NET ENERGY VALUES OF SOYBEAN HULLS AND WHEAT MIDDLINGS FED TO GROWING AND FINISHING PIGS

BY

LAURA LYNN STEWART

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THESIS

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Professor Hans-Henrik Stein

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ABSTRACT

Net energy systems have been used in Europe to more accurately predict energy utilization of pigs, but have not been widely accepted in North America. The use of NE is important when using high fiber ingredients because of the overestimation of energy by the ME system in pig diets. Therefore, our objective was to measure NE in 2 high fiber ingredients, soybean hulls (**SBH**) and wheat middlings (**WM**), in growing pigs and in finishing pigs. An experiment was conducted to measure effects of including 30% soybean hulls (SBH) or 30% wheat middlings (WM) in corn soybean meal based diets. Forty growing (initial BW: 25 kg) and 40 finishing (initial BW: 85 kg) barrows were randomly allotted to 5 treatment groups within each stage of growth with 8 pigs per group. Two groups (16 pigs) at each stage of growth served as the initial slaughter groups (**ISG**) and were harvested at the initiation of the trial. The remaining 3 treatment groups were randomly assigned to 3 experimental diets that were provided on an ad libitum basis for 28 d in the grower phase and for 35 d in the finisher phase. All pigs were harvested at the conclusion of the feeding period. Results showed that during the grower phase, ADG and G:F were greater ($P < 0.05$) for pigs fed the control corn-soybean meal diet (1.15 kg and 0.56 kg/kg) than for pigs fed the SBH (0.97 kg and 0.47 kg/kg) or the WM (0.89 kg and 0.48 kg/kg) diets. In growing pigs, hot and chilled carcass weights and dressing percentage were lower ($P < 0.05$) for pigs fed the SBH and WM diets compared with pigs fed the basal diet. The total amount of fat in the carcass was lower ($P < 0.05$) for pigs fed the SBH and WM diets than for pigs fed the control diet. The percentage and total amount of fat in the carcass was lower ($P < 0.05$) in ISG pigs than in pigs fed the treatment diets. In finishing pigs, no differences in carcass concentrations of fat or protein were observed among treatments, but total concentration of fat was greater ($P < 0.05$) in pigs fed the basal diet (41.5 kg) than in pigs fed SBH or WM diets (35.0 and 36.7 kg). The ISG pigs had a lower ($P < 0.05$) concentration of fat, but a greater concentration of protein ($P < 0.05$) than pigs fed the treatment diets. In the growing and finishing phases, total energy was greater in the pigs fed the basal diet than in pigs fed the SBH or WM diets, but the amount of total protein did not differ among the treatments. The total fat concentration was greater ($P < 0.001$) in growing and finishing pigs fed the basal diets than in pigs fed the SBH or WM diets, therefore, the difference in energy concentration can be attributed to the increased fat concentration. In the growing and finishing phases, the final total empty body energy was greater ($P < 0.001$) in the pigs fed the basal diet than in pigs fed the SBH and WM diets. The energy retained was also greater ($P < 0.05$) in the pigs fed the basal diet than in pigs fed the SBH and WM diets. Maintenance energy and total NE were also greater ($P < 0.01$) in the pigs fed the basal diet than in pigs fed the SBH or WM diet. Net energy values in SBH and WM for growing pigs (354 and 863 kcal/kg) were not different from the values in finishing pigs (959 and 1,030 kcal/kg). In conclusion, the inclusion of SBH and WM in diets fed to growing and finishing pigs, reduces the NE value of the diet and energy retained in the body. However, ADG and G:F is reduced only in growing pigs.

Key words: pig, NE, soybean hulls, wheat middlings, body composition

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LIST OF ABBREVIATIONS

AA	Amino Acid (s)
ADF	Acid detergent fiber
ADFI	Average daily feed intake
ADG	Average daily gain
AOAC	Association of Analytical Chemists
Arg	Arginine
B	Blood weight
BW	Body weight
°C	Degrees Celsius
CP	Crude Protein
Cys	Cysteine
d	day
DP	Dressing percentage
EE	Either extract
EM	energy used for operational maintenance
GE	Gross Energy
G:F	gain to feed ratio
h	Hours
H	Heart weight
HCW	Hot carcass weight
HI	Heat increment
His	Histidine

Ile	Isoleucine
ISG	Initial slaughter group
ISGE	Energy of pigs in initial slaughter group
INRA	Institut National de la Recherche Agronomique, Saint Gilles, Fr
IU	International units
K	Kidney weight
Kcal	Kilocalories
kg	Kilograms
Leu	Leucine
Li	Liver weight
Lu	Lung weight
LW	Live weight
Lys	Lysine
Mcal	Megacalories
ME	Metabolizable energy
Met	Methionine
MLW	Mean metabolic body weight
NDF	Neutral detergent fiber
NE	Net energy
NRC	National Research Council
Phe	Phenylalanine
S	Spleen weight
SBH	Soybean hulls

SEM	Standard error of the mean
TBEI	Total body energy, initial
Thr	Threonine
TW	Total weight
Trp	Tryptophan
U.S.	United States of America
V	Viscera weight
Val	Valine
VFA	Volatile fatty acids
WM	Wheat middlings

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CHAPTER 1

INTRODUCTION

Swine production focuses on the cost of feed as the main expense in most countries with energy sources having the greatest influence on the feed cost. Therefore, it is important to accurately predict the energy concentration in swine diets to ensure lower production costs. The swine industry in the U.S. uses ME and DE systems as a means of describing the utilization of energy by pigs. However, research on different energy systems has been conducted in European countries such as France, The Netherlands, and Denmark and the use of the NE system has been established in these countries. The NE system is favored because it more accurately predicts the “true” energy values of a feed ingredient by the pig (Noblet, 2007) when compared to the ME system. Therefore, research to improve the knowledge of energy utilization in pigs needs to be conducted and NE values of feed ingredients need to be measured to reduce costs in swine production.

The production of co-products from bio-refining of raw agricultural materials has increased in the U.S. These co-products generally contain greater quantities of fiber than traditional feed ingredients because the starch and the fat have been removed or partially removed from the feed. This leads to a reduction in the quantities of feedstuffs containing starch for pigs, and an increase in feedstuffs containing fiber. Net energy more accurately predicts the amount of energy used and retained in the pig for fibrous feedstuffs when compared to the ME system (Payne and Zijlstra, 2007), because it takes into account the amount of energy used for fermentation by the pig. Thus, high fiber ingredients should be evaluated on a NE basis because of an increase in the amount of heat produced from fermentation, or heat increment (HI) of the fibrous ingredients in the hindgut of the pig. The increase in HI can be affected by biological factors including age, feeding status, and nutrient content of the feed (Ewan, 2001). It has been hypothesized that as pigs grow, the number of microbes increases in the hindgut, which suggests that finishing pigs have an increased capacity for utilization of energy from high fiber feedstuffs when compared to growing pigs (Kass et al., 1980). Theoretically, finishing pigs should have a greater NE of high fiber ingredients than growing pigs but this hypothesis has not been tested. The increased HI in pigs fed high fiber ingredients will result in an overestimation of the energy concentration of fiber containing ingredients when using the ME system, and NE values of these ingredients, therefore, need to be measured.

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CHAPTER 2

EFFECTS OF DIETARY FIBER ON NET ENERGY SYSTEMS IN GROWING AND FINISHING PIGS:

LITERATURE REVIEW

INTRODUCTION

The NE system is used to describe energy utilization in swine diets in several European countries including France and the Netherlands. The concept of the NE system has been investigated by many researchers from the early 1900's (Armsby, 1917, cited from: Baldwin, 1995). However, the NE concept did not appeal to the swine industry in North America until the mid 1990's because of modest speculation of using the DE or ME energy systems for diet formulation.

Utilization of energy

To understand the NE system, the dietary needs and utilization of energy in the pig must be partitioned (Figure 2.1). Gross energy is the heat of combustion of a feed ingredient, which is the maximum amount of energy that is available for use by the animal (Ewan, 2001). The amount of GE in a fed ingredient, usually described in kilocalories per gram (**kcal/g**), depends on the concentration of carbohydrate, fat, and protein in the ingredient. For example, carbohydrates provide 3.7 kcal/g of glucose to 4.2 kcal/g of starch, while protein provides 5.6 kcal/g, and fat provides 9.4 kcal/g (Ewan, 2001). Gross energy has been measured for most feed ingredients using bomb calorimetry.

After ingestion, only a percentage of the GE is absorbed in the intestinal tract of the pig. The remaining part is excreted in the feces. By subtracting the energy in the feces from the energy that was ingested, the amount of DE in the diet is calculated. Thus, DE is the amount of energy that is absorbed from the GI-tract and is available for utilization by the pig. Digestible energy is simple to determine and apply, but it overestimates the energetic value of feedstuffs or diets of low energy concentration relative to that of feedstuffs or diets of high energy concentrations (Just, 1975). The NRC (1998) uses DE to estimate the net absorption of energy provided by the feed ingested by the pig. The chemical composition of feed ingredients determines the DE in the ingredient, with positive effects of ether extract and negative effects of fiber and ash.

The concentration of ME in a feed ingredient is calculated by subtracting the amount of heat of combustion from the urine (**UE**) and the gases of the digestive tract from the DE in the ingredient (Ewan, 2001). The ME concentration in a diet can be calculated by measuring the amount of GE in the feed that the animal consumes and subtracting the amount of GE in the output from the animal in the form of urine and fecal energy. Gaseous energy represents the energy in the methane produced by the animal. Growing pigs average an energy loss of 0.4% of DE intake to gaseous energy, but this estimate is doubled in adult sows (Noblet, 2006). However, in most cases the gaseous energy is ignored when ME is calculated. Thus, ME is a measure of the amount of energy that is available for the metabolic processes in the pig (Just, 1982b).

Metabolizable energy can be divided into NE and heat increment (**HI**) and the NE is the difference between ME and HI. The NE can be used for maintenance (**NE*m***) of the animal or it can be used for production (**NE*p***). Net energy for maintenance is energy that is used to maintain the physiological functions of the animal, e.g., to keep the animal alive and maintain body temperature. The NE used for NE*p*, is used for milk production or protein and fat accretion. Net energy values for growth represent the portion of the feed energy supplied in excess of the maintenance requirement, which the animal is able to store as lean tissue and fat (Baldwin, 1995). Therefore, the net energy value of an ingredient may differ according to the species by which it is consumed and the purpose for which it is used (Baldwin, 1995).

Heat increment in relation to net energy systems

The HI is the amount of heat released as a result of the energy costs of the digestive and metabolic processes (NRC, 1998), because it is produced by the digestion and metabolism of nutrients in feed ingredients and by fermentation in the gastrointestinal tract (Ewan, 2001). However, HI is not used for production processes, but can be used to maintain body temperature during extreme conditions (NRC, 1998). Heat increment can be divided into two portions (Armsby, 1917, cited from: Baldwin, 1995): i) the heat needed for digestion and assimilation of feed for maintenance, called the heat increment of maintenance (**HI*m***), and ii) the HI associated with maintaining a constant body temperature and with product synthesis (**HI*p***). Therefore, the amount of heat produced by growing pigs is variable depending on the environmental temperature and the energy concentration of the diet. The major environmental factors that influence heat production are temperature and physical activity of the animal (NRC, 1998). Therefore, when the temperature is below the thermoneutral zone of the pig, the animal will expend more energy to keep warm and a decrease in environmental temperature below the critical temperature results in an increase in heat production (Noblet et al., 1985). As a result, heat production used for production is lower when pigs are housed in environments below their critical temperature than if they are housed within the thermoneutral zone (Mount, 1974). The upper thermoneutral temperature is not well defined but research has been conducted to identify the lower critical temperature. In weanling pigs, a linear increase in heat production was documented when environmental temperatures fell from 28 to 20°C (Noblet et al., 1985).

There are many biological and environmental factors that affect the HI, such as age, feeding status of the animal, and the nutrient and ingredient concentration of the feed. When fiber concentration in the diet is increased, the energy concentration usually decreases. More nutrients are transferred to the hind gut where a large proportion of the protein and carbohydrates are fermented to ammonia, amines, volatile fatty acids, etc. (Just, 1983). Increased fermentation will increase the HI.

The HI is sometimes referred to as waste energy because of the lack of production associated with HI, but because HI is used to maintain body temperature, this is an important part of thermoregulation of the animal. Dietary energy is first used to meet the NE_m, which includes the energy required to sustain life and to maintain body temperature (Ewan, 2001). If the supply of NE is greater than the requirement for NE_m, the remaining energy is used for production (NE_p).

SYSTEMS USED TO MEASURE NET ENERGY

Three different energy systems are in use in France, the Netherlands, and Denmark. The French and the Dutch system are based on NE values from animal experiments and use prediction equations, whereas the Danish system is based on the potential physiological energy (**PPE**) in a feed ingredient. This system is based on the amount of energy released from adenosine tri-phosphate (**ATP**) bonds at the cellular level of pigs when they consume the feed ingredient.

The French NE system

The French system, based on research conducted by Jean Noblet and coworkers at the Institut National de la Recherche Agronomique (**INRA**) uses indirect calorimetry to measure heat production and equations are available from numerous experiments. The system is based on measurements of energy losses in feces and urine, and to physical activity, and on estimates of fermentable fractions in the hindgut of the animal. Noblet and Shi (1991) showed that energy utilization of the animal is based on determining the digestibility coefficient of energy (**DCe**). The DCe is equivalent to the ratio between DE and GE, whereas the ME:DE ratio is equal to the ratio between metabolizable energy and digestible energy (Noblet and Shi, 1993). Depending on the nutrient content of the feedstuff, the DCe can vary among feed ingredients. Starch and sugars are highly digestible while the digestibility coefficient for crude protein can vary modestly. However, the most variation of the DCe is associated with the amount of fiber, defined as the sum of non-starch polysaccharides and lignin, in the feed, which has much lower DCe than other nutrients (Noblet and Perez, 1993; Noblet and Shi, 1993). It was concluded that DCe is negatively related to the amount of fiber in the feed ingredient. Therefore, as the amount of dietary fiber is increased in the diet, the DCe is decreased in a linear pattern (Noblet and Perez, 1993).

Values for DE and ME are calculated from the energy in fecal and urine collections and in methane, while NE is obtained in respiration chambers from energy balance studies (Noblet et. al., 1993a). Using this system, nitrogen losses in the air, in the form of condensed water in outgoing air, are measured (Noblet and Etienne, 1987). Therefore, indirect calorimetry is used to estimate heat production of the animal and all metabolic functions from activity and respiration are measured and estimated. According to the techniques described by Noblet et al. (1994) for estimating the NE value of diets, it is necessary to determine the fasting heat production of the animal to estimate the amount of HI produced by the pig. In sows, fasting heat production at zero activity are highly variable with a range of 12.21 MJ/d to 16.70 MJ/d depending on the BW and the activity of the sow (Noblet et al., 1993b; Noblet et al., 1993c). Therefore, a coefficient of activity is measured in the system where the daily duration of the pig standing is measured on a per pig basis.

Metabolic demands differ among growing pigs and sows; therefore, prediction equations have been developed for each production stage. These equations allow the animal to meet daily nutrient requirements depending on the chemical characteristic of the feedstuff. Noblet et al. (1994) calculated 11 prediction equations that may be used to determine NE in feed ingredients for growing pigs. However, out of these 11 prediction equations, 3 main equations are used:

$$\text{NE (kcal/kg)} = 2.892\ \text{DCP} + 8.365\ \text{DEE} + 3.418\ \text{ST} + 2.844\ \text{SU} + 2.055\ \text{Dresidue}$$

$$\text{NE (kcal/kg)} = 0.703\ \text{DE} + 1.58\ \text{EE} + 0.47\ \text{ST} - 0.97\ \text{CP} - 0.98\ \text{CF}$$

$$\text{NE (kcal/kg)} = 0.730\ \text{ME} + 1.31\ \text{EE} + 0.37\ \text{ST} - 0.67\ \text{CP} - 0.97\ \text{CF}$$

where:

DCP = digestible CP

DEE = digestible ether extract

ST = starch

SU = sugar

Dresidue = digestible OM – digestible CP – digestible ether extract – ST – SU

DE = digestible energy

EE = ether extract

CF = crude fiber

ME = metabolizable energy

These equations vary in the estimation of NE by using various analytical procedures and regression methods.

The Dutch NE System

The Central Bureau Livestock Feeding (**CVB**) is responsible for formulating a NE system in the Netherlands. The CVB uses a variation of one of Noblet's calculated NE prediction equations.

Adaptations of the prediction equations differ from Noblet's work by determining the digestibility of starch and sugars by different procedures. Noblet used the indirect polarimetric method of Ewers (**Starch-Ew**) to measure the amount of digestible starch (Noblet et al., 1994). In feed samples evaluated by CVB, values for starch measured by an enzymatic method using amyloglucosidase (**Starch-Am**) were lower than the Starch-Ew values (Blok, 2006). Therefore, the CVB replaced the Starch-Ew method with the Starch-Am method. In contrast to Noblet's work, the CVB also split the total sugar fraction of the feed into a portion that is degradable enzymatically and a fermentable fraction of sugar (Blok, 2006).

Another modification to Noblet's equation is that the CVB calculated the digestible crude fat fraction in the ingredient using a digestible ether extract with an acid hydrolysis method instead of ether extract.

The CVB also predicts a fermentable carbohydrate fraction, where the fermentable sugars and starches are considered in the equation, whereas the INRA values disregard these values. Despite these differences in chemical analysis, the CVB uses the database system of prediction equations established by Noblet and coworkers. However, a new prediction equation based on these modified analyses has been developed:

NE (kcal/kg) = 2.796 DCP + 8.542 DEE–acid + 3.380 ST-Am-e + 3.047 SU-e + 2.328 FCH

where:

NE = net energy, being the sum of energy retained and calculated NEm

DCP = digestible CP

DEE = digestible ether extract using acid hydrolysis

DCFat-h = digestible crude fat, based on analysis of petroleum ether soluble fraction after prior acid hydrolysis (g/kg DM)

ST-Am-e = enzymatic digestible fraction of the Starch fraction, analyzed according to the amyloglucosidase method (g/kg DM)

SU-e = enzymatic degradable fraction of total sugar fraction (g/kg DM)

FCH = fermentable carbohydrate fraction, being the Starch-Am-f + Sug-f + DNSP (g/kg DM)

where:

DNSP = digestible OM – digestible CP – digestible ether extract using acid hydrolysis – ST-Am – 0.95 SU

where:

0.95 = correction factor for disaccharides for ingredients

The Danish System

The PPE system that was developed by Boisen, estimates the potential physiological energy in a feed ingredient based on the oxidation of nutrients used for synthesis of ATP and *in vitro* digestibility methods. The PPE is a quantification of the energy in a feed ingredient for the cellular synthesis of ATP, which is the universal energy donor for energy requiring processes in living organisms (Boisen, 2007). Therefore, the PPE value of nutrients is the potential production of ATP from the central metabolite, Acetyl-Coenzyme A (**AcCoA**), during the complete oxidation process of nutrients by living cells (Figure 2.2). The PPE of different nutrients are not influenced by their actual utilization for oxidation or deposition and, therefore, the contributions of the PPE from feed ingredients are additive in diets (Boisen, 2007). For the production of ATP, the PPE of nutrients have been documented (Boisen and Verstegen, 2000). It is believed that PPE is a universal measurement of energy that can be used for all farm animals (Boisen, 2007). Although many *in vitro* digestibility coefficents for nutrients, have been measured, there is still a need for more data in this area. The Danish PPE system is based on the fact that theoretically, the actual feed value is influenced by the specific use of the energy. Therefore, animal experiments performed under certain circumstances should not be used to measure the feed value (Boisen, 2007). The feeding value can be based on the composition of the feed ingredient itself, and recommendations for the most favorable composition can be based on information about the specific production of the pig (Boisen, 2007).

For practical industry applications, it is important to evaluate actual batches of feedstuffs for the concentration of standardized ileal digestible AA and PPE so the diets can be formulated according to the weight of the pig (Boisen, 2007). With these methods, the PPE system relies on *in vitro* digestibility values for the digestibility of AA and protein. Boisen states that *in vitro* procedures are reliable in measuring variation in digestibility of nutrients in feed ingredients and contribute to a more accurate composition of diets fed to pigs.

ENERGY REQUIREMENTS OF THE PIG

Two approaches have been used to assess energy requirements of pigs, the empirical and the factorial methods. The empirical method establishes requirements based on optimizing pig performance in response to varying levels of energy intake (Ewan, 2001). This focuses on the impacts that a certain feedstuff has on individual carcass and growth characteristics. Empirical data have been the principal indications by which energy requirements have been estimated (ARC, 1981).

The factorial approach is based on the energy required to maintain aspects of production, i.e., milk, growth, and maintenance of the animal. The factorial method identifies each component of growth, which may be subdivided further to provide a detailed description of energy usage of the animal. Therefore, energy requirements can be divided into 3 parts: fat accretion, protein accretion, and maintenance requirements. The energy requirements for each of these 3 components are added together to calculate the total energy requirement of the animal.

In growing pigs, maintenance requirements can be estimated from the difference between energy retained in the animal and the ME intake (Ewan, 2001). The maintenance requirements have been measured by measurements of heat production after the animals have been fasted for various periods of time. However, measurements of fasting heat production vary with the duration of the fast, the previous diet ingested by the animal, and with the difference in activity between fasted and unfasted animals (Ewan, 2001).

Another approach to measuring maintenance energy is to use the comparative slaughter method (Just et al., 1982a; Just et al., 1982b). This procedure is based on an extrapolating of a linear regression line to the point of zero energy used for maintenance. The comparative slaughter method differs from the French system because Noblet includes a measurement of fasting heat production as energy used for maintenance in the pig. Using this method, pigs are fed graded levels of a common diet in which a linear regression analysis can be conducted (Figure 2.3). The NE intake is calculated as the sum of energy retention and the maintenance requirement determined by calculation.

DIETARY FIBER

Methods to measure dietary fiber

The Weende system has been used to classify carbohydrates in crude fiber (**CF**) and nitrogen free extract. Although this procedure has been used as the industry standard, it has some shortcomings. It is assumed that the crude fiber fraction contains the fibrous portion of the feedstuff including cellulose and lignin. However, the CF procedure does not include hemicelluloses, a portion of the lignin, and the acid insoluble ash. Crude fiber is not an actual measure of the amount of non-starch polysaccharides (**NSP**), because cellulose, hemicellulose, and lignin are included in the measurement by only 50 to 80%, 20%, and 10 to 50%, respectively (Van Soest and McQueen, 1973, cited from: Grieshop et al., 2001). Therefore, procedures used to measure the amount of NDF and ADF in the diets use detergents to estimate the amount of hemicellulose, cellulose, and lignin. The difference between NDF and ADF is the hemicellulose in the sample. While measurements of NDF and ADF improve the accuracy of the fiber analysis, both fail to estimate the amount of soluble fiber in the ingredient. However, procedures using gravimetric-enzymatic analysis of fibrous materials quantify fiber classes based on chemical properties (Prosky et al., 1985). Therefore, methods have been developed to calculate the amount of total dietary fiber (**TDF**). While the gravimetric methods assume that the resulting fraction is fiber, the component analysis method of TDF measures the amount of sugars present in a substrate and sums them to determine NSP concentrations using gas-liquid chromatography (Englyst and Hudson, 1993).

Fiber concentrations in feed ingredients

Certain alternative ingredients contain a higher amount of fiber than corn and soybean meal. Kornegay (1981) showed that soybean hulls could be included in growing-finishing diets at a level of 15% without a depression in ADG or ADFI. A reduction in ADG became apparent when pigs were fed diets containing 25% soybean hulls, but pigs fed 6% soybean hulls had comparable ADG to control pigs (Kornegay, 1978). Therefore, small inclusions of soybean hulls may be a good alternative to corn and soybean meal based diets.

Many factors must be considered when including high fiber ingredients into swine rations. The quality of fiber may be affected by the fiber source, variations between manufacturers, and differences in processing methods. This variability among high fiber ingredients influences digestibility values in growing and finishing pigs. Utilization of fiber sources is influenced by diet inclusion rate, age and weight of the animal, and genetic variation among pigs (NRC, 1998).

Digestion of non-starch polysaccarides

Non starch polysaccharides mainly serve as the structural elements in plant materials, therefore NSP are comprised of plant cell walls, i.e., cellulose and betaglucans, non-cell wall NSP, i.e., pectins and mannans, and resistant starch. These plant fractions have a low digestibility in the small intestine of the pig. Swine do not secrete the enzymes needed for degradation of NSP. Therefore, NSP is passed on to the large intestine where microbial enzymes digest beta 1, 4 bonds of NSP sources. However, ingested NSP are digested by anaerobic microbes in the hind gut of the pig (Kennelly et al., 1981; Just, 1983; Just et al., 1983). Levels of digestion depend on the source and level of inclusion of NSP along with the age of the animal as microbial capacity in the hind gut increase with age. Most sources of NSP are highly fermentable, with fermentation resulting in production of volatile fatty acids (**VFA**) that can be absorbed from the hindgut of pigs. With the increase in the concentration of anaerobic microbes as a result of increased NSP concentrations in the diet, NSP concentrations can affect intestinal cell proliferation. Jin et al. (1994), showed a 33% and 43% increase in the rate of jejunum and colon cell proliferation in growing pigs fed diets containing 10% wheat straw.

Diets high in NSP may also change the microbial population in the hind gut. In addition to altering the microbial profile, intestinal microbial populations may adapt to diets containing a high amount of NSP. The concentration of cellulolytic bacteria in the feces was found to be greater in pigs fed a diet consisting of 35% dehydrated alfalfa meal than a diet consisting of no alfalfa meal (Varel et al., 1984). This research suggests a gradual adaptation of the microbial cellulase activity in the hind gut to the alfalfa meal diet. Along with altering intestinal cell growth and microbial populations, NSP may also increase the weight of the gastrointestinal tract. Kass et al. (1980) reported a significant increase in organ weights of pigs fed diets containing 20, 40, and 60% alfalfa meal, respectively, compared with pigs fed a control diet without alfalfa meal.

As microbial populations change in the hind gut of the intestinal tract, fiber can influence dietary nutrient metabolism including the metabolism of AA, lipids, and minerals. Higher levels of high fiber ingredients in diets have been shown to decrease DM, N, and AA digestibility in growing pigs (Den Hartog et al., 1988). The concentration of DM in feces is increased if fiber is included in the diet. This suggests that the time the feed spends in the gastrointestinal tract influences total water excretion. After microbial populations act upon the NSP fractions of the feed, they are sloughed into the intestinal lumen and excreted in the fecal matter.

Diets containing fibrous feedstuffs can decrease N utilization by increasing secretions of endogenous N. Schulze et al. (1995) showed an increase of ileal N losses of

1.884 g/kg of DMI when pigs were fed diets containing 200 g of NDF with 59% and 41% resulting from endogenous and exogenous losses, respectively.

ENERGY IN NON-STARCH POLYSACCHARIDES

Energy in fiber sources

In the large intestine of the pig, NSP is fermented to produce VFA, methane, carbon dioxide, and water. The main VFA produced by fermentation include acetic acid, propionic acid, and butyric acid, which are absorbed by simple diffusion in the large intestine and transported and metabolized in the liver as an energy source (Just, 1983). While the digestion and absorption of VFA in the hind gut has been researched, the amount of energy obtained by this fermentative process is harder to estimate. However, energy derived from VFA contribution in pigs has been estimated from 5 to 28 percent of the maintenance energy requirement, depending on the amounts of feed consumed and fiber concentrations in the diet (Kass et al., 1980). Along with a wide range of energy contribution to the pig, the site of absorption in the pig, i.e., the small intestine or large intestine plays a role in efficiency of energy digested. Energy from microbial fermentation in the hind gut is less efficient (52 versus 76 percent) than energy digested in the small intestine (Noblet et al., 1994). This inefficiency with the site of energy absorption, i.e., small or large intestine, may explain the differences in lower NE values of ingredients containing fiber. When fiber is increased in the diet, energy concentration usually is decreased. This decrease in energy results in nutrients being transferred to the hind gut where the NSP fractions are fermented and the HI is increased. Therefore, when compared to DE and ME values, ingredients containing fiber have an overestimated value. For example, corn, which is thought to be a relatively high energy ingredient for non-ruminants, has an estimated ME value of 2,970 kcal/kg and a NE value of 2,650 kcal/kg while wheat middlings have and estimated ME value of 2,530 kcal/kg and a NE value of 1,830 kcal/kg (Payne and Zijlstra, 2007). The reduction in energy values among the ME and NE values results because the NE system accounts for HI of the pig, which reduces the value and more accurately predicts the energy efficiency of wheat middlings. When a high starch ingredient is compared with a high protein ingredient, such as soybean meal, the benefits of using the NE system are apparent. Wheat and soybean meal have similar DE and ME values (Sauvant et al., 2004), suggesting that both ingredients have the same energy values. However, NE in wheat and soybean meal is 2,510 kcal/kg and 1,940 kcal/kg, respectively (Payne and Zijlstra, 2007). This demonstrates the importance of the use of the NE system to more accurately predict how energy is utilized in the pig.

CONCLUSION

From the above literature review, there is an apparent need to investigate the physiological effects of fiber in a NE system on growing and finishing pigs. Current NE studies have been conducted in European countries but have not been successful in building producer confidence in using the NE system in North America. An increase of bio-refining plants using corn, switchgrass, and corn stover, continue to remove additional sources of starch from feedstuffs. This use of starch in bio-fuel processing, will result in higher fiber concentrations in co-products to be fed to pigs in the near future. There is a need for research of NE systems in North America to compare values to

European systems and increase knowledge of energy values of ingredients specific to North America in order to implement the NE system.

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FIGURES

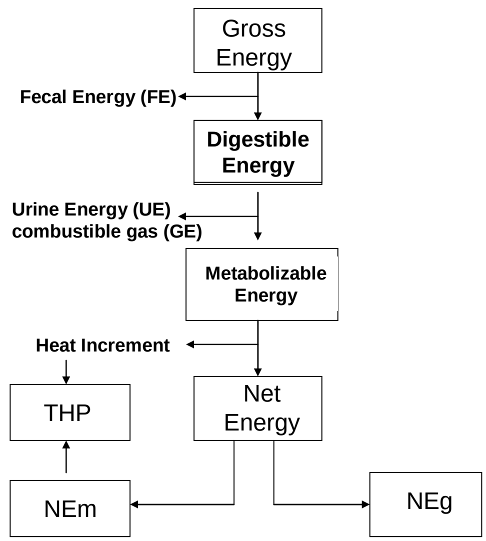

Figure 2.1. Illustration of the utilization of energy by the pig Abbreviations: THP: Total Heat Production, NEm: Net energy for maintenance, NEg: Net energy for gain. (Ewan, 2001, page 86 in Swine Nutrition)

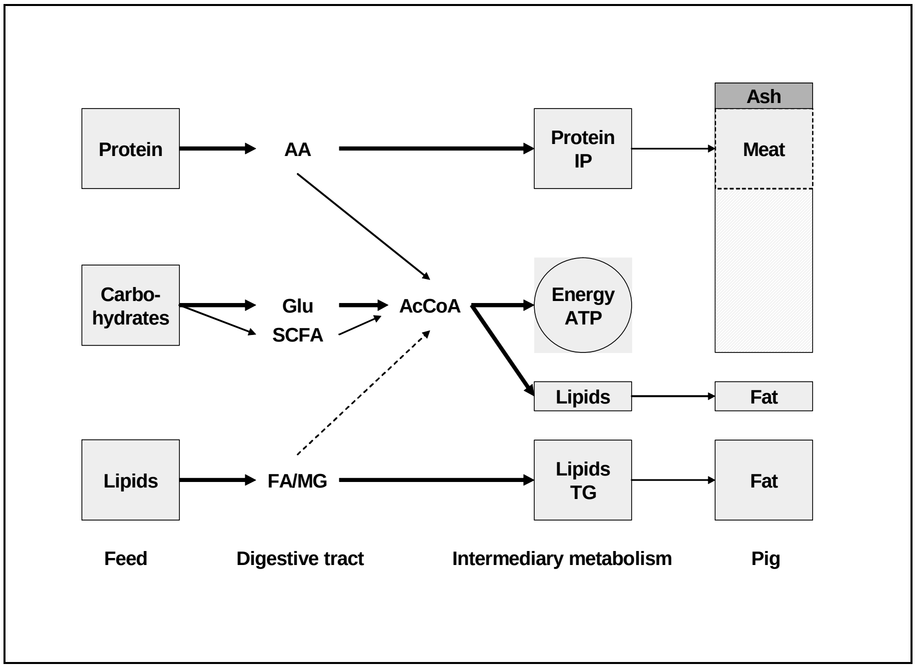

Figure 2.2. Metabolism of digestible nutrient fractions to energy or deposited nutrients in the pig

Abbreviations: AA: amino acids; IP: ideal protein; Glu: glucose; SCFA: short-chained fatty acids;

AcCoA: Acetyl Coenzyme A; FA: fatty acids; MG: monoacyl-glycerols; TG: triacyl-glycerols

(Boisen, 2007)

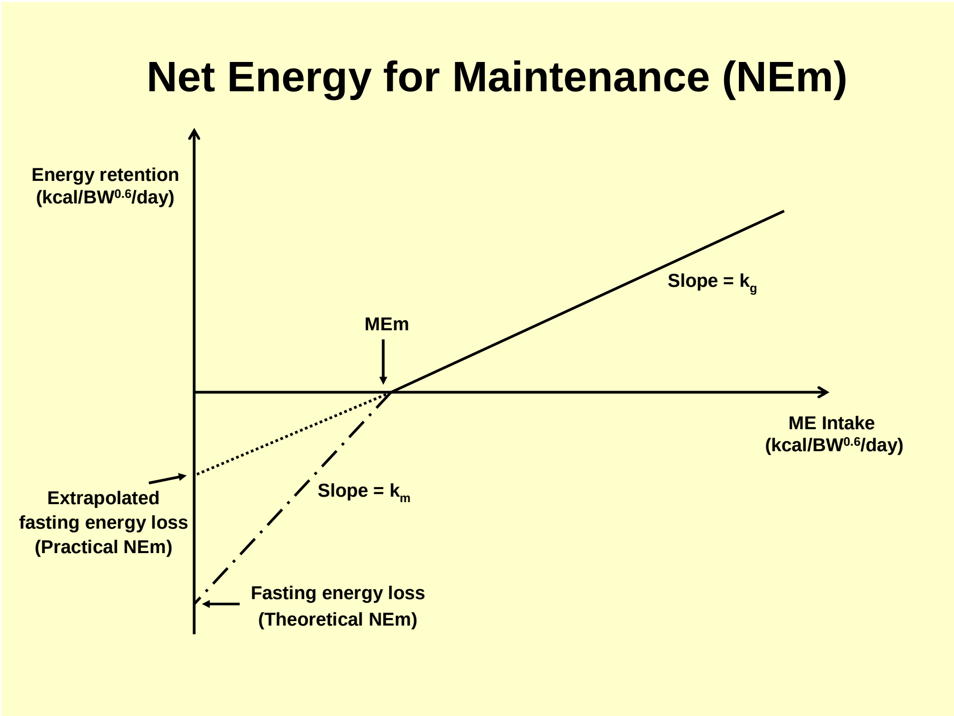

Figure 2.3. Determining maintenance energy of pigs using the comparative slaughter method by extrapolating a linear regression line to the point of zero energy used for maintenance (practical NEm), while determining maintenance energy can also be measured by fasting energy loss (theoretical NEm). (de Lange and Birkett, 2005)

CHAPTER 3

EFFECT OF SIZE OF PIG ON NET ENERGY OF SOYBEAN HULLS AND WHEAT MIDDLINGS

ABSTRACT

The objective of this experiment was to measure the NE in soybean hulls (**SBH**) and wheat middlings (**WM**) in growing and finishing pigs and determine if finishing pigs utilize the energy in SBH and WM better than growing pigs. Forty growing (initial BW: 25 kg) and 40 finishing (initial BW: 85 kg) barrows were randomly allotted to 5 treatment groups within each stage of growth with 8 pigs per group. Two groups (16 pigs) at each stage of growth served as the initial slaughter groups (ISG) and were harvested at the initiation of the trial. The remaining 3 groups were randomly assigned to 3 diets; basal, SBH, and WM, that were provided on an ad libitum basis for 28 d in the grower phase and for 35 d in the finisher phase. All pigs were harvested at the conclusion of the feeding period. During the grower phase, ADG and G:F were greater ($P < 0.05$) for pigs fed the basal corn-soybean meal diet (1.15 kg and 0.56 kg/kg) than for pigs fed the SBH (0.97 kg and 0.47 kg/kg) or the WM (0.89 kg and 0.48 kg/kg) diets. In growing pigs, hot and chilled carcass weights and the dressing percentage were lower ($P < 0.05$) for pigs fed the SBH and WM diets compared with pigs fed the basal diet, but weights of blood and viscera did not differ among treatments. The total fat concentration was greater ($P < 0.001$) in growing and finishing pigs fed the basal diets than in pigs fed the SBH or WM diets, therefore, the difference in energy concentration can be attributed to the increased fat concentration. The energy retained was greater ($P < 0.001$) in pigs fed the basal diet than in pigs fed the SBH and WM diets. Maintenance energy was also greater ($P < 0.01$) in pigs fed the basal diet than in pigs fed the SBH or WM diet because pigs fed the basal diet were heavier than pigs fed the SBH and WM diets. The NE of the basal diet was 2074 and 2220 kcal/kg for the growing and finishing pigs, respectively. These values were greater ($P < 0.05$) than for the SBH (1609 and 1813 kcal/kg) and WM (1746 and1863 kcal/kg) diets. The NE in SBH was calculated at 354 and 863 kcal/kg for growing and finishing pigs, respectfully. The corresponding values for the WM were 959 and 1,030 kcal/kg. These values were not different. In conclusion, SBH and WM affect performance, body composition, and NE values more in growing pigs than in finishing pigs, but there is no difference in the NE for SBH and WM between growing and finishing pigs.

Key words: pig, NE, soybean hulls, wheat middlings, body composition

INTRODUCTION

High fiber feed ingredients are usually not used in swine diets in North America. However, the Energy Policy Act of 2005 mandated an increase in the production of corn-based ethanol in the US. As ethanol production is increased, the demand for starch derived from corn is also greater. Therefore, producers have to adjust to increased corn prices by using alternative feed ingredients. These ingredients often have high fiber concentrations. This adjustment may be difficult for producers because energy values for fibrous feedstuffs are not well defined.

Historically, the energy concentration in feedstuffs has been defined using DE and ME values. However, these values may overestimate the energy concentration of fibrous feedstuffs because of an increase in the heat increment when these ingredients are fed. The NE system is believed to more accurately predict the energy value of fibrous feedstuff because NE values do not include the energy used for heat increment (Just et al., 1983). However, NE values do include nutrients absorbed from the hind gut after fermentation of fiber and Noblet et al. (1994) showed that NE systems estimate the actual energy value of feedstuffs better than ME systems.

Currently, there is no research being conducted on NE of high fiber ingredients in North America, but because European research has shown that NE systems are more accurate than ME systems, it is important to measure the NE of fibrous feedstuffs.

Finishing pigs have increased digestibility of fiber compared with growing pigs because they have increased microbial capacity for fermentation in the hind gut (Just, 1983). This suggests that finishing pigs may have a greater NE of fibrous feedstuffs than growing pigs, but this hypothesis has never been tested. Therefore, the objective of this experiment was to measure NE in 2 high fiber ingredients, soybean hulls (**SBH**) and wheat middlings (**WM**), in growing pigs and compare these values to values obtained in finishing pigs.

MATERIALS AND METHODS

Animals and housing

Forty growing and 40 finishing barrows originating from the matings of line 337 boars to C 22 females (Pig Improvement Company, Franklin, KY) were obtained from the University of Illinois Swine Research Center. The average initial BW of the pigs were 25.4 ± 0.7 kg and 84.8 ± 0.9 kg for the growing and finishing pigs, respectively. Within each stage of growth, animals were allotted to 5 treatment groups according to BW with 8 pigs per treatment. Two treatment groups (16 pigs) at each stage of growth served as initial slaughter groups (**ISG**) and were harvested at the initiation of the trial. The other 3 treatment groups were randomly assigned to 3 experimental diets that were provided for 28 d in the grower phase and for 35 d in the finisher phase. At the end of the experimental period, all pigs were harvested.

Pigs were housed in an environmentally controlled building with the ambient temperature maintained between 18 and 24°C. The experiment was conducted from September, 2006, to January, 2007. Treatments were randomized within the building. All pigs were housed in individual pens (0.9 X 1.8 m) equipped with a fully-slatted concrete floor, a feeder, and a bowl shaped waterer. The experiment was approved by the Institutional Animal Care and Use Committee at the University of Illinois.

Diets, feeding, sample and live data recording

Commercial sources of corn, soybean meal, SBH, and WM were obtained and the same batch of these ingredients was used for all diets (Table 3.1). Three grower diets and 3 finisher diets were prepared (Table 3.2). The first diet was a basal corn and soybean meal-based diet. Vitamins, salt, and minerals were included in this diet to exceed estimated nutrient requirements (NRC, 1998). Chromic oxide was included in the diet as an indigestible marker. The second diet contained 70% (as-fed basis) of the basal diet and 30% (as-fed basis) of SBH. The last diet contained 70% of the basal diet and 30% (as-fed basis) of WM. Calculated ME values in the diets fed to the growing pigs were 3,384, 2,969, and 3,277 kcal ME per kg (as-fed basis) in the basal, SBH, and the WM diet, respectively. The basal diet contained 3.48% ADF while the SBH and WM diets contained 15.81 and 5.64% ADF, respectively. Concentrations of NDF were 8.88%, 24.28%, and 16.87% for the basal, SBH, and WM diets, respectively. Calculated ME values in finishing diets were 3,413, 2,989, and 3,296 kcal per kg (as-fed basis) in the basal, SBH, and the WM diet, respectively. The basal diet for finishing pigs contained 3.08% ADF and the SBH and the WM diets contained 15.54% and 5.37% ADF, respectively. Concentrations of NDF were 9.01%, 24.40%, and 16.99% in the basal, SBH, and WM diets, respectively. Pigs were allowed ad-libitum access to feed and water throughout the duration of the trial. Feed samples were collected each week and were pooled within the grower and finisher phases, respectively. The pooled feed samples were stored at -20°C until analyzed.

Individual pig BW were recorded when pigs were allotted to treatment diets, and weekly thereafter. Daily feed allotments were recorded and feed that was left in the feeders was weighed at the conclusion of each phase, and data for feed disappearance for each pig were summarized. Average daily feed intake, ADG, and G:F for each pig and within each treatment group were calculated.

Each week during the experiment, pens were scraped clean of all fecal material on d 5. Fresh fecal samples were collected on d 6 from each pig, and the fecal samples were pooled within pig at the end of each phase and used to calculate energy and nutrient digestibility.

Slaughter procedures and sample collection

In both the grower and finisher phases, the comparative slaughter procedure was used to determine energy retention for each diet. Pigs were weighed in the afternoon the d before they were harvested. Pigs were then fasted for 16 h and weighed again. At harvest, pigs were stunned using a model ES hog stunner (Best & Donovan, Cincinnati, OH). Stunning was performed in the cranial region of the pig, posterior to the ears, followed by exsanguination. Care was taken to ensure that all blood was collected from the animals and a total blood weight was recorded. Two 150 mL bottles, containing EDTA as an anticoagulant, were filled with blood and stored at -20°C until analyzed. Blood samples were freeze dried and ground prior to sample analysis.

All carcasses were split down the midline from the groin to the chest cavity. The viscera were removed and the weight was recorded. Weights were also recorded on a bench scale (Doran Scales Incorporated, Batavia, IL) for other body organs including liver, heart, kidney, lungs, and spleen. The gastrointestinal tract was separated from the other organs and was flushed with water to remove digesta. The emptied tract was patted dry and the empty gastrointestinal weight was recorded. The empty gastrointestinal tract and the body organs were stored in a cooler overnight. The following day, the viscera, including the gastrointestinal tract and the internal organs, were ground in a Butcher Boy (Lasar Manufacturing Company, Los Angeles, CA) meat mincer. The viscera were ground once using a 10 mm die and twice using a 2 mm die to form a homogeneous puree. Ground viscera was mixed and 2 sub-samples, approximately 700 g each, were collected for analysis. Samples were further ground using a food processor (Proctor Silex, Hamilton Beach, CA) and then freeze dried and ground again, prior to chemical analysis.

Hot carcass weights were recorded using a Toledo (Worthington, OH) scale mounted on the carcass rail. The carcasses were stored in a 4°C cooler for 16 h. Prior to grinding, a chilled weight was recorded and the carcasses were cut into pieces to fit the grinding apparatus (Autio Company, Astoria, OR). The finishing pigs had a size that made it necessary to use a bone saw to split the carcass into sides and a hand saw was then used to split the head medially from the posterior to the frontal section. This was done to ensure adequate mixing of the contents of the skull.

Carcasses of the growing pigs were ground twice using a 12 mm diameter die and approximately 5 kg sample was taken from the carcass and stored at -20°C. The carcasses of the finishing pigs were ground twice using an 18 mm diameter die. For the second grind, the carcass was split off into 2 equal barrels. One of the barrels was chosen at random and dumped into a mixer (Keebler Company, Chicago, IL) to ensure even distribution and sampling of the carcass. The mixed carcass was placed into a stainless steel bin and approximately 8 kg of the ground carcass was collected and stored at -20°C. The frozen samples were then thawed in a cooler at 4°C for 16 h and cut into half inch slices of carcass using a band saw (Hobart Company, Troy, OH). These carcass slices were ground twice through a Butcher Boy meat grinder (Lasar Manufacturing Company Incorporated, Los Angeles, CA) using a 2 mm die. Three sub-samples were collected. The carcass sample used for analysis was freeze dried and ground, the other 2 samples were kept as extra samples.

Chemical analysis

All samples were analyzed in duplicate. Ground carcass samples, fecal samples, diets, and feed ingredients were analyzed for DM (procedure 4.1.06; AOAC, 2005). Pooled feed samples and fecal samples were also analyzed for concentrations of chromic oxide. Pooled feed samples, feed ingredients, carcass, viscera, and blood samples were analyzed for GE on a 6300 model automatic calorimeter (Parr Instruments, Moline, IL) using benzoic acid as the calibration standard. Nitrogen was measured by combustion (procedure 968.06; AOAC, 2005) on an Elementar Rapid N-cube protein/nitrogen apparatus (Elementar Americas Incorporated, Mt. Laurel, NJ) on the pooled feed samples, feed ingredients, carcass, viscera, and blood samples using aspartic acid as a calibration standard. Crude fat was determined in carcass, viscera, and blood samples by ether extraction using a Soxtec 2050 automated analyzer (FOSS North America, Eden Prairie, MN). Crude fat in feed and fecal samples were analyzed after acid hydrolysis with 9 N HCl (procedure 920.30; AOAC, 2005) followed by ether extraction.

Calculations

Data for ADFI, ADG, and G:F were calculated for each pig and then summarized within each diet and phase. The dressing percentage for each pig was calculated using the following equation:

$$DP = (HCW \times 100)/LW$$

where DP is the dressing percentage, HCW is the hot carcass weight of the pig (kg), and LW is the recorded live weight of the pig (kg). The total weight of all carcasses was calculated using the following equation:

$$TW = HCW + B + V + Li + H + K + Lu + S$$

where TW is the total weight (kg) of the pig carcass, HCW is the hot carcass weight of the animal (kg), B is the blood weight (kg), V is the full viscera weight (kg), Li is the weight of the liver (kg), H is the weight of the heart (kg), K is the weight of the kidney (kg), Lu is the lung weight (kg), and S is the spleen weight (kg). This total weight was compared with the live weight of the pigs to check the accuracy of the recorded weights of the different body components.

The energy in the pigs at harvest was calculated as the sum of the energy in the blood, viscera, and empty body. The average energy concentration in the body of the pigs in the ISG was used to calculate the initial energy in the body of the pigs that were fed the experimental diets. The following equation was used for this calculation:

$$TBEI = LW \times ISGE$$

where TBEI is the total body energy at the start of the experiment (kcal), LW is the initial live weight of the pig (kg), and the ISGE is the energy in the pigs in the ISG (kcal/kg). The energy retained was calculated by subtracting the energy in the pigs at the start of the experiment from the energy in the pigs at the conclusion of the experiment.

The maintenance requirement of the pigs was calculated by multiplying the mean metabolic body weight ($kg^{0.60}$) of each pig by 179 kcal according to Noblet et al. (1994). Therefore, the total energy used for maintenance was calculated as follows:

$$EM = MLW \times 179 \times d$$

where EM is the energy used for maintenance of the animal, MLW is the mean metabolic body weight of the pig ($kg^{0.60}$), and d is the number of days the animal was on trial. The total NE in the diet was calculated by summing the energy used for maintenance and the energy retained in the body. The NE values for SBH and WM were then calculated using the difference procedure by subtracting 70% of the NE in the basal diet from the NE calculated for the SBH and the WH diets.

Statistical analysis

Data were analyzed within each phase of growth using the Proc Mixed procedure of SAS (Littell et al., 1996). Outliers for growth performance data were identified using the Proc Univariate procedure in SAS. No data were determined as outliers. A contrast statement was used to compare values for the pigs in the ISG group and values for the pigs fed the 3 treatment diets. An analysis of variance was used to compare values for pigs fed the basal, SBH, and WM diets. Diet was the main effect and pig was a random effect in the model. The model used the restricted maximum likelihood method to estimate variance and the ‘Kenwood-Roger’ option (Littell et al., 1996) to determine the degrees of freedom. Treatment means were separated using the LSMeans statement and the DIFF option of Proc Mixed. The NE values obtained for SBH and WM were compared between growing and finishing pigs using a t-test. The pig was the experimental unit in all analyses and $P = 0.05$ was used as the level of significance.

RESULTS

For the growing phase, the initial BW did not differ among treatments; however, the final BW for pigs fed the SBH and WM diets were lower ($P < 0.05$) than for pigs fed the basal diet (Table 3.3). Pigs fed the basal diet also had greater ($P < 0.05$) ADG and G:F than pigs fed the SBH and WM diets, while ADFI was not affected by treatment. For the finishing phase, no differences among treatments were observed although pigs fed the basal or the SBH diets tended ($P = 0.07$) to be heavier at the end of the experiment than pigs fed the WM diet.

In the growing phase, live weights, carcass weights, and weight of all body components except the spleen weight and the full viscera as a percentage of live weight were lower ($P < 0.05$) for pigs in the ISG group than for pigs fed the basal, SBH, or WM diets (Table 3.4). The dressing percentage was also lower ($P < 0.05$) for the ISG pigs than for the other pigs.

At the conclusion of the grower phase, live weight, hot carcass weight, chilled carcass weight, and dressing percentage were lower ($P < 0.05$) for pigs fed the SBH or WM diets compared with pigs fed the basal diet. The full and empty viscera weights were not different among treatments. However, the full and empty viscera weight as a percentage of live weight were lower ($P < 0.01$) for the pigs fed the basal diet when compared to pigs fed the SBH and WM diets. Weights of the viscera, liver, heart, and spleen were not different among treatments, but weights of kidneys and lungs were lower ($P < 0.05$) for pigs fed the SBH or WM diets compared with pigs fed the basal diet.

For the finishing phase, all data for the ISG group were lower ($P < 0.05$) than the data for the other 3 groups except for the full viscera as a percentage of the live weight of the pig (Table 3.5). The hot carcass weight of the finishing pigs fed the basal diet was greater ($P < 0.05$) than for pigs fed the SBH or WM diets. However, live weight, chilled weight, and dressing percentage, did not differ among treatments. Weights of full and empty viscera, liver, heart, kidneys, and lungs were not different among treatments, but the spleen weight of pigs fed the basal diet was greater ($P < 0.05$) than for pigs fed the SBH and WM diets. However, full viscera weight as a percentage of live weight were greater (*P* < 0.001) for pigs fed the SBH and WM diets when compared to pigs fed the basal diet, but the empty viscera as a percentage of live weight were not different among treatments for the finishing phase.

The fat, protein, and energy concentration in the blood was greater (*P* < 0.05) in the ISG grower pigs than in pigs fed the treatment diets (Table 3.6). However, fat, protein, and energy concentration in the viscera, and fat and energy concentration in the carcass were lower (P < 0.05) in ISG pigs than in the other pigs. The percentages of fat, protein, and energy concentration in the blood were not different among pigs fed the 3 treatment diets. The fat percentage in the viscera was greater (*P* < 0.01) for pigs fed the basal or WM diets compared with pigs fed the SBH diet. The protein percentage in the viscera was greater (*P* < 0.01) for pigs fed the SBH diet than for pigs fed the basal or the WM diets. However, the energy concentration in the viscera was greater for pigs fed the basal and WM diets when compared to pigs fed the SBH diet. The percentage of fat in the carcass was lower (*P* < 0.01) for pigs fed the SBH and WM diets than for pigs fed the basal diet, but the percentage of protein in the carcass did not differ among treatments. Energy concentration in the carcass was lower (*P* < 0.05) for pigs fed the SBH diet when compared to pigs fed the basal and WM diets.

In the finishing phase, ISG pigs had greater (*P* < 0.05) concentration of fat, protein, and energy in the blood and of protein in the carcass than pigs fed the 3 treatment diets. However, concentrations of fat and energy in the viscera and carcass were lower in ISG pigs than in pigs fed the treatment diets. There were no differences among pigs fed the 3 treatment diets for the percentage of fat or the concentration of energy in the blood, but pigs fed the WM diet tended (*P* = 0.07) to have a greater percentage of protein in the blood than pigs fed the other diets. Fat percentage and energy in the viscera was not different among treatments, but the percentage of protein in the viscera was different among all treatments ($P < 0.001$) with the pigs fed the WM diet having the greatest percentage followed by the SBH and basal diets, respectively. No differences were detected for percentages of fat and protein or the concentration of energy in the carcass of the finishing pigs.

When comparing the amount of fat, protein, and energy in the blood, viscera, and carcass of the ISG pigs to the other 3 groups, for both the grower and finisher pigs, all data were lower ($P < 0.05$) for the ISG pigs except for the amount of fat in the blood and the total energy concentration (Table 3.7). In the growing phase, the total amount of fat, protein, and energy in the blood was not different among treatments. However, the amount of fat in the viscera was greater ($P = 0.01$) for the pigs fed the basal and the WM diets than for pigs fed the SBH diet, but the amount of protein and energy in the viscera did not differ among treatments. The weight of the carcasses and the amount of fat in the carcass were greater for the pigs fed the basal diet than for pigs fed the SBH and WM diets ($P < 0.001$). However, the amount of protein in the carcass was higher ($P < 0.05$) for pigs fed the basal diet when compared to pigs consuming the SBH and WM diets. The concentration of energy in the carcass was greater ($P < 0.001$) for pigs fed the basal diet than for pigs fed the SBH and WM diets. The total weight of the blood, viscera, and carcass was lower ($P < 0.001$) for the pigs fed the SBH and WM diets when compared to pigs fed the basal diet. The total amount of fat, protein, and energy in the blood, viscera, and carcass was greater ($P < 0.005$) for the pigs fed the basal diet, than for pigs fed the SBH and WM diets.

For the finishing phase, there were no differences in the amount of blood, or the amount of fat, protein, or energy in the blood between pigs fed the basal diet or pigs fed the SBH and WM diets. There was no difference among treatments in the weight of the viscera or in the amount of fat and energy in the viscera among treatments. However, the amount of protein in the viscera was lower ($P < 0.05$) for pigs fed the basal and WM diets than for pigs fed the SBH diet. There was no difference among treatments for the weight of the carcass or the amount of protein in the carcass. However, the amounts of fat and energy in the carcass were lower ($P < 0.05$) for pigs fed the SBH and WM diets when compared to pigs fed the basal diet. There were no differences in total weight or the amount of protein among treatments. However, the total amount of fat was lower ($P < 0.001$) for pigs fed the SBH and WM diets when compared to pigs fed the basal diet. Pigs fed the WM diet also contained less ($P < 0.05$) energy than pigs fed the basal diets while pigs fed the SBH diet contained an amount of energy that was not different from pigs fed the other 2 diets.

In the growing phase, the initial amount of energy in the empty body of the pigs was not different among treatments (Table 3.8). However, the final amount of energy ($P < 0.001$) and the energy retained ($P < 0.001$) in the pigs was greater in pigs fed the basal diet than in pigs fed the SBH or WM diets, but there were no differences between pigs fed the SBH and WM diets. The total NE value was also greater ($P < 0.001$) in the basal diet than in the SBH and WM diets, but the SBH and WM diets were not different. Differences were not detected among treatments in total feed intake. However, the concentration of NE in the feed was greater ($P < 0.01$) for the basal diet than for the SBH or WM diets, but the SBH and WM diets were similar.

In the finishing phase, initial total empty body energy of the pigs was not different among treatments. However, the final empty body energy and the energy retained in the pigs were greater ($P < 0.05$) in pigs fed the basal diet than in pigs fed the WM diet, but pigs fed the SBH diet had empty body energy concentration and energy retention that was not different from pigs fed the other diets. The energy used for maintenance, was less ($P < 0.05$) for pigs fed the SBH than for pigs fed the basal diet, but pigs fed the WM diet had maintenance energy similar to pigs fed the other diets. The total NE of the basal diet was greater ($P < 0.05$) than for the WM diet, but the SBH diet was not different from the other 2 diets. There were no differences in the total feed ingested among treatment groups, but the NE concentration in the basal diet was greater ($P = 0.05$) than for the SBH and WM diets, but there was no differences between the SBH and WM diets.

In the growing phase, the NE of the basal diet was calculated at 2,101 kcal/kg (Table 3.9). The calculated NE value was 2,139 kcal/kg if calculations are based on NRC (1998), but 2,276 kcal/kg if calculations are based on values from Sauvant et al., (2004). For the SBH diet, NRC and values from Sauvant et al., (2004) were 1,782 kcal/kg and 1,894 kcal/kg respectively, while the NE values from the current study was 1,577 kcal/kg. The NE values for the WM diet was 1,759 kcal/kg, but the calculated values from NRC (1998) and Sauvant et al., (2004) were 1,965 kcal/kg and 2,145 kcal/kg, respectively.

For the finishing phase, the NE value was 2,220 kcal/kg for the basal diet. However, values of 2,212 and 2,405 kcal/kg were calculated from NRC (1998) and Sauvant et al., (2004). The NE value for the SBH diet was 1,813 kcal/kg while values of 1,834 and 1,945 kcal/kg were calculated from the NRC (1998) and Sauvant et al., (2004), respectively. For the WM diet, a NE value of 1,863 kcal/kg was calculated, while values of 2,016 and 2,235 kcal/kg were calculated from NRC (1998) and Sauvant et al. (2004), respectively.

The NE values of SBH that were calculated by difference from the NE of the diets, were 354 kcal/kg for the growing pigs and 863 kcal/kg for the finishing pigs. Net energy values of WM were 959 kcal/kg for the growing pigs and 1,030 kcal/kg for the finishing pigs (Table 3.10). No differences in NE values of diets or ingredients (SBH or WM) were measured between growing and finishing pigs.

DISCUSSION

The inclusion of SBH and WM in diets affects pig performance more during the growing phase than during the finishing phase. The final weights of the pigs, ADG, and G:F were all negatively affected by 30% inclusion of SBH or WM in the growing phase. However, negative affects were not observed for ADG and G:F in the finishing pigs, suggesting that these pigs used the additional energy that was produced from increased fermentation in the hindgut.

Previous research has shown that feed ingredients high in fiber increase the intestinal mass of the pigs (Kass et al., 1980), but the current study did not verify this observation for finishing pigs. However, Hochstetler et al. (1959) reported no difference in viscera weight among growing-finishing pigs fed cellulose, oat bran, or alfalfa diets. Gargallo and Zimmerman (1981) also reported that levels of dietary sunflower hulls ranging from 2 to 20% did not affect the weight of empty intestines. Thus, there are several studies that have shown no differences in viscera weight when fiber was added to the diet, and the results from this experiment are in agreement with these observations.

The total energy content in the growing and finishing pigs was affected by the amount of fat in the blood, viscera, and carcass of the pig. Growing pigs fed the basal diet had greater total energy concentration than the pigs fed the SBH and WM diets. However the pigs retained similar amounts of protein regardless of treatments, but pigs fed the basal diet retained more fat than pigs fed the other diets. Therefore, the main reason for the greater retention of energy in the growing pigs can be attributed to the increase in fat concentrations. In the finishing pigs, the energy concentrations were greater for pigs fed the basal diet, than for pigs fed the SBH and WM diets (361 mcal, vs. 328, and 314 mcal). However, the amount of total protein retained in the body was similar among treatments, but the concentration of fat was greater in pigs fed the basal diet than in pigs fed the SBH and WM diets. Therefore, the increase in total energy in the finishing pigs is also explained by the increase in fat concentration.

A lower NE value for the diets containing SBH and WM was calculated than for the basal diet. Considering the differences between enzymatic digestion in the small intestine and fermentation in the large intestine by pigs consuming low or high fiber diets, it is assumed that the nutrients absorbed by the pigs is influenced by the type of diet consumed. Pigs consuming SBH and WM absorbed much of the energy as VFA, whereas pigs fed the basal diet absorbed more glucose. It is assumed that absorption of VFA is energetically less efficient than absorption of glucose (Just, 1983). Therefore, pigs fed the SBH and WM diets absorbed less energy than pigs fed the basal diet. In addition, fermentation is relatively inefficient in young pigs, which explains why the NE of SBH and WM was lower for growing pigs than for finishing pigs. The efficiency of fermentation is improved as pigs become older. The finishing pigs, therefore, were less affected by SBH and WM in the diet than the growing pigs. The NE of WM has been reported as 1,560 and 1,840 kcal/kg (NRC, 1998; Sauvant et al., 2004) and the NE of SBH has been reported at 1,003 kcal/kg (Sauvant et al., 2004). The values measured in this study were 354 and 863 kcal NE/kg for SBH and 959 and 1,030 for WM. The reason for the lower values obtained in the current study may be that the HI increases in pigs consuming high fiber diets. This increased HI is accounted for when the comparative slaughter method is used. Therefore, this procedure more accurately predicts the maintenance requirements and the energy retained by the pig than the indirect calorimetry procedure, and the comparative slaughter method predicts a lower NE value of high fiber diets than indirect calorimetry as previously shown by Just et al. (1983).

Although the NE values for WM obtained in this study are lower than some previous values (NRC, 1998; Sauvant et al., 2004), similar values have been reported. In growing pigs, Pals and Ewan (1978) reported NE values of 910 kcal/kg, which is similar to the value of 959 kcal/kg from the current study in the growing pigs. The lower NE values obtained in some studies may be attributed to variation among sources of WM. Cromwell et al. (2000) showed large variation in both nutrient composition and laboratory analysis among 14 sources of WM. Therefore, possible discrepancies in NE values of ingredients may be due to variation in ingredient composition. No U.S. values have previously been reported for NE in SBH, but data from this experiment indicates that the NE value is lower in SBH than in WM.

Net energy values for both diets and ingredients were not different between the growing and finishing pigs. Based on these results it is concluded that there are no differences between NE values for growing and finishing pigs.

IMPLICATIONS

Diets result in the highest cost of pig production accounting for approximately 60% of production costs. Therefore, with the use of NE values to more accurately predict the energy use of the pig, it will result in a cost benefit situation for producers. With an increase in fiber containing ingredients available to be used in swine diets, such as co-products, there is an increased need to be able to use these ingredients to meet the energy requirements of the pig. By taking into account the fermentative capacity of the hindgut, NE systems more accurately predict the use of fiber by the animal than the ME system. While the age of the pig and variation in diet ingredients help to explain some of the variation in diet and ingredient NE values that have been reported, NE systems using fiber as an ingredient need to be further evaluated.

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TABLES

Table 3.1. Ingredient composition of growing and finishing diets (as-fed basis)

	Growing			Finishing		
Diet:	Basal	Wheat middlings	Soybean hulls	Basal	Wheat middlings	Soybean hulls
Ingredient, %						
Wheat middlings	-	30.00	-	-	30.00	-
Soybean hulls	-	-	30.00	-	-	30.00
Soybean meal, 48%	31.80	22.26	22.26	16.10	11.27	11.27
Corn	62.62	43.83	43.83	78.96	55.27	55.27
Soybean oil	2.00	1.40	1.40	2.00	1.40	1.40
Limestone	1.15	0.805	0.805	1.00	0.700	0.700
Monocalcium phosphate	1.22	0.854	0.854	0.73	0.511	0.511
Chromic oxide	0.50	0.35	0.35	0.50	0.35	0.35
Vitamin premix [1]	0.21	0.147	0.147	0.21	0.147	0.147
Micromineral premix [2]	0.50	0.35	0.35	0.50	0.35	0.35
Total	100.00	100.00	100.00	100.00	100.00	100.00

[1]Vitamin premix provided the following quantities of vitamins per kilogram of complete diet: vitamin A, 340.90 IU; vitamin D_3, 34.09 IU; vitamin E, 4.55 IU; vitamin K, 0.227 mg; riboflavin, 0.455; vitamin B12, 0.002 mg; D-pantothenic acid, 1.250 mg; niacin, 1.705 mg; choline, 14.761 mg.

Table 3.1. continued

[2]Micromineral premix provided the following quantities of minerals per kilogram of complete diet: manganese, 5,710 mg; copper, 2,290 mg; iodine, 100 mg; selenium 85.7 mg.

Table 3.2. Calculated nutrient composition (as-fed basis) of growing and finishing diets[1]

	Growing			Finishing		
Diet:	Basal	Wheat	Soybean	Basal	Wheat	Soybean
Ingredient, %		Middlings	Hulls		Middlings	Hulls
Energy, kcal ME/kg	3,384	3,277	2,969	3,413	3,296	2,989
CP, %	20.30	18.98	18.38	14.20	14.71	14.11
ADF, %	3.48	5.64	15.81	3.08	5.37	15.54
NDF, %	8.88	16.87	24.28	9.01	16.99	24.40
Ca, %	0.77	0.58	0.73	0.58	0.44	0.60
P, %	0.65	0.74	0.51	0.49	0.62	0.39
P, digestible, %	0.28	0.31	0.21	0.18	0.24	0.14
Indispensable AA, %[2]						
Arg	1.34	1.23	1.15	0.85	0.89	0.81
His	0.55	0.52	0.51	0.39	0.40	0.39
Ile	0.86	0.76	0.77	0.57	0.56	0.56
Leu	1.78	1.57	1.52	1.37	1.28	1.23
Lys	1.12	0.96	1.05	0.69	0.66	0.75
Met + cys	0.67	0.65	0.59	0.51	0.53	0.48
Phe	1.00	0.91	0.88	0.69	0.70	0.67
Thr	0.77	0.69	0.55	0.53	0.52	0.38
Try	0.24	0.23	0.22	0.15	0.17	0.15
Val	0.97	0.90	0.87	0.67	0.70	0.66

Table 3.2. continued

[1]Based on NRC, 1998.

[2]Standardized ileal digestible.

Table 3.3. Effects of treatments on growth performance of growing and finishing pigs[1]

Item	Diet:	Basal	Soybean hulls	Wheat middlings	SEM	*P*-value
Growing phase						
Initial wt, kg		24.5	25.4	25.7	0.38	0.10
Final wt, kg		56.7^{y}	52.6^{x}	50.7^{x}	1.13	0.004
ADG, kg		1.15^{y}	0.97^{x}	0.89^{x}	0.05	0.001
ADFI, kg		2.08	2.07	1.85	0.10	0.20
G:F, kg/kg		0.56^{y}	0.47^{x}	0.48^{x}	0.03	0.03
Finishing phase						
Initial wt, kg		85.70	84.10	84.10	1.10	0.51
Final wt, kg		126.48	126.93	121.25	1.80	0.07
ADG, kg		1.17	1.22	1.06	0.05	0.10
ADFI, kg		3.20	3.41	3.12	0.13	0.30
G:F, kg/kg		0.36	0.36	0.33	0.02	0.38

Table 3.3. continued

[x, y] Means within a row lacking a common superscript letter are different ($P = 0.05$).

[1]Data are means of 8 observations per treatment. The growing phase lasted 28 d and the finishing phase lasted 35 d.

Table 3.4. Weights of carcass and body components of growing pigs in the initial slaughter group (ISG) and in pigs fed the experimental diets for 28 d[1,2]

Slaughter group: Item	ISG	Basal	Soybean hulls	Wheat middlings	SEM	*P*-value[3]
Live wt, kg	24.00	51.53^{y}	46.28^{x}	45.90^{x}	1.05	0.001
Hot carcass wt, kg	19.08	41.81^{y}	36.00^{x}	36.20^{x}	0.94	<0.001
Dressing percentage, %	79.52	81.15^{y}	77.74^{x}	78.83^{x}	0.48	0.002
Chilled carcass wt, kg	18.75	41.30^{y}	35.60^{x}	35.70^{x}	0.93	<0.001
Blood wt, kg	0.76	2.16	2.03	2.09	0.95	0.61
Full viscera wt, kg	4.03	7.40	8.04	7.43	0.21	0.90
Full viscera wt, % of live wt	16.78	14.36^{y}	17.42^{x}	16.22^{x}	0.44	0.0003
Empty viscera wt, kg	2.02	3.56	3.62	3.65	0.11	0.84
Empty viscera wt, % of live wt	8.41	6.92^{y}	7.84^{x}	7.99^{x}	0.25	0.01
Liver wt, kg	0.63	1.06	0.97	0.99	0.04	0.19
Heart wt, kg	0.14	0.22	0.21	0.24	0.03	0.56
Kidney wt, kg	0.16	0.28^{y}	0.22^{x}	0.24^{x}	0.01	0.002
Lungs wt, kg	0.39	0.86^{y}	0.73^{x}	0.68^{x}	0.43	0.02
Spleen wt, kg	0.08	0.10	0.09	0.19	0.06	0.29
Total wt[4], kg	23.87	51.37^{y}	46.06^{x}	45.72^{x}	1.05	0.002

$^{x, y}$ Means within a row lacking a common superscript are different ($P = 0.05$).

[1]All data for ISG were different ($P < 0.05$) from data for the other 3 groups except for dressing percentage, full viscera as a percentage of live weight, and spleen weights.

[2] n = 16 for ISG, n = 8 for all other groups.

[3]*P*-value for the comparison of pigs fed the experimental diets.

[4]Total weight = sum of measured hot carcass weight, and the weights of blood, full viscera, liver, heart, kidney, lungs, and spleen.

Table 3.5. Weights of carcass and body components of finishing pigs in the initial slaughter group (ISG) and in pigs fed the experimental diets for 35 d[1,2]

Slaughter group: Item	ISG	Basal	Soybean hulls	Wheat middlings	SEM	*P*-value[3]
Live wt, kg	80.94	121.75	121.00	116.60	1.66	0.08
Hot carcass wt, kg	67.05	103.45[y]	99.60[x]	97.88[x]	1.50	0.03
Dressing percentage, %	82.85	85.00	82.40	84.00	0.42	0.11
Chilled carcass wt, kg	66.40	102.70	98.85	97.40	7.31	0.11
Blood wt, kg	3.41	4.78	5.40	4.63	0.28	0.15
Full viscera wt, kg	10.34	13.43	16.34	14.24	0.53	0.34
Full viscera wt, % of live wt	12.76	11.05[x]	13.49[y]	12.18[x]	0.31	<0.0001
Empty viscera wt, kg	8.57	11.16	11.69	11.10	0.27	0.88
Empty viscera wt, % of live wt	10.59	9.17	9.66	9.52	0.20	0.22
Liver wt, kg	1.35	1.75	1.77	1.77	0.07	0.83
Heart wt, kg	0.30	0.43	0.41	0.41	0.01	0.21
Kidney wt, kg	0.34	0.44	0.44	0.43	0.02	0.72
Lungs wt, kg	1.12	1.40	1.20	1.30	0.11	0.52
Spleen wt, kg	0.14	0.24[y]	0.20[x]	0.20[x]	0.01	0.05
Total wt[4], kg	80.78	121.66	120.59	116.74	1.85	0.07

[x, y] Means within a row lacking a common superscript are different ($P = 0.05$).

[1]All data for ISG were lower ($P < 0.05$) than for the other 3 groups except for full viscera as a percentage of live weight ($P = 0.14$).

[2] n = 16 for ISG, n = 8 for all other groups.

[3]*P*-value for the comparison of pigs fed the experimental diets.

[4]Total weight = sum of measured hot carcass weight, and the weights of blood, full viscera, liver, heart, kidney, lungs, and spleen.

Table 3.6. Fat, protein, and energy concentration in blood, viscera, and carcass of growing and finishing pigs [1, 2] (DM based)

Item	ISG	Basal	Soybean hulls	Wheat middlings	SEM	*P*-value[3]
Growing phase						
Blood						
Fat, %	0.74	0.23	0.23	0.25	0.04	0.89
Protein, %	95.92	90.15	90.00	90.04	0.20	0.85
Energy, kcal/kg	5,490	5,312	5,295	5,302	14	0.68
Viscera						
Fat, %	17.32	22.54[x]	18.51[y]	21.80[x]	0.75	0.002
Protein, %	65.70	58.01[x]	62.08[y]	58.26[x]	0.81	0.003
Energy, kcal/kg	5,649	5,912[x]	5,673[y]	5,834[x]	46	0.005
Carcass						
Fat, %	29.63	38.90[y]	33.34[x]	35.00[x]	1.18	0.009
Protein, %	57.43	58.48	58.64	57.59	2.19	0.94
Energy, kcal/kg	5,984	6,319[x]	6,046[y]	6,201[x]	63	0.02
Finishing phase						
Blood						
Fat, %	0.46	0.27	0.32	0.36	0.04	0.38
Protein, %	97.13	89.51	89.39	91.22	0.59	0.07
Energy, kcal/kg	5,506	5,265	5,267	5,323	23	0.14

Table 3.6. continued

Viscera						
Fat, %	44.40	49.22	47.76	47.25	1.29	0.54
Protein, %	45.56	40.17[x]	44.83[y]	49.39[z]	1.28	< 0.001
Energy, kcal/kg	6,873	7,172	7,110	7,052	80	0.26
Carcass						
Fat, %	49.54	55.79	55.37	54.86	1.27	0.88
Protein, %	38.83	31.14	34.72	34.99	1.13	0.46
Energy, kcal/kg	7,000	7,292	7,122	7,134	68	0.47

[x, y, z] Means within a row lacking a common superscript are different (*P* = 0.05).

[1]All data for ISG were different (*P* < 0.05) from data for the other 3 groups except for the percentage of protein in the carcass in the growing phase and the percentage of protein in the viscera of the finishing phase.

[2] n = 16 for ISG, n = 8 for all other groups.

[3]*P*-value for the comparison of pigs fed the experimental diets.

Table 3.7. Fat, protein, and energy quantity in blood, viscera, and carcass of growing and finishing pigs [1, 2]

Item	ISG	Basal	Soybean Hulls	Wheat middlings	SEM	*P*-value[3]
Growing phase						
Blood, kg	0.76	2.16	2.03	2.09	0.09	0.62
Fat, g/pig	0.932	0.874	0.848	0.960	0.17	0.88
Protein, kg/pig	0.126	0.345	0.321	0.337	0.02	0.51
Energy, mcal	0.72	2.03	1.89	1.99	0.87	0.52
Viscera, kg	2.01	3.56	3.62	3.65	0.11	0.89
Fat, kg/pig	0.07	0.19^{x}	0.15^{y}	0.19^{x}	0.01	0.01
Protein, kg/pig	0.27	0.49	0.49	0.50	0.02	0.98
Energy, mcal	2.36	5.05	4.51	4.98	0.18	1.10
Carcass, kg	18.74	41.25^{y}	35.55^{x}	35.70^{x}	0.93	0.0003
Fat, kg/pig	1.65	6.27^{y}	4.16^{x}	4.30^{x}	0.27	<0.0001
Protein, kg/pig	3.18	9.43^{y}	7.30^{x}	7.08^{x}	0.47	0.003
Energy, mcal	33.23	101.73^{y}	75.22^{x}	76.22^{x}	3.49	<0.0001
Total, kg	21.51	46.97^{y}	41.20^{x}	41.44^{x}	0.99	0.0006
Fat, kg/pig	1.72	6.47^{y}	4.31^{x}	4.48^{x}	0.27	<0.0001
Protein, kg/pig	3.58	10.27^{y}	8.12^{x}	7.91^{x}	0.49	0.004
Energy, mcal	36.31	108.82^{y}	81.61^{x}	83.18^{x}	3.60	<0.0001
Finishing phase						
Blood, kg	3.40	4.78	5.40	4.63	0.28	0.15
Fat, g/pig	3.06	2.35	3.09	3.06	0.46	0.44

Table 3.7. continued

Protein, kg/pig	0.64	0.78	0.85	0.79	0.05	0.53
Energy, mcal	3.62	4.61	5.03	4.59	0.28	0.48
Viscera, kg	8.57	11.16	11.69	11.10	0.27	0.26
Fat, kg/pig	1.12	1.78	1.82	1.68	0.11	0.68
Protein, kg/pig	1.15	1.45^{x}	1.69^{y}	1.74^{x}	0.06	0.009
Energy, mcal	17.38	25.92	26.91	25.02	2.35	0.59
Carcass, kg	66.36	102.68	99.63	97.43	1.44	0.06
Fat, kg/pig	13.83	25.34	23.02	21.97	1.09	0.11
Protein, kg/pig	10.87	14.02	14.44	13.86	2.78	0.67
Energy, mcal	195.61	330.65^{y}	296.28^{x}	284.87^{x}	11.71	0.03
Total, kg	78.34	118.61	116.71	112.68	0.13	0.41
Fat, kg/pig	14.96	27.12	24.84	23.65	1.13	0.11
Protein, kg/pig	12.65	16.25	16.98	16.39	0.50	0.57
Energy, mcal	216.61	361.18^{y}	328.22^{xy}	314.49^{x}	11.93	0.03

$^{x, y}$ Means within a row lacking a common superscript are different (P = 0.05).

[1]All data for ISG were different (P < 0.05) from data for the other 3 groups except for fat (g/pig) in the blood and total energy (P = 0.07) for growing and finishing pigs.

[2] n = 16 for ISG, n = 8 for all other group

[3]*P*-value for the comparison of pigs fed the experimental diets.

Table 3.8. Net energy of corn-soybean meal diets without (basal) or with the inclusion of soybean hulls or wheat middlings fed to growing and finishing pigs[1]

Item	Basal	Soybean hulls	Wheat middlings	SEM	*P*-value
Growing phase					
Total empty body energy, initial, mcal	34.70	36.01	36.35	0.58	0.13
Total empty body energy, final, mcal	108.82[y]	81.61[x]	83.18[x]	3.60	<0.0001
Energy retained, mcal	74.12[y]	45.60[x]	46.83[x]	3.59	<0.0001
Maintenance energy, mcal[2]	46.14[y]	44.37[x]	43.81[x]	0.55	0.018
Total NE, mcal	120.26[y]	89.97[x]	90.64[x]	3.91	<0.0001
Total feed intake, kg	58.22	57.43	51.89	2.74	0.23
NE in feed, mcal/kg	2.034[y]	1.597[x]	1.735[x]	0.09	0.004
Finishing phase					
Total empty body energy, initial, mcal	218.17	214.10	214.16	3.18	0.59
Total empty body energy, final, mcal	361.18[y]	328.22[x y]	314.49[x]	11.93	0.03

Table 3.8. continued

Energy retained, mcal	143.01^{y}	114.13$^{x y}$	100.33^{x}	10.95	0.03
Maintenance energy, mcal[2]	103.46^{y}	100.01^{x}	101.23$^{x y}$	0.80	0.019
Total NE, mcal	246.48^{y}	214.14$^{x y}$	201.56^{x}	11.42	0.03
Total feed intake, kg	111.71	119.42	109.31	2.74	0.30
NE in feed, mcal/kg	2.206^{y}	1.793^{x}	1.844^{x}	0.12	0.05

$^{x, y}$ Means within a row lacking a common superscript letter are different (*P* = 0.05).

[1]Data are means of 8 observations per treatment. The growing phase lasted 28 d and the finishing phase lasted 35 d.

[2]Calculated by multiplying the mean metabolic body weight (kg $^{0.60}$) of each pig by 179 kcal (Noblet et al., 1994) and number of d the animal was on trial.

Table 3.9. Net energy of growing and finishing diets compared to values from NRC and INRA

	NE kcal/kg		
Diet:	NRC[1]	INRA[2]	Current study[3]
Growing phase			
Basal	2139	2276	2101
SBH	1782[4]	1894	1577
WM	1965	2145	1759
Finishing phase			
Basal	2212	2405	2220
SBH	1834[4]	1985	1813
WM	2016	2235	1863

[1]Nutrient Requirements of Swine, 1998.

[2] From Tables of composition and nutritional value of feed materials, INRA, Sauvant et al., 2004.

[3]Maintenance of pigs calculated as 179 kcal/kg$^{.60}$ from Noblet et al., 1994.

[4] Soybean hull values were not available from NRC. Values in table calculated from Noblet's equation, (0.726 x ME) + (13.3 x % EE) + (3.9 x % St) - (6.7 x % CP) - (8.7 x % ADF), page 5, NRC, with proximate analysis values from INRA, Sauvant et al., 2004.

Table 3.10. Net energy of diets and ingredients fed to growing and finishing pigs

	NE kcal/kg			
Diets	Grower	Finisher	SEM	*P*- value
Basal	2101	2220	124	0.55
Soybean hulls	1577	1813	101	0.12
Wheat middlings	1759	1863	104	0.49
Ingredient				
Soybean hulls	354	863	338	0.31
Wheat middlings	959	1,030	347	0.88