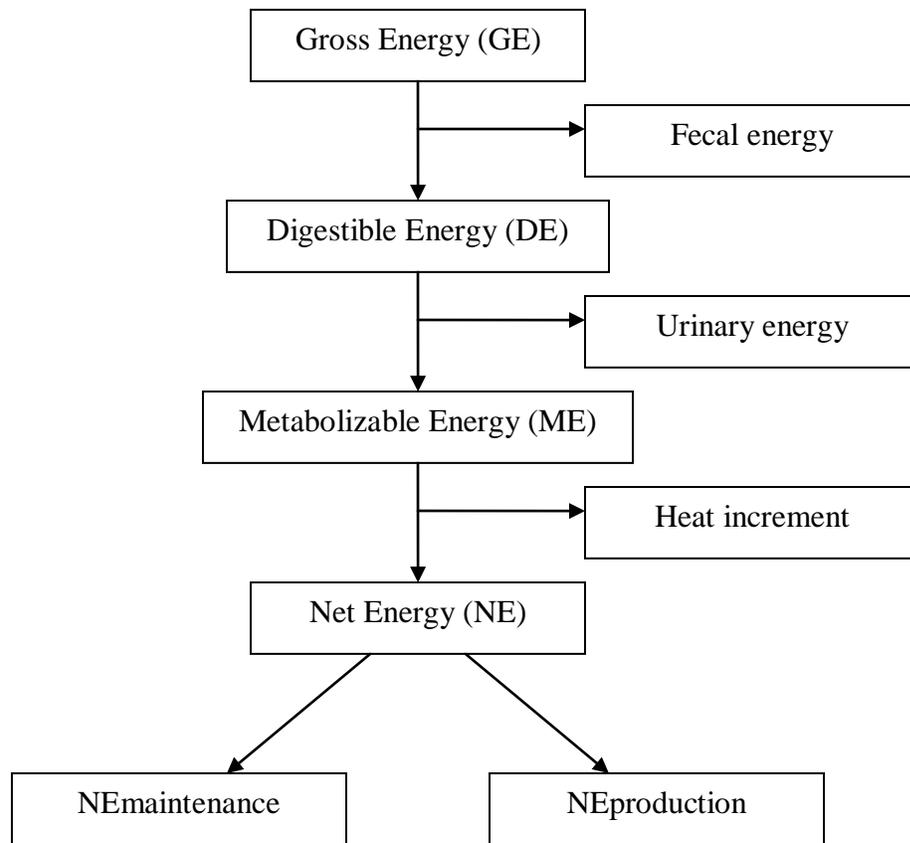


Figure 1.1. Energy utilization within pigs.

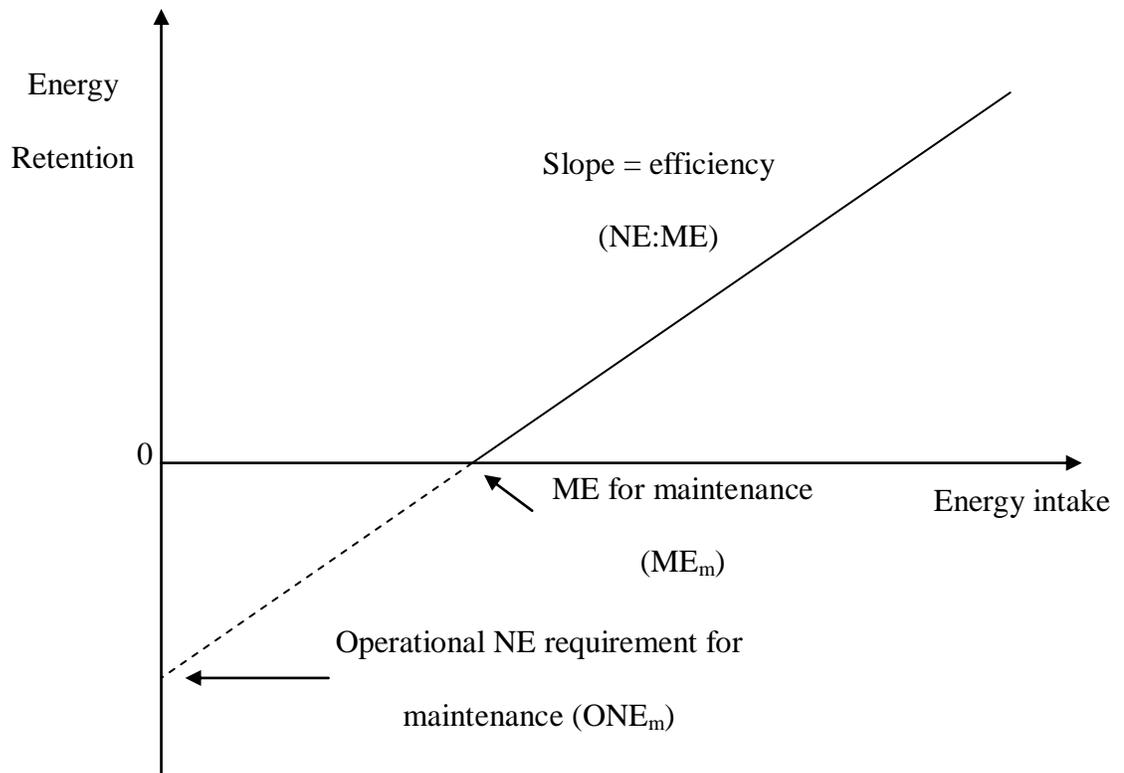


Figure 1.2. Estimation of the energy requirement for maintenance from energy retention (kcal/BW^{0.6}/d) and energy intake (kcal/BW^{0.6}/d) in pigs. Adjusted from Ewan (2001).

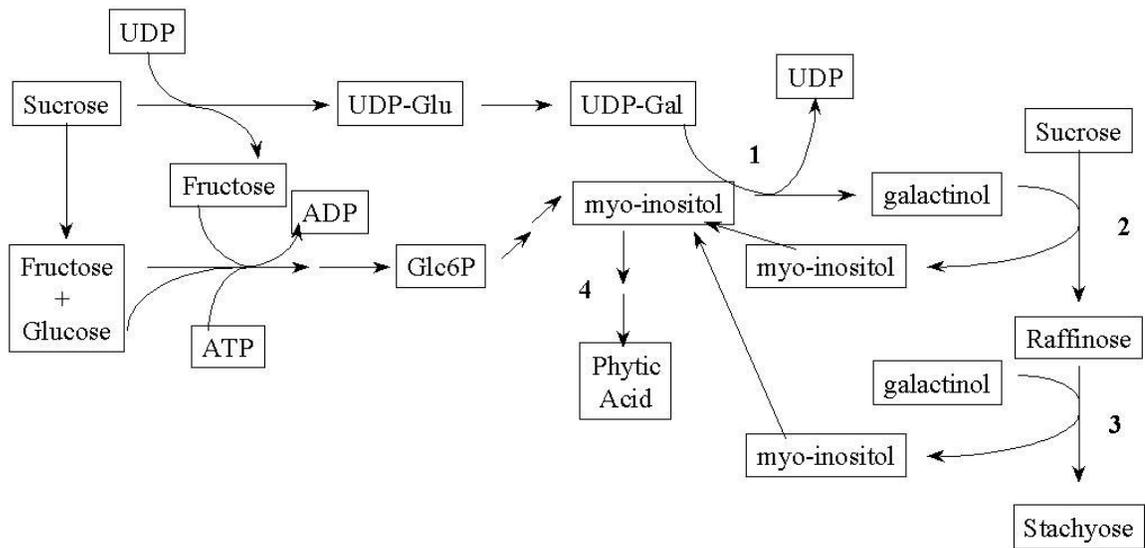


Figure 1.3. Soluble carbohydrate synthesis in the soybean. Enzymes selected to be reduced: 1) galactinol synthase; 2) raffinose synthase; 3) stachyose synthase; 4) myo-I, 1P synthase.

Chapter II

INFLUENCE OF LOCATION AND STAGE OF GROWTH ON THE OPERATIONAL NET ENERGY REQUIREMENT FOR MAINTENANCE IN PIGS

ABSTRACT

A serial slaughter experiment was conducted to measure the Operational NE requirement for maintenance (ONE_m) for growing and finishing pigs. The objective was to measure the effect of the stage of growth on ONE_m and to determine if ONE_m differs for pigs at different locations. The experiments were conducted at the University of Illinois (UIUC), at the University of Missouri (MO), and at the Prairie Swine Centre, Saskatoon (PSC). Similar protocols were used at all locations. A total of 48 growing (initial BW: 23 kg) and 48 finishing (initial BW: 83 kg) barrows were used at each location. Within each stage of growth, pigs were allotted to eight outcome groups of six barrows according to BW. Within each outcome group, each pig was randomly allotted to one of six treatment groups. Two treatment groups at each stage of growth within each location served as an initial slaughter group. The remaining pigs were assigned to four dietary treatments and harvested at the conclusion of the experiment. Growing pigs at all locations and finishing pigs at MO and PSC were fed 1.40, 1.90, 2.40, or 2.90 times the assumed ME requirement for maintenance (ME_m ; 191 kcal/kg $BW^{0.6} \cdot d^{-1}$), but finishing pigs at UIUC were fed 1.85, 2.20, 2.55, or 2.90 times ME_m . Results showed that ADG for

growing pigs increased (linear, $P < 0.01$) and ADG for finishing pigs also increased (linear and quadratic, $P < 0.01$ at UIUC; linear, $P < 0.01$ at MO and PSC) as feeding level increased. Lipid gain and energy retention for both growing and finishing pigs increased (linear, $P < 0.01$) with feeding level at all locations. The efficiency (NE:DE) of energy utilization was greater ($P < 0.01$) for finishing pigs (0.72, 0.54, and 0.78 at UIUC, MO, and PSC) than for growing pigs (0.56, 0.41, and 0.46 at UIUC, MO, and PSC). The ONE_m was also greater ($P < 0.01$) for finishing pigs (219, 123, and 270 kcal/kg $BW^{0.6} \cdot d^{-1}$ at UIUC, MO, and PSC) than for growing pigs (128, 115, and 78 kcal/kg $BW^{0.6} \cdot d^{-1}$ at UIUC, MO, and PSC). The NE:DE and ONE_m were different ($P \leq 0.05$) among locations, and the interaction between the stage of growth and location for ONE_m was significant ($P < 0.01$). In conclusion, the NE:DE and ONE_m for finishing pigs are greater than for growing pigs, and values for NE:DE and ONE_m differ among locations. The location interacts with stage of growth for ONE_m , which suggests that it may be necessary to use different values for ONE_m to estimate NE requirements and for calculating the NE of diets evaluated at different stages of growth or at different locations.

INTRODUCTION

In growing animals, the NE of a diet is estimated as the sum of the energy retained in the body (NE_g) and the amount of energy required for basic body functions (NE_m ; Baldwin, 1995). The NE_m may be estimated as fasting heat production (FHP), but FHP may not be an accurate measure of NE_m for commercially-fed pigs because of the

difference in energy metabolism between fasted pigs and pigs that are allowed free access to feed (Baldwin, 1995).

An alternative procedure to estimate NE_m is to regress energy retention on energy intake for pigs fed graded levels of energy. By extrapolating this regression line to zero energy intake, the y-intercept of the equation is considered an estimate of NE_m (Ewan, 2001). To distinguish the NE_m estimated by regression analysis from the NE_m measured by FHP, the estimate obtained from regression analysis is called the operational net energy for maintenance (ONE_m). This regression also allows estimating diet NE_g concentration as the slope of the regression line for the relationship between energy retention and feed intake.

Estimates of ONE_m and NE_m for pigs vary from 117 to 181 kcal/kg $BW^{0.6}$ (Noblet and Henry, 1991; Noblet et al., 1994a,b; de Lange et al., 2006). Currently, the French NE system is using a value of 179 kcal/kg $BW^{0.6}$ for NE_m . Several factors such as animals and location may influence values for NE_m and ONE_m (Baldwin and Bywater, 1984). Ideally, these values should be measured under the same conditions as those used to measure the NE value of diets because of the direct impact of NE_m and ONE_m on NE values (Boisen and Verstegen, 1998). To our knowledge, no experiments have been conducted in North America to determine the effect of pig BW and of experiment location on the ONE_m of pigs. The objective of this experiment, therefore, was to estimate the ONE_m in both growing and finishing pigs to measure the effect of the stage of growth on ONE_m . The second objective was to determine if ONE_m is constant among different locations.

MATERIALS AND METHODS

The experiment was conducted at the University of Illinois, Urbana (UIUC), at the University of Missouri, Columbia (MO), and at the Prairie Swine Centre Inc., Saskatoon, SK, Canada (PSC). Similar experimental protocols were used at all locations and all animal procedures were approved by the Institutional Animal Care and Use Committee at each location.

Animals, Housing, and Experimental Design

A total of 48 growing and 48 finishing barrows were used at each location (Table 2.1). Pigs at UIUC and PSC originated from the matings of line 337 sires to C-22 females (Pig Improvement Company, Hendersonville, TN, and PIC Canada, Winnipeg, MB, respectively). Pigs at MO were the offspring of C-22 females mated to T4 males (Pig Improvement Company, Hendersonville, TN). The 48 pigs at each stage of growth and within each location were selected from a larger group of pigs based on BW and ADG during a two wk pre-experimental period in which pigs were allowed ad libitum access to a corn soybean meal based diet. The 48 pigs used at each location and within each stage of growth (growing and finishing stages) were allotted to eight outcome groups of six barrows according to BW. Within each outcome group, pigs were randomly allotted to one of six treatment groups with eight pigs per treatment group. Two treatment groups at each stage of growth and at each location were randomly chosen to serve as the initial slaughter group and all pigs in these two treatment groups were harvested at the start of

the experiment. Pigs on the remaining treatment groups were randomly assigned to four dietary treatments and harvested at the conclusion of the experiment.

Pigs at each location were housed individually in a pen equipped with a single space dry feeder and a nipple waterer in an environmentally controlled building. The thermoneutral zone was assumed to be between 20 and 25°C for growing pigs and between 15 and 20°C for finishing pigs.

The individual BW of pigs was recorded weekly. Daily feed allowances were provided in two equal meals and water was available at all times. Orts were collected and weighed daily and daily feed disappearance was assumed to represent daily feed intake. The experimental period was 28 d for growing pigs and 35 d for finishing pigs.

Dietary Treatments

Each location used similar diets consisting primarily of corn and soybean meal (Table 2.2). Diets were formulated to exceed current estimates of nutrient requirements when expressed as dietary concentrations (NRC, 1998) by at least 10% because pigs were restricted in their feed intake. Small differences in the chemical composition of the diets reflected different nutrient profiles of local ingredients. Chromic oxide (0.40%) was included in the diets at UIUC and MO, and celite (0.50%) was added to the diets at PSC as indigestible markers. No antibiotic growth promoters were used. All pigs within each stage of growth received the same diet that was provided in a mash form throughout the experimental period. All growing pigs at all locations and finishing pigs at MO and PSC were provided feed in the amount of 1.40, 1.90, 2.40, or 2.90 times the assumed ME requirement for maintenance (ME_m), but finishing pigs at UIUC were fed 1.85, 2.20, 2.55,

or 2.90 times the assumed ME_m . The ME_m was assumed to be 191 kcal/kg $BW^{0.60}$ for individually housed pigs. For a pig weighing 50 kg, this value is equivalent to 106 kcal/kg $BW^{0.75}$ (NRC, 1998). The reason for using a value of 191 kcal/kg $BW^{0.6}$ for ME_m rather than 106 kcal/kg $BW^{0.75}$ is that values calculated from kg $BW^{0.60}$ more accurately predict the metabolic BW of growing pigs than values based on kg $BW^{0.75}$ (Noblet et al., 1991). Daily feed allowance was adjusted weekly according to the BW of each pig.

Sample Collection and Slaughter Procedure

At the conclusion of the experiment, ADG, ADFI, and G:F for each pig were calculated and summarized within each feeding level. Fresh fecal samples were collected on d 7 of each week from each pig by grab sampling. Fecal samples collected each week were pooled within pig at the conclusion of the experiment, lyophilized, and finely ground before chemical analyses.

The comparative slaughter procedure was used to estimate energy retention in the pigs (de Goey and Ewan, 1975). Pigs were weighed on the last day of the experiment and feed was withheld for 16 h. Pigs at UIUC and MO were then transported to the meat science laboratory where they were weighed again, and euthanized by captive-bolt stunning followed by exsanguination. At PSC, pigs were transported to the surgery room, weighed, and euthanized. Care was taken to ensure that all blood was collected from each pig. The carcass was split down the midline from the groin to the chest cavity and the viscera were removed.

At UIUC, the carcass, the viscera, and the blood were collected, weighed, and processed separately. Carcasses were stored at 4°C for 16 h, weighed and cut into pieces

to fit into a grinding apparatus (Autio Company, Astoria, OR). Carcasses were ground twice using a 12 mm die for growing pigs and an 18 mm die for finishing pigs. Ground carcasses were then mixed in a mixer (Keebler Company, Chicago, IL). After one minute of mixing, approximately 8 kg of carcass was collected and stored at -20°C. The frozen carcass samples were thawed at 4°C for 16 h and cut into half inch slices using a band saw (Hobart Company, Troy, OH). The carcass slices were ground twice through a meat grinder (Lasar manufacturing Company Incorporated, Los Angeles, CA) using a 2 mm die and subsamples for chemical analyses were collected.

The digestive tracts were flushed with water to remove digesta without squeezing of the intestines. The emptied tract was combined with other organs including the liver, kidney, spleen, and lungs and then patted dry. The weight of the viscera was recorded and the viscera was stored at 4°C overnight. The cooled viscera were ground in a Butcher Boy (Lasar Manufacturing Company, Los Angeles, CA) meat mincer using a 10 mm die followed by a second grind using a 2 mm die. Ground viscera were mixed and two subsamples were collected. The subsamples were ground again in a food processor (Proctor Silex, Hamilton Beach, CA) and the final subsamples were collected. All subsamples of carcass, viscera, and blood were lyophilized to a constant weight and finely ground prior to chemical analyses.

At MO and PSC, carcass, viscera, and blood were collected separately, but processed together. After the removal of digesta from the digestive tract, the emptied digestive tract, other organs, and blood were returned to the carcass and the digesta-free BW was recorded. Carcasses were then stored at -20°C for later grinding. The whole digesta-free body was weighed prior to grinding and cut into smaller pieces and passed

through a 10 mm die two times and a 5 mm die two times using a meat grinder (Autio Company, Astoria, OR). Following each pass, the mince was collected into a barrel and mixed prior to the next pass through the grinder. On the final pass, five subsamples of 250 g were obtained as the material left the grinder. Each of these five samples were placed on a flat surface on waxed paper, flattened to a thickness of 5 cm and quartered. Random quarters from each of the 5 subsamples were collected, lyophilized to a constant weight, and finely ground for chemical analyses.

Chemical Analyses

All three locations followed similar procedures for chemical analyses for DM, GE, CP, and lipids. In the analyses for body composition, UIUC conducted chemical analyses separately for carcass, viscera, and blood, but MO and PSC conducted chemical analyses on the whole digesta-free body. All analyses were performed on duplicate samples and analyses were repeated if results from duplicate samples varied more than 5% from the mean. The DM of diets and fecal samples was determined by oven drying at 135°C for 2 h (procedure 930.15; AOAC, 2005). The DM of carcass, viscera, and blood was calculated by freeze drying to a constant weight and this value was used to calculate the whole body concentration of energy, protein, and lipids. The GE of diets, fecal samples, and body components were measured using an adiabatic bomb calorimeter (Model 6300, Parr Instruments, Moline, IL). Benzoic acid was used as the standard for calibration. The concentration of N was measured using the combustion method (procedure 990.03; AOAC, 2005) and protein was calculated as $N \times 6.25$. The concentration of lipids was determined using the ether extraction method (procedure 2003.06; AOAC, 2005). Diets

and fecal samples from UIUC and MO were analyzed for the concentrations of chromium (Fenton and Fenton, 1979), but diets and fecal samples from PSC were analyzed for acid insoluble ash (McCarthy et al., 1974). The crude fiber concentration in diets was measured using the Weende method (procedure 962.09; AOAC, 2005). Diet samples were also analyzed for ash (procedure 942.05; AOAC, 2005).

Calculations

The apparent total tract digestibility (ATTD) of energy in diets fed to each pig was calculated according to Chastanet et al. (2007) and the DE of the diet at each feeding level was calculated by multiplying the GE of the diet by the apparent total tract digestibility of energy. Retention of energy, protein, and lipids was calculated as the difference between the initial estimated quantity of energy, protein, and lipids and the final quantity of energy, protein, and lipids, respectively. Energy retention was also calculated from protein gain and lipid gain as 5.66 and 9.46 kcal/g for protein and lipids, respectively (Ewan, 2001). The initial body composition of pigs was determined from the body composition of pigs in the initial slaughter group as previously outlined (Oresanya et al., 2008). For linear regression analyses, the measurement of energy retention and DE intake were expressed as kcal/kg BW^{0.6}·d⁻¹ based on the average metabolic BW for each pig during the experiment. The DE intake was calculated for each pig by multiplying the DE of the diet by the total feed intake of the pig.

Statistical Analysis

All data were analyzed using the MIXED procedure of SAS (Littell et al., 1996; SAS Inst. Inc., Cary, NC). Homogeneity of the variances was verified using the UNIVARIATE procedure of SAS. The residual vs. the predicted plot procedure was used to analyze data for outliers. Orthogonal polynomial contrasts were used to determine linear and quadratic effects of feeding level on growth performance, ATTD of energy, carcass composition, and retention of protein, lipids, and energy of pigs at each stage of growth within each location. The LSMEANS procedure was used to calculate the mean values for all feeding levels. The pig was the experimental unit, and an alpha-value of 0.05 was used to assess significance among means. If the mean retention of energy or lipids for a treatment group was negative this treatment group was not included in the regression analysis to prevent overestimating the ONE_m because the regression line for energy retention has a steeper slope below than above zero energy retention (Baldwin, 1995). All growing pigs fed at the lowest feeding level at all three locations, growing pigs fed at the second lowest feeding level at MO, and finishing pigs fed at the lowest feeding level at MO and PSC had negative energy or lipid retention, and therefore, those treatment groups were excluded from the regression analyses.

Values for studentized residuals and difference in fits statistic (DFFITS) were also estimated to identify outliers in the regression analyses (Kutner et al., 2005). One growing pig at UIUC was identified as an outlier and was removed from the regression analysis.

Linear regression analyses were conducted to determine the relationship between energy retention ($\text{kcal/kg BW}^{0.6} \cdot \text{d}^{-1}$) and DE intake ($\text{kcal/kg BW}^{0.6} \cdot \text{d}^{-1}$) at each stage of

growth within each location. The x-intercept and y-intercept were considered the DE requirement for maintenance (DE_m) and ONE_m , respectively, and the slope of the regression equation represented the efficiency (NE:DE) of DE intake for energy retention (Ewan, 2001). The effects of stage of growth and location on NE:DE and ONE_m were determined using an analysis of covariance with DE intake as a covariate (Noblet et al., 1994b; Littell et al., 1996). The statistical model included the stage of growth, location, DE intake, and the interactions (stage of growth \times DE intake, location \times DE intake, stage of growth \times location, and stage of growth \times location \times DE intake). The stage of growth and location were fixed effects in the model. The interaction terms were sequentially removed from the model if they were not significant.

RESULTS

Pig Performance, Carcass Composition, and Retention of Energy, Protein, and Lipids

In the growing phase, ADG increased (linear, $P < 0.01$) at UIUC (Table 2.3), MO (Table 2.4), and PSC (Table 2.5) as feeding level increased. The G:F also increased (linear, $P < 0.01$ at UIUC and PSC; linear and quadratic, $P < 0.01$ at MO) as feeding level increased. The ATTD of energy decreased with feeding level at UIUC (linear and quadratic, $P < 0.01$) and at PSC (linear, $P < 0.01$), but feeding level did not influence the ATTD of energy at MO. The digesta-free BW increased (linear, $P < 0.01$) with feeding level at all locations. The concentration of protein decreased (linear, $P < 0.01$ at UIUC and MO; linear and quadratic, $P < 0.05$ at PSC), but the concentration of lipids and energy in the digesta-free body increased (linear, $P < 0.01$ at UIUC and MO; linear and

quadratic, $P < 0.01$ at PSC) as feeding level increased. The total amount of protein, lipids, and energy in the digesta-free body, protein gain, lipid gain, measured energy retention, and calculated energy retention increased (linear, $P < 0.01$) at all locations as feeding level increased. Lipid gain:protein gain also increased with feeding level at UIUC and MO (linear, $P < 0.05$) and at PSC (linear and quadratic, $P < 0.01$).

In the finishing phase, ADG increased (linear and quadratic, $P < 0.01$ at UIUC; linear, $P < 0.01$ at MO and PSC) as feeding level increased and G:F increased (linear and quadratic, $P < 0.05$) with feeding level at all locations. The ATTD of energy was not influenced by feeding level at UIUC and at PSC but a trend for quadratic effect ($P = 0.05$) of feeding level on ATTD of energy was observed at MO. The digesta-free BW increased (linear and quadratic, $P < 0.01$ at UIUC; linear, $P < 0.01$ at MO and PSC) with feeding level at all locations. The concentration of protein decreased (linear and quadratic, $P < 0.05$ at UIUC; linear, $P < 0.01$ at MO and PSC), but the concentration of lipids and energy in the digesta-free body increased (linear, $P < 0.01$) as feeding level increased at all locations. The total amount of protein in the digesta-free body and protein gain increased (linear and quadratic, $P < 0.01$ at UIUC; linear, $P < 0.01$ at MO and PSC) as feeding level increased. The total amount of lipids and energy in the digesta-free body, lipid gain, lipid gain:protein gain, measured energy retention, and calculated energy retention also increased (linear, $P < 0.01$) as feeding level increased at all locations.

NE:DE and Operational Net Energy Requirement for Maintenance

The NE:DE was greater ($P < 0.01$) for finishing pigs (0.72 at UIUC, 0.54 at MO, and 0.78 at PSC) than for growing pigs (0.56, 0.41, and 0.46 at UIUC, MO, and PSC,

respectively) and the NE:DE tended to be different ($P = 0.05$) among locations (Table 2.6). There was no interaction between stage of growth and location for NE:DE. The ONE_m was greater ($P < 0.01$) for finishing pigs (219, 123, and 270 kcal/kg $BW^{0.6} \cdot d^{-1}$ at UIUC, MO, and PSC, respectively) than for growing pigs (128, 115, and 78 kcal/kg $BW^{0.6} \cdot d^{-1}$ at UIUC, MO, and PSC, respectively). The ONE_m was also different ($P < 0.01$) among locations. The interaction between stage of growth and location for ONE_m was significant ($P < 0.01$) because the ONE_m was lower ($P < 0.05$) for growing pigs at UIUC and PSC than for finishing pigs, but the ONE_m was not different between growing pigs and finishing pigs at MO.

DISCUSSION

Pig Performance, Carcass Composition, and Retention of Energy, Protein, and Lipids

An increase in growth performance and retention of energy, protein, and lipids was observed for growing and finishing pigs at all locations as feeding level increased. This result was expected and agrees with previous observations (de Greef, 1992; Bikker et al., 1995, 1996a, b). Protein gain at the highest feeding level was 122.7, 109.4, and 125.4 g/d for growing pigs and 116.2, 118.4, and 136.0 g/d for finishing pigs at UIUC, MO, and PSC, respectively. In a subsequent experiment at UIUC, protein gain was 161.3 and 171.5 g/d, respectively for growing and finishing pigs that were allowed free access to a corn-soybean meal diet (Kil, 2008). It is, therefore, likely that the protein gain of both growing and finishing pigs obtained in the current experiment is below the potential maximum for protein gain and that pigs were in the energy dependent phase of body

protein deposition (de Greef et al. 1994). The increase in lipid gain:protein gain that was observed as feeding level increased has also been observed in previous experiments (de Greef et al., 1994; Oresanya et al., 2008).

At all locations, finishing pigs had greater lipid gain and lipid gain:protein gain compared with growing pigs across all feeding levels. This observation indicates that more dietary energy is utilized for lipid gain in finishing pigs than in growing pigs as has previously been reported (de Greef et al., 1994).

All growing and finishing pigs fed 1.4 times ME_m lost body energy or had negative lipid gain, but positive protein gain. Growing pigs fed 1.9 times ME_m at MO also lost body lipids. This observation agrees with data showing that animals that are fed near or slightly below the energy requirement for maintenance for relatively short periods mobilize body lipids to support protein retention (Quiniou et al., 1999). Apparently, the value for ME_m (191 kcal/kg $BW^{0.6} \cdot d^{-1}$) that was predicted from NRC (1998) and used in this experiment, underestimated the real ME_m of the pigs at all locations. Based on the data for energy retention, the calculated ME_m ($DE_m \times 0.96$) for growing and finishing pigs respectively were 219, 269, and 163 kcal/kg $BW^{0.6} \cdot d^{-1}$ and 292, 219, and 332 kcal/kg $BW^{0.6} \cdot d^{-1}$, respectively, at UIUC, MO, and PSC. The average calculated ME_m for all pigs was 249 kcal/kg $BW^{0.6} \cdot d^{-1}$, which is close to 242 and 250 kcal/kg $BW^{0.6} \cdot d^{-1}$ as has previously been reported (Noblet et al., 1991, 1994a, 1999). However, the large variation in ME_m among locations implies that it may be inaccurate to use 1 value for ME_m at all locations.

NE:DE and Operational Net Energy Requirement for Maintenance

The values for NE:DE for growing pigs estimated in this experiment are lower than the value of 0.70 that has been reported (Noblet et al., 1994a) although the values observed for finishing pigs at UIUC and PSC are close to 0.70. Diet composition and methodology used in different experiments (Just, 1982; Chwalibog, 1991; Birkett and de Lange, 2001) and the environment (Black, 1995; Le Bellego et al., 2002) may influence estimates for NE:DE. Therefore, it is likely that the difference in NE:DE among locations may be explained by differences in environmental factors. In particular, the differences in room temperature among locations may have influenced the estimates for NE:DE. It is also possible that differences in pig factors and the health status of the pigs may have influenced the NE:DE because these factors may influence the marginal lipid deposition to protein deposition ratio. The greater NE:DE for finishing pigs than for growing pigs is a result of increased utilization of energy for lipid deposition (de Greef et al., 1994) because the energetic efficiency for lipid deposition is greater than for maintenance and protein deposition (Just et al., 1983; Black, 1995). The lack of an interaction between the stage of growth and location on NE:DE indicates that the effect of stage of growth on the NE:DE was not influenced by location.

The greater ONE_m for finishing pigs than for growing pigs at PSC and UIUC was unexpected because an appropriate exponent for expressing the metabolic BW is expected to maintain the proportionality between ONE_m and BW (Chwalibog, 1991; Noblet et al., 1994b), which should have resulted in similar values for ONE_m in growing and finishing pigs. The fact that growing pigs had lower ONE_m than finishing pigs suggests that an exponent lower than 0.60 is needed to account for the differences

between growing and finishing pigs at PSC and UIUC. An exponent of 0.42 was previously suggested as appropriate to express ME_m in 45 to 165 kg pigs (Noblet et al., 1994b), but because of the interaction between location and stage of growth that we observed in this experiment, the present data do not allow us to calculate an exponent that would be appropriate at all locations.

The ONE_m varied among locations and the interaction between the stage of growth and location for ONE_m indicates that ONE_m is dependent on both the stage of growth and location. In previous experiments (Noblet and Henry, 1991; Noblet et al., 1994a,b; de Lange et al., 2006), the estimates of ONE_m for pigs varied from 117 to 181 kcal/kg $BW^{0.6}$. Large variations in ME_m among experiments have also been reported (Wenk et al., 1980). The variation in ONE_m among previous experiments is mainly caused by differences in animal factors such as sex, BW, and genotype (Just et al., 1983; Noblet et al., 1994b, 1999; Knap, 2000) and environmental factors such as temperature, facility, pen space, and management (Chwalibog, 1991; Close, 1996; Birkett and de Lange, 2001). Noblet and Henry (1991) suggested that the ONE_m would be similar if experimental conditions such as animals and environmental factors are similar. It has also been suggested that the ONE_m measured under a specific condition is not representative for other conditions (Boisen, 2007). The current data support this hypothesis.

The variation in NE values for diets that are calculated from different NE systems is primarily caused by differences in ONE_m among NE systems (Noblet et al., 1994a). Therefore, it can be expected that the calculated NE values of diets or ingredients will depend on location because of differences in ONE_m among locations. However, even if ONE_m is different among locations and as a consequence, calculated NE values differ

among locations, the NE of diets or ingredients measured at each location will have the same hierarchy (de Lange et al., 2006).

In conclusion, results from this experiment indicate that under the conditions of this experiment it appears that location affects the NE:DE and ONE_m of growing and finishing pigs. It also appears that location interacts with stage of growth on ONE_m , but data from this experiment do not support the hypothesis that the ONE_m for growing and finishing pigs always is constant. Therefore, the use of a constant ONE_m may be inaccurate for estimating NE requirements and calculating the NE of diets and ingredients measured at different stages of growth and at different locations.

Table 2.1. Experimental conditions at participating locations.

Items	Location ¹		
	UIUC	MO	PSC
Growing pigs			
Total number of pigs	48	48	48
Pigs per treatment	8	8	8
Initial BW (\pm SD), kg	22.9 \pm 2.17	25.1 \pm 1.58	22.1 \pm 1.83
Days on trial, d	28	28	28
Average room temperature, °C	24	22	24
Pen size, m ²	0.90 \times 1.80	1.22 \times 1.68	0.88 \times 1.79
Flooring	Concrete slats	Cast iron slats	Concrete slats
Finishing pigs			
Total number of pigs	48	48	48
Pigs per treatment	8	8	8
Initial BW (\pm SD), kg	80.7 \pm 4.15	89.3 \pm 2.92	80.4 \pm 1.70
Days on trial, d	35	35	35
Average room temperature, °C	19	22	15
Pen size, m ²	0.90 \times 1.80	1.22 \times 1.68	0.88 \times 1.79
Flooring	Concrete slats	Cast iron slats	Concrete slats

¹UIUC = University of Illinois; MO = University of Missouri; PSC = Prairie Swine Centre.

Table 2.2. Composition of experimental diets (as-fed basis)

Items	Location ¹ :	Growing pigs			Finishing pigs		
		UIUC	MO	PSC	UIUC	MO	PSC
Ingredients, %							
Ground corn		59.41	60.24	59.60	72.63	71.95	71.37
Soybean meal ²		34.78	33.93	33.93	22.12	22.73	22.73
Soybean oil		3.00	-	-	3.00	-	-
Choice white grease		-	3.00	-	-	3.00	-
Tallow		-	-	3.00	-	-	3.00
Dicalcium phosphate		0.79	0.81	0.80	0.45	0.45	0.43
Ground limestone		0.97	0.82	0.67	0.75	0.72	0.47
Salt		0.20	0.50	0.50	0.20	0.50	0.50
Vitamin premix ³		0.10	0.20	0.50	0.10	0.15	0.50
Mineral premix ³		0.35	0.10	0.50	0.35	0.10	0.50
Cr ₂ O ₃		0.40	0.40	-	0.40	0.40	-
Celite ⁴		-	-	0.50	-	-	0.50
Total		100.00	100.00	100.00	100.00	100.00	100.00
Energy and nutrients ⁵							
DM, %		88.21	89.62	92.64	87.34	88.47	92.24
GE, mcal/kg		3.966	4.155	4.192	4.042	4.086	4.200
ME, mcal/kg		3.459	3.446	3.407	3.484	3.468	3.434
CP, %		21.45	21.12	20.55	16.54	16.77	16.38
Lys, %		1.20	1.18	1.15	0.86	0.87	0.85
Ether extract, %		5.30	5.15	5.05	4.65	4.73	5.64
Crude fiber, %		1.88	2.21	2.07	1.66	2.00	2.16
Ash, %		5.76	6.22	5.73	3.93	4.77	4.43
Ca, %		0.66	0.61	0.55	0.46	0.45	0.36
Bioavailable P, %		0.22	0.22	0.22	0.14	0.14	0.14

¹UIUC = University of Illinois; MO = University of Missouri; PSC = Prairie Swine Centre.

²Soybean meal with 47.5% CP was used at UI and MO, but soybean meal with 46% CP was used at PSC.

³Commercial vitamin and mineral premixes available at each location were used.

⁴Celite (Celite corporation, Lompoc, CA), provided as a source of acid insoluble ash; Composition: moisture, 0.8%; SiO₂, 89.4%; Na₂O, 3.8%; Al₂O₃, 3.4%; Fe₂O₃, 1.3%; MgO, 0.6%; CaO, 0.5%; and TiO₂, 0.2%.

⁵Data for ME, Lys, Ca, and bioavailable P were calculated from NRC (1998). All other values were analyzed.

Table 2.3. Effect of feeding level on growth performance, energy digestibility, carcass composition, and retention of protein, lipids, and energy of pigs^{1,2} (University of Illinois)

Item	Feeding level:	Growing pigs					Finishing pigs					Growing pigs			Finishing pigs		
		ISG ³	1.4	1.9	2.4	2.9	ISG ³	1.85	2.20	2.55	2.90	SEM	L	Q	SEM	L	Q
Growth performance																	
Initial BW, kg		22.71	22.88	23.19	23.38	22.31	80.45	80.63	80.68	80.45	80.88	0.791	0.67	0.39	1.543	0.71	0.56
Final BW, kg		22.71	29.69	35.38	40.31	44.31	80.45	86.06	95.75	100.50	105.69	1.164	<0.01	0.47	1.689	<0.01	<0.01
ADG, kg		-	0.243	0.435	0.605	0.786	-	0.155	0.431	0.573	0.709	0.024	<0.01	0.82	0.025	<0.01	<0.01
ADFI, kg		-	0.538	0.765	1.017	1.241	-	1.433	1.756	2.067	2.385	0.018	<0.01	0.94	0.021	<0.01	0.80
G:F, kg/kg		-	0.457	0.569	0.594	0.632	-	0.108	0.246	0.277	0.297	0.029	<0.01	0.22	0.013	<0.01	<0.01
ATTD of energy, ⁵ %		-	86.21	86.78	85.80	83.70	-	86.07	86.59	85.93	86.39	0.475	<0.01	<0.01	0.342	0.85	0.94
Carcass composition																	
DF BW, ⁶ kg		18.98	24.06	29.22	32.90	36.04	74.59	81.45	91.51	95.63	100.12	1.035	<0.01	0.33	1.666	<0.01	<0.01
DF BW, ⁶ kg DM		5.41	6.38	8.15	10.11	11.39	28.42	31.48	34.93	38.38	41.14	0.330	<0.01	0.46	0.986	<0.01	0.48
Protein, g/kg		570	665	628	582	560	436	443	455	434	403	11.8	<0.01	0.56	9.1	<0.01	0.02
Lipid, g/kg		260	155	196	252	285	446	420	416	446	476	16.5	<0.01	0.83	10.0	<0.01	0.10
Energy, mcal/kg		5.55	5.34	5.45	5.73	5.76	6.78	6.73	6.64	6.90	6.95	0.079	<0.01	0.64	0.046	<0.01	0.12
Retention																	
Protein, kg/pig		3.08	4.23	5.11	5.88	6.36	12.38	13.89	15.88	16.64	16.52	0.194	<0.01	0.31	0.354	<0.01	<0.01
Lipids, kg/pig		1.41	1.01	1.61	2.55	3.26	12.69	13.27	14.54	17.13	19.61	0.185	<0.01	0.78	0.707	<0.01	0.19
Energy, mcal/pig		30.0	34.1	44.4	57.9	65.6	192.8	212.3	231.8	264.9	285.9	2.00	<0.01	0.52	7.47	<0.01	0.83
Protein gain, g/d		-	40.3	70.4	97.0	119.3	-	42.2	98.8	121.4	116.2	5.07	<0.01	0.45	7.44	<0.01	<0.01
Lipid gain, g/d		-	-14.5	6.2	39.3	66.9	-	15.6	51.7	126.8	195.7	6.26	<0.01	0.59	15.10	<0.01	0.29
Lipid:protein, ⁷ g/g		-	-0.38	0.05	0.41	0.58	-	0.50	0.56	1.10	1.83	0.103	<0.01	0.21	0.314	<0.01	0.29
MER, ⁸ mcal/d		-	0.14	0.49	0.96	1.29	-	0.54	1.09	2.06	2.63	0.058	<0.01	0.81	0.130	<0.01	0.94
CER, ⁹ mcal/d		-	0.09	0.46	0.92	1.31	-	0.39	1.05	1.87	2.51	0.066	<0.01	0.88	0.133	<0.01	0.88

¹n = 16 for initial slaughter group, n = 8 for all feeding levels.

²Data are least square means.

³ISG = initial slaughter group.

⁴*P*-value for linear (L) and quadratic (Q) effects were obtained from orthogonal polynomial contrast analyses among feeding levels, but data for ISG were not included in these analyses.

⁵ATTD of energy = apparent total tract digestibility of energy.

⁶DF BW = digesta-free BW which was the sum of the weight of chilled carcass, empty viscera, and blood.

⁷Lipid:protein = the ratio of daily lipid gain to daily protein gain.

⁸MER = measured energy retention obtained from bomb calorimetry analyses.

⁹CER = energy retention calculated from protein and lipid gain as 5.66 and 9.46 kcal/g for protein and lipid, respectively (Ewan, 2001).

Table 2.4. Effect of feeding level on growth performance, energy digestibility, carcass composition, and retention of protein, lipids, and energy of pigs^{1,2} (University of Missouri)

Item	Feeding level:	Growing pigs					Finishing pigs					Growing pigs			Finishing pigs		
		ISG ³	1.4	1.9	2.4	2.9	ISG ³	1.4	1.9	2.4	2.9	SEM	L	Q	SEM	L	Q
Growth performance																	
Initial BW, kg		25.08	25.09	25.06	25.09	25.06	89.30	89.36	89.30	89.36	89.30	0.588	0.88	0.99	1.086	0.88	1.00
Final BW, kg		25.08	25.74	31.81	36.43	41.05	89.30	91.63	102.06	108.86	119.12	0.986	<0.01	0.47	1.155	<0.01	0.94
ADG, kg		-	0.023	0.241	0.405	0.571	-	0.065	0.364	0.557	0.852	0.028	<0.01	0.36	0.030	<0.01	0.94
ADFI, kg		-	0.534	0.764	0.997	1.209	-	1.127	1.589	2.046	2.537	0.016	<0.01	0.57	0.011	<0.01	0.03
G:F, kg/kg		-	0.044	0.314	0.407	0.471	-	0.058	0.230	0.272	0.336	0.033	<0.01	<0.01	0.022	<0.01	0.02
ATTD of energy, ⁵ %		-	86.41	85.75	86.33	86.61	-	88.23	87.86	85.53	87.67	0.554	0.62	0.38	0.617	0.16	0.05
Carcass composition																	
DF BW, ⁶ kg		22.84	22.33	26.93	32.77	36.67	81.90	82.21	94.23	100.40	109.81	0.846	<0.01	0.68	0.977	<0.01	0.19
DF BW, ⁶ kg DM		6.55	5.72	7.49	9.62	10.77	31.59	31.35	38.06	40.75	45.48	0.325	<0.01	0.35	0.829	<0.01	0.24
Protein, g/kg		564	744	695	638	627	433	474	422	417	393	15.9	<0.01	0.24	15.1	<0.01	0.34
Lipid, g/kg		291	105	165	245	251	458	405	454	469	492	20.2	<0.01	0.19	15.7	<0.01	0.42
Energy, mcal/kg		5.80	4.93	5.33	5.66	5.76	6.59	6.36	6.61	6.66	6.84	0.091	<0.01	0.10	0.072	<0.01	0.60
Retention																	
Protein, kg/pig		3.67	4.26	5.15	6.13	6.73	13.64	14.76	16.01	16.89	17.81	0.155	<0.01	0.35	0.324	<0.01	0.60
Lipids, kg/pig		1.93	0.62	1.29	2.38	2.74	14.51	12.82	17.30	19.20	22.45	0.219	<0.01	0.48	0.913	<0.01	0.50
Energy, mcal/pig		38.1	28.3	40.2	54.5	62.2	208.2	199.7	251.6	271.9	311.2	2.44	<0.01	0.39	7.43	<0.01	0.40
Protein gain, g/d		-	21.0	53.0	87.8	109.4	-	31.1	67.1	92.1	118.4	4.44	<0.01	0.25	10.97	<0.01	0.66
Lipid gain, g/d		-	-46.6	-22.4	16.3	29.4	-	-48.7	79.6	133.7	226.7	7.37	<0.01	0.46	23.65	<0.01	0.46
Lipid:protein, ⁷ g/g		-	-1.25	-0.47	0.18	0.26	-	-1.58	2.52	1.78	2.33	0.497	0.03	0.49	0.885	<0.01	0.06
MER, ⁸ mcal/d		-	-0.35	0.08	0.59	0.87	-	-0.25	1.24	1.81	2.94	0.074	<0.01	0.32	0.178	<0.01	0.32
CER, ⁹ mcal/d		-	-0.32	0.09	0.65	0.90	-	-0.29	1.13	1.79	2.82	0.084	<0.01	0.34	0.188	<0.01	0.31

¹n = 16 for initial slaughter group, n = 8 for all feeding levels.

²Data are least square means.

³ISG = initial slaughter group.

⁴*P*-value for linear (L) and quadratic (Q) effects were obtained from orthogonal polynomial contrast analyses among feeding levels, but data for ISG were not included in these analyses.

⁵ATTD of energy = apparent total tract digestibility of energy.

⁶DF BW = digesta-free BW which was the sum of the weight of chilled carcass, empty viscera, and blood.

⁷Lipid:protein = the ratio of daily lipid gain to daily protein gain.

⁸MER = measured energy retention obtained from bomb calorimetry analyses.

⁹CER = energy retention calculated from protein and lipid gain as 5.66 and 9.46 kcal/g for protein and lipid, respectively (Ewan, 2001).

Table 2.5. Effect of feeding level on growth performance, energy digestibility, carcass composition, and retention of protein, lipids, and energy of pigs^{1,2} (Prairie Swine Centre)

Item	Feeding level:	Growing pigs					Finishing pigs					Growing pigs			Finishing pigs		
		ISG ³	1.4	1.9	2.4	2.9	ISG ³	1.4	1.9	2.4	2.9	SEM	P-value ⁴		SEM	P-value ⁴	
												L	Q		L	Q	
Growth performance																	
Initial BW, kg		22.03	21.99	22.09	22.13	22.10	80.45	80.35	80.49	80.47	80.38	0.682	0.69	0.75	0.633	0.98	0.86
Final BW, kg		22.03	28.55	33.30	37.42	42.21	80.45	80.24	89.84	99.85	109.13	0.809	<0.01	0.98	1.171	<0.01	0.89
ADG, kg		-	0.234	0.400	0.546	0.718	-	-0.003	0.268	0.554	0.821	0.016	<0.01	0.86	0.029	<0.01	0.95
ADFI, kg		-	0.520	0.734	0.965	1.202	-	1.062	1.482	1.926	2.405	0.013	<0.01	0.14	0.010	<0.01	<0.01
G:F, kg/kg		-	0.452	0.546	0.567	0.597	-	-0.004	0.180	0.287	0.342	0.024	<0.01	0.19	0.018	<0.01	<0.01
ATTD of energy, ⁵ %		-	87.90	87.36	87.85	86.30	-	90.37	89.63	90.16	90.18	0.363	0.01	0.18	0.245	0.98	0.11
Carcass composition																	
DF BW, ⁶ kg		20.17	26.43	31.12	34.92	39.05	75.34	77.75	85.74	95.81	104.84	0.776	<0.01	0.72	1.472	<0.01	0.73
DF BW, ⁶ kg DM		5.69	7.14	9.01	10.65	11.93	28.63	27.32	31.40	38.10	42.57	0.383	<0.01	0.44	1.049	<0.01	0.86
Protein, g/kg		567	674	610	583	566	465	548	475	442	424	9.1	<0.01	0.02	15.9	<0.01	0.09
Lipid, g/kg		267	149	239	272	297	444	361	428	470	485	11.5	<0.01	<0.01	18.5	<0.01	0.17
Energy, mcal/kg		6.06	5.54	5.96	6.12	6.21	6.83	6.36	6.75	6.94	7.00	0.055	<0.01	<0.01	0.097	<0.01	0.11
Retention																	
Protein, kg/pig		3.22	4.79	5.49	6.21	6.75	13.23	14.81	14.88	16.81	17.98	0.228	<0.01	0.74	0.499	<0.01	0.28
Lipids, kg/pig		1.52	1.09	2.16	2.91	3.54	12.77	10.02	13.43	17.93	20.71	0.152	<0.01	0.16	0.858	<0.01	0.76
Energy, mcal/pig		34.6	39.7	53.7	65.2	74.1	196.0	174.9	212.1	264.3	298.3	2.452	<0.01	0.30	9.01	<0.01	0.86
Protein gain, g/d		-	55.9	80.4	105.8	125.4	-	45.4	46.8	102.2	136.0	6.06	<0.01	0.69	14.51	<0.01	0.27
Lipid gain, g/d		-	-15.5	22.5	49.1	71.7	-	-78.6	18.2	146.9	226.8	5.22	<0.01	0.15	23.49	<0.01	0.72
Lipid:protein, ⁷ g/g		-	-0.40	0.29	0.46	0.57	-	-2.48	0.51	1.66	1.99	0.085	<0.01	<0.01	0.801	<0.01	0.11
MER, ⁸ mcal/d		-	0.19	0.68	1.09	1.41	-	-0.60	0.45	1.95	2.92	0.073	<0.01	0.24	0.241	<0.01	0.88
CER, ⁹ mcal/d		-	0.17	0.67	1.06	1.39	-	-0.49	0.44	1.97	2.92	0.073	<0.01	0.25	0.227	<0.01	0.96

¹n = 16 for initial slaughter group, n = 8 for all feeding levels.

²Data are least square means.

³ISG = initial slaughter group.

⁴*P*-value for linear (L) and quadratic (Q) effects were obtained from orthogonal polynomial contrast analyses among feeding levels, but data for ISG were not included in these analyses.

⁵ATTD of energy = apparent total tract digestibility of energy.

⁶DF BW = digesta-free BW which was the sum of the weight of chilled carcass, empty viscera, and blood.

⁷Lipid:protein = the ratio of daily lipid gain to daily protein gain.

⁸MER = measured energy retention obtained from bomb calorimetry analyses.

⁹CER = energy retention calculated from protein and lipid gain as 5.66 and 9.46 kcal/g for protein and lipid, respectively (Ewan, 2001).

Table 2.6. Effect of stage of growth and location on the efficiency of DE for energy retention and operational net energy requirement for maintenance (ONE_m) in growing and finishing pigs^{1,2,3}

Item	Location:	Growing pigs			Finishing pigs			<i>P</i> – value ⁴		
		UIUC	MO	PSC	UIUC	MO	PSC	Stage	Location	Stage × Location
NE:DE ⁵		0.56 ± 0.058	0.41 ± 0.141	0.46 ± 0.056	0.72 ± 0.057	0.54 ± 0.078	0.78 ± 0.104	< 0.01	0.05	0.47
ONE_m ⁶		128 ± 25.2	115 ± 70.9	78 ± 26.7	219 ± 26.4	123 ± 36.8	270 ± 52.2	< 0.01	< 0.01	< 0.01

¹UIUC = University of Illinois; MO = University of Missouri; PSC = Prairie Swine Centre.

²n = 23 for growing pigs at UIUC; n = 16 for growing pigs at MO; n=24 for growing pigs at PSC; n = 32 for finishing pigs at UIUC; n = 24 for finishing pigs at MO; n = 24 for finishing pigs at PSC.

³Values for NE:DE and ONE_m represent the regression coefficients ± SE that were obtained from linear regression analysis within the stage of growth at each location.

⁴*P*-value for effects of stage of growth and location were determined using an analysis of covariance with DE intake as a covariate (Noblet et al., 1994b; Littell et al., 1996).

⁵NE:DE = efficiency of DE for energy retention.

⁶Operational NE requirement for maintenance (kcal/kg BW^{0.6}·d⁻¹).

Chapter III

NET ENERGY CONTENT OF COMMERCIAL AND LOW- OLIGOSACCHARIDE SOYBEAN MEAL IN DIETS FED TO GROWING AND FINISHING PIGS

ABSTRACT

Two experiments were conducted in order to determine the NE of commercial and low-oligosaccharide soybean meal (SBM) in growing and finishing pig diets. Forty growing (initial BW = 26 kg) and 40 finishing (initial BW = 89 kg) barrows were allotted to one of five groups with eight replications based upon initial BW within each growth period. Two groups were randomly selected to serve as an initial slaughter group. The remaining groups were randomly assigned to either a basal, commercial SBM (C-SBM), or low-oligosaccharide SBM (LO-SBM) diet and harvested at the conclusion of the study. Pigs were individually penned and were *ad-lib* fed for 28 and 35 days for the grower and finishing phases, respectively. The basal diet contained corn, fishmeal, and casein as protein sources, but did not contain any SBM. The test diets were obtained by mixing 75% of the basal diet with 25% of either the C-SBM or LO-SBM. During the growing phase, ADG and G:F were increased ($P < 0.01$) when a source of SBM was added to the basal diet. However, there were no differences in ADG (1.02 vs. 0.96 kg/d) and G:F (0.54 vs. 0.52) between the diets containing C-SBM and LO-SBM, respectively. During the finisher phase, the addition of a SBM source reduced ($P < 0.05$) ADG (1.17 vs. 1.32 kg/d) and ADFI (3.59 vs. 3.94 kg/d) but did not affect G:F ($P > 0.1$) when compared to the

basal diet. Apparent total tract digestibility of protein was increased ($P < 0.001$) in both the grower (80.0 vs. 68.3%) and finishing (84.4 vs. 75.5%) phases when a SBM source was added to the basal diet. During the grower phase, lipid accretion (125.5 vs. 187.6 g/d) was reduced ($P < 0.006$) and protein accretion was increased ($P < 0.05$) when a SBM source was added to the basal diet. Protein accretion was higher ($P < 0.05$) in pigs consuming C-SBM (179.5 g/d) when compared to LO-SBM (157.1 g/d). While not statistically different ($P > 0.05$), the NE (DM basis) of LO-SBM was numerically greater than that of C-SBM in both the grower (1,990 vs. 1,634 kcal/kg) and finishing (2,554 vs. 2,150 kcal/kg) periods. The NE of the SBM sources were also numerically greater ($P > 0.05$) in the finishing period than in the growing period.

INTRODUCTION

Soybean products, in particular soybean meal (SBM), have traditionally been utilized in swine diets as a source of highly available amino acids, with 8.6 million tones utilized in swine diets in 2007 (Soy Stats, 2008). While containing high levels of lysine, threonine, tryptophan, isoleucine, and other amino acids, SBM is an excellent complement to other ingredients that may be deficient in these amino acids.

With recent increases in dietary energy costs, the energetic composition, as well as amino acid composition, of feedstuffs has become a determinate of dietary inclusion levels. On a gross (4,132 vs. 3,869 kcal/kg; Sauvante et al., 2004) and digestible (3,685 vs. 3,525 kcal/kg; NRC, 1998) basis, SBM contains more energy than corn. However, when expressed on a metabolizable (3,420 vs. 3,380 kcal/kg; NRC, 1998) or net (2,395 vs.

2,020 kcal/kg; NRC, 1998) basis, corn contains more energy than SBM. This inefficiency of energy utilization does not appear to be due to problems in the digestion of the protein fraction of the meal, but rather to the poor digestion of the carbohydrate portion of the meal (Sebastian et al., 1999). This is supported by work conducted by Coon et al. (1990), in which SBM ME content was increased by 600 kcal/kg in roosters when oligosachharides were removed from the SBM.

Recently, SBM varieties have been produced in which the enzymes required for stachyose, raffinose, and galactinol synthesis are reduced, resulting in increases of glucose and sucrose concentrations within the soybean. These changes in carbohydrate concentrations should theoretically increase the energy concentrations within the SBM produced from these soybeans.

Therefore, the purpose of these studies was to determine the net energy content of commercial and low-oligosaccharide soybean meal in growing and finishing pigs.

MATERIALS AND METHODS

Animals, Housing, and Experimental Design

All animals were cared for in accordance with the Animal Care and Use Committee guidelines at the University of Missouri.

Forty growing (initial BW = 26 kg) and 40 finishing (initial BW = 89 kg) barrows (T4 × C22, PIC, Franklin, KY) were allotted to one of five groups with eight replications per group based upon initial BW within each growth period. Two groups were randomly selected within each growth period to serve as an initial slaughter group (ISG). The

remaining groups were randomly assigned to either a basal, commercial (C-SBM), or low-oligosaccharide SBM (LO-SBM) diet and were harvested at the conclusion of the study.

All pigs were individually penned in 1.22×1.68 m pens with fully-slatted cast iron flooring, a single-hole feeder, and a nipple waterer. The experimental period was 28 d for the growing phase and 35 d for the finishing phase.

Dietary Treatments

At each growth phase, a basal diet (Table 3.1) void of SBM was formulated and mixed as a single batch. The basal diet contained corn, fishmeal, and casein as protein sources, but did not contain any SBM. Synthetic amino acids were added to maintain SID lysine and SID AA:Lys ratios that met or exceeded the recommendations set forth for this specific genetic line. Two additional diets were formulated by mixing 75% of the basal diet and 25% (as-is basis) of C-SBM (Table 3.1) and 75% of the basal diet and 25% (as-is basis) of LO-SBM (Table 3.1). Proximate and amino acid analysis of the C-SBM and LO-SBM are located in Table 3.2. Chromic oxide was included in the basal diet at 0.40% to serve as an indigestible marker. Vitamins and trace minerals were included in the basal diet to meet or exceed the estimated nutrient requirements (NRC, 1998) for pigs at each growth stage. All diets were void of antibiotic growth promoters, were fed in a meal form, and the pigs were allowed *ad libitum* access to the diets

Collection of Data and Samples

Pig weights and feed disappearance were recorded weekly after the initiation of the study and feed offerings were recorded daily in order to calculate ADG, ADFI, and G:F.

Fresh fecal grab samples were obtained on d 6 of each week from each pig. Fecal samples were pooled within pig over the course of the experiments and at the conclusion of the experiments were lysophilized to a constant weight and finely ground before chemical analysis.

The comparative slaughter method was used to estimate the retention of energy, protein, and lipids in pigs fed each diet (de Goey and Ewan, 1975). Pigs were weighed on the last day of the experiment and feed was withheld for 16 h. Pigs were then transported to the meat science laboratory at the University of Missouri, and euthanized by electrical and captive-bolt stunning. Care was taken to ensure that minimal blood loss occurred from the carcass. The carcass was split down the midline from the groin to the chest cavity and the digestive tract was removed, leaving the blood and all other organs inside the body cavity. Carcasses were weighed and frozen at -20°C for later grinding.

The digestive tracts were flushed with water to remove digesta and then weighed and frozen at -20°C for later grinding. Total digesta-free (TDF) BW weight was determined by the addition of the carcass weight and the digestive tract weight. The TDF body was weighed prior to grinding and cut into smaller sections and passed through a 10 mm die two times and a 5 mm die two times using a whole body grinder (Autio Company, Astoria, OR). Following each pass, the mince was collected into a barrel and mixed prior to the next pass through the grinder. On the final pass, five subsamples of 250 g were

obtained as the material left the grinder. Each of these five samples was placed on a flat surface on waxed paper, flattened to a thickness of 5 cm and quartered. Random quarters from each of the five subsamples were collected, lysophilized to a constant weight, and finely ground for chemical analyses.

Chemical Analysis

All analyses were performed in duplicate samples and analyses were repeated if results from duplicate samples varied more than 5% from the mean. The DM of diets was determined by oven drying at 135°C for 2 h (method 930.15; AOAC, 2005). The DM of the TDF body and fecal samples were calculated by lysophilization to a constant weight and this value was used to calculate the whole body concentration of energy, protein, and lipids. The GE of diets, fecal samples, and TDF body were measured using an adiabatic bomb calorimeter (Parr Instruments, Moline, IL). Benzoic acid was used as the standard for calibration. The concentration of N was measured using the combustion method (method 990.03; AOAC, 2005) and protein was calculated as $N \times 6.25$. The concentration of lipids was determined using the ether extraction method (method 2003.06; AOAC, 2005). Diets and fecal samples were analyzed for the concentrations of chromium (Fenton and Fenton, 1979).

Calculations

The apparent total tract digestibility (ATTD) of energy and nutrients in diets fed to each treatment group was calculated according to Chastanet et al. (2007). The ATTD of

energy and lipids in C-SBM and LO-SBM were calculated using the difference method (Adeola, 2001).

Retention of energy, protein, and lipids during the experimental period was calculated from the difference between the initial quantity of energy, protein, and lipids and the final quantity of energy, protein, and lipids, respectively. The initial body composition of the experimental pigs was determined from the body composition of pigs from the initial slaughter group (Oresanya et al., 2008). The energy retention was also calculated from protein gain and lipid gain assuming that protein and lipids contain 5.66 and 9.46 kcal/g, respectively (Ewan, 2001).

The daily operational maintenance requirement for each pig was calculated by multiplying the mean metabolic body weight ($\text{kg}^{0.6}$) by 156 kcal according to results from our previous experiment (Chp. 2). The NE for each diet was then calculated from the sum of energy retention and the total operational maintenance requirement (Ewan, 2001). The NE of C-SBM and LO-SBM were calculated using the difference method by subtracting the NE contribution from the basal diet from the NE of the diets containing C-SBM and LO-SBM (de Goey and Ewan, 1975). All diet and SBM NE values within are reported on a DM basis.

Statistical Analysis

All data were analyzed by ANOVA utilizing the PROC MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). Individual pig served as the experimental unit. Diet was the main effect in the model. The LSMEANS procedure was used to calculate mean

values and the PDIFF option was used to separate treatment means. An alpha-value of $P < 0.05$ was used to assess significance among means.

RESULTS

Pig Performance and Nutrient Digestibility

At the conclusion of the growing phase, final BW did not differ between the treatments (Table 3.3). Average daily gain was increased ($P < 0.05$) when the C-SBM treatment was compared to the basal treatment at 1.02 vs. 0.88 kg/d, respectively. There was no difference in ADG between the basal (0.88 kg/d) and LO-SBM (0.96 kg/d) treatments or the two SBM treatments. No differences were observed in ADFI between the treatments. Feed efficiency (G:F) was increased ($P < 0.001$) when the C-SBM and LO-SBM treatments were compared to the basal treatment at 0.54, 0.52, and 0.44, respectively.

At the conclusion of the finishing phase, final BW did not differ between the treatments (Table 3.3.). The feeding of the C-SBM diet reduced ADG ($P < 0.05$) when compared to the basal treatment at 1.13 vs. 1.32 kg/d, respectively. Average daily gain did not differ between the basal and LO-SBM treatments or between the SBM treatments. The feeding of C-SBM and LO-SBM treatments reduced ADFI ($P < 0.05$) when compared to the basal treatment at 3.60, 3.58, and 3.94 kg/d, respectively. Feed efficiency did not differ between the treatments.

During the growing phase, energy ATTD (Table 3.3.) did not differ between the treatments. However, crude protein ATTD was increased ($P < 0.001$) when the C-SBM and LO-SBM treatments were compared to the basal treatment at 79.51, 80.46, and 68.29%, respectively. Additionally, acid ether extract ATTD was increased ($P < 0.05$) when the C-SBM and LO-SBM treatments were compared to the basal treatment at 58.13, 59.02, and 48.04%, respectively.

During the finishing phase, energy and acid ether extract ATTD (Table 3.3.) did not differ ($P > 0.05$) between the treatments. However, crude protein ATTD was increased ($P < 0.05$) when SBM treatments were fed at 75.51, 84.20, and 84.50% for the basal, C-SBM, and LO-SBM treatments, respectively.

Carcass Composition and Retention of Energy, Protein, and Lipids

At the conclusion of the growing phase, TDF BW and TDF body DM were not influenced by treatment (Table 3.4). Total digesta-free body protein (466.63, 556.41, and 517.73 g/kg), TDF body lipid (414.31, 303.76, and 349.68 g/kg), and TDF body energy (6.52, 5.98, and 6.22 mcal/kg) differed ($P < 0.001$) between the basal, C-SBM, and LO-SBM treatments, respectively. Total digesta-free body total protein was increased ($P < 0.05$) in pigs receiving the C-SBM treatment at 7.78, 8.88, and 8.25 kg/pig for the basal, C-SBM, and LO-SBM treatments, respectively. Total digesta-free body total lipid content was greatest ($P < 0.05$) in pigs receiving the basal treatment at 7.01, 4.90, and 5.64 kg/pig for the basal, C-SBM, and LO-SBM treatments, respectively. Total digesta-free body total energy content did not differ between the treatments.

Total digesta-free body protein gain differed ($P < 0.001$) between all treatments at 140.03, 179.48, and 157.07 g/d for the basal, C-SBM, and LO-SBM treatments, respectively. Total digesta-free body lipid gain was greatest ($P < 0.006$) in the basal treatment (187.61 g/d) and did not differ between the C-SBM (112.09 g/d) and LO-SBM (138.87 g/d) treatments. The ratio of TDF body lipid:protein gain was greatest ($P < 0.001$) in the basal treatment (1.33) and did not differ between the C-SBM (0.62) and LO-SBM (0.88) treatments. Measured and calculated energy retention did not differ among treatments.

At the conclusion of the finishing phase, TDF BW of the basal treatment was greater than that of the C-SBM treatment (127.20 vs. 119.49 kg; $P < 0.05$; Table 3.5). There were no other differences in TDF BW. There were no differences in concentration, total amount, or accretion rate of TDF body protein, lipid, or energy between the treatments. Additionally, measured and calculated energy retention did not differ among treatments.

NE of Diets and Soybean Meal varieties

Initial body energy, final body energy, energy retention, total operational maintenance, total NE intake, and total feed intake did not differ between treatments in the growing phase (Table 3.6). However, the NE of the basal treatment diet (2,221 kcal/kg) was greater ($P < 0.05$) than that of the C-SBM treatment diet (2,059 kcal/kg). There was no difference between the NE of the LO-SBM treatment diet (2,146 kcal/kg) and that of the basal and C-SBM treatment diets.

Initial body energy, final body energy, energy retention, total operational maintenance, total NE intake, and NE of diets did not differ between treatments in the finishing phase (Table 3.6). However, total feed intake was greatest ($P < 0.049$) in the basal treatment.

While not statistically different ($P > 0.05$), the NE content of LO-SBM was numerically greater than that of the C-SBM in the growing period (1,990 vs. 1,634 kcal/kg) and in the finishing period (2,554 vs. 2,150 kcal/kg; Table 3.7). Additionally, growth period did not statistically affect the NE content of the SBM sources, however, the NE of both SBM sources was numerically higher in the finishing period than in the growing period (Table 3.8).

DISCUSSION

In the present experiments, a typical commercial SBM and a low-oligosaccharide SBM source that is currently not commercially available were utilized. The nutrient content (Table 3.2.) of the commercial SBM was consistent with published values (NRC, 1998; Grieshop et al., 2003).

Pig Performance and Nutrient Digestibility

During the growing period, ADG and G:F increased in both the C-SBM and LO-SBM treatments. However, during the finishing phase, ADG and ADFI were reduced in both the C-SBM and LO-SBM treatments. The increase in ADG and G:F within the growing period would indicate that perhaps the basal diet did not meet all of the amino

acid/protein requirements of that treatment. However, when 25% of the basal diet was replaced by either the C-SBM or LO-SBM, the nutrient requirements of the pigs were met, which would be indicated by the increase in growth rate and feed efficiency. Based upon the amino acid analysis of the diets, valine appeared to be the first limiting amino acid on a total basis. Additionally, previous work (Kendall, 2004) has indicated that a minimal protein to lysine ratio of 15 g CP/g SID Lys is necessary to maximize growth performance. In the basal diet, this ratio was 13.8, which is at a level that could potentially impair growth (Kendall, 2004).

During the finishing period, ADG and ADFI were reduced when the C-SBM and LO-SBM treatments were fed, while G:F remained unchanged. Therefore, the reductions in growth performance would have been feed intake driven. This would have been indicative of the C-SBM and LO-SBM treatments providing protein and amino acid levels that were above that of the pig's requirements which resulted in reduced feed intake and a subsequent reduction in ADG (Chen et al., 1999; Friesen et al., 1994).

Increases in crude protein digestibility were observed in both the C-SBM and LO-SBM treatments in the growing and finishing periods. This difference would be expected due to the primary protein source in the basal diet being corn and SBM, a more highly digestible protein source (NRC, 1998), being the primary source of protein in the SBM treatments. Additionally, it has been reported (Rao and McCracken, 1991; Gómez et al., 2002) that there is an inverse relationship between feed intake and nutrient digestibility. Within these experiments, ADFI was at least numerically greater in the basal treatment and nutrient digestibilities were at least numerically increased in the SBM treatments within each growth phase.

Carcass Composition and Retention of Energy, Protein, and Lipids

During the growing period, the ratio of lipid to protein gain was greatest in the pigs consuming the basal diet. The large discrepancy between the basal and SBM diets may be do to the afore mentioned possibility of limiting amino acid or total nitrogen levels in the basal diet. This possibility is in agreement with lipid:lean gain ratios that were calculated from data presented by Kerr et al. (2003). In the Kerr et al. (2003) data, the lipid:lean gain ratio of 23 to 37 kg pigs fed a 16% CP diet was 1.44. If the CP level was reduced to 12%, the lipid:lean gain ratio was increased to 2.66. However, when sufficient levels of synthetic amino acids were added to the 12% CP diet, the lipid:lean gain ratio was reduced to 1.59. Similar reductions in lean accretion and increases in lipid accretion have been reported by others when diets with insufficient levels of CP or total nitrogen have been fed (Gómez et al., 2002; Tuitoek et al., 1997).

When the LO-SBM diet was fed during the growing period, lean accretion was decreased and lipid accretion was numerically increased which resulted in a greater lipid:lean gain ratio compared to the pigs consuming the C-SBM diet. Amino acid content of the two SBM sources were similar and when the SBM sources were added to the basal diet, dietary amino levels were in excess of the pigs requirement. Therefore, differences in lean and lipid accretion are not associated with amino acid deficiencies, but perhaps are associated with the numerical increase in NE content of the LO-SBM.

NE of Diets and SBM varieties

In the growing period, NE content of the basal and C-SBM diets were lower than values that were calculated using published ingredient NE values (NRC, 1998; Sauvant et

al., 2004). During the finishing period, diet NE values were closer to calculated values. Growing period NE values in the present study are possibly underestimated due to the increased level of lipid content in the TDF body of pigs fed the basal diet.

Reductions in NE content of the SBM diets during the growing period are contributed to the amount of corn being replaced by SBM and the subsequent differences in NE content of these ingredients. These differences in diet NE content were not observed during the finishing period which could be explained by the numerical increase in the NE content of the SBM sources when fed in the finishing period compared to the growing period.

On a DM basis, the NE content of LO-SBM was 356 and 404 kcal/kg higher than that of C-SBM in the growing and finishing periods, respectively. While not statistically different, the NE content of the LO-SBM may be physiologically greater than that of the C-SBM. Previous work investigating energy values of corn varieties, Adeola and Bajjalieh (1997) utilized corn varieties that differed by 370 kcal/kg of ME. The resulting performance indicated significant increases in feed efficiency with increased ME values. Additionally, increases in dietary ME values of 130 kcal/kg (Smith et al., 1999) and 250 kcal/kg (Chiba et al., 1991) resulted in linear improvements in growth performance.

In the present study, NE values of the SBM sources were numerically greater in the finishing period than the growing period. Previous work by Noblet et al. (1994) observed increases of dietary DE and ME values of diets with increasing body weight. However, dietary NE values remained unchanged. Additionally, Noblet et al. (1994) observed numeric increases in the NE of various ingredients with increasing bodyweight. Observed increases in diet and ingredient energy levels with increasing bodyweight could

be attributed to increased hindgut utilization and reduced passage rate of digesta in heavier pigs.

The increase in NE content of LO-SBM could be attributed to several factors. Low-oligosaccharide soybean meal varieties contain reduced levels of raffinose and stachyose. These oligosaccharides have been associated with reductions in energy digestibility (Coon et al., 1990; van Kempen et al., 2006) and reductions in CP and amino acid digestibilities (van Kempen et al., 2006; Smiricky et al., 2002). Additionally, the presence of these unabsorbable oligosaccharides has been shown to increase acidity of the lower intestinal tract and thereby increasing digesta passage rate (Coon et al., 1990; van Kempen et al., 2006). This increase in digesta passage rate would lead the observed reductions in nutrient digestibilities do to reduced digesta contact with the absorptive properties within the digestive tract.

When oligosaccharides are removed from the SBM, the concentrations of glucose and fructose remain relatively the same, while sucrose levels are increased (present study; Parsons et al., 2000). The NE content of sucrose is reported to be 2,730 kcal/kg on an as-is basis (NRC, 1998). Utilizing the analyzed sucrose values in the C-SBM and LO-SBM sources that were used in the present study, 171 and 353 kcal/kg of NE would be supplied by the sucrose in the C-SBM and LO-SBM sources, respectively.

In conclusion, data from these experiments would suggest that the NE content of LO-SBM is numerically greater than that of C-SBM. Additionally, the NE content of both SBM sources was numerically greater in the finishing period than in the growing period.

Table 3.1. Basal diet composition

Ingredients	Growth period	
	Growing	Finishing
Corn	86.92	90.42
Fish Meal	3.75	2.50
Casein	3.75	2.50
Choice white grease	1.00	1.00
Dicalcium phosphate	1.70	1.10
Limestone	0.78	0.66
Salt	0.25	0.25
L-Lysine HCL	0.35	0.31
DL-Methionine	0.18	0.16
L-Threonine	0.21	0.20
L-Tryptophan	0.07	0.07
L-Isoleucine	0.25	0.18
Vitamin premix ¹	0.25	0.15
Trace mineral premix ²	0.15	0.10
Chromic oxide	0.40	0.40
Total	100.00	100.00
Nutrient Content, calculated		
Digestible energy, Mcal/kg	3.47	3.50
SID Lysine, %	1.05	0.83
SID Methionine, %	0.44	0.38
SID Methionine + Cysteine, %	0.60	0.54
SID Threonine, %	0.66	0.58
SID Isoleucine, %	0.60	0.49
SID Tryptophan, %	0.19	0.17
Calcium, %	0.70	0.52
Phosphorus, %	0.60	0.49

¹ Provided per kilogram of final growing diet: vitamin A, 11,000 IU; vitamin D3, 1,100 IU; vitamin E, 22 IU; vitamin B12, 0.03 mg; Menadione, 3.99 mg; riboflavin, 8.25 mg; D-pantothenic acid, 28.05 mg; and niacin, 33 mg. Provided per kilogram of final finishing diet: vitamin A, 6,614 IU; vitamin D3, 661 IU; vitamin E, 13.2 IU; riboflavin, 4.96 mg; vitamin B12, 0.02 mg; Menadione, 2.4 mg; D-pantothenic acid, 16.9 mg; niacin, 19.8 mg.

² Provided per kilogram of final growing diet: Fe, 165.3 mg; Zn, 165.3 mg; Mn, 33 mg; Cu, 16.5 mg; I, 0.3 mg; and Se, 0.29 mg. Provided per kilogram of final finishing diet: Iron, 110 mg; Zinc, 110 mg; Manganese, 22 mg, copper, 11 mg; iodine, 0.2 mg; selenium 0.198 mg.

Table 3.2. Analyzed nutrient composition of commercial SBM and low-oligosaccharide SBM (as-is basis)

Nutrient	SBM variety	
	Commercial	Low-oligosaccharide
Gross Energy, Mcal/kg	4.09	4.25
Crude protein, %	48.44	51.80
Dry matter, %	89.26	91.12
Organic matter, %	82.34	85.05
Crude fat, %	2.17	1.12
Crude fat (acid hydrolysis), %	4.10	3.45
Crude Fiber, %	2.91	2.63
Starch, %	9.00	5.40
Starch, (enzymatic digestion), %	7.87	1.04
Amino Acids		
Lysine, %	3.08	3.20
Methionine, %	0.66	0.68
Methionine + cysteine, %	1.35	1.33
Threonine, %	1.89	1.84
Tryptophan, %	0.64	0.60
Isoleucine, %	2.15	2.28
Valine, %	2.23	2.30
Histidine, %	1.25	1.32
Arginine, %	3.54	4.17
Leucine, %	3.67	3.80
Phenylalanine, %	2.38	2.48
Soluble Sugars		
Glucose, %	0.018	0.027
Fructose, %	0.027	0.024
Sucrose, %	6.28	12.95
Raffinose, %	1.06	0.32
Stachyose, %	5.56	0.41

Table 3.3. Effects of commercial (C-SBM) and low-oligosaccharide (LO-SBM) soybean meal on growth performance of growing and finishing pigs and apparent total tract digestibility (ATTD) of energy and nutrients.¹

Items	Basal	C-SBM	LO-SBM	S.E.	<i>P</i> -value
Growing pigs					
Initial BW, kg	26.83	26.76	26.73	0.501	0.991
Final BW, kg	51.39	55.25	53.69	1.141	0.083
ADG, kg	0.88 ^y	1.02 ^x	0.96 ^{xy}	0.030	0.013
ADFI, kg	2.01	1.90	1.88	0.086	0.531
G:F, kg/kg	0.44 ^y	0.54 ^x	0.52 ^x	0.019	<0.001
ATTD, %					
Energy	78.59	80.32	81.23	1.237	0.328
Crude Protein	68.29 ^y	79.51 ^x	80.46 ^x	1.491	<0.001
Acid ether extract ²	48.04 ^y	58.13 ^x	59.02 ^x	2.699	0.015
Finishing pigs					
Initial BW, kg	89.10	89.13	89.13	1.247	1.000
Final BW, kg	135.46	128.54	131.60	2.234	0.114
ADG, kg	1.32 ^x	1.13 ^y	1.21 ^{xy}	0.053	0.048
ADFI, kg	3.94 ^x	3.60 ^y	3.58 ^y	0.108	0.049
G:F, kg/kg	0.34	0.31	0.34	0.011	0.185
ATTD, %					
Energy	81.61	83.96	82.82	0.896	0.203
Crude Protein	75.51 ^y	84.20 ^x	84.50 ^x	0.994	<0.001
Acid ether extract ²	48.86	56.94	54.23	2.457	0.084

¹ Data are least square means of 32 observations in each growing phase.

² Acid ether extract = acid hydrolyzed ether extract.

^{xy} Means within a row without common superscripts differ ($P < 0.05$).

Table 3.4. Effects of commercial (C-SBM) and low-oligosaccharide (LO-SBM) soybean meal on carcass composition and total amount of energy, protein, and lipids in growing pigs.¹

Items	ISG ²	Basal	C-SBM	LO-SBM	S.E.	<i>P</i> -value
Total DF body ³						
DF BW, kg	23.87	46.68	49.70	48.32	1.090	0.179
DF body DM, kg	6.65	16.80	16.00	16.00	0.588	0.570
Protein, g/kg	582.90	466.63 ^z	556.41 ^x	517.73 ^y	11.568	<0.001
Lipid, g/kg	265.35	414.31 ^x	303.76 ^z	349.68 ^y	14.394	<0.001
Energy, mcal/kg	5.79	6.52 ^x	5.98 ^z	6.22 ^y	0.074	<0.001
Total protein, kg/pig	3.87	7.78 ^y	8.88 ^x	8.25 ^y	0.183	0.002
Total lipids, kg/pig	1.77	7.01 ^x	4.90 ^y	5.64 ^y	0.428	0.009
Total energy, mcal/pig	38.51	109.77	95.92	99.75	4.709	0.135
Protein gain, g/d	---	140.03 ^z	179.48 ^x	157.07 ^y	5.038	<0.001
Lipid gain, g/d	---	187.61 ^x	112.09 ^y	138.87 ^y	14.651	0.006
Lipid:protein, g/g ⁴	---	1.33 ^x	0.62 ^z	0.88 ^y	0.085	<0.001
MER, mcal/d ⁵	---	2.55	2.06	2.20	0.152	0.094
CER, mcal/d ⁶	---	2.57	2.08	2.20	0.152	0.091

¹Data are least square means of 32 observations in each growing phase.

²ISG = Initial slaughter group arithmetic means.

³Total DF body = Total digesta-free body.

⁴Lipid:protein = ratio of daily lipid gain to daily protein gain.

⁵MER = measured energy retention.

⁶CER = calculated energy retention.

^{xyz}Means within a row without common superscripts differ ($P < 0.05$).

Table 3.5. Effects of commercial (C-SBM) and low-oligosaccharide (LO-SBM) soybean meal on carcass composition and total amount of energy, protein, and lipids in finishing pigs.¹

Items	ISG ²	Basal	C-SBM	LO-SBM	S.E.	<i>P</i> -value
Total DF body ³						
DF BW, kg	81.42	127.20 ^x	119.49 ^y	122.10 ^{xy}	1.905	0.029
DF body DM, kg	30.59	55.87	52.73	53.74	1.247	0.215
Protein, g/kg	452.30	360.16	353.75	365.63	11.570	0.771
Lipid, g/kg	449.31	521.64	551.46	547.64	16.064	0.378
Energy, mcal/kg	6.40	7.06	6.92	7.00	0.129	0.744
Total protein, kg/pig	13.75	20.02	18.60	19.60	0.453	0.098
Total lipids, kg/pig	13.82	29.29	29.13	29.46	1.347	0.985
Total energy, mcal/pig	195.91	393.87	364.83	376.21	10.558	0.171
Protein gain, g/d	---	223.72	172.72	208.52	15.885	0.089
Lipid gain, g/d	---	553.76	547.94	559.77	45.219	0.983
Lipid:protein, g/g ⁴	---	2.65	3.35	2.83	0.384	0.428
MER, mcal/d ⁵	---	7.07	6.03	6.44	0.337	0.114
CER, mcal/d ⁶	---	6.50	6.16	6.48	0.406	0.804

¹Data are least square means of 32 observations in each growing phase.

²ISG = Initial slaughter group arithmetic means.

³Total DF body = Total digesta-free body.

⁴Lipid:protein = ratio of daily lipid gain to daily protein gain.

⁵MER = measured energy retention.

⁶CER = calculated energy retention.

^{xyz}Means within a row without common superscripts differ ($P < 0.05$).

Table 3.6. Net energy of basal, commercial (C-SBM), and low-oligosaccharide (LO-SBM) soybean meal diets fed during the growing and finishing phases. ¹

Items	Basal	C-SBM	LO-SBM	S.E.	<i>P</i> -value
Growing pigs					
Initial body energy, mcal	38.40	38.30	38.26	0.717	0.991
Final body energy, mcal	109.77	95.92	99.75	4.709	0.135
Energy retention, mcal	71.38	57.62	61.48	4.258	0.094
Total OPM, mcal ²	38.79	40.03	39.62	0.496	0.236
Total NE intake, mcal	110.17	97.65	101.11	4.653	0.182
Total feed intake, kg	56.31	53.24	52.59	2.407	0.531
NE of diets, kcal/kg	2,221 ^x	2,059 ^y	2,146 ^{xy}	41.84	0.044
Finishing pigs					
Initial body energy, mcal	195.79	195.85	195.85	2.740	1.000
Final body energy, mcal	393.87	364.83	376.21	10.558	0.171
Energy retention, mcal	198.08	168.98	180.37	9.445	0.114
Total OPM, mcal ³	90.32	89.46	89.54	0.726	0.654
Total NE intake, mcal	288.41	258.44	269.91	9.835	0.119
Total feed intake, kg	137.94 ^x	126.15 ^y	125.42 ^y	3.765	0.049
NE of diets, kcal/kg	2,382	2,303	2,405	76.86	0.621

¹Data are least square means of 32 observations in each growing phase.

²Total operational maintenance requirement (OPM) is calculated by multiplying the mean metabolic BW (kg^{0.6}) of each pig by 156 kcal (Chap. 3) and the number of days in experiments (28 d for growing pigs and 35 d for finishing pigs).

^{xy}Means within a row without common superscripts differ ($P < 0.05$).

Table 3.7. Net energy values of commercial (C-SBM) or low-oligosaccharide (LO-SBM) soybean meal in growing and finishing pigs.¹

Items	C-SBM	LO-SBM	S.E.	<i>P</i> -value
Growing pigs				
NE, kcal/kg	1,634	1,990	176.19	0.175
Finishing pigs				
NE, kcal/kg	2,150	2,554	273.38	0.313

¹Data are least square means of 32 observations in each growing phase.

Table 3.8. Comparison of net energy values of commercial (C-SBM) or low-oligosaccharide (LO-SBM) soybean meal between growing and finishing pigs.¹

Items	Growing	Finishing	S.E.	<i>P</i> -value
C-SBM	1,634	2,150	237.11	0.147
LO-SBM	1,990	2,554	222.62	0.095

¹Data are least square means of 32 observations in each growing phase.

Chapter IV

NET ENERGY OF GLYCEROL IN GROWING AND FINISHING PIGS

ABSTRACT

Two experiments were conducted in order to determine the NE of glycerol in growing and finishing pig diets. Thirty-two growing (initial BW = 26 kg) and 32 finishing (initial BW = 89 kg) barrows were allotted to one of four groups with eight replications based upon initial BW within each growth period. Two groups were randomly selected to serve as an initial slaughter group. The remaining groups were randomly assigned to either a basal or basal + glycerol diet and harvested at the conclusion of the study. Pigs were individually penned and were *ad-lib* fed for 28 and 35 days for the grower and finishing phases, respectively. The basal diet contained corn, fishmeal, and casein as protein sources, but did not contain any SBM. The test diets were obtained by mixing 92% of the basal diet with 8% glycerol. During both phases of growth, performance was unaffected ($P > 0.10$) by the addition of glycerol to the basal diet. Apparent total tract digestibility of energy and protein were not different ($P > 0.10$) between the treatments. Apparent total tract digestibility of lipids was increased ($P = 0.019$) during the finishing period with the addition of glycerol to the basal diet. The accretion of lipid, protein, and energy were not different ($P > 0.10$) between the treatments during each growth phases. While not statistically different ($P > 0.05$) between

phases, the NE (DM basis) of glycerol was numerically lower in the growing period than the finishing period at 2,740 and 3,461 kcal/kg, respectively.

INTRODUCTION

With the ever increasing demand for and production of alternative energy sources, co-products from this energy sector are available that have potential uses as livestock feed. Glycerol is the main co-product from the production of biodiesel and with an estimated 2.7 billion liters of biodiesel being produced in 2008, 210 million kg of glycerol would be available (NBB, 2009).

The metabolism of glycerol mainly occurs within the liver and kidney (Lin, 1977) and is subsequently converted to glucose via gluconeogenesis or oxidized for energy via glycolysis and the citric acid cycle (Robergs and Griffin, 1998). With glycerol gluconeogenesis being limited by the availability of glycerol, the addition of glycerol to the diet has the potential of being a valuable dietary energy source (Kerr et al., 2007).

Studies have shown that the addition of glycerol to swine diets can be done in moderation without negatively affecting performance (Groesbeck et al., 2008, Hinson et al., 2008, Lammers et al., 2008b, Stevens et al., 2008, Duttlinger et al., 2008), however, little work has been done investigating the energy value of glycerol. Recent work has involved the determination of the digestible and metabolizable energy concentrations of glycerol (Lammers et al., 2008a), yet no work has been completed to determine the net energy concentration.

Therefore, the objective of the current study was to determine the net energy concentration of glycerol in growing and finishing pigs utilizing the comparative slaughter method.

MATERIALS AND METHODS

Animals, Housing, and Experimental Design

All animals were cared for in accordance with the Animal Care and Use Committee guidelines at the University of Missouri.

Thirty-two growing (initial BW = 26 kg) and 32 finishing (initial BW = 89 kg) barrows (T4 × C22, PIC, Franklin, KY) were allotted to one of four groups with eight replications per group based upon initial BW within each growth period. Two groups were randomly selected within each growth period to serve as an initial slaughter group (ISG). The remaining groups were randomly assigned to either a basal or glycerol diet and were harvested at the conclusion of the study.

All pigs were individually penned in 1.22 × 1.68 m pens with fully-slatted cast iron flooring, a single-hole feeder, and a nipple waterer. The experimental period was 28 d for the growing phase and 35 d for the finishing phase.

Dietary Treatments

At each growth phase, a basal diet (Table 4.1) void of SBM was formulated and mixed as a single batch. The basal diet contained corn, fishmeal, and casein as protein sources, but did not contain any SBM. Synthetic amino acids were added to maintain SID

lysine and SID AA:Lys ratios that met or exceeded the requirement determined for this specific genetic line. An additional diet was formulated by mixing 92% of the basal diet and 8% glycerol (Table 4.1). Chromic oxide was included in the basal diet at 0.40% to serve as an indigestible marker. Vitamins and trace minerals were included in the basal diet to meet or exceed the estimated nutrient requirements (NRC, 1998) for pigs at each growth stage. All diets were void of antibiotic growth promoters, were fed in a meal form, and the pigs were allowed *ad libitum* access to the diets.

Collection of Data and Samples

Pig weights and feed disappearance were recorded weekly after the initiation of the study and feed offerings were recorded daily in order to calculate ADG, ADFI, and G:F.

Fresh fecal grab samples were obtained on d 6 of each week from each pig. Fecal samples were pooled within pig over the course of the experiments and at the conclusion of the experiments were lysophilized to a constant weight and finely ground before chemical analysis.

The comparative slaughter method was used to estimate the retention of energy, protein, and lipids in pigs fed each diet (de Goey and Ewan, 1975). Pigs were weighed on the last day of the experiment and feed was withheld for 16 h. Pigs were then transported to the meat science laboratory at the University of Missouri, and euthanized by electrical and captive-bolt stunning. Care was taken to ensure that minimal blood loss occurred from the carcass. The carcass was split down the midline from the groin to the chest

cavity and the digestive tract was removed, leaving the blood and all other organs inside the body cavity. Carcasses were weighed and frozen at -20°C for later grinding.

The digestive tracts were flushed with water to remove digesta and then weighed and frozen at -20°C for later grinding. Total digesta-free (TDF) BW weight was determined by the addition of the carcass weight and the digestive tract weight. The TDF body was weighed prior to grinding and cut into smaller sections and passed through a 10 mm die two times and a 5 mm die two times using a whole body grinder (Autio Company, Astoria, OR). Following each pass, the mince was collected into a barrel and mixed prior to the next pass through the grinder. On the final pass, five subsamples of 250 g were obtained as the material left the grinder. Each of these five samples was placed on a flat surface on waxed paper, flattened to a thickness of 5 cm and quartered. Random quarters from each of the five subsamples were collected, lysophilized to a constant weight, and finely ground for chemical analyses.

Chemical Analysis

All analyses were performed in duplicate samples and analyses were repeated if results from duplicate samples varied more than 5% from the mean. The DM of diets was determined by oven drying at 135°C for 2 h (method 930.15; AOAC, 2005). The DM of the TDF body and fecal samples were calculated by lysophilization to a constant weight and this value was used to calculate the whole body concentration of energy, protein, and lipids. The GE of diets, fecal samples, and TDF body were measured using an adiabatic bomb calorimeter (Parr Instruments, Moline, IL). Benzoic acid was used as the standard for calibration. The concentration of N was measured using the combustion method

(method 990.03; AOAC, 2005) and protein was calculated as $N \times 6.25$. The concentration of lipids was determined using the ether extraction method (method 2003.06; AOAC, 2005). Diets and fecal samples were analyzed for the concentrations of chromium (Fenton and Fenton, 1979).

Calculations

The apparent total tract digestibility (ATTD) of energy and nutrients in diets fed to each treatment group was calculated according to Chastanet et al. (2007). The ATTD of energy and lipids in C-SBM and LO-SBM were calculated using the difference method (Adeola, 2001).

Retention of energy, protein, and lipids during the experimental period was calculated from the difference between the initial quantity of energy, protein, and lipids and the final quantity of energy, protein, and lipids, respectively. The initial body composition of the experimental pigs was determined from the body composition of pigs from the initial slaughter group (Oresanya et al., 2008). The energy retention was also calculated from protein gain and lipid gain assuming that protein and lipids contain 5.66 and 9.46 kcal/g, respectively (Ewan, 2001).

The daily operational maintenance requirement for each pig was calculated by multiplying the mean metabolic body weight ($\text{kg}^{0.6}$) by 156 kcal according to results from our previous experiment (Chp. 2). The NE for each diet was then calculated from the sum of energy retention and the total operational maintenance requirement (Ewan, 2001). The NE of glycerol was calculated using the difference method by subtracting the NE

contribution from the basal diet from the NE of the diet containing glycerol (de Goey and Ewan, 1975). All diet and glycerol NE values within are reported on a DM basis.

Statistical Analysis

All data were analyzed by ANOVA utilizing the PROC MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). Individual pig served as the experimental unit. Diet was the main effect in the model. The LSMEANS procedure was used to calculate mean values. An alpha-value of $P < 0.05$ was used to assess significance among means.

RESULTS AND DISCUSSION

The glycerol utilized in this study contained similar glycerol, DM, methanol, and free fatty acid values to that used in previous studies (Table 4.2.; Groesbeck et al., 2008; Lammers et al., 2008a; Lammers et al., 2008b).

Growth performance during the growing and finishing phases (Table 4.3.) did not differ ($P > 0.10$) between pigs receiving the basal and basal + glycerol diets. Additionally, ATTD of energy and crude protein did not differ ($P > 0.10$) between the treatments during each phase of growth. Acid ether extract digestibility did not differ ($P = 0.83$) during the growing phase, however, it was increased from 48.86 to 54.99% ($P = 0.019$) with the feeding of the basal + glycerol diet during the finishing phase. Typically, fat digestibility values will increase with increasing levels of lipid inclusion in the diet due to reductions in endogenous fat losses (Jørgensen et al., 1993).

No differences were observed in DF body protein or lipid concentrations ($P > 0.05$) during the growing and finishing phases (Tables 4.4 and 4.5). However, DF body energy content was increased from 6.52 to 6.70 mcal/kg ($P < 0.044$) in the growing pigs with the feeding of the basal + glycerol diet. Additionally, no differences ($P > 0.05$) were observed for protein gain, lipid gain, or energy retention during the growing and finishing phases.

Total operational maintenance requirement, total NE intake, and total feed intake were similar ($P > 0.05$) between the basal and basal+glycerol diets during both the growing and finishing phases (Table 4.6.). Additionally, dietary NE values were similar between the basal and basal+glycerol diets during the growing (2,221 vs. 2,245 kcal/kg) and finishing (2,382 vs. 2,409 kcal/kg) phases.

Digestible and metabolizable energy values of glycerol (Table 4.7.) were 3,898 and 3,854 kcal/kg, respectively, during the growing phase and 3,771 and 3,747 kcal/kg, respectively, during the finishing period. The DE and ME values were similar ($P > 0.10$) between the two growth phases. The ratio of ME:DE was 0.993 and 0.996 for the growing and finishing phases, respectively. These high ratios indicate that the glycerol utilized in this study was readily utilized by the animals as an energy source. This is indicative of the fact that these ME:DE ratios are greater than that of soybean oil (0.96) and corn (0.97), which are both regarded as well utilized energy sources (NRC, 1998).

The NE content of glycerol was 2,740 and 3,461 kcal/kg for the growing and finisher phases, respectively. As with DE and ME, the NE value of glycerol did not differ ($P = 0.465$) between the phases of growth. The ratio of NE:ME was 0.699 and 0.717 for the growing and finishing phases, respectively.

In the present study, NE values of glycerol was numerically greater in the finishing period than the growing period. Previous work by Noblet et al. (1994) observed increases of dietary DE and ME values of diets with increasing body weight. However, dietary NE values remained unchanged. Additionally, Noblet et al. (1994) observed numeric increases in the NE of various ingredients with increasing bodyweight. Observed increases in diet and ingredient energy levels with increasing bodyweight could be attributed to increased hindgut utilization and reduced passage rate of digesta in heavier pigs.

Very limited work has been done in regards to the determination of energy values for swine. Lammers et al. (2008a) have reported that the DE and ME of glycerol was 3,880 and 3,325 kcal/kg, respectively, on a DM basis, with the body weight of the animal having no influence on the energy value. The DE value reported by Lammers et al. (2008a) is very similar to the average value that we obtained in the present study (3,835 kcal/kg). However, the ME value reported by Lammers et al. (2008a) is much lower than the average of 3,801 kcal/kg that we observed in the current experiment. This discrepancy is potentially due to differences in the calculation of the ME of glycerol. In the study by Lammers et al. (2008a), ME values were obtained by subtracting urinary energy from DE. In the present study, urine collections were not performed and ME was subsequently calculated from DE by the equation:

$$\text{ME} = \text{DE} * (1.003 - (0.0021 * \text{CP}\%)) \quad (\text{Noblet and Perez, 1993}).$$

This difference in the determination of ME can also explain the high DE:ME ratios that were observed in the present study.

With an average NE:ME ratio of 0.71 observed in the present study, it would appear as though glycerol is more efficiently utilized as an energy source when compared to other energy components of swine diets, such as corn and choice white grease that have NE:ME ratios of 0.70 and 0.64, respectively (NRC, 1998).

With an NE value of 2,740 and 3,461 kcal/kg for growing and finishing pigs, respectively, and a high NE:ME ratio relative to other energy feedstuffs, it would appear as though glycerol can be utilized in swine diets as an energy source. However, due to potentially high methanol and sodium values, precaution needs to be taken when glycerol is utilized in swine diets. Additionally, high inclusion rates can lead to feed handling issues such as bridging within bins and feeders.

Table 4.1. Basal diet composition

Ingredients	Growth period	
	Growing	Finishing
Corn	86.92	90.42
Fish Meal	3.75	2.50
Casein	3.75	2.50
Choice white grease	1.00	1.00
Dicalcium phosphate	1.70	1.10
Limestone	0.78	0.66
Salt	0.25	0.25
L-Lysine HCL	0.35	0.31
DL-Methionine	0.18	0.16
L-Threonine	0.21	0.20
L-Tryptophan	0.07	0.07
L-Isoleucine	0.25	0.18
Vitamin premix ¹	0.25	0.15
Trace mineral premix ²	0.15	0.10
Chromic oxide	0.40	0.40
Total	100.00	100.00
Nutrient Content, calculated		
Digestible energy, Mcal/kg	3.47	3.50
SID Lysine, %	1.05	0.83
SID Methionine, %	0.44	0.38
SID Methionine + Cysteine, %	0.60	0.54
SID Threonine, %	0.66	0.58
SID Isoleucine, %	0.60	0.49
SID Tryptophan, %	0.19	0.17
Calcium, %	0.70	0.52
Phosphorus, %	0.60	0.49

¹ Provided per Fogram of final growing diet: vitamin A, 11,000 IU; vitamin D3, 1,100 IU; vitamin E, 22 IU; vitamin B12, 0.03 mg; Menadione, 3.99 mg; riboflavin, 8.25 mg; D-pantothenic acid, 28.05 mg; and niacin, 33 mg. Provided per kilogram of final finishing diet: vitamin A, 6,614 IU; vitamin D3, 661 IU; vitamin E, 13.2 IU; riboflavin, 4.96 mg; vitamin B12, 0.02 mg; Menadione, 2.4 mg; D-pantothenic acid, 16.9 mg; niacin, 19.8 mg.

² Provided per kilogram of final growing diet: Fe, 165.3 mg; Zn, 165.3 mg; Mn, 33 mg; Cu, 16.5 mg; I, 0.3 mg; and Se, 0.29 mg. Provided per kilogram of final finishing diet: Iron, 110 mg; Zinc, 110 mg; Manganese, 22 mg, copper, 11 mg; iodine, 0.2 mg; selenium 0.198 mg.

Table 4.2. Analyzed nutrient composition of glycerol

Nutrient	
Gross Energy, kcal/kg (DM basis)	4,217
Moisture, %	14.71
Methanol, ppm	133.71
Sodium Chloride, %	6.52
Free fatty acids, %	0.18
pH	5.00

Table 4.3. Effects of glycerol on growth performance of growing and finishing pigs and apparent total tract digestibility (ATTD) of energy and nutrients.¹

Items	Basal	Glycerol	S.E.	<i>P</i> -value
Growing pigs				
Initial BW, kg	26.83	26.86	0.517	0.965
Final BW, kg	51.39	52.97	1.229	0.379
ADG, kg	0.88	0.93	0.037	0.315
ADFI, kg	2.01	2.11	0.087	0.447
G:F, kg/kg	0.44	0.44	0.014	0.871
ATTD, %				
Energy	78.73	80.10	1.102	0.396
Crude Protein	68.25	69.05	1.963	0.777
Acid ether extract ²	48.95	48.12	2.716	0.833
Finishing pigs				
Initial BW, kg	89.10	89.55	1.273	0.807
Final BW, kg	135.46	136.47	2.279	0.759
ADG, kg	1.32	1.34	0.054	0.837
ADFI, kg	3.94	4.02	0.114	0.626
G:F, kg/kg	0.34	0.33	0.012	0.827
ATTD, %				
Energy	81.61	83.02	0.821	0.243
Crude Protein	75.51	75.63	1.394	0.953
Acid ether extract ²	48.86	54.99	1.623	0.019

¹Data are least square means of eight observations in each growing phase.

²Acid ether extract = acid hydrolyzed ether extract.

Table 4.4. Effects of glycerol on carcass composition and total amount of energy, protein, and lipids in growing pigs.¹

Items	ISG ²	Basal	Glycerol	S.E.	<i>P</i> -value
Total DF body ³					
DF BW, kg	23.87	46.68	47.14	1.171	0.786
DF body DM, kg	6.65	16.80	17.44	0.599	0.465
Protein, g/kg	582.90	466.25	438.13	10.929	0.094
Lipid, g/kg	265.35	414.31	446.23	12.774	0.103
Energy, mcal/kg	5.79	6.52	6.70	0.056	0.044
Total protein, kg/pig	3.87	7.78	7.63	0.187	0.573
Total lipids, kg/pig	1.77	7.01	7.79	0.440	0.234
Total energy, mcal/pig	38.51	109.77	116.95	4.780	0.309
Protein gain, g/d	---	140.03	134.39	5.717	0.499
Lipid gain, g/d	---	187.61	215.35	15.352	0.225
Lipid:protein, g/g ⁴	---	1.33	1.62	0.100	0.068
MER, mcal/d ⁵	---	2.55	2.80	0.161	0.286
CER, mcal/d ⁶	---	2.57	2.80	0.163	0.338

¹Data are least square means of eight observations in each growing phase.

²ISG = Initial slaughter group arithmetic means.

³Total DF body = Total digesta-free body.

⁴Lipid:protein = ratio of daily lipid gain to daily protein gain.

⁵MER = measured energy retention.

⁶CER = calculated energy retention.

Table 4.5. Effects of glycerol on carcass composition and total amount of energy, protein, and lipids in finishing pigs.¹

Items	ISG ²	Basal	Glycerol	S.E.	P-value
Total DF body ³					
DF BW, kg	81.42	127.20	127.16	2.079	0.988
DF body DM, kg	30.59	55.87	56.87	1.366	0.614
Protein, g/kg	452.30	360.16	349.82	1.209	0.556
Lipid, g/kg	449.31	521.64	568.29	1.964	0.117
Energy, mcal/kg	6.40	7.06	7.22	0.150	0.470
Total protein, kg/pig	13.75	20.02	19.84	0.448	0.779
Total lipids, kg/pig	13.82	29.29	32.39	1.665	0.210
Total energy, mcal/pig	195.91	393.87	410.25	10.919	0.308
Protein gain, g/d	---	223.72	214.76	17.588	0.725
Lipid gain, g/d	---	553.76	662.11	54.468	0.183
Lipid:protein, g/g ⁴	---	2.65	3.26	0.431	0.335
MER, mcal/d ⁵	---	7.07	7.62	0.338	0.271
CER, mcal/d ⁶	---	6.50	7.48	0.483	0.177

¹Data are least square means of eight observations in each growing phase.

²ISG = Initial slaughter group arithmetic means.

³Total DF body = Total digesta-free body.

⁴Lipid:protein = ratio of daily lipid gain to daily protein gain.

⁵MER = measured energy retention.

⁶CER = calculated energy retention.

Table 4.6. Net energy of basal and glycerol diets fed during the growing and finishing phases.¹

Items	Basal	Glycerol	S.E.	<i>P</i> -value
Growing pigs				
Initial body energy, mcal	38.40	38.44	0.770	0.967
Final body energy, mcal	109.77	116.95	4.780	0.309
Energy retention, mcal	71.38	78.51	4.516	0.286
Total OPM, mcal ²	38.79	39.00	0.465	0.759
Total NE intake, mcal	110.17	117.51	4.877	0.308
Total feed intake, kg	56.31	59.03	2.448	0.447
NE of diets, kcal/kg	2,221	2,245	39.969	0.672
Finishing pigs				
Initial body energy, mcal	195.79	196.77	2.796	0.807
Final body energy, mcal	393.87	410.25	10.919	0.308
Energy retention, mcal	198.08	213.48	9.454	0.271
Total OPM, mcal ²	90.32	90.57	0.723	0.813
Total NE intake, mcal	288.41	304.05	9.905	0.285
Total feed intake, kg	137.94	140.78	4.009	0.626
NE of diets, kcal/kg	2,382	2,409	78.159	0.813

¹Data are least square means of eight observations in each growing phase.

²Total operational maintenance requirement (OPM) is calculated by multiplying the mean metabolic BW (kg^{0.6}) of each pig by 156 kcal (Chap. 3) and the number of days in experiments (28 d for growing pigs and 35 d for finishing pigs).

Table 4.7. Energy values of glycerol in growing and finishing pigs.¹

Items	Growing	Finishing	S.E.	<i>P</i> -value
DE, kcal/kg	3,898	3,771	591.4	0.882
ME, kcal/kg	3,854	3,747	578.2	0.897
NE, kcal/kg	2,740	3,461	676.2	0.465
ME:DE	0.993	0.996	0.003	0.507
NE:ME	0.699	0.717	0.117	0.917

¹Data are least square means of eight observations in each growing phase.

Chapter V

IMPACT OF DIETARY ENERGY LEVEL AND RACTOPAMINE (PAYLEAN®) ON GROWTH PERFORMANCE, CARCASS CHARACTERISTICS, AND MEAT QUALITY OF FINISHING PIGS

ABSTRACT

A total of 72 TR-4 × C22 finishing barrows (Initial BW = 99.8 kg) reared in individual pens were allotted to one of six dietary treatments in a 2 × 3 factorial design with two levels of ractopamine (RAC, 0 and 7.4 ppm, Paylean®, Elanco Animal Health) and three levels of dietary energy (High: 3,538 kcal ME, Medium: 3,369 kcal ME, Low: 3,318 kcal ME) to determine the effects of the feeding of RAC and dietary energy levels on growth performance, carcass characteristics, and meat quality of finishing pigs. High energy diets were corn-SBM based with 4% added fat, medium energy diets were corn-SBM based with 0.5% added fat, and low energy diets were corn-SBM based with 0.5% added fat and 15% wheat middlings (WM). Diets within RAC levels were formulated to contain the same g SID Lys:ME (0 ppm: 1.82, 7.4 ppm: 2.65). Individual pig weights and feed disappearance were recorded at the beginning and conclusion (d 21) of the study. On d 21, pigs were harvested for determination of carcass characteristics and meat quality. No RAC × energy level interactions were observed for any parameters of interest. Final BW (125.2 vs. 121.1 kg), ADG (1.2 vs. 1.0 kg/d), and F:G (2.57 vs. 3.30) were improved ($P < 0.001$) with the feeding of RAC. The feeding of the low energy diets reduced ($P <$

0.001) final BW (120.4 vs. 125.7 kg) and ADG (0.98 vs. 1.23 kg/d) when compared to the high energy diets. Feed:Gain was impaired ($P < 0.002$) when the medium (3.00) and low (3.15) energy diets were compared to the high (2.67). Feeding RAC increased ($P < 0.05$) HCW (93.6 vs. 89.9 kg) and LEA (51.2 vs. 44.2 cm²). Loin pH decline was reduced ($P < 0.05$) with the feeding of RAC. The feeding of the low energy diets reduced ($P < 0.001$) HCW when compared to the high and medium energy diets and reduced ($P < 0.03$) 10th rib BF when compared to the high energy diet. These data suggest that the feeding of RAC effectively improved growth performance and carcass characteristics while having little to no detrimental effects on meat quality. Reductions in energy content of the diet by adding 15% WM resulted in reductions in ADG, F:G, and 10th rib BF. There were no RAC \times energy level interactions, which indicate that the improvements resulting from RAC are present, regardless of energy level of the diet.

INTRODUCTION

In today's swine industry, feed costs represent up to 50 to 70% of the total cost of production. The energy content of the diet is a major determinant of pig performance and is the single most expensive component of the diet. With recent fluctuations in energy costs, questions have been raised as to what are the effects of removing non-grain energy sources from the diet and additional dietary energy reductions with the addition of low-energy feedstuffs such as wheat middlings.

Energy intake drives protein deposition until a plateau is reached and then any further increase in energy results in fat deposition (de Lange et al., 2001). Ractopamine

hydrochloride (Paylean[®]) alters this deposition pattern by increasing the partitioning of energy to protein accretion by decreasing lipogenesis and increasing lipolysis in adipose tissue and increasing protein synthesis in muscle tissue (Adeola et al., 1990; Williams et al., 1994). The study of Williams et al., 1994, suggested that ractopamine was able to produce maximum lean deposition at low energy intake levels. However, the genotype of pig used in the afore mentioned study are quite different than our current high-lean growth genetics.

Therefore, the objective of the present study is to evaluate the potential interactions between energy density of the diet and ractopamine inclusion on growth performance and carcass characteristics of modern high-lean gain genetic lines of pigs.

MATERIALS AND METHODS

All animals were cared for in accordance with University of Missouri Animal Care and Use Committee regulations.

Animals and Housing

Seventy-two finishing barrows (TR4 × C22, PIC, Franklin, KY) with an initial BW of 99.8 ± 5.05 kg were randomly allotted within a 2×3 factorial arrangement with nine replications per treatment. The treatments included two levels of ractopamine (RAC; 0 vs. 7.4 ppm) and three levels of dietary energy (high, medium, and low).

All pigs were individually penned in 1.22×1.68 m pens with fully-slatted cast iron flooring, a single-hole feeder, and a nipple waterer with feed and water available *ad libitum*. The experimental period lasted for 21 d.

Diets

The three levels of dietary ME were obtained by varying the amount of added fat in the diet and with the addition of low energy content feedstuffs. High energy diets (0 ppm RAC = 3,538 kcal/kg ME, 7.4 ppm RAC = 3,536 kcal/kg ME, Avg. ME = 3,537 kcal/kg) were typical corn-SBM diets with 4% added fat. Medium energy diets (0 ppm RAC = 3,371 kcal/kg ME, 7.4 ppm RAC = 3,366 kcal/kg ME, Avg. ME = 3,369 kcal/kg) were corn-SBM diets with 0.5% added fat. This minimal level of fat supplementation was utilized for dust suppression purposes. Low energy diets (0 ppm RAC = 3,320 kcal/kg ME, 7.4 ppm RAC = 3,314 kcal/kg ME, Avg. ME = 3,317 kcal/kg) were corn-SBM diets with 0.5% added fat and 15% wheat middlings (WM). All diets within RAC treatments were formulated to contain equal g SID Lys:ME ratios (0 ppm RAC = 1.82, 7.4 ppm RAC = 2.65). These ratios are what were obtained from the high energy diets and were maintained in the diets with medium and low energy levels by holding SBM inclusion rates constant and adjusting the inclusion rates of synthetic L-Lys. Other synthetic amino acids (Met and Thr) were supplemented in order to maintain constant ratios in relation to SID Lys across all energy levels within RAC treatments. All other nutrients were formulated to meet or exceed the estimated requirements for pigs at this stage of growth (NRC, 1998).

Carcass Data Collection

At the conclusion of the study (d 21) animals were transported to the meat science laboratory at the University of Missouri. Upon arrival, pigs were allowed to rest in lairage for a minimum of 1.5 hr. Animals were slaughtered utilizing industry accepted practices. Carcass weights were obtained and then carcasses were allowed to chill for a period of 24 hr. After 24 hr, chilled carcass weights were recorded and first rib, last rib, and last lumbar midline backfat depths were obtained from the right half of the carcass. The right half of the carcass was then ribbed at the 10th rib to facilitate the measurement of 10th rib backfat (3/4 off of the midline) and loin eye area (LEA), objective color scores L*, a*, and b* (Konica Minolta Sensing, Inc., Japan), and subjective color and marbling scores (National Pork Producers Council Meat Quality Standards, Des Moines, IA, USA).

Loin muscle drip loss percent was determined using a method adapted from Honikel et al. (1986). Briefly, a loin core (approximately 10 g sample) was removed from each carcass. The loin sample was weighed and then suspended on a barbless hook with string attached to the hook. The string on each sample's hook was threaded through the bottom of an inverted plastic cup, placed inside of a whirl-pack bag, and suspended for a period of 24 hr at 4° C before being removed from the hook and re-weighed.

Loin pH and Temperature Measurements

Loin pH and temperature measurements were obtained at 45 min and 3, 6, 9, 12, and 24 hr post-mortem. Measurements were obtained by inserting an MPI pH probe (Meat Probes Inc., Topeka, KS, USA) into the loin between the 10th and 11th rib.

Glycolytic Potential

At 24 hr post-mortem, a 2.54 cm thick loin muscle chop was removed from the right side of each carcass, placed in a whirl-pack bag, and frozen at -20° C. Samples were sent to the University of Illinois for determination of glycolytic potential utilizing methods adapted from Hartschuh et al. (2002).

Statistical Analysis

All data were analyzed by ANOVA utilizing the PROC GLM procedure of SAS (SAS Inst. Inc., Cary, NC). Individual pig served as the experimental unit. The statistical model included RAC level, energy level, and the interaction of RAC and energy. However, there were no interactions between RAC and energy levels, therefore the interaction was removed from the model and only the main effects of RAC and energy levels are presented. The LSMEANS procedure was used to calculate mean values and the DUNCAN option was used to separate treatment means. An alpha-value of 0.05 was used to assess significance among means

RESULTS AND DISCUSSION

Growth Performance and Carcass Characteristics.

The feeding of a RAC program increased ADG (1.21 vs. 1.01 kg/d; $P < 0.001$) and subsequent final body weight (125.21 vs. 121.13 kg; $P < 0.001$) when compared to the diets without RAC (Table 5.2). This increase in ADG combined with a tendency ($P = 0.069$) for ADFI to be reduced with the feeding of a RAC program resulted in F:G being

improved ($P < 0.001$) from 3.30 to 2.57. While numerous research trials have been conducted in regards to the effects of feeding RAC programs, this work has typically been done with RAC included at 5, 10, 15, or 20 ppm and to our knowledge, there has been no published data in which RAC was included at 7.4 ppm. However, the responses in growth performance observed in the present study are similar to those observed in studies in which either a 5 or 10 ppm RAC program were fed (Jones et al., 2000; Weber et al., 2006; Crome et al., 1996; Armstrong et al., 2004; Carr et al., 2005). Daily intake of SID Lys was increased ($P < 0.001$) with the feeding of a RAC program at 27.75 vs. 20.28 g/d. This increase in intake of SID Lys would be expected due to the increased nutrient density of the RAC program diets.

The feeding of the diet with the lowest energy level resulted in reduced ($P < 0.001$) ADG and final body weight when compared to the high and medium energy diets (Table 5.2). Average daily feed intake did not differ ($P > 0.10$) between the high and medium energy diets. However, when the low energy diets were fed, there was a tendency ($P < 0.10$) for ADFI to be reduced when compared to the high and medium energy diets. Feed efficiency was impaired ($P = 0.002$) when the medium (3.00) and low (3.15) energy level diets were compared to the high (2.67) energy level diet, however there was no difference between the medium and low energy levels. Additionally, daily ME intake did not differ ($P < 0.05$) between the high and medium energy diets. However, daily ME intake was reduced ($P < 0.05$) when the low energy diet was fed. It is well known that when the energy density of swine diets is increased, ADFI is reduced and feed efficiency is improved (De La Llata et al., 2001; Smith et al., 1999; Weber et al., 2006). In the present study, ADFI was numerically increased and F:G was impaired when the medium energy

diet was fed. However, when the low energy diet was fed, ADFI was reduced instead of increased as would be expected (Steerley and Ewan, 1983). This reduction in feed intake can be attributed to the fact that the reduced energy level in the low energy diet was obtained with the addition of WM to the diet at an inclusion rate of 15%. The addition of a bulky feedstuff such as WM results in increased gut fill and thereby reduces the capacity of feed intake (NRC, 1998). This reduction in the capacity for increased feed intake of the low energy diet resulted in the observed reduction in daily ME intake. Daily intake of SID Lys did not differ ($P > 0.10$) between the high (25.23 g/d) and medium (24.56 g/d) energy levels, but was reduced ($P = 0.013$) with the feeding of the low energy diet (22.26 g/d). While daily intake of SID Lys was reduced with the feeding of the low energy diet, this level of intake was greater than NRC (1998) recommendations.

Hot carcass weights from pigs receiving the RAC program were 3.74 kg heavier (93.63 vs. 89.89 kg; $P < 0.001$) than that of the control animals (Table 5.3). The feeding of a RAC program tended ($P = 0.075$) to reduce 1st rib backfat and reduced ($P = 0.037$) last lumbar backfat (20.37 vs. 23.00 mm) while having no effect ($P > 0.05$) on 10th rib backfat. Additionally, loin eye area was increased ($P < 0.001$) from 44.19 to 51.21 cm² with the feeding of a RAC program. The observed increases in carcass weight and loin eye area are in agreement with previous research in which various levels of RAC have been fed (Jones et al., 2000; Weber et al., 2006; Uttaro et al., 1993; Carr et al., 2005; Yen et al., 1990). However, in the present study there was no observed reduction in 10th rib backfat, which is contradictory to previous research (Williams et al., 1994; Uttaro et al., 1993; Crome et al., 1996; See et al., 2004; Carr et al., 2005). This contradiction may be attributed to the fact that in the present study pigs were individually housed and were

allowed *ad libitum* feed intake, while in previous studies in which 10th rib backfat was reduced with the feeding of a RAC program, pigs were either group housed or limit fed.

Objective a* values were reduced (16.05 vs. 16.68; $P = 0.006$) and b* values tended to be reduced ($P = 0.099$) with the feeding of a RAC program. Additionally, subjective color values were reduced (2.54 vs. 2.89; $P = 0.041$) with the feeding of a RAC program. Contradictory data exists in regards to the effects of feeding a RAC program on subsequent meat quality. Objective a* and b* values have been reported to be reduced with the feeding of a RAC program (Uttaro et al., 1993; Carr et al., 2005), while Fernández-Dueñas et al. (2008) reported that only b* values were reduced with the feeding of a RAC program. While objective meat quality values have been reported to be negatively impacted by the feeding of a RAC program, subjective color, marbling, and firmness scores are typically unaffected by the feeding of a RAC program (Weber et al., 2006; Crome et al., 2006; Fernández-Dueñas et al., 2008).

Hot carcass weights were reduced ($P < 0.001$) when the low energy level diet (89.04 kg) was compared to the high (93.78 kg) and medium (92.46 kg) energy level diets (Table 5.3). Reducing dietary energy to the medium level did not effect 10th rib backfat depths ($P > 0.05$) when compared to the high energy level diet. However, further reduction in dietary energy to the low level resulted in 10th rib backfat depths being reduced ($P < 0.05$) from 25.05 mm in the pigs consuming the high energy diet to 21.59 mm in the pigs consuming the low energy level diet. The observed reduction in 10th rib backfat when the lowest energy diet was fed is in agreement with previous work by Apple et al. (2004) in which 10th rib fat depth was reduced by 5% when dietary energy concentration was reduced from 3.48 to 3.30 Mcal/kg. However, others (Smith et al.,

1999; De la Llata et al., 2001; Weber et al., 2006) have reported that carcass characteristics are unaffected by dietary energy level.

Objective color values were not affected ($P > 0.10$) by dietary energy level, however, subjective color values tended to be increased ($P < 0.10$) when the low energy diets were compared to the high energy diets at 2.94 vs. 2.47, respectively. Previous studies involving the feeding of diets with various energy densities have consistently observed no effects on meat quality when energy density was reduced (Szabó et al., 2001; Apple et al., 2004; Armstrong et al., 2004; Weber et al., 2006).

The lack interactions between the feeding of a RAC program and varying energy levels would suggest that regardless of dietary energy level being fed, the feeding of a RAC program elucidates improvements in growth performance and carcass characteristics. It is well known that the feeding of RAC increases the partitioning of energy from lipid accretion to protein accretion through reducing lipogenesis and increasing lipolysis in adipose tissue and increasing protein synthesis in muscle tissue (Adeola et al., 1990; Williams et al., 1994). The results from this study appear to validate the hypothesis set forth by Williams et al. (1994) in that it appears that regardless of the energy level of the diet, RAC is able to increase lean deposition by partitioning enough energy to maximize protein accretion. Therefore, protein and lean deposition can be increased with the feeding of a RAC program, regardless of the energy level present in the diet.

Glycolytic Potential, pH, and Temperature

Loin muscle pH values (Table 5.4) were increased ($P < 0.02$) at 3, 6, and 9 hr post-mortem with the feeding of a RAC program. Additionally, ultimate pH values (24 hr post-mortem) were increased ($P = 0.008$) from 5.74 to 5.88 with the feeding of a RAC program. Loin temperature values were not affected ($P > 0.05$) with the feeding of a RAC program at any time point. The increase in ultimate loin pH is contradictory to previous research that has indicated that when a RAC program is fed, loin muscle pH values are unaffected (Carr et al., 2005; Weber et al., 2006; Fernández-Dueñas et al., 2008). The observed reductions in pH decline and increased ultimate pH can have a positive impact on the final tenderness of the meat (Huff-Lonergan et al., 2000). Additionally, it has been proposed that even small differences in pH decline and ultimate pH can have large differences in many aspects of meat quality (Puolanne et al., 2002).

Loin muscle pH values were reduced ($P < 0.05$) at 9 and 12 hr post-mortem when the low energy diets were compared to the high energy diets. Additionally, ultimate pH tended to be reduced ($P < 0.078$) when the low energy diets (5.76) were compared to the high energy diets (5.89). Loin temperature values were not affected ($P > 0.05$) by dietary energy level at any time point. When the medium and low energy diets were formulated, dietary starch concentrations were increased due to an increased inclusion rate of corn in the medium energy diet and the addition of 15% WM in the low energy diet. Leheska et al. (2002), Bee et al. (2006), and Tikk et al. (2005) have reported that when dietary starch levels are increased, pH decline is accelerated and ultimate pH is reduced due to reductions in muscle glycogen levels. However, in the present study, pH decline and ultimate pH appear to be independent of measured glycolytic potential.

IMPLICATIONS

Results of the present study indicate that the feeding of a RAC program with 7.4 ppm RAC yields improvements in growth performance and carcass characteristics that are similar to results observed when RAC is included at 5 or 10 ppm. Additionally, the feeding of a RAC program could potentially improve meat quality through increased ultimate loin pH values. The feeding of reduced dietary energy levels can negatively impact growth performance while maintaining similar or slightly improved carcass characteristics. The absence of interactions between the feeding of a RAC program and various dietary energy levels indicates that a RAC program response is present, regardless of dietary energy concentrations.

Table 5.1. Dietary Composition.

Ractopamine, ppm	0			7.4		
	High	Medium	Low	High	Medium	Low
Energy						
Ingredients						
Corn	80.64	84.22	69.57	68.78	72.45	57.83
SBM, 48%	13.25	13.25	13.25	25.00	25.00	25.00
Wheat middlings	0.00	0.00	15.00	0.00	0.00	15.00
Choice white grease	4.00	0.50	0.50	4.00	0.50	0.50
Dicalcium phosphate	0.60	0.55	0.00	0.50	0.45	0.00
Limestone	0.70	0.73	1.00	0.75	0.78	0.98
Salt	0.40	0.40	0.40	0.40	0.40	0.40
L-Lysine	0.153	0.105	0.033	0.15	0.085	0.005
DL-Methionine	0.00	0.00	0.00	0.085	0.045	0.00
L-Threonine	0.013	0.00	0.00	0.045	0.008	0.00
Vitamine premix ¹	0.15	0.15	0.15	0.15	0.15	0.15
Trace mineral premix ²	0.10	0.10	0.10	0.10	0.10	0.10
Paylean ^{®3}	0.00	0.00	0.00	0.038	0.038	0.038
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated composition						
ME, kcal/kg	3,538	3,371	3,320	3,536	3,366	3,314
Crude protein, %	13.14	13.38	14.48	17.81	18.00	19.07
SID Lysine, %	0.64	0.61	0.60	0.94	0.89	0.88
g SID Lys/kcal ME	1.82	1.82	1.82	2.65	2.65	2.65
P, %	0.43	0.43	0.43	0.46	0.46	0.47
Ca, %	0.47	0.47	0.47	0.50	0.50	0.50

¹ Provided per kilogram of final diet: vitamin A, 6,614 IU; vitamin D3, 661 IU; vitamin E, 13.2 IU; riboflavin, 4.96 mg; vitamin B12, 0.02 mg; Menadione, 2.4 mg; D-pantothenic acid, 16.9 mg; niacin, 19.8 mg.

² Provided per kilogram of final diet: Iron, 110 mg; Zinc, 110 mg; Manganese, 22 mg, copper, 11 mg; iodine, 0.2 mg; selenium 0.198 mg.

³ Elanco Animal Health, Greenfield, IN.

Table 5.2. Effect of ractopamine (0 vs. 7.4 ppm) and dietary energy level on finisher pig performance.

	Ractopamine, ppm			Energy ¹				P-Values	
	0	7.4	SEM	High	Medium	Low	SEM	Ractopamine	Energy
d 0 BW, kg	99.81	99.79	0.392	99.84	99.77	99.79	0.480	0.976	0.994
d 21 BW, kg	121.13	125.21	0.756	125.67 ^x	123.45 ^x	120.38 ^y	0.925	< 0.001	< 0.001
Total BW gain, kg	21.32	25.42	0.612	25.83 ^x	23.69 ^y	20.59 ^z	0.750	< 0.001	< 0.001
ADG, kg	1.01	1.21	0.029	1.23 ^x	1.13 ^x	0.98 ^y	0.036	< 0.001	< 0.001
ADFI, kg	3.29	3.07	0.081	3.23 ^a	3.31 ^{ab}	3.00 ^c	0.099	0.069	0.085
F:G	3.30	2.57	0.074	2.67 ^y	3.00 ^x	3.15 ^x	0.091	< 0.001	0.002
ME intake, Mcal/d	11.21	10.46	0.274	11.42 ^x	11.14 ^x	9.95 ^y	0.336	0.545	0.008
SID Lys intake, g/d	20.28	27.75	0.583	25.23 ^x	24.56 ^x	22.26 ^y	0.714	< 0.001	0.013

^{abc} Means within a row without common superscripts differ (P < 0.10).

^{xyz} Means within a row without common superscripts differ (P < 0.05).

¹ Energy levels; High = 3,537 avg. kcal/kg ME; Medium = 3,369 avg. kcal/kg ME; Low = 3,317 avg. kcal/kg ME.

Table 5.3. Effect of ractopamine (0 vs. 7.4 ppm) and dietary energy level on finisher pig carcass characteristics.

	Ractopamine, ppm			Energy ¹				P-Values	
	0	7.4	SEM	High	Medium	Low	SEM	Ractopamine	Energy
Hot carcass wt, kg	89.89	93.63	0.669	93.78 ^x	92.46 ^x	89.04 ^y	0.820	< 0.001	< 0.001
Yield, %	74.19	74.77	0.297	74.61	74.88	73.95	0.363	0.170	0.186
Chilled carcass wt, kg	86.23	89.48	0.665	89.95 ^x	88.12 ^x	85.50 ^y	0.814	0.001	0.001
Cooler shrink, %	4.02	4.39	0.349	4.07	4.62	3.93	0.428	0.454	0.491
1 st rib BF, mm	43.13	40.12	1.171	43.74	39.72	41.42	1.434	0.075	0.149
10 th rib BF, mm	24.08	22.62	0.757	25.05 ^x	23.42 ^{xy}	21.59 ^y	0.927	0.180	0.039
Last rib BF, mm	33.68	33.54	1.064	34.43	33.44	32.95	1.303	0.926	0.717
Last lumbar BF, mm	23.00	20.37	0.869	23.00	21.66	20.39	1.065	0.037	0.233
Loin eye area, cm ²	44.19	51.21	1.187	47.51	47.35	48.24	1.454	< 0.001	0.898
L [*]	57.28	57.48	0.560	57.10	57.94	57.10	0.685	0.802	0.609
a [*]	16.68	16.05	0.156	16.21	16.22	16.67	0.191	0.006	0.158
b [*]	9.19	8.66	0.221	8.81	8.85	9.12	0.270	0.099	0.683
Color ²	2.89	2.54	0.118	2.47 ^b	2.72 ^{ab}	2.94 ^a	0.145	0.041	0.081
Marbling ³	1.37	1.30	0.103	1.31	1.28	1.42	0.126	0.612	0.712
Drip loss, %	6.21	5.11	0.608	5.42	5.98	5.58	0.745	0.207	0.862

^{ab}Means within a row without common superscripts differ (P < 0.10).

^{xy}Means within a row without common superscripts differ (P < 0.05)

¹Energy levels; High = 3,537 avg. kcal/kg ME; Medium = 3,369 avg. kcal/kg ME; Low = 3,317 avg. kcal/kg ME.

²On a scale of 1-5, 1 being pale/pinkish gray and 5 being dark purplish red.

³On a scale of 1-5, 1 being devoid to practically devoid and 5 being moderately abundant or greater.

Table 5.4. Effect of ractopamine (0 vs. 7.4 ppm) and dietary energy level on glycolytic potential, pH measurements, and temperature of loin muscle.

	Ractopamine, ppm			Energy ¹				<i>P</i> -Values	
	0	7.4	SEM	High	Medium	Low	SEM	Ractopamine	Energy
Glucose-6-phosphate, $\mu\text{mol/g}$	10.74	8.46	0.694	8.94	9.64	10.28	0.849	0.025	0.564
Lactate, $\mu\text{mol/g}$	96.65	98.05	2.645	96.82	100.77	94.47	3.240	0.709	0.388
Glycolytic potential	118.12	114.98	3.182	114.69	120.04	114.92	3.897	0.488	0.552
pH (time post harvest)									
45 min	6.14	6.13	0.042	6.18	6.11	6.11	0.051	0.935	0.520
3 hr	5.72	5.87	0.039	5.83	5.76	5.80	0.048	0.009	0.557
6 hr	5.73	5.88	0.035	5.89 ^a	5.77 ^{ab}	5.76 ^b	0.043	0.004	0.078
9 hr	5.76	5.87	0.033	5.90 ^x	5.82 ^{xy}	5.73 ^y	0.041	0.022	0.021
12 hr	5.75	5.87	0.041	5.91 ^x	5.79 ^{xy}	5.73 ^y	0.050	0.052	0.045
24 hr	5.74	5.88	0.035	5.89 ^a	5.78 ^{ab}	5.76 ^b	0.043	0.008	0.078
Temperature (time post harvest), C°									
45 min	38.88	39.13	0.355	39.10	39.34	38.59	0.435	0.634	0.470
3 hr	25.25	25.44	0.428	25.72	25.55	24.75	0.524	0.758	0.384
6 hr	14.88	14.93	0.281	15.09	15.31	14.31	0.344	0.918	0.109
9 hr	10.76	10.78	0.276	10.74	11.02	10.55	0.339	0.971	0.618
12 hr	6.83	7.05	0.279	7.23	6.90	6.67	0.342	0.576	0.507
24 hr	2.46	2.64	0.104	2.58	2.53	2.54	0.127	0.233	0.950

^{ab}Means within a row without common superscripts differ ($P < 0.10$).

^{xy}Means within a row without common superscripts differ ($P < 0.05$).

¹Energy levels; High = 3,537 avg. kcal/kg ME; Medium = 3,369 avg. kcal/kg ME; Low = 3,317 avg. kcal/kg ME.

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VITA

Rodney “Buddy” Hinson was born on June 24, 1980, in Fayetteville, Arkansas, to Rodney J. and Linda Hinson. During his youth, Buddy developed a passion for agriculture both on the family farms and through his involvement in 4-H and FFA. Upon graduating high school, Buddy began his collegiate endeavors at the College of the Ozarks majoring in Animal Science. After his Junior year, Buddy realized that he had a passion to further his education through post-graduate studies. In order to obtain this goal he transferred to the University of Arkansas to continue his undergraduate studies in Animal Science. While at the University of Arkansas, Buddy was employed at the University Swine Research and Teaching farm. Upon completion of his undergraduate studies in 2002, Buddy began working on his M.S. in swine nutrition under Drs. Allan Sutton and Brian Richert at Purdue University studying the effects of diet modifications on growth performance, carcass characteristics, and nutrient mass balance in swine reared under both research and commercial conditions. Upon completion of his M.S. in 2005, Buddy began work on his PhD under the direction of Dr. Gary Allee at the University of Missouri, evaluating Net Energy systems and energy requirements in swine. Buddy has been the author or co-author on three peer-reviewed manuscripts and forty-one abstracts. Buddy was married in 2001 to his wife Michelle and they have three children, Caleb, Zach, and Sara.