DIGESTIBILITY AND ENERGETIC UTILIZATION OF LIPIDS BY PIGS

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ABSTRACT

Five experiments were conducted to investigate the digestibility and energetic utilization of lipids by pigs. In Exp. 1, the effect of the form of dietary fat (liquid or intact form) and the concentration of dietary NDF on ileal and total tract endogenous losses of fat (ELF), on apparent ileal (AID) and apparent total tract digestibility (ATTD) of fat, and on true ileal (TID) and true total tract digestibility (TTTD) of fat by growing pigs were determined. Results showed that increasing dietary liquid fat or intact fat increased (linear and quadratic, $P < 0.05$) the AID and ATTD of fat. Apparent digestibility of liquid fat (81.9%) was greater ($P < 0.001$) than of intact fat (63.2%). The estimates of ELF were lower ($P < 0.05$) for liquid fat than for intact fat at the end of the ileum and over the entire intestinal tract. The TID (93.8%) and TTTD (94.2%) of liquid fat were greater ($P < 0.05$) than the TID (78.6%) and TTTD (84.1%) of intact fat. Increasing dietary NDF had a quadratic effect ($P < 0.05$) on the ATTD of fat, but did not influence the AID, TID, and TTTD of fat. It is concluded that liquid fat induces a lower ELF and has a greater apparent and true digestibility than intact fat at the end of the ileum and over the entire intestinal tract. Purified NDF has little influence on apparent and true digestibility of fat.

In Exp. 2, the operational NE requirement for maintenance (ONE_m) for growing and finishing pigs was measured. The effect of the stage of growth and experiment locations on ONE_m was determined. The experiment was conducted at the University of Illinois (UIUC), the University of Missouri (MO), and the Prairie Swine Centre (PSC). 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. 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. Experiment location influences the NE:DE and 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. 3, the effect of sources or levels of dietary lipids on the NE of diets and lipids fed to growing and finishing pigs was measured. The NE of diets increased (linear, $P < 0.01$) with increasing level of SBO (2,032, 2,186, and 2,292 kcal/kg for diets containing 0, 5, or 10% SBO). The NE of the diet containing 10% CWG (2,431 kcal/kg) was greater ($P < 0.05$) than the NE of the diet containing 10% SBO. The average NE of diets was greater ($P < 0.01$) for finishing pigs (2,509 kcal/kg) than for growing pigs (1,961 kcal/kg). The NE of SBO included at 5% (5,102 kcal/kg) was not different from the NE of SBO included at 10% (4,619 kcal/kg), but the NE of CWG (6,017 kcal/kg) was greater ($P < 0.05$) than the NE of SBO. The stage of growth had no impact on the NE of lipids. In conclusion, the NE of diets increases with lipid level. The NE of lipids is not affected by the level of dietary lipids, but the NE of CWG is greater than the NE of SBO.

In Exp. 4, the effect of dietary lipids on the NE of corn in growing and finishing pigs was measured. For growing and finishing pigs, the NE of diets containing supplemental lipids was greater ($P < 0.01$) than the NE of diets containing no supplemental lipids. The NE of corn in the diet containing supplemental lipids (2,053kcal/kg) was not different from the NE of corn in the diet containing no supplemental lipids (2,197 kcal/kg). The NE of corn was greater ($P < 0.05$) for finishing pigs (2,607 kcal/kg) than for growing pigs (1,643 kcal/kg). In conclusion, the NE of corn is not affected by the presence of lipids in the diet, but the NE of corn is greater for finishing pigs than for growing pigs.

In Exp. 5, the objective was to compare NE values for diets and ingredients measured in North America ($\mathrm{NE}_{\mathrm{NA}}$) and values predicted from the French ($\mathrm{NE}_{\mathrm{INRA}}$), the Dutch ($\mathrm{NE}_{\mathrm{CVB}}$), and the Danish (PPE) energy systems. Values for $\mathrm{NE}_{\mathrm{NA}}$ of most diets fed to growing pigs were lower ($P < 0.05$) than values predicted from $\mathrm{NE}_{\mathrm{INRA}}$ and $\mathrm{NE}_{\mathrm{CVB}}$. However, values for $\mathrm{NE}_{\mathrm{NA}}$ of most diets fed to finishing pigs were more comparable with values predicted from $\mathrm{NE}_{\mathrm{INRA}}$ and $\mathrm{NE}_{\mathrm{CVB}}$. In general, values for $\mathrm{NE}_{\mathrm{NA}}$ were closer to PPE values than to $\mathrm{NE}_{\mathrm{INRA}}$ and $\mathrm{NE}_{\mathrm{CVB}}$ values. The measured $\mathrm{NE}_{\mathrm{NA}}$ values for all ingredients fed to growing pigs were also lower ($P < 0.05$) than values predicted from $\mathrm{NE}_{\mathrm{INRA}}$ and $\mathrm{NE}_{\mathrm{CVB}}$. For both growing and finishing pigs, the measured $\mathrm{NE}_{\mathrm{NA}}$ values for soybean oil (SBO) and choice white grease (CWG) were lower ($P < 0.01$) than values predicted from $\mathrm{NE}_{\mathrm{INRA}}$ and $\mathrm{NE}_{\mathrm{CVB}}$. The values for $\mathrm{NE}_{\mathrm{NA}}$ of SBO and CWG were also lower than the PPE values of SBO and CWG. In conclusion, values for $\mathrm{NE}_{\mathrm{INRA}}$ and $\mathrm{NE}_{\mathrm{CVB}}$ of diets and ingredients fed to growing pigs are greater than the values measured in North America but $\mathrm{NE}_{\mathrm{INRA}}$ and $\mathrm{NE}_{\mathrm{CVB}}$ predict values for finishing pigs that were closer to $\mathrm{NE}_{\mathrm{NA}}$ values than the values for growing pigs. All the European energy systems predict greater energy values of lipids than the measured energy values of lipids in North America.

Keywords: Dietary lipids, digestibility, NE, pigs, European energy system.

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LIST OF ABBREVIATIONS

AA	Amino acid
ADF	Acid detergent fiber
ADFI	Average daily feed intake
ADG	Average daily growth
AD	Apparent digestibility
AID	Apparent ileal digestibility
AOAC	Association of Official Analytical Chemists
ATTD	Apparent total tract digestibility
BW	Body weight
Ca	Calcium
CP	Crude protein
Cu	Copper
CVB	The Central Bureau Livestock Feeding
CWG	Choice white grease
DE	Digestible energy
DE_m	Digestible energy requirement for maintenance
DM	Dry matter
DP	Dressing percentage
EE	Ether extract
ELF	Endogenous losses of fat
Fe	Iron

FHP	Fasting heat production
GIT	Gastrointestinal tract
G:F	Gain to feed ratio
GE	Gross energy
I	Iodine
INRA	Institut National de la Recherche Agronomique, Saint Gilles, France
Lys	Lysine
L-SBM	Low oligosaccharides soybean meal
ME	Metabolizable energy
ME	Metabolizable energy
ME_m	Metabolizable energy requirement for maintenance
Mn	Manganese
MO	Missouri
N	Nitrogen
NaCl	Sodium chloride
NDF	Neutral detergent fiber
NE	Net energy
NE_m	Net energy requirement for maintenance
NRC	National Research Council
OM	Organic matter
ONE_m	Operational net energy requirement for maintenance
P	Phosphorus
PPE	Potential physiological energy

PSC	Prairie Swine Centre
r^2	Coefficient of determination
SAS	Statistical analysis system
SBH	Soybean hulls
SBM	Soybean meal
SBO	Soybean oil
Se	Selenium
SEM	Standard error of the mean
SID	Standardized ileal digestibility
TAG	Triacylglycerides
TID	True ileal digestibility
TTTD	True total tract digestibility
UIUC	The University of Illinois at Urbrana-Champaign
US	United States of America
WM	Wheat middlings
Zn	Zinc

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CHAPTER 1

INTRODUCTION

Lipids are important components in diets fed to swine because of their high energy value and the primary role of lipids for swine diets is to increase the energy density of the diets (Stahly, 1984; Azain, 2001). Therefore, an accurate determination of the bioavailability of dietary lipids is important. The bioavailability of dietary lipids for pigs is usually determined as the digestibility. The true digestibility of lipids is an estimate of the amount of digestible lipids that originates from the diet because the effect of endogenous losses of fat (**ELF**) on digestibility is excluded (Low, 1980). Although lipids in swine diets may originate from either intact fat in feed ingredients or supplemented liquid fat, the effect of the form of dietary lipids on ELF and on the true digestibility has not been investigated. The ELF in pigs has most often been measured over the entire intestinal tract and the calculation of the true digestibility of lipids has been limited to the true total tract digestibility rather than true ileal digestibility of lipids. Dietary fiber influences the digestibility of CP and AA (Souffrant, 2001), but little is known about the effect of dietary fiber on the true digestibility of lipids.

After absorption, lipids are stored directly as triacylglycerol in the body or they are oxidized for ATP production (Birkett and de Lange, 2001). However, the current DE and ME systems in North America do not account for the energetic efficiencies of dietary lipids for ATP production or body lipids. Thus, these systems may not accurately determine the energy value of dietary lipids. To accurately determine the true energy value of dietary lipids and other nutrients, European countries have adopted a NE system because the NE system accounts for the energetic efficiency of digested nutrients in pigs (Noblet et al., 1994a).

The NE of a diet is estimated as the sum of the energy retained in the body and the amount of energy required for basic body functions (Baldwin, 1995), the latter is called the NE for maintenance (**NE_m**). The NEm has been estimated as fasting heat production or via regression analysis (Birkett and de Lange, 2001), and the NEm estimated by the regression analysis is called the operational NE requirement for maintenance (**ONE_m**).

The reported estimates of ONE_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, 179 kcal/kg $BW^{0.6}$ (Noblet et al., 1994a) is used for ONE_m in some of the European NE systems. However, various factors including animals and environment may affect the ONE_m (Baldwin and Bywater, 1984). Ideally ONE_m should be measured under the same conditions as those used to measure the NE value of diets because of the direct impact of ONE_m on NE values (Boisen and Verstegen, 1998). No experiments, however, have been conducted to investigate the effect of the BW of pigs or the environment on the ONE_m of pigs in North America.

The NE of dietary lipids may be influenced not only by the digestibility, but also by the final metabolic utilization (de Lange and Birkett, 2005). Both source and inclusion rate of dietary lipids may affect the digestibility (Stahly, 1984) and the metabolism of lipids in pigs (Allee et al., 1971, 1972). The stage of growth (growing vs. finishing pigs) may also affect the metabolic utilization of dietary lipids because of different potential for lipid retention (de Greef et al., 1994). However, the effects of source and level of lipids and the stage of growth on the NE value of dietary lipids have not been investigated.

The North American swine industry currently uses a significant amount of dietary lipids to increase energy density of diets. In this situation, it is likely that most of the starch in corn is utilized for ATP production rather than for lipogenesis (Jakobsen and Thorbek, 1993). If no lipids are added to the diet, some of the starch may be used for lipogenesis, which has a greater efficiency than when starch is used for ATP synthesis (Black, 1995). The purpose for which starch is used can, therefore, influence the NE of starch-containing ingredients such as corn. However, the impact of dietary lipids on the NE value of corn has not been measured. Dietary lipids may also have a different impact on the NE of corn in pigs at different stages of growth because finishing pigs retain more body lipids than growing pigs (de Greef et al., 1994).

The objectives of the work presented in this dissertation are to measure the effect of the form of dietary lipids and of dietary NDF on ileal and total tract endogenous losses and apparent and true digestibility of dietary lipids in diets fed to growing pigs. The second objective is to determine the ONE_m for growing and finishing pigs and to measure the impact of environment on the ONE_m for pigs. The third objective is to determine the NE of soybean oil and choice white grease in diets fed to growing and finishing pigs. The fourth objective is to investigate the effects of dietary lipids on the NE value of corn in growing and finishing pigs. The final objective is to compare NE values measured in North America and energy values predicted from European energy systems.

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CHAPTER 2

DIGESTIBILITY AND ENERGETIC UTILIZATION OF LIPIDS BY PIGS: LITERATURE REVIEW

Dietary Lipids

Lipids are organic compounds that are soluble in organic solvent but hardly soluble in water (Bondi, 1987). Lipids are important dietary components for pigs because of high energy values and because they supply fat-soluble vitamins, essential fatty acids, and molecular signaling substances (Mayes, 2000a). Dietary lipids may improve growth performance and feed efficiency and may modify the composition of body lipids in pigs (Stahly, 1984). Fatty acids and triacylglycerol (**TAG**) are major components in dietary lipids although phospholipids and cholesterol also are present (Drackley, 2000; Bauer et al., 2005). Fatty acids are alphatic carboxylic acids containing a number of carbons that are saturated or unsaturated (Mayes, 2000a). The chain length, the degree of saturation, and geometric configuration of double bonds in fatty acids determines the physicochemical properties of fatty acids (Enser, 1984), which in turn affects the utilization of lipids for pigs (Azain, 2001).

Digestion and Absorption of Dietary Lipids

Digestion of dietary lipids differs from the digestion of other nutrients because lipids are water insoluble (Low, 1980). Lipid digestion in the gastrointestinal tract (**GIT**) requires both physical processes and enzymatic hydrolysis. The physical processes include the emulsification that is necessary for the enzymatic digestion of lipids in the hydrophilic condition of the GIT (Bauer et al., 2005). Bile acids, which are synthesized in the liver after conjugation of cholesterol derivatives with glycine or taurine, are the primary emulsifier because the amphipatic property of bile acids can react with both hydrophobic groups and hydrophilic groups in digesta passing through the GIT (Bauer et al., 2005). Gastric lipase in the stomach start hydrolyzing dietary lipids and lipid molecules are then further hydrolyzed with pancreatic enzymes containing colipase, pancreatic TAG lipase, carboxyl ester lipase, and phospholipase in the small intestine (Drackley, 2000). The enzymatic hydrolysis of lipids converts less polar lipid molecules including TAG and phospholipids to more polar molecules such as monoacylglycerol, free fatty acids, free cholesterol, and lysophospholipids.

The products of lipid digestion combine with bile acids and form mixed micelles or unilamellar vesicles before absorption into the enterocytes (Bauer et al., 2005). The uptake of lipid digestion products in the enterocytes is accomplished by passive diffusion or via fatty acid transporters (Drackley, 2000; Gurr et al., 2002) in the mid-jejunum and in the ileum of pigs (Sambrook, 1979). Absorbed lipid products are bound to fatty acid binding proteins and transported to the endoplasmic reticulum where they are re-esterified and assembled with apolipoprotein (A-I, A-IV, and B-48) to form chylomicrons (Gurr et al., 2002; Tso, 2006). The chylomicron is then exported into the lacteals in the villi and taken up by the lymphatic system and transported away from the GIT (Tso, 2006).

Lipid Metabolism

Absorbed lipids are either stored as TAG or utilized for ATP synthesis in the body (Birkett and de Lange, 2001). In theory, the energetic efficiency of dietary lipids for ATP production is 66%, while the efficiency is 90% if they are directly incorporated into body lipids (Black, 1995). Therefore, the energetic efficiency of lipids depends on their final utilization in the body (Black, 1995). The synthesis of TAG requires fatty acids that originate from the hydrolysis of plasma lipoproteins or non-esterified fatty acids or from de novo lipogenensis (Dunshea and D’Souza, 2003). For de novo lipogenesis in pigs, the adipose tissue is the primary active site and glucose is the main substrate; however, de novo lipogenesis may also occur in the liver where acetate, lactate, and propionate rather than glucose may be used as substrates (O’Hea and Leveille, 1969).

The energy status and stress conditions of animals determine whether lipids are being synthesized or catabolized in adipose tissue (Drackley, 2000; Dunshea and D’Souza, 2003). When animals suffer from negative energy balance or stress, the TAG in adipose tissue is hydrolyzed by hormone-sensitive lipase (Drackley, 2000). Activation of hormone-sensitive lipase is stimulated by catecholamine or glucagon and is inhibited by insulin (Arner, 2005). When fatty acids are released into the blood, they are transported into peripheral tissues and utilized for ATP synthesis through β-oxidation or re-esterified into TAG (Sul, 2006).

Factors Affecting Lipid Digestibility

The digestibility of lipids by pigs is affected by several factors including physicochemical properties of lipids, other dietary components, and animals.

(1) Physicochemical properties of dietary lipids. The chain length of fatty acids, the relative ratio of unsaturated fatty acids to saturated fatty acids, the degree of unsaturation, the position of fatty acids on the glycerol molecule and the amount of moisture, insoluble impurities, and unsaponifiable matter are factors that influence the digestibility of lipids. The digestibility of fatty acids increases with increasing unsaturation and decreasing chain length (Freeman et al., 1968; Stahly, 1984).

Saturated fatty acids such as palmitic acids and stearic acids are less digestible than unsaturated fatty acids that contain at least 18 carbons (Wiseman et al., 1990; Powles et al., 1995; Kabara and Wachter, 2000). The absorption of saturated fatty acids may be increased by the addition of unsaturated fatty acids in diets because unsaturated fatty acids may increase micelle formation from saturated fatty acids (Carlson and Bayley, 1968; Freeman et al., 1968; Jørgensen et al. 1992). The effect of the ratio of saturated fatty acids to unsaturated fatty acids on lipid digestibility may be more pronounced for young pigs than for old pigs (Powles et al., 1995). Lipid digestibility is often in the range from 85 to 92% when the ratio of unsaturated fatty acids to saturated fatty acids is more than 1.5, while lipid digestibility decreases when the ratio is less than 1.3 (Stahly, 1984).

(2) Dietary factors. Dietary fiber depresses lipid digestibility due to an increase in passage rate of digesta and insolublization of dietary lipids in the GIT (Stahly, 1984; Bach Knudsen and Hansen, 1991; Smits and Annison, 1996). A 1% increase in the concentration of dietary fiber depresses the apparent digestibility of lipids by approximately 1.5% (Just et al., 1980). Dietary minerals may also have an adverse effect on lipid digestibility (Stahly, 1984). Increasing levels of dietary minerals decrease the digestibility of fatty acids over the entire intestinal tract, but not before the end of the ileum because of soap formation between fatty acids and minerals in the hindgut of pigs (Jørgensen et al. 1992). Increasing dietary protein may also decrease apparent digestibility of lipids (Adams and Jensen, 1985) because the binding of free fatty acids to AA may reduce their availability to absorption (Sklan et al., 1975). In contrast, Jørgensen et al. (1992) reported that higher levels of dietary CP increase the apparent ileal digestibility of fatty acids because undigested protein might stabilize micelle formation.

(3) Animal factors. Animals inevitably produce a certain amount of endogenous fat (**ELF**) in the GIT (Low, 1980). The ELF originates from bile acids, desquamated cells, exudates from the mucosa, and microorganism (Eyssen, 1973; Clement, 1975; Sambrook, 1979). The amount of ELF may be influenced by dietary lipid intake, lipid source, and dietary fiber concentration (Freeman et al., 1968; Juste et al., 1983; Bach Knudsen and Hansen, 1991; López Bote et al., 2001). Apparent digestibility of lipids increases with the concentration of dietary lipid because the ELF exhibits a relatively greater effect on the apparent digestibility of lipids at low levels of dietary lipids than at high levels (Just et al., 1980; Jørgensen et al., 1993). Therefore, Low (1980) suggested that ELF should be considered when lipid digestibility is measured. Lipid digestibility should be measured at the end of ileum rather than over the entire GIT due to a complication of biohydrogenation and of additional contributions of ELF from the hindgut of pigs (Duran-Montgé et al., 2007).

Factors Affecting the Metabolism of Dietary Lipids

Most dietary lipids may be directly incorporated into body lipids in normally-fed growing pigs (Chwalibog et al., 1992; Chwalibog and Thorbek, 1995) and the amount and composition of body lipids is closely related to the levels and characteristics of dietary lipids (Azain, 2001). Approximately 73% of body lipids in pigs that were raised from 20 to 80 kg BW originate from de novo lipogenesis (Madsen et al., 1992). Increasing intake of dietary lipids may decrease de novo lipogenesis by inhibiting the activity of lipogenic enzymes (Allee et al., 1971, 1972; Steffen et al., 1978; Doreau and Chilliard, 1997). Depressive effects of dietary lipids on de novo lipogenensis may also be associated with the chain length of fatty acids (Smith et al., 1996) and saturation of fatty acids (Kouba and Mourot, 1998, 1999). Therefore, it is likely that the levels and sources of dietary lipids (Allee et al., 1971, 1972; Morgan, 1992; Averette Gatlin et al., 2002) and the potential retention of body lipids, which is affected by gender, genotype, and stage of growth (Wood, 1984; Nürnberg et al., 1998; Averette Gatlin et al., 2003), determine the final metabolism of lipids in the body. Metabolic modifiers including porcine somatotropin, β-agonists, sex hormones, and dietary additives such as conjugated linoleic acid may reduce lipid retention in pigs by decreasing de novo lipogenesis and possibly increasing lipolysis (Dunshea et al., 2005).

Energy Metabolism

Energy is obtained from the oxidation of organic compounds in diets (Whittemore, 2006). While nutrients act as building blocks in the body, energy is utilized for maintenance and production (Rijnen et al., 2004). In animal nutrition, therefore, energy represents an overall quality associated with dietary nutrients (Moehn et al., 2005). The potential energy in diets can be stored in chemical components in the body or can be utilized for biological functions in the form of ATP (Emmans, 1999). Energy metabolism is divided into 2 categories. Catabolism produces energy by oxidation of fuel molecules in the exergonic reaction, while anabolism synthesizes body components in the endergonic reaction (Mayes, 2000b). All processes in these 2 reactions must be a coupled exergonic-endergonic system and the overall net change in energy must be exergonic (Mayes, 2000b). It is estimated that the oxidation of long chain fatty acids generates 112 to146 moles of ATP compared with 38 moles of ATP generated by the oxidation of glucose and 6 to 42 moles of ATP generated by the oxidation of amino acids (Blaxter, 1989; adapted from Oresanya, 2005). However, the energy from nutrient oxidation is only partially captured in the form of ATP and some of the energy is lost as heat. The energy in ATP is not fully utilized and is also dissipated as heat when ATP is used for biological functions.

Energy Utilization of Pigs

Dietary energy is utilized for maintenance or stored as protein or lipids in pigs (van Milgen and Noblet, 2003). It is assumed that energy in pigs is first prioritized for maintenance (Lizardo et al., 2002) and the energy requirement for maintenance accounts for approximately one third of total dietary energy utilization in growing pigs (Black and de Lange, 1995; NRC, 1998). Energy intake in excess of energy requirement for maintenance is stored as protein or lipids (Lizardo et al., 2002) and the retention of protein and lipids accounts for approximately two thirds of dietary energy utilization in pigs (NRC, 1998).

Energy Requirement for Maintenance

Energy utilization for maintenance is associated not only with basic body functions such as blood flow, respiration, muscle tone, ion balance, immune system, and tissue turnover, but also with physical activity, ingestion and digestion of feed, and the control of homeostasis in the body (Baldwin, 1995; Black and de Lange, 1995). The energy requirement for maintenance is expressed as the ME requirement for maintenance (**$\mathbf{ME_m}$**) or the NE requirement for maintenance (**$\mathbf{NE_m}$**).

The ME_m or NE_m is typically expressed proportionally to metabolic BW as an exponential function (aBW^b, NRC, 1998). This expression was adapted based on the proportionality between fasting heat production (**FHP**) and metabolic BW (Kleiber, 1975; Chwalibog, 1991). In theory, an appropriate exponent maintains the proportionality between BW and the maintenance requirement (Chwalibog, 1991). The metabolic BW of animals has been expressed as $BW^{0.75}$ because there is a linear relationship between FHP and $BW^{0.75}$ in mature and postabsorptive animals from different species (Kleiber, 1975). The exponent of 0.75, however, may be inaccurate when applied to FHP within a species or for growing animals (Thonney et al., 1976; Baldwin and Bywater, 1984). When 0.75 was used as the exponent, ME_m decreased with increasing BW for growing pigs (Chwalibog, 1991). This may be due to changes in body composition and changes in the size of visceral organs to relative body size during the growing phase (Tess et al., 1984; Noblet et al., 1991). It has been suggested that an exponent of 0.60 is more appropriate than 0.75 for growing pigs to predict the maintenance requirement (Brown, 1982; Noblet et al., 1994a; van Milgen et al., 1998). However, there has been no universal agreement about which exponent is the appropriate one to use for pigs (Chwalibog, 1991; Noblet et al., 1994b; Noblet et al., 1999).

Estimation of the Energy Requirement for Maintenance

The maintenance requirement for pigs can be estimated in pigs that are fasted or fed a restricted amount of energy to reach zero energy retention (Chwalibog, 1991). However, those methods have been criticized because of differences in energy metabolism between fasted pigs and pigs that are allowed free access to feed (Baldwin, 1995). Another approach is to determine the maintenance requirement statistically as a conceptual constant number (Verstegen, 2001; van Milgen et al., 2008). Using this procedure, the maintenance requirement is estimated by regressing the energy retention obtained for animals consuming graded levels of energy on energy intake. The x-intercept of this regression represents ME_m and the y-intercept represents NE_m (de Goey and Ewan, 1975; Ewan, 2001). The latter may be called the operational NE requirement for maintenance (**ONE_m,** Figure 2.1). The ME_m can also be estimated from the difference between total energy intake and energy used for protein and lipid retention (Birkett and de Lange, 2001). Estimates of ME_m for pigs vary from 92 to 160 kcal/ $BW^{0.75}$ and the average estimate for ME_m is 106 kcal/ $BW^{0.75}$ (NRC, 1998). When 0.60 is used as the exponent for metabolic BW, the estimates for ME_m are 186 kcal/$kg^{0.6}$ (de Lange et al., 2006), 218 kcal/$kg^{0.6}$ (Just et al, 1983), 208 to 250 kcal/$kg^{0.6}$ (Noblet et al., 1991, 1994a), or 215 to 239 kcal/$kg^{0.6}$ (van Milgen et al., 1998).

Estimates of the ONE_m for pigs are between 71 and 81 kcal/ $BW^{0.75}$ (Robles and Ewan, 1982; Just et al., 1983). When 0.6 is used as the exponent, however, the estimates for ONE_m were 117 kcal/$kg^{0.6}$ (de Lange et al., 2006), 151 kcal/$kg^{0.6}$ (Schiemann et al., 1972), 148 kcal/$kg^{0.6}$ (Just et al., 1983), and 179 kcal/$kg^{0.6}$ (Noblet et al., 1994a).

Factors Affecting the Energy Requirement for Maintenance

Variations in the maintenance requirement among pigs are caused by age, gender, genotype, physiological state, environment, and feeding strategy (Baldwin, 1995). Specific conditions such as thermoregulation, immune system activation, disease, and stress may also influence the maintenance requirement (Bray et al., 1997; Knap, 2000; Verstegen, 2001).

The FHP of growing pigs is 16% lower at 33°C than at 23°C (van Milgen and Noblet, 2000). Likewise, pigs have 4% greater energy requirement for maintenance for each 1°C reduction in the ambient temperature when they are kept below the lower critical temperature due to increased heat production for maintaining body temperature (Close, 1996). The maintenance requirement may also increase if the temperature is above the evaporative critical temperature because of increased respiration rate. However, the energy cost for panting is relatively small and a reduction in feed intake decreases the metabolic rate. Therefore, hot temperature may have little impact on the energy requirement for maintenance (Black, 1995; Giles et al., 1998).

The size of the GIT, liver, kidney, and heart as well as the relative ratio of body protein to body lipids have a significant effect on the energy requirement for maintenance (Koong et al., 1983; van Milgen et al., 1998; Knap, 2000). Total heat production from metabolically active organs accounts for 25-30% of basal heat production (Baldwin and Bywater, 1984). Body organs and GIT has 3 to 4 times greater contribution to FHP than muscles, while lipids in the body may have a negative impact on FHP (Tess et al., 1984; van Milgen et al., 1998; Noblet et al., 1999). Genotype, gender, feeding strategy, and stage of growth can influence the size of metabolically active organs and body muscle, and therefore, may contribute to variations in the energy requirement for maintenance (Tess et al., 1986; Baldwin, 1995; Noblet et al., 1999).

Indirect calorimetry is often used for measuring FHP. The estimates of FHP, however, vary with the period of fasting, the type and amounts of previously fed diets, and the physical activity of animals (van Milgen et al., 1998; Ewan, 2001; de Lange et al., 2006). Short-term fasting may better represent the FHP of growing animals because animals may adapt FHP by responding to the feeding level (Koong et al., 1983; van Milgen et al., 1998, Noblet et al. 1999). Restriction of the physical activity of animals in metabolism cages may decrease FHP and group-housed pigs have a greater heat production than individually-housed pigs (van Milgen and Noblet, 2000).

The comparative slaughter method is also used for estimating the energy requirement for maintenance (Just, 1982; Quiniou et al., 1995; Reynolds, 2000). This approach can be used in long-term experiments and more closely simulate the practical feeding system than indirect calorimetry method (Reynolds, 2000). However, measurements of body energy retention may induce errors because the initial energy concentration of experimental pigs is predicted from a different group of pigs that is slaughtered at the initiation of experiment (Quiniou et al., 1995). To minimize variation in body chemical composition among animals, relatively long experimental period and a large number of animals in the initial slaughter group are necessary (Boisen and Verstegen, 2000).

Estimates of energy retention, however, tend to be greater if measured by indirect calorimetry than by the comparative slaughter method (Quiniou et al., 1995; van Milgen and Noblet, 2003) because pigs in a respiratory chamber decrease the physical activity and thermoregulation (Baldwin and Bywater, 1984; Reynolds, 2000).

Gross Energy

Gross energy (**GE**) represents the maximum quantity of energy (or heat) that is obtained from the complete oxidation of organic materials in diets (Ewan, 2001; Figure.2.2). The total amount of GE is derived from the OM in the diet and the amount of GE in a diet depends on the degree of oxidation of dietary components as expressed in the ratio of C and H to O_2 (McDonald et al., 2002). Dietary nutrients have average GE values of 3.7 kcal/g for glucose, 4.2 kcal/g for starch, 5.6 kcal/g for protein, and 9.4 kcal/g for lipids, whereas fermentative products have GE values of

3.5, 5.0, 5.9, and 13.1 kcal/g for acetate, propionate, butyrate, and methane, respectively (McDonald et al., 2002).

Digestible Energy

The DE of diets is calculated from the difference between dietary GE and GE excreted in the feces (Noblet and Henry, 1993). Energy that is consumed by animals and is not excreted in the feces is assumed to be absorbed and available to the animal (de Lange and Birkett, 2005). The DE is an apparent measurement of the energy value of the diet because the endogenous losses of energy are not considered (Reynolds, 2000). The DE of most diets varis between 70 and 90 % of GE. The variation is caused by several factors such as the level and source of dietary fiber or dietary lipids, the amount of dietary minerals, feed intake, and feed processing (Just, 1982; Noblet, 1996; Black, 2000; Verstegen, 2001). Animal factors such as age or BW also influence the DE of diets (Shi and Noblet, 1993; Noblet and van Milgen, 2004).

Metabolizable Energy

The ME is calculated by subtracting energy excreted in urine and gases from DE (Noblet, 1996). Energy losses in urine are related to urinal N concentration (Noblet and van Milgen, 2004). On average, 50% of absorbed N is used for body protein synthesis and the remaining 50% of absorbed N is excreted in the urine (Just, 1982). However, the ME value only accounts for energy losses as urinary excretion and gases, but do not consider the energy cost for urinary excretion (Birkett and de Lange, 2001). Energy that is consumed by animals and is not excreted in the feces, urine, or gases is assumed to be available to the animal (de Lange and Birkett, 2005).The ME is considered a better estimate of available energy to pigs than DE because ME accounts for urinary energy losses, which are influenced by the dietary protein (Just, 1982; Moehn et al., 2005). In growing pigs, the average energy losses in urine and as methane are 3.3 and 0.4 % of DE intake, respectively (Noblet, 1996), and the average ratio of DE to ME in commercial diets is approximately 0.96 (Noblet et al., 1994a; NRC, 1998). Methane energy losses are associated with fermentation of dietary fiber and the ME of diets, therefore, may also vary with the amount and characteristics of dietary fiber (Noblet, 1996; NRC, 1998).

A correction of the ME to nitrogen equilibrium (nitrogen corrected metabolizable energy, **ME_n**) has been proposed to eliminate the impact of nitrogen retention on ME:DE (Morgan et al., 1975). The ME_n has been suggested to be a better estimate of available energy from protein sources than ME (Morgan et al., 1975; Robles and Ewan, 1982; de Lange and Birkett, 2005). For calculation of ME_n for pigs, 9.17 kcal of ME per g of nitrogen retention is subtracted from the measured ME values (Morgan et al., 1975).

Net Energy

The NE is calculated as the sum of NE_m and retained energy (Noblet, 2007). The NE value can also be calculated from DE or ME if the efficiency of ME utilization for NE (**NE:ME**) or DE utilization for NE (**NE:DE**) is known (Baldwin and Bywater, 1984; de Lange, 2008). The ratio of NE to ME represents the energetic efficiency of ME for maintenance and production and thus depends on the particular biochemical pathways for the purpose of utilization (e.g., maintenance vs. energy retention) in animals (Black, 2000). Theoretical values for NE:ME have been proposed for energetic efficiencies of digestible nutrients for ATP production and lipid retention (Black, 1995, Table 2.1). The NE:ME of digestible nutrients is 58, 82, and 90% for protein, starch, and fat, respectively, and the average for the NE:DE and

NE:ME is 71.0 and 73.9%, respectively (Noblet et al., 1994a). Because the NE value is obtained based on the energetic efficiency of digestible nutrients, values for NE more closely represent the available energy in the diet than values for DE and ME (Noblet et al., 1994a; Moehn et al., 2005; Noblet, 2007).

Energy Systems

An energy system is assigning energy values to feed ingredients. These values are supposed to be additive in mixed diets and are used to calculate the energy concentration in mixed diets (Emmans, 1999). An appropriate energy system is able to accurately estimate the amount of energy required for maintenance and production and to correctly rank energy values in various feed ingredients (Noblet et al., 1994a; Rijnen et al., 2004). The quality of an energy system is based on the predictability of animal performance from the system (Noblet and Henry, 1993).

DE and ME Systems

The DE and ME systems have been used in the North American swine industry because values for DE and ME are relatively easy to measure and these values are assumed to be additive in mixed diets (NRC, 1998; de Lange and Birkett, 2005). The DE and ME systems are compatible because DE values can be readily converted to ME values, assuming that the average efficiency (ME:DE) is 0.96 (Noblet et al., 1994a; NRC, 1998). However, ME:DE varies with BW (Noblet et al., 1994b), the amount and quality of protein (Whittemore, 1997), and the amount and characteristics of fermentable fiber in the diet (Le Goff and Noblet, 2001). The ME of dietary lipids is theoretically similar to the DE of dietary lipids. Values for DE and ME are additive in mixed diets only if they are measured in pigs at the same stage of growth and fed a similar amount of diet as the pigs fed the mixed diets (Rijnen et al., 2004). The DE and ME systems may underestimate the energy value of lipids and starch, but overestimate the energy value of protein and fiber (Noblet et al., 1994a; Noblet, 2007), because ingestion of these nutrients results in different levels of heat production (Noblet et al., 1994a; Black, 1995). Therefore, DE and ME systems may have limitations in accurately predicting the energy cost for growth performance of pigs (Le Bellego et al., 2001; Rijnen et al., 2004; Wu et al., 2007).

NE System

The NE system has been used in some European countries to overcome the limitations of DE and ME systems (de Lange and Birkett, 2005). The advantages of NE over DE and ME include a better prediction of growth performance and body composition of animals (Verstegen, 2001; Noblet, 2007; Oresanya et al., 2008). This advantage is more obvious if a diet contains many different feed ingredients than if a diet contains primarily corn and soybean meal (Le Bellego et al., 2001; Patience and Beaulieu, 2005; de Lange, 2008). The utilization of N may also be improved because diets can be more accurately formulated (Le Bellego et al., 2001; Payne, 2006; Noblet, 2007). The NE system may reduce the feed cost if this system can be used to more accurately rank feed ingredients in terms of energy value (Patience and Beaulieu, 2005; Payne, 2006).

European NE Systems

The NE systems in France, the Netherlands, and Germany were developed using similar principles to predict the NE values of mixed diets. Using these systems, it is assumed that the chemical composition and nutrient digestibility of feed ingredients can be obtained from tabulated values, that the amount of digestible nutrients in each ingredient is additive in mixed diets without interaction among feed ingredients, and that the utilization of a digestible nutrient for energy in the body is independent of the other digestible nutrients (Bakker, 1996). Prediction equations for the NE of feed ingredients are determined using data obtained from the chemical composition and digestibility of nutrients.

The French NE System

The French NE system was developed by Noblet and his coworkers who conducted numerous experiments at the Institut National de la Recherche Agronomique (INRA). The NE values of 61 diets containing a variety of feed ingredients and fed to lean-genotype growing pigs (35 kg of initial BW) at a high ME intake (550 kcal of ME/kg BW $^{0.6}$) or at a low ME intake (330 kcal of ME/ BW $^{0.6}$) were measured (Noblet et al., 1994a). Energy digestibility and energy losses in feces, urine, and gases were measured. Heat production was measured by the indirect calorimetry method. The average FHP 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 FHP 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., 1994a). Components of digestible nutrients in the equations were later modified and 3 equations were developed (Sauvant et al., 2004). It is assumed that these 3 equations are applicable to both mixed diets and feed ingredient fed to growing pigs (Noblet and van Milgen, 2004; Sauvant et al., 2004).

The Dutch NE System

The Central Bureau Livestock Feeding (CVB) has developed the Dutch NE system. This system uses the concentration of digestible nutrients in feed ingredients to estimate the NE values of diets and feed ingredients, assuming that extra energy retention is obtained from extra intake of digestible nutrients (Rijnen et al., 2004). The Dutch NE system separates total digestible carbohydrates (i.e., starch and sugar) into an enzymatically-digestible fraction and a fermentable fraction (Blok, 2006). Starch is analyzed using an enzymatic procedure and sugar is analyzed as enzymatically-digestible sugar and fermentable sugar. Dietary lipids are analyzed using the acid hydrolyzed ether extract method for both feeds and feces.

The Danish Potential Physiological Energy (PPE) System

The Danish feed system uses assumed concentrations of digestible nutrients in feed ingredients that contribute to the potential physiological energy (**PPE)** in diets fed to pigs. Data for concentration of digestible nutrients in feed ingredients are derived from feed ingredient tables. The value for PPE of nutrients is the potential energy value for ATP production when digestible nutrients are completely oxidized in animals (Boisen, 2003, Table 2.2). The PPE of different nutrients is independent of their metabolic utilization (e.g., oxidation or retention), and therefore, the PPE calculated from various feed ingredients or digestible nutrients are additive in diets containing a mixture of feed ingredients and are independent of animal factors (Boisen, 2007). The PPE system also uses standardized ileal digestible AA in feed ingredients to describe digestibility values for AA (Boisen, 2007). The system uses in vitro digestibility values for estimating the digestibility of CP, AA, OM, lipids, and carbohydrates. The system also requires the analysis of enzyme indigestible ileal DM to correct for the costs of digestion, which includes endogenous synthesis of protein and lipids throughout the GIT.

Comparison of European Energy Systems

The NE values for diets and feed ingredients are affected by the energy evaluation system that is used (Noblet and van Milgen, 2004). Therefore, the accuracy and applicability of an energy system depend on the relative contribution of energy from different digestible nutrients (Boisen, 2007). Starch is used as the standard reference for estimating energy contributions of other nutrients because starch is considered a main energy source for pigs (Boisen, 2007). The energy contribution of nutrients relative to starch among European energy systems is presented in Table 2.3. The relative contribution of different digestible nutrient fractions is comparable among energy systems. Therefore, the hierarchy of energy values for diets and feed ingredients is expected to be similar among the European energy systems although absolute energy values are different.

Limitation of Current European NE Systems

The current European NE systems use a single NE value for dietary lipids. For example, the French NE system uses 7,122 kcal/kg as the NE of dietary lipids regardless of the source of lipids or the level of lipids in the diet. Although it may be practically acceptable to use 1 value for dietary lipids, the NE of dietary lipids may be influenced by the source and level of dietary lipids, which can determine the digestibility and the metabolizability of dietary lipids (Birkett and de Lange, 2001; de Lange and Birkett, 2005). European NE systems use the same NE values of feed ingredients for both growing and finishing pigs. However, finishing pigs use more energy and nutrients for lipid gain than growing pigs (de Greef et al., 1994), which may influence the NE value of feed ingredients (Birkett and de Lange, 2001; de Lange and Birkett, 2005).

The current NE systems were developed based on the assumption that digestibility and energetic utilization of a nutrient in animals is constant and that there are no interactions among nutrients in their utilization (Rijnen et al., 2004; de Lange, 2008). However, the values for the digestibility and metabolizability of nutrients in mixed diets are not always additive because of possible interactions (Bakker, 1996). For instance, increasing levels of dietary lipids may decrease the NE of starch because of increased utilization of starch for ATP production instead of de novo lipogenesis (Jakobsen and Thorbek, 1993; Black, 1995).

The European NE systems use different equations to predict the NE of diets and ingredients because each system has its own methods and experimental conditions (Boisen, 2007, Table 2.4). Therefore, NE values are different among these NE systems (Whittemore, 1997; Noblet and van Milgen, 2004).

SUMMARY

Lipids are important dietary energy source in swine nutrition. An accurate determination of the bioavailability of dietary lipids is important for assessing the true feeding value of dietary lipids. The true digestibility is considered a better estimate for the amount of digestible lipids in a feed ingredient than apparent digestibility of lipids. However, little information is available on ELF and the true digestibility of lipids. The NE of dietary lipids may be a more accurate energy value than DE and ME. However, the effects of the source and level of dietary lipids and the stage of growth of pigs on the NE value of dietary lipids have not been determined. There is also a possibility that dietary lipids may affect the utilization of dietary starch and thus change the NE of starch-containing feed ingredients such as corn. The impact of dietary lipids on NE of starch-containing ingredients may also vary with the stage of growth, but there have been no experiments to test this hypothesis. The NE values measured under one specific condition may not be applicable to other conditions but there are no data from experiments where the effect of location was measured.

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Table 2.1. Estimates of the energetic efficiencies with different nutrients used for ATP production or lipid retention in pigs[1]

	Efficiency of energy yield (%)			
	Microbial fermentation			
	Heat	Methane	ATP production	Lipid retention
Fatty acids	-	-	66	90
Glucose	-	-	68	74
Amino acids	-	-	58	53
Digested fiber	6	10	50	62

[1] Derived from Black (1995).

Table 2.2. Calculations of energy values for diets in the potential physiological energy (PPE) system[1]

Nutrient fraction	Calculation of fractions (g/kg)	Energy factor (kJ/g)
RDCP[2]	CP × EDN[7] / 100	9.9
RDCF[3]	Crude fat × 0.9 / 100	31.7
EDC[4]	OM[8] × EDOMi/100 – (RDCP+RDCF)	11.7
FERMC[5]	OM × (EDOM-EDOMi) / 100	7.0
EIDMi[6]	OM × (100-EDOMi) / 100 + 0.3 × Ash	-2.8

[1] Derived from Boisen (2007).

[2] RDCP = in vitro ileal digestible CP (g/kg DM).

[3] RDCF = calculated ileal digestible crude fat (g/kg DM).

[4] EDC = in vitro ileal digestible carbohydrates.

[5] FERMC=fermentable carbohydrate (g/kg DM); energy value of absorbed VFA from fermentable organic matter.

[6] EIDMi=enzyme undigested ileal DM (g/kg DM); Energy factor for EIDMi = estimated energy costs for extra losses of protein and lipids from the intestinal tract.

[7] EDN=enzyme digestibility of N.

[8] OM = organic matter, i.e. DM – ash.

Table 2.3. Energy values of digestible nutrients relative to starch in NE systems and the potential physiological energy (PPE) system [1,2]

MJ/kg	NE_{INRA}[3]	NE_{CVB}[4]	PPE[5]
Starch	14.4(100)	14.1(100)	11.7(100)
CP	11.3(78)	11.7(83)	9.9(85)
Crude fat	35.0(243)	35.7(253)	31.7(271)
FMC[6]	12.1(84)	9.74(69)	7.0(60)

[1] Data were derived from Boisen (2007).

[2] Values in parenthesis is relative energy value of nutrient to energy value of starch (100).

[3] Noblet and van Milgen (2004).

[4] Blok (2006).

[5] Boisen (2007).

[6] Fermentable carbohydrate.

Table 2.4. Coefficients in prediction equations of European energy systems[1]

Digestible nutrients, g/kg	NE_{INRA}[2]	NE_{CVB}[3]	PPE[4]
CP	2.89	2.80	2.37
Lipids	8.37	8.54	7.58
Total Starch	3.42	-	-
ED-starch[5]	-	3.38	-
Total sugar	2.84	-	-
ED-sugar[6]	-	3.05	-
EDC[7]	-	-	2.80
FCH[8]	2.06	2.33	1.67

[1] The unit of coefficients is kcal/g.

[2] Sauvant et al. (2004).

[3] Blok (2006).

[4] Boisen (2007).

[5] Enzymatically digestible starch.

[6] Enzymatically digestible sugar.

[7] Ileal digestible carbohydrates.

[8] Fermentable carbohydrates.

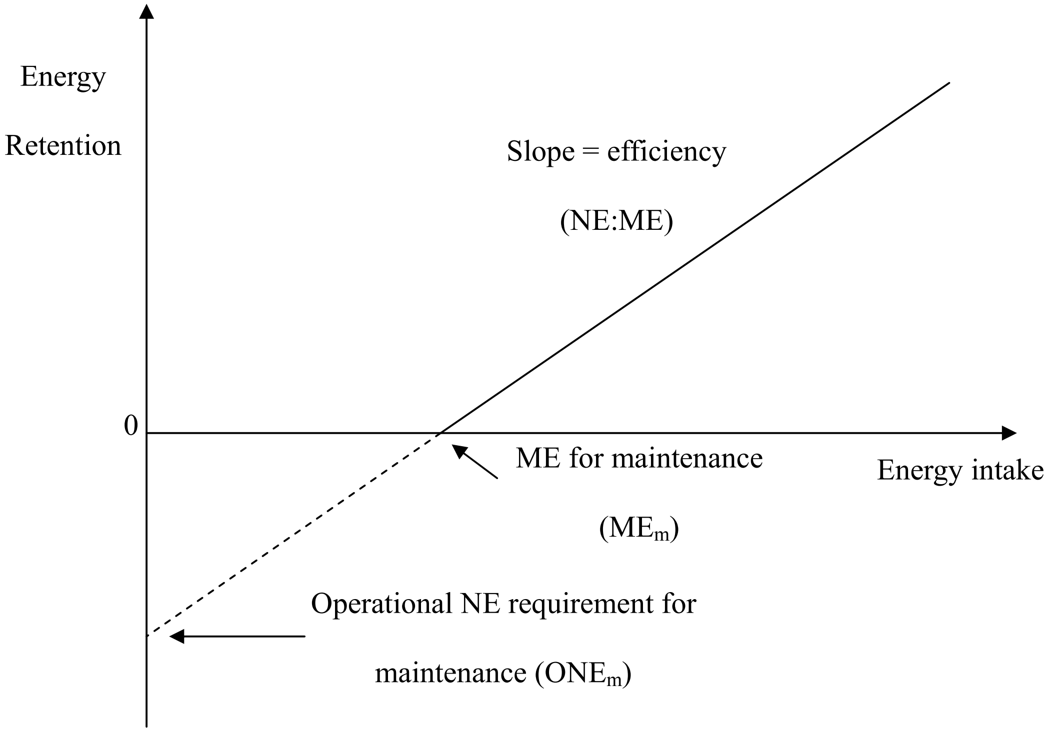

Figure 2.1. Estimation of the energy requirement for maintenance from energy retention (kcal/BW0.6 /d) and energy intake (kcal/BW0.6 /d) in pigs. Adjusted from Ewan (2001).

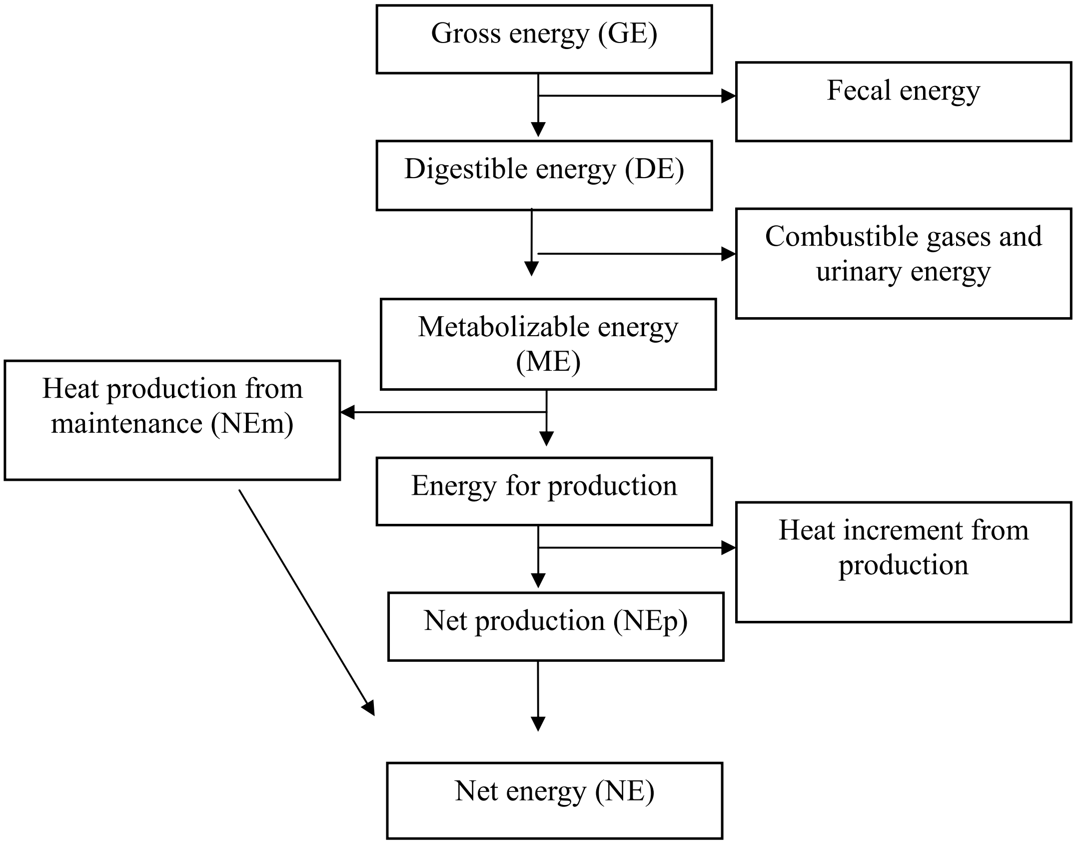

Figure 2.2. Energy utilization by pigs. Adjusted from Boisen and Verstegen, (2000).

CHAPTER 3

EFFECT OF THE FORM OF DIETARY FAT AND THE CONCENTRATION OF DIETARY NDF ON ILEAL AND TOTAL TRACT ENDOGENOUS LOSSES AND APPARENT AND TRUE DIGESTIBILITY OF FAT IN DIETS FED TO GROWING PIGS

ABSTRACT

An experiment was conducted to determine the effect of the form of dietary fat (liquid or intact) and of dietary NDF on ileal and total tract endogenous losses of fat (ELF), on apparent ileal (AID) and apparent total tract digestibility (ATTD) of fat, and on true ileal (TID) and true total tract digestibility (TTTD) of fat by growing pigs. A semi-purified basal diet that contained 1.27% fat was formulated and 3 diets were formulated by adding 2.0, 4.0, and 6.0% liquid fat from corn oil to the basal diet. Three additional diets were formulated by adding 3.1, 6.2, or 9.3% Solka floc to the diet containing 4% corn oil. The remaining 4 diets were prepared by adding 0.0, 3.0, 6.0, or 9.0% intact fat from whole corn germ meal to a diet based on defatted corn germ meal. Eleven barrows (initial average BW: 38.1 ± 4.15 kg) were surgically fitted with a T-cannula in the distal ileum and allotted to an 11 × 11 Latin square design. The AID and ATTD of fat in all diets were measured. The ELF, TID and TTTD of fat were estimated using the regression method. The AID and ATTD of fat were also corrected for TID and TTTD of fat in all diets by ELF derived from each form of fat. Results showed that increasing dietary liquid fat increased (linear and quadratic, $P < 0.001$) the AID and ATTD of fat. Increasing dietary intact fat increased (linear and quadratic, $P < 0.05$) the AID and ATTD of fat. There was no interaction between the form of fat and the collection site. Apparent digestibility of liquid fat (81.9%) was greater ($P < 0.001$) than of intact fat (63.2%). The estimates of ELF were lower ($P < 0.05$) for liquid fat than for intact fat at the end of the ileum and over the entire intestinal tract. The TID (93.8%) and TTTD (94.2%) of liquid fat were greater ($P < 0.05$) than the TID (78.6%) and TTTD (84.1%) of intact fat. Increasing dietary liquid fat had no linear and quadratic effects on the TID and TTTD of fat, but increasing dietary intact fat exhibited a quadratic effect ($P < 0.05$) on the TTTD of fat. Increasing dietary NDF had a quadratic effect ($P < 0.05$) on the ATTD of fat, but did not influence the AID, TID, and TTTD of fat. In conclusion, liquid fat induces a lower ELF and has a greater apparent and true digestibility than intact fat at the end of the ileum and over the entire intestinal tract. Purified NDF has little influence on apparent and true digestibility of fat.

Keywords: apparent digestibility, endogenous loss, fat, neutral detergent fiber, pig, true digestibility

INTRODUCTION

Estimation of endogenous losses of nutrients from the digestive tract is required for the determination of true digestibility of nutrients. Values for endogenous losses in pigs of CP and AA (Stein et al., 2001; Moter and Stein, 2004) and of P (Dilger and Adeola, 2006; Petersen and Stein, 2006) have been published. Values for endogenous losses of fat (**ELF**) in pigs have also been reported in a few experiments, but the results were inconsistent (Freeman et al., 1968; Adams and Jensen, 1984; Jørgensen et al., 1993). Thus, determination of fat digestibility has mostly been limited to apparent digestibility and true digestibility is not usually calculated.

The amount of ELF can be influenced by many factors including dietary fat intake, fat source, and dietary fiber concentration (Freeman et al., 1968; Juste et al., 1983; Bach Knudsen and Hansen, 1991). Although fat in swine diets may originate from either intact fat in feed ingredients or supplemented liquid fat (Azain, 2001), the effect of the form of fat on ELF has not been investigated. Moreover, ELF in pigs has been mostly measured over the entire intestinal tract and it is not known if the ELF at the end of the ileum is different from the ELF over the entire intestinal tract. Therefore, it is not known if true digestibility of fat at the end of ileum is different from true digestibility of fat over the entire intestinal tract.

Dietary NDF may decrease the apparent digestibility of fat because dietary fiber may increase the amount of ELF (Bach Knudsen and Hansen, 1991). However, little is known about the effect of dietary NDF on true digestibility of fat.

The objectives of this experiment were to estimate ELF in growing pigs and to measure the influence of the form of fat (liquid or intact) and of dietary NDF on the apparent and true digestibility of fat. An additional objective was to compare estimates for ELF and fat digestibility at the end of the ileum and over the entire intestinal tract.

MATERIALS AND METHODS

Animals, Housing, and Experimental Design

Eleven growing barrows (initial average BW: 38.1 ± 4.15 kg, SD) originating from the matings of SP-1 boars to Line 401 females (Ausgene Intl. Inc., Gridley, IL) were used in this experiment. Each pig was surgically equipped with a T-cannula in the distal ileum using procedures adapted from Stein et al. (1998). Pigs were housed individually in 1.2 × 1.8 m pens that had fully slatted tri-bar floors. A feeder and a nipple drinker were installed in each pen. Room temperature was maintained at 20 to 22℃ throughout the experiment. Pigs were allotted to an 11 × 11 Latin square design with 11 periods and 11 diets. Each experimental period lasted 7 d. The animal part of the experiment was conducted at South Dakota State University (Brookings, SD). The experiment was approved by the Institutional Animal Care and Use Committee at South Dakota State University.

Diets, Feeding, and Sample Collection

Eleven diets were prepared (Table 3.1). A basal diet (1.27% acid hydrolyzed fat, DM basis) was formulated based on maize flaking grits, casein, sucrose, and cornstarch. Three diets with increasing concentrations of liquid fat were formulated by adding 2.0, 4.0, or 6.0% corn oil to the basal diet. The analyzed values of acid hydrolyzed fat in these diets were 3.22, 5.14, and 6.85% (DM basis), respectively. Three additional diets were formulated by adding 3.0, 6.0, or 9.0% NDF from Solka floc (97% NDF) to the diet containing 4% corn oil. This diet contained 2.73% NDF (DM basis) and the analyzed concentrations of NDF in the 3 diets containing Solka floc were 5.78, 9.24, and 11.28% (DM basis), respectively. The remaining 4 diets were formulated by using casein, maize flaking grits, and varying amounts of defatted corn germ meal and whole corn germ meal. By increasing the amount of whole corn germ meal at the expense of defatted corn germ meal and cornstarch, the analyzed concentrations of acid hydrolyzed fat increased from 3.03% to 5.26, 7.70, and 9.74% (DM basis), respectively. Vitamins, salt, and minerals were included in all diets to meet or exceed the estimated requirements for growing pigs (NRC, 1998). Chromic oxide (0.40%) was included in all diets as an indigestible marker.

Pigs were provided a daily quantity of feed that was calculated to supply 3 times the estimated maintenance requirement for energy (i.e., 106 kcal ME/kg$^{0.75}$; NRC, 1998) in 2 equal meals at 0800 and 1700. The BW of all pigs was recorded at the beginning of each experimental period, and the amount of feed supplied during the following period was calculated based on this BW. The BW of all pigs was also recorded at the end of the experiment. Water was available at all times.

The initial 4 d of each period were considered an adaptation period to the experimental diet. On d 5, fresh fecal samples were collected from each pig and stored at -20℃. Ileal digesta samples were collected continuously for 9 h on d 6 and 7 in plastic bags as described previously (Stein et al., 1999). Bags were removed whenever they were filled with digesta and stored at -20℃.

Chemical Analyses

At the end of the experiment, ileal and fecal samples were thawed and pooled within animal and diet. A subsample of ileal digesta was collected. These subsamples and the fecal samples were dried at 60^{o}C in a forced air oven for 96 and 72 h, respectively, and all samples were finely ground. Samples of diets, ileal digesta, and feces were analyzed for DM (procedure 4.1.06; AOAC, 2000), acid hydrolyzed fat (Stoldt, 1952), and chromium (Fenton and Fenton, 1979). The concentrations of NDF in all diets were also analyzed.

Calculations

The apparent ileal digestibility (**AID**) and apparent total tract digestibility (**ATTD**) of fat were calculated for each diet according to Stein et al. (2007). The true ileal digestibility (**TID**) and true total tract digestibility (**TTTD**) of fat from the 2 different sources of fat (liquid and intact fat) were calculated using the regression method (Jørgensen et al., 1993). Apparently digested fat (g/kg DMI) at the end of the ileum or over the entire intestinal tract was regressed against dietary fat intake (g/kg DM). The Y-intercept from the regression equation was considered the endogenous loss of fat, and the slope represented the true digestibility of fat (Jørgensen et al., 1993). The TID and TTTD of liquid fat or intact fat were also calculated by correcting the AID and ATTD of fat for ELF derived from each form of fat at the corresponding collection site, and TID and TTTD of fat in diets containing increasing concentrations of dietary NDF was calculated from the ELF estimated in diets containing liquid fat (Stein et al., 2007).

Statistical Analyses

All data were analyzed using the PROC MIXED procedure in SAS (SAS Stat Inc., Cary, NC). Homogeneity of the variance was verified using the UNIVARIATE procedure of SAS. The residual vs. the predicted plot procedure was used to check for outliers in the data. Diet was a fixed effect and pig and period were the random effects in the model. The interaction between the collection site and the form of fat was included in the model. However, the interaction was not significant, and therefore only main effects were included in the model and were presented. The LSMEANS procedure was used to calculate mean values of all dietary treatments. Orthogonal polynomial contrast was used to determine linear and quadratic effects of increasing dietary concentrations of liquid fat, intact fat, or dietary NDF. The PROC REG procedure in SAS was used to estimate the Y-intercept for determination of ELF and the slope for determination of TID and TTTD of liquid fat and intact fat. Intercepts and slopes were compared between the 2 forms of fat and between sample collection sites (at the end of the ileum and over the entire intestinal tract) using confidence intervals derived from the standard errors of the respective regression coefficients (Dilger and Adeola, 2006). The pig was the experimental unit for all analyses, and an alpha-value of 0.05 was used to assess significance in all analyses.

RESULTS

All pigs remained healthy and easily consumed their diets throughout the experiment. Mean BW of pigs at the start and at the end of the experiment were 38.1 ± 1.25 and 97.0 ± 2.01 kg, respectively. The ADG of pigs was 0.77 kg throughout the experiment, which is considered normal because the pigs were not allowed to consume their diets on an ad libitum basis.

Values for AID (70.6, 81.9, 87.7, and 89.1%) and ATTD (66.6, 80.6, 87.9, and 88.7%) of fat increased (linear and quadratic, $P < 0.001$) as the dietary inclusion of liquid fat increased (Table 3.2). Likewise, values for AID (52.7, 65.1, 71.1, and 70.0%) and ATTD (47.6, 57.4, 69.0, 71.9%) of fat increased (linear and quadratic, $P < 0.05$) as the dietary inclusion of intact fat increased. Total apparently digested fat increased (linear, $P < 0.001$) at the end of the ileum (9.0, 26.4, 45.1, and 61.0 g/kg DMI) and over the entire intestinal tract (8.4, 26.1, 45.2, and 60.6 g/kg DMI) as the dietary inclusion of liquid fat increased. Total apparently digested fat also increased (linear, $P < 0.001$) at the end of the ileum (16.0, 34.3, 54.7, and 68.1 g/kg DMI) and over the entire intestinal tract (14.4. 30.2, 53.1, 70.0 g/kg DMI) as the dietary inclusion of intact fat increased. The apparent digestibility of fat was greater ($P < 0.001$) in diets containing liquid fat (81.9%) than in diets containing intact fat (63.2%), but the total quantity of apparently digested fat was lower ($P < 0.05$) in diets containing liquid fat (35.1 g/kg DMI) than in diets containing intact fat (42.9 g/kg DMI; Table 3.3).

The estimates of ELF at the end of the ileum for liquid fat and for intact fat were 3.28 and 7.27 g/kg DMI, respectively (Table 3.4). The estimates of ELF over the entire intestinal tract for liquid fat and for intact fat were 3.77 and 12.08 g/kg DMI, respectively. The amount of ELF at the end of the ileum and over the entire intestinal tract was lower ($P < 0.05$) for liquid fat than for intact fat. The amount of ELF for liquid fat was not different between collection sites. However, the amount of ELF for intact fat was greater ($P < 0.05$) for the entire intestinal tract than at the end of the ileum.

The TID for liquid fat and for intact fat were 93.8 and 78.6 %, respectively. The TTTD for liquid fat and for intact fat were 94.2 and 84.1%, respectively. The TID and TTTD of fat were greater ($P < 0.05$) for liquid fat than for intact fat. However, there was no difference between the TID and TTTD of fat within each source of fat.

The AID and ATTD of fat were corrected for TID and TTTD of fat in all diets by ELF at the end of ileum (3.28 g/kg DMI for liquid fat and 7.27 g/kg DMI for intact fat) and over the entire intestinal tract (3.77 g/kg DMI for liquid fat and 12.08 g/kg DMI for intact fat; Table 3.5). Increasing dietary liquid fat had no linear or quadratic effect on the TID (96.3, 92.1, 94.1, and 93.9%) or TTTD (96.2, 92.3, 95.3, and 94.2%) of fat. There was no linear or quadratic effect of increasing dietary intact fat on TID of fat (76.7, 78.9, 80.5, and 77.4%), but there was a quadratic effect ($P < 0.05$) of increasing dietary intact fat on TTTD (87.5, 80.3, 84.7, and 84.3%) of fat.

There was no effect of the dietary inclusion of NDF on the AID, TID, or

TTTD of fat (Table 3.6), but a quadratic effect ($P < 0.05$) of the dietary inclusion of dietary NDF on the ATTD of fat (87.9, 86.3, 86.0, and 87.0%) was observed. The average values for the AID (87.4%) and TID (93.8%) of fat were not different from the average values for the ATTD (86.9%) and TTTD (94.3%) of fat.

DISCUSSION

Effect of Dietary Fat Intake on Apparent Digestibility of Fat

A curvilinear increase in the AID and ATTD of fat as dietary fat intake increased was observed for both liquid fat and intact fat. This result agrees with previous results from growing pigs (Just et al., 1980; Jørgensen et al., 1993) and from poultry (San Juan and Villamide, 2000). The AID and ATTD of fat increased to a plateau, indicating the ELF exhibits a greater effect on the apparent digestibility of fat at low levels of dietary fat than at high levels (Jørgensen et al., 1993). It has also been reported that the relative contribution of endogenous losses of AA to total excretion of AA decreases as dietary concentration of AA increases (Fan and Sauer, 1997).

Endogenous Losses of Fat

There was a linear relationship between total apparently digested fat and dietary fat intake at the end of the ileum and over the entire intestinal tract for both liquid fat and intact fat. Accordingly, the linear regression procedure can be used to determine ELF, TID, and TTTD of liquid fat and intact fat (Jørgensen et al., 1993).

The ELF for liquid fat at the end of the ileum that was measured in this experiment (3.28 g/kg DMI) is close to the value of 4.74 g/kg DMI that was reported by Jørgensen et al. (1993). Values for the ELF of liquid fat over the entire intestinal tract ranging from 4.4 to 22.4 g/kg DMI have been reported for diets containing corn oil (Adams and Jensen, 1984) or soybean oil (Jørgensen et al. 1993; Jørgensen and Fernández, 2000), but the value estimated in this experiment (3.77 g/kg DMI) is close to the lowest value of the range. When intact fat was added to the diets, the ELF (7.27 g/kg DMI) at the end of the ileum in this experiment was greater than the value of 2.0 g/kg DMI for diets containing various feed ingredient (Shi and Noblet, 1993). The ELF over the entire intestinal tract has been reported to vary from 6.1 to 8.7 g/kg DMI when high-oil corn (Adams and Jensen, 1984) or sunflower seeds (Adams and Jensen, 1985) was included in the diets, which is lower than our value of ELF (12.08 g/kg DMI) over the entire intestinal tract. The reason for the differences in the estimates of ELF between this experiment and previously reported values may be that the lowest concentrations of dietary fat and the range of concentrations of dietary fat were different among experiments, which are critical for regression coefficients (Dilger and Adeola, 2006). Fat sources (Freeman et al., 1968; López Bote et al., 2001), non-fat dietary components (Jørgensen et al. 1992a), and animals (Jørgensen et al. 1992b) may also influence the estimates of ELF.

The quantities of ELF at the end of the ileum and over the entire tract that were measured for intact fat were greater than for liquid fat. This may be explained by the greater concentration of fiber in diets containing intact fat compared with diets containing liquid fat. The greater concentration of dietary fiber may depress the absorption of dietary fat as well as the reabsorption of endogenous fat (e.g., bile acids) before the end of ileum, leading to increased amount of ELF both at the end of the ileum and over the entire intestinal tract (Bach Knudsen and Hansen, 1991; Smits and Annison, 1996). The greater concentration of dietary fiber may also facilitate microbial growth in the hindgut of pigs, which may increase the amount of ELF in the hindgut of pigs (Eyssen, 1973; Bach Knudsen et al., 1991). This may explain why the ELF for intact fat was greater over the entire intestinal tract than at the end of ileum, while the ELF for liquid fat was not different between collection sites.

Apparent and True Digestibility of Liquid Fat and Intact Fat

The values for apparent digestibility of liquid fat (81.9%) and of intact fat (63.2%) that were measured in this experiment are comparable to values measured in corn oil (80%; Carlson and Bayley, 1968) and in corn (59.6%; Adeola and Bajjalieh, 1997). The greater apparent digestibility of liquid fat than of intact fat agrees with previous results with soybeans (Agunbiade et al., 1992), palm kernels (Agunbiade et al., 1999), and sunflower seeds (San Juan and Villamide, 2000). Based on the data for ELF obtained in this experiment, it is concluded that the lower apparent digestibility of intact fat than of liquid fat is partly caused by the greater amount of ELF for intact fat than for liquid fat.

The TTTD of liquid fat (94.2%) estimated in this experiment is greater than the value (84.7%) for corn oil previously reported (Adams and Jensen, 1984), but it is within the range (91.2 to 97.7%) of the values reported for the TTTD of soy oil (Adams and Jensen, 1984; Jørgensen et al., 1993; Jørgensen and Fernández, 2000). The TID (78.6%) of intact fat is comparable with previously reported values of 77.0% TID of fat in diets containing a combination of feed ingredients (Shi and Noblet, 1993). However, the TTTD (84.1%) of intact fat was greater than the TTTD of fat in corn (77.6%), soybeans (72.1%), and sunflower seeds (75.0%) reported by Adams and Jensen (1984). The variation in TID and TTTD of fat among experiments may be due to the differences in dietary fat intake, diet composition, fat sources, and animals among experiments.

The greater true digestibility of liquid fat than of intact fat regardless of collection site implies that the greater apparent digestibility of liquid fat than of intact fat is not only caused by the lower amount of ELF for liquid fat than for intact fat. The greater true digestibility of liquid fat indicates that liquid fat may have physiochemical properties that make it easier to be digested and absorbed than intact fat. Intact fat may be encased in the membrane of fat cells and thus more resistant to the formation of emulsions and enzymatic digestion than liquid fat (Adams and Jensen, 1984; Bach Knudsen et al., 1993).

Apparent Digestibility of Fat vs. True Digestibility of Fat

The non-linear increase in apparent digestibility of fat as the concentration of dietary liquid fat or intact fat increased indicates that apparent digestibility of fat is influenced by dietary fat intake because of the relative contribution of ELF on total outflow of fat. Excluding the effect of ELF on apparent digestibility of fat, true digestibility of fat can be measured by correcting apparent digestibility with ELF and can be considered constant across dietary fat intake (Freeman et al.,1968; Adams and Jensen, 1984). This is supported by our results that dietary fat intake exhibited no linear or quadratic effect on TID and TTTD of liquid fat and TID of intact fat. However, TTTD of intact fat showed a quadratic relationship with dietary fat intake in this experiment. We have no clear explanation for this result. Therefore, our data confirm that true digestibility is superior to apparent digestibility for the determination of fat digestibility because of the independency of dietary fat intake.

Ileal vs. Total Tract Digestibility of Fat

The AID (73.6%) of fat measured in this experiment was not different from the ATTD (71.5%) of fat. This observation is in contrast with results showing that the ATTD of fat is lower than the AID of fat because of a net synthesis of fat in the hindgut of pigs (Shi and Noblet, 1993; Bakker, 1996). The reason for this difference may be that the greater concentrations of dietary NDF and different sources of dietary fiber were used in the previous experiments by Shi and Noblet (1993) and Bakker (1996), which may increase the synthesis of endogenous fat by microbes in the hindgut of pigs. Dietary fat is digested and absorbed before the end of the ileum (Low, 1980; Drackley, 2000) and thus the synthesis of endogenous fat in the hindgut of pigs contributes to the difference between AID and ATTD of fat. This is also confirmed by our results of no differences between the TID and TTTD of liquid fat or intact fat, indicating no net absorption of fat in the hindgut of pigs.

Effect of dietary NDF on Apparent and True Digestibility of Fat

Increasing dietary NDF did not influence the AID, TID, and TTTD of fat, but a quadratic effect of increasing dietary NDF on ATTD of fat was observed. These results were unexpected because it has been reported that increasing dietary NDF decreases the apparent digestibility of fat (Just et al., 1980; Bakker, 1996; Hensen et al., 2006). The depressive effect of fiber on fat digestibility may, however, be more associated with the characteristics of fiber (e.g., viscosity) rather than with the concentration of fiber (Fahey et al., 1990; Smits and Annison, 1996). Accordingly, purified NDF that was used in this experiment may interact less with fat in the intestinal tract than natural NDF (Schulze et al., 1995), possibly due to the simplified physicochemical structure of purified NDF, which may in turn lead to less depressive impact on apparent and true digestibility of fat compared with natural NDF (Sambrook, 1979).

In conclusion, results from this experiment indicate that liquid fat induces a lower ELF and has a greater apparent and true digestibility than intact fat at the end of the ileum and over the entire intestinal tract. The amount of ELF induced by intact fat is lower at the end of the ileum than over the entire intestinal tract because dietary fiber results in extra synthesis of endogenous fat in the hindgut. Apparent digestibility of fat and true digestibility of fat at the end of the ileum and over the entire intestinal tract are similar, which indicates that there is no net absorption of fat in the hindgut of pigs. Purified form of dietary NDF has little influence on apparent and true digestibility of fat.

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Table 3.1. Composition of experimental diets (as-is basis)

	Liquid fat				Dietary NDF addition			Intact fat			
Ingredient, % Diet:	1	2	3	4	5	6	7	8	9	10	11
Casein	9.50	9.50	9.50	9.50	9.50	9.50	9.50	8.00	8.00	8.00	8.00
Maize flaking grits	63.17	63.17	63.17	63.17	63.17	63.17	63.17	34.21	34.21	34.21	34.21
Defatted corn germ meal	-	-	-	-	-	-	-	36.60	24.40	12.20	-
Whole corn germ meal	-	-	-	-	-	-	-	-	12.20	24.40	36.60
Cornstarch	14.20	12.20	10.20	8.20	7.10	4.00	0.90	7.71	5.14	2.57	-
Corn oil	-	2.00	4.00	6.00	4.00	4.00	4.00	-	-	-	-
Sucrose	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Solka floc	-	-	-	-	3.10	6.20	9.30	-	2.57	5.14	7.71
Limestone	0.75	0.75	0.75	0.75	0.75	0.75	0.75	1.10	1.10	1.10	1.10
Monocalcium phosphate	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Potassium carbonate	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40

Table 3.1 (Cont.)

Magnesium oxide	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Salt	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin premix [1]	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Trace mineral premix [2]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Chromic oxide	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Analyzed composition, % (DM basis)											
Acid hydrolyzed fat	1.27	3.22	5.14	6.85	5.12	4.87	5.29	3.03	5.26	7.70	9.74
NDF	3.00	2.77	2.73	2.90	5.78	9.24	11.28	17.10	16.28	15.71	14.18

[1] Provided the following quantities of vitamins per kilogram of complete diet: Vitamin A, 6,594 IU as vitamin A acetate; vitamin D_3, 989 IU as D-activated animal sterol; vitamin E, 33 IU as alpha tocopherol acetate; vitamin K_3, 2.6 mg as menadione dimethylpyrimidinol bisulphite; thiamin, 2.0 mg as thiamine mononitrate; riboflavin, 5.9 mg; Pyridoxine, 2.0 mg as pyridoxine hydrochloride; vitamin B_{12}, 0.026 mg; D-pantothenic acid, 20 mg as calcium pantothenate; niacin, 33 mg; folic acid, 0.66 mg; and biotin, 0.1 mg.

Table 3.1 (Cont.)

[2] Provided the following quantities of minerals per kilogram of complete diet: Cu, 16 mg as copper sulfate; Fe, 165 mg as iron sulfate; I, 0.36 mg as potassium iodate; Mn, 44 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 165 mg as zinc oxide.

Table 3.2. Apparent ileal digestibility (AID) and apparent total tract digestibility (ATTD) of fat and total digested fat (TDF) in diets containing liquid fat or intact fat

		Liquid fat (g/kg DM)					*P*-value		Intact fat (g/kg DM)					*P*-value	
Items	Total fat:	12.7	32.2	51.4	68.5	SEM	Linear	Quadratic	30.3	52.6	77.0	97.4	SEM	Linear	Quadratic
AID of fat, %		70.6	81.9	87.7	89.1	1.11	<0.001	<0.001	52.7	65.1	71.1	70.0	1.46	<0.001	<0.001
$TADF_i$, g/kg DMI [1]		9.0	26.4	45.1	61.0	0.47	<0.001	0.387	16.0	34.3	54.7	68.1	0.88	<0.001	0.054
ATTD of fat, %		66.6	80.6	87.9	88.7	1.20	<0.001	<0.001	47.6	57.4	69.0	71.9	1.24	<0.001	0.020
$TADF_t$, g/kg DMI [2]		8.4	26.1	45.2	60.6	0.54	<0.001	0.908	14.4	30.2	53.1	70.0	0.73	<0.001	0.056

[1] $TADF_i$ = total apparently digested fat at the end of the ileum.

[2] $TADF_t$ = total apparently digested fat over the entire intestinal tract.

Table 3.3. Apparent digestibility (AD) of fat and total apparently digested fat (TADF) in diets containing liquid fat or intact fat

	Form of fat		Collection site			*P*-value[1]	
Items	Liquid fat	Intact fat	End of the ileum	Entire intestinal tract	SEM	Form of fat	Collection site
AD of fat, %	81.9	63.2	73.6	71.5	1.04	<0.001	0.160
TADF, g/kg DMI	35.1	42.9	39.3	38.6	2.29	0.017	0.829

[1] Interaction between form of fat and collection site was not significant.

Table 3.4. Regression of total apparently digested fat (g/kg DMI) at the end of the ileum and over the entire intestinal tract on dietary fat intake (g/kg DM)[1]

Items	Regression equation	SE of the slope	SE of the intercept	R^2	Estimated ELF[2] (g/kg DMI)	Estimated true digestibility of fat (%)
End of the ileum						
Liquid fat	$y = 0.938x - 3.28$	0.0117	0.531	0.99	3.28^{x}	93.8^{y}
Intact fat	$y = 0.786x - 7.27$	0.0179	1.245	0.98	7.27^{y}	78.6^{x}
Entire intestinal tract						
Liquid fat	$y = 0.942x - 3.77$	0.0140	0.637	0.99	3.77^{x}	94.2^{y}
Intact fat	$y = 0.841x - 12.08$	0.0156	1.083	0.99	12.08^{z}	84.1^{x}

^{x,y,z} Within a column, values lacking a common superscript are different ($P < 0.05$).

[1] n=44.

[2] ELF = endogenous losses of fat.

Table 3.5. True ileal digestibility (TID) of fat and true total tract digestibility (TTTD) of fat in diets containing liquid fat or intact fat

		Liquid fat (g/kg DM)					*P*-value		Intact fat (g/kg DM)					*P*-value	
Items	Total fat:	12.7	32.2	51.4	68.5	SEM	Linear	Quadratic	30.3	52.6	77.0	97.4	SEM	Linear	Quadratic
TID of fat, %[1]		96.3	92.1	94.1	93.9	1.23	0.309	0.076	76.7	78.9	80.5	77.4	1.46	0.474	0.062
TTTD of fat, %[2]		96.2	92.3	95.3	94.2	1.20	0.554	0.190	87.5	80.3	84.7	84.3	1.24	0.371	0.008

[1] TID = true ileal digestibility of fat by correcting apparent ileal digestibility of fat with the endogenous losses of fat derived from each form of fat at the end of ileum (3.28 g/kg DMI for liquid fat and 7.27 g/kg DMI for intact fat).

[2] TTTD = True total tract digestibility of fat by correcting apparent total digestibility of fat with the endogenous losses of intact fat derived from each form of fat over the entire intestinal tract (3.77 g/kg DMI for liquid fat and 12.08 g/kg DMI for intact fat).

Table 3.6. Effect of the inclusion of dietary NDF on apparent ileal digestibility (AID) and apparent total tract digestibility (ATTD) of fat, and true ileal digestibility (TID) and true total tract digestibility (TTTD) of fat

	NDF levels (g/kg DM):	27.3	57.8	92.4	112.8			P-value	
Items	Fat levels (g/kg DM):	51.4	51.2	48.7	52.9	Mean	SEM	Linear	Quadratic
AID of fat, %		87.7	86.6	87.5	87.6	87.4	0.70	0.799	0.254
ATTD of fat, %		87.9	86.3	86.0	87.0	86.9	0.71	0.186	0.043
TID of fat, %[1]		94.1	93.1	94.2	93.8	93.8	0.70	0.907	0.508
TTTD of fat, %[1]		95.3	93.8	93.7	94.1	94.3	0.71	0.145	0.130

[1] TID and TTTD of fat were corrected from the endogenous losses of fat estimated in diets containing liquid fat.

CHAPTER 4

OPERATIONAL NET ENERGY REQUIREMENT FOR MAINTENANCE IN GROWING AND FINISHING PIGS

ABSTRACT

An experiment was conducted to measure the operational NE requirement for maintenance (ONE_m) for growing and finishing pigs. The objective was to determine the effect of the stage of growth on ONE_m and to investigate if ONE_m differs for pigs at different experiment locations. The experiment was conducted at the University of Illinois (UIUC), the University of Missouri (MO), and the Prairie Swine Centre (PSC). Similar protocols were used at each location. A total of 48 growing (initial BW: 23 kg) and 48 finishing (initial BW: 83 kg) barrows were used at each location and within each stage of growth, pigs were allotted to 8 outcome groups of 6 barrows according to BW. Within each outcome group, pigs were randomly allotted to 1 of 6 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 4 dietary treatments and harvested at the conclusion of the experiment. All growing pigs and finishing pigs at MO and PSC were fed 1.40, 1.90, 2.40, or 2.90 times ME requirement for maintenance (ME_m), but finishing pigs at UIUC were fed 1.85, 2.20, 2.55, or 2.90 times ME_m. The ME_m was assumed to be 191 kcal/kg $BW^{0.6}\cdot d^{-1}$. 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$_{\text{m}}$ 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$_{\text{m}}$ were different ($P \leq 0.05$) among locations. The interaction between the stage of growth and location for ONE$_{\text{m}}$ was significant ($P < 0.01$). In conclusion, the NE:DE and ONE$_{\text{m}}$ for finishing pigs are greater than for growing pigs. Experiment location influences the NE:DE and ONE$_{\text{m}}$. The experiment location interacts with stage of growth on ONE$_{\text{m}}$, which suggests that different values for ONE$_{\text{m}}$ should be used for calculating the NE of diets measured in different stage of growth and experiment location.

Keywords: energy retention, maintenance requirement, net energy, pig, stage of growth, experiment location

INTRODUCTION

The NE of a diet is estimated as the sum of the energy retained and the amount of energy required for basic body functions (Baldwin, 1995); the latter is called the NE for maintenance (**NE$_{\text{m}}$**). The NE$_{\text{m}}$ is often estimated as fasting heat production (**FHP**), but FHP may not always be an accurate measure of NEm 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$_{\text{m}}$ 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 this regression 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**).

The reported estimates of ONE_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, 179 kcal/kg $BW^{0.6}$ (Noblet et al., 1994a) is used for ONE_m in European NE systems. However, various factors including animals and environment may influence the ONE_m (Baldwin and Bywater, 1984). Ideally ONE_m, therefore, should be measured under the same conditions as those used to measure the NE value of diets because of the direct impact of ONE_m on NE values (Boisen and Verstegen, 1998). No experiments have been conducted to investigate the effect of the BW of pigs and environment on the ONE_m of pigs in North America, leading to difficulties in measuring the NE of diets.

The objective of this study, therefore, was to estimate the ONE_m in both growing and finishing pigs to determine the impact of the stage of growth on ONE_m. The second objective was to determine if ONE_m is constant among different experiment 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 (**PSC**). Similar experimental protocols were used at each experiment location and all animal procedures were approved by the Institutional Animal Care and Use Committee at each experiment location.

Animals, Housing, and Experimental Design

A total of 144 growing and 144 finishing barrows were used (Table 4.1). 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 Ltd., Winnipeg, Manitoba, Canada). Pigs at MO were the offspring of C-22 females mated to T4 males (Pig Improvement Company, Hendersonville, TN). All pigs used in the experiment were selected based on BW and ADG during a 2 wk pre-experimental period. At each experiment location and within each stage of growth (growing and finishing stages), pigs were allotted according to BW to 8 outcome groups of 6 barrows. Within each outcome group, pigs were randomly allotted to 1 of 6 treatment groups with 8 pigs per treatment group. Two groups at each stage of growth and at each experiment location served as an initial slaughter group and all pigs in these 2 treatment groups were harvested at the start of the experiment. The remaining pigs were assigned to 4 dietary treatments and harvested at the conclusion of the experiment.

Pigs at each experiment location were housed individually in a pen equipped with a feeder and a nipple waterer in an environmentally controlled building. The individual BW of pigs was recorded weekly. Daily feed allowances were provided in 2 equal meals and water was available at all times. Orts were collected and weighed daily. The experimental period was 28 d for growing pigs and 35 d for finishing pigs.

Dietary Treatments

Each experiment location used similar diets consisting primarily of corn and soybean meal (Table 4.2). Diets were formulated to exceed current estimates of nutrient requirements (NRC, 1998) by at least 10% because pigs were restricted in their feed intake. Small difference in chemical composition of the diets reflected different nutrient profiles of local ingredients. Chromic oxide was included in the diets at UIUC and MO, and celite 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 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 $BW^{0.6}$. For a pig weighing 50 kg, this value is equivalent to 106 kcal/ kg $BW^{0.75}$ (NRC, 1998). Daily feed allowance was adjusted weekly according to the BW of each pig.

Samples 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 end 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 were then transported to the meat science laboratory at each experiment location, weighed again, and euthanized by captive-bolt stunning followed by exanguination. 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. Approximately 30 kg of the ground carcass was collected and further mixed in a mixer (Keebler Company, Chicago, IL). After 1 min of mixing, approximately 8 kg of carcass was collected and stored at -20°C. The frozen carcass samples were then 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. 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 then stored at 4°C overnight. The cooled viscera were ground in a Butcher Boy meat mincer using a 10 mm die followed by a second grind using a 2 mm die. Ground viscera were mixed and 2 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 freeze dried 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 weight of 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 2 times and a 5 mm die 2 times using a 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, 5 subsamples of 250 g were obtained as the material left the grinder. Each of these 5 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 5 subsamples were collected, lyophilized to a constant weight, and finely ground for chemical analyses.

Chemical Analyses

All 3 experiment locations followed similar procedures for chemical analyses for DM, energy, protein, 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 including carcass, viscera, and blood. 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 and fecal samples was determined by oven drying at 135°C for 2 h (method 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 (method 990.03; AOAC, 2005) and protein was calculated as N × 6.25. The concentration of lipids was determined using the ether extraction method (method 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 (method 962.09; AOAC, 2005). Diet samples were also analyzed for ash (method 942.05; AOAC, 2005).

Calculations

The apparent total tract digestibility 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 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. 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 according to previously outlined procedures (Oresanya et al., 2008). For linear regression analyses, the measurement of energy retention and DE intake were expressed as kcal/kg $BW^{0.6} \cdot d^{-1}$ based on the average metabolic BW calculated from the metabolic BW (kg $BW^{0.6}$) that was recorded each week during the experiment.

Statistical Analysis

All data were analyzed using the MIXED procedure (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. No outliers were identified. Orthogonal polynomial contrasts were used to determine linear and quadratic effects of the feeding level on growth performance, carcass composition, and retention of protein, lipids, and energy of pigs at each stage of growth within each experiment location. The LSMEANS procedure was used to calculate the mean values for all feeding levels. The individual pig was the experimental unit, and an alpha-value of 0.05 was used to assess significance among means.

Feeding levels with negative energy or lipid retention were not included in the regression analyses 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). Consequently, all growing pigs fed at the lowest feeding level at all 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 were excluded in 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 for an outlier, and therefore removed from the regression analyses.

Linear regression analyses were conducted to determine the relationship between energy retention (kcal/kg $BW^{0.6}\cdot d^{-1}$) and DE intake (kcal/kg $BW^{0.6}\cdot d^{-1}$) at each stage of growth within each experiment 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 experiment 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 × DE intake, location × DE intake, stage of growth × location, and stage of growth × location × DE intake). The stage of growth and experiment location were fixed effects in the model. If there was no interaction, the interaction terms were sequentially removed from the model.

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 4.3), MO (Table 4.4), and PSC (Table 4.5) 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 digesta-free BW increased (linear, $P < 0.01$) with feeding level at all experiment 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 experiment locations as feeding level increased. Lipid gain:protein gain also increased (linear, $P < 0.05$ at UIUC and MO; linear and quadratic, $P < 0.01$ at PSC) with feeding level.

In the finishing phase, ADG for finishing pigs increased (linear and quadratic, $P < 0.01$ at UIUC; linear, $P < 0.01$ at MO and PSC) as feeding level increased. The G:F increased (linear and quadratic, $P < 0.05$) with feeding level at all experiment locations. 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 experiment 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 experiment 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 experiment locations.

Operational Net Energy Requirement for Maintenance

The NE:DE 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) and the NE:DE tended to be different ($P = 0.05$) among locations (Table 4.6). There was no interaction between stage of growth and location on 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) than for growing pigs (128, 115, and 78 kcal/kg $BW^{0.6}\cdot d^{-1}$ at UIUC, MO, and PSC). 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 for growing pigs at UIUC and PSC than for finishing pigs, but the ONE_m was not different between growing and finishing pigs at MO.

DISCUSSION

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

An increase in growth performance, carcass composition, and retention of energy, protein, and lipids was observed for growing and finishing pigs at all 3 locations as feeding level increased. This result was expected and agrees with previous observations (de Greef, 1992; Bikker et al., 1995, 1996a,b). The linear increase in protein gain with feeding level observed in this experiment supports the concept of a linear-plateau deposition of protein to energy intake (Whittemore and Fawcett, 1976). 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, we observed protein gain of 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 et al., unpublished data). This result was obtained from pigs that had similar BW and reared under similar experimental conditions as those used at UIUC in this experiment. 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. The increase in lipid gain:protein gain that was observed for growing pigs and finishing pigs 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 mobilize body lipids to support protein retention if they are fed near or below the energy requirement for maintenance (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 ME_m 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, 1999; Noblet et al., 1994a). However, the large variation in ME_m among locations implies that it is inaccurate to use 1 value for ME_m at all locations.

Operational Net Energy Requirement for Maintenance

The values for NE:DE for growing pigs estimated in this experiment is lower than the value of 0.70 that has been reported (Noblet et al., 1994a). However, the value for NE:DE for finishing pigs at UIUC and PSC is close to the value of 0.70 reported by Noblet et al. (1994a). Diet composition and methodology used in the experiments (Just, 1982; Chwalibog, 1991; Birkett and de Lange, 2001), and the environment (Black, 1995; Le Bellego et al., 2002) may influence the estimate for NE:DE. Therefore, it is likely that the difference in NE:DE among locations may be explained by differences in environmental factors among locations. 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 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 different at each location.

The greater ONE_m for finishing pigs than for growing pigs 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). According to Birkett and de Lange (2001), the ONE_m is affected by the NE:DE because of the strong correlation between slope and intercept in the regression line. In the present experiment, the greater NE:DE for finishing pigs than for growing pigs, which was caused by the increased lipid retention in finishing pigs, lead to a steeper slope of the regression line, which resulted in a lower y-intercept and, therefore, a greater estimate for ONE_m in finishing pigs is obtained than growing pigs.

The ONE_m varied among locations. 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 $BW^{0.6}$. This observation agrees with Wenk et al. (1980) who reported large variations in ME_m among different experiments. The variation in ONE_m among previous experiments is mainly caused by differences in animal factors (Just et al., 1983; Noblet et al., 1994b, 1999; Knap, 2000), and environmental factors (Chwalibog, 1991; Close, 1996; Birkett and de Lange, 2001). Noblet and Henry (1991) suggested that the ONE_m would be similar if the experimental conditions such as animal and environment factors are similar. 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 locations. It has 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 for diets that are calculated from different NE systems is primarily caused by differences in ONE_m among systems (Noblet et al., 1994a). Therefore, it can be expected that the calculated NE values of diets or ingredients will depend on the location due to different values for ONE_m among locations. However, NE of diets or ingredients measured at each location will have the same hierarchy of NE values among diets and ingredients although the absolute values of NE may change with each location (de Lange et al., 2006).

In conclusion, results from this experiment indicate that experiment location affects the NE:DE and ONE_m, and the location interacts with stage of growth on ONE_m. Therefore, the use of a constant ONE_m is inaccurate for calculating the NE of diets and ingredients measured at different stages of growth and at different locations.

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Table 4.1. Experimental conditions at participating experiment locations

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

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

Table 4.2. Ingredient composition of experimental diets[1] (as-fed basis)

	Growing pigs			Finishing pigs		
Items	UIUC	MO	PSC	UIUC	MO	PSC
Ingredients, %						
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
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_2O_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

Table 4.2 (Cont.)

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

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

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

[3] Commercial vitamin and mineral premix available at each station were used.

[4] Celite (Celite corporation, Lompoc, CA), provided as a source of acid insoluble ash; Composition: moisture, 0.8%; SiO2, 89.4%; Na_2O, 3.8%; Al_2O_3, 3.4%; Fe_2O_3, 1.3%; MgO, 0.6%; CaO, 0.5%; and TiO_2, 0.2%.

[5] Data for ME, Lys, Ca, and bioavailable P were calculated from NRC (1998).

Table 4.3. Effects of feeding levels on growth performance, carcass composition, and retention of protein, lipids, and energy of pigs[1,2] (University of Illinois)

	Growing pigs					Finishing pigs					Growing pigs			Finishing pigs		
												P-value[4]			*P*-value[4]	
Feeding levels:	ISG[3]	1.4	1.9	2.4	2.9	ISG[3]	1.85	2.2	2.55	2.9	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		29.69	35.38	40.31	44.31		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
Carcass composition																
DF BW,[5] 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, 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

Table 4.3 (Cont.)

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,[6] 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,[7] 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,[8] 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

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

[2] Data are least square means.

Table 4.3 (Cont.)

[3] ISG = initial slaughter group.

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

[5] Digesta-free BW = the sum of the weight of chilled carcass, empty viscera, and blood.

[6] Lipid:protein = the ratio of daily lipid gain to daily protein gain.

[7] MER = measured energy retention obtained from bomb calorimetry analyses.

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

Table 4.4. Effects of feeding levels on growth performance, carcass composition, and retention of protein, lipids, and energy of pigs[1,2] (University of Missouri)

	Growing pigs					Finishing pigs					Growing pigs			Finishing pigs		
												P-value[4]			*P*-value[4]	
Feeding levels:	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		25.74	31.81	36.43	41.05		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
Carcass composition																
DF BW,[5] 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, 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

Table 4.4 (Cont.)

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,[6] 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,[7] 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,[8] 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

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

[2] Data are least square means.

Table 4.4 (Cont.)

[3] ISG = initial slaughter group.

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

[5] Digesta-free BW = the sum of the weight of chilled carcass, empty viscera, and blood.

[6] Lipid:protein = the ratio of daily lipid gain to daily protein gain.

[7] MER = measured energy retention obtained from bomb calorimetry analyses.

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

Table 4.5. Effects of feeding levels on growth performance, carcass composition, and retention of protein, lipids, and energy of pigs[1,2] (Prairie Swine Centre)

	Growing pigs					Finishing pigs					Growing pigs			Finishing pigs		
												P-value[4]			*P*-value[4]	
Feeding levels:	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	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		28.55	33.30	37.42	42.21		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
Carcass composition																
DF BW,[5] 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, 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

Table 4.5 (Cont.)

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,[6] 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,[7] 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,[8] 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

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

[2] Data are least square means.

Table 4.5 (Cont.)

[3] ISG = initial slaughter group.

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

[5] Digesta-free BW = the sum of the weight of chilled carcass, empty viscera, and blood.

[6] Lipid:protein = the ratio of daily lipid gain to daily protein gain.

[7] MER = measured energy retention obtained from bomb calorimetry analyses.

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

Table 4.6. Effects of stage of growth and experiment location on the efficiency of DE intake to energy retention and operational net energy requirement for maintenance (ONEm) in growing and finishing pigs[1,2,3]

Stage of growth:	Growing pigs			Finishing pigs			*P* – value[4]		
Locations:	UIUC	MO	PSC	UIUC	MO	PSC	Stage	Location	Stage × Location
Efficiency[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

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

[2] Number of observation: n = 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.

[3] Values for NE:DE and ONE_m represented 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 experiment location were determined using an analysis of covariance with DE intake as a covariate (Noblet et al., 1994b; Littell et al., 1996).

Table 4.6 (Cont.)

[5] Efficiency of DE utilization for energy retention (NE:DE).

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

CHAPTER 5

NET ENERGY OF SOYBEAN OIL AND CHOICE WHITE GREASE IN DIETS FED TO GROWING AND FINISHING PIGS

ABSTRACT

An experiment was conducted to determine the NE of 2 sources of dietary lipids in growing and finishing pigs and to evaluate the effects of inclusion rate of dietary lipids on the NE of lipids in growing and finishing pigs. Soybean oil (SBO) and choice white grease (CWG) were used. Forty eight growing (initial BW: 22 kg) and 48 finishing (initial BW: 84 kg) barrows were used, and within each stage of growth, pigs were allotted to 8 outcome groups of 6 barrows based on BW. Within each outcome group, pigs were randomly allotted to 1 of 6 treatment groups. Two treatments at each stage of growth served as an initial slaughter group. The remaining pigs were assigned to 4 different diets and harvested at the conclusion of the experiment. The basal diet contained corn, soybean meal, and no supplemental lipids. Three additional diets were formulated by mixing 95% of the basal diet and 5% of SBO, 90% of the basal diet and 10% of SBO, and 90% of the basal diet and 10% of CWG. Results showed that ADG and G:F for finishing pigs and apparent total tract digestibility of energy for growing and finishing pigs increased (linear, $P < 0.05$) with lipid level, but was not affected by lipid source. The lipid gain:protein gain and energy retention also increased (linear, $P \leq 0.05$) with lipid level in growing and finishing pigs. There was no interaction between lipid level and stage of growth or between lipid source and stage of growth on the NE of diets and ingredients. The NE of diets increased (linear, $P < 0.01$) with increasing level of SBO (2,032, 2,186, and 2,292 kcal/kg for diets containing 0, 5, or 10% SBO). The NE of the diet containing 10% CWG (2,431 kcal/kg) was greater ($P < 0.05$) than the NE of the diet containing 10% SBO. The average NE of diets was greater ($P < 0.01$) for finishing pigs (2,509 kcal/kg) than for growing pigs (1,961 kcal/kg). The NE of SBO included at 5% (5,102 kcal/kg) was not different from the NE of SBO included at 10% (4,619 kcal/kg), but the NE of CWG (6,017 kcal/kg) was greater ($P < 0.05$) than the NE of SBO. The stage of growth had no impact on the NE of lipids. In conclusion, the NE of diets increases with lipid level. The NE of lipids is not affected by the level of dietary lipids, but the NE of CWG is greater than the NE of SBO.

Key words: choice white grease, inclusion rate, NE, pig, soybean oil, stage of growth

INTRODUCTION

Lipids are valuable ingredients in swine diets because of their high energy concentration (Stahly, 1984). Currently, DE and ME systems are used in North America to predict the energy values of dietary lipids, but these systems have been criticized because they do not account for the energetic efficiency of metabolizing dietary lipids (de Lange and Birkett, 2005), and DE and ME systems may underestimate the energy value of dietary lipids (Noblet et al., 1994a). Therefore, it has been suggested that NE systems allow for a more accurate prediction of the energy value of dietary lipids than DE and ME systems (Noblet et al., 1994a).

Dietary lipids are digested, absorbed, and either oxidized to yield energy in the form of ATP or incorporated into body lipids (Birkett and de Lange, 2001). In theory, the energetic efficiency of dietary lipids for ATP production is 66%, while the efficiency is 90% if they are directly incorporated into body lipids (Black, 1995).

Therefore, the NE of dietary lipids is influenced not only by the digestibility, but also by the metabolic utilization (de Lange and Birkett, 2005). Both source and inclusion rate of dietary lipids may affect lipid digestibility (Stahly, 1984) and lipid metabolism in pigs (Allee et al., 1971, 1972). The stage of growth (growing vs. finishing pigs) may also affect the metabolic utilization of dietary lipids because finishing pigs have a greater potential for lipid deposition than growing pigs (de Greef et al., 1994). These factors are, therefore, expected to affect the NE of dietary lipids, but these hypotheses have not been investigated.

The objectives of this experiment, therefore, were to determine the NE of 2 sources of dietary lipids (i.e., soybean oil and choice white grease) in growing and finishing pigs and to evaluate the effects of inclusion rate of dietary lipids on the NE of lipids in growing and finishing pigs.

MATERIALS AND METHODS

Animals, Housing, and Experimental Design

The experiment was approved by the Institutional Animal Care and Use Committee at the University of Illinois. The experiment was conducted using 48 growing and 48 finishing barrows that were the offspring of line 337 sires mated to C-22 females (Pig Improvement Company, Hendersonville, TN). The average initial BW of pigs was 22.13 ± 1.78 kg and 84.17 ± 5.80 kg for growing and finishing pigs, respectively. All pigs used in the experiment were selected based on BW and ADG during a 2-wk pre-experimental period. Within each stage of growth, pigs were allotted to 8 outcome groups of 6 barrows according to BW. Within each outcome group, pigs were randomly allotted to 1 of 6 treatment groups. Two treatment groups at each stage of growth served as an initial slaughter group and all pigs in these 2 treatment groups (n = 16) were harvested at the start of experiment. The remaining 4 treatment groups within each stage of growth were assigned to 4 dietary treatments and all pigs (n = 32) in these treatment groups were harvested at the conclusion of the experiment.

Pigs were housed individually in 0.9 × 1.8 m pens in an environmentally controlled building. Pens were equipped with a feeder, a nipple waterer, and a fully-slatted concrete floor. The experimental period was 28 d for growing pigs and 35 d for finishing pigs.

Dietary Treatments

Commercial sources of soybean oil (**SBO**) and choice white grease (**CWG**) were obtained and analyzed for chemical composition (Table 5.1). Four diets at each stage of growth were formulated (Table 5.2). The basal diet contained corn, soybean meal, and no supplemental dietary lipids. Three additional diets were formulated by mixing 95% of the basal diet and 5% of SBO (as-is basis), 90% of the basal diet and 10% SBO (as-is basis), and 90% of the basal diet and 10% of CWG (as-is basis). Chromic oxide (0.50%) was included as an indigestible marker in the basal diet. Vitamins and trace minerals were also included in the basal diet to exceed the estimated nutrient requirements (NRC, 1998) for pigs at each stage of growth. No antibiotic growth promoters were used and all diets were provided in a meal form. Pigs were allowed ad libitum access to feed and water during the entire experimental period.

Collection of Data and Samples

The BW of pigs was recorded at the initiation of the experiment and at the end of each week thereafter. The allotment of feed to each pig was recorded daily and feed left in the feeder was recorded on the same day as the BW of pigs was recorded. At the end of the experiment, ADG, ADFI, and G:F for each pig were calculated and summarized within treatment and stage of growth.

Fresh fecal samples were collected on d 7 from each pig by grab sampling. Fecal samples collected each week were pooled within pig at the end of the experiment, lyophilized, and finely ground before chemical analyses.

The comparative slaughter procedure was used to estimate the retention of energy, protein, and lipids in pigs fed each diet (de Goey and Ewan, 1975). Slaughter procedures and carcass measurements were similar to those previously described (Kil et al., unpublished data). In short, carcass, viscera, and blood were collected from each pig at harvest and processed separately. The digestive tract was flushed with water to remove digesta. All carcass and viscera were ground to obtain subsamples and all subsamples of carcass, viscera, and blood were lyophilized and finely ground prior to chemical analyses.

Chemical Analyses

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 and fecal samples was determined by oven drying at 135°C for 2 h (method 930.15; AOAC, 2005). The DM of body components (i.e., carcass, viscera, and blood) was calculated by freeze drying to a constant weight. The GE of diets, feces, 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 in diets, feces and body components was measured using the combustion method (method 990.03; AOAC, 2005) on an Elementar Rapid N-cube protein/nitrogen apparatus (Elementar Americas Inc., Mt. Laurel, NJ). Aspartic acid was used as a calibration standard and CP was calculated as N × 6.25. The concentration of lipids in diets and body components was determined using the petroleum ether extraction method (method 2003.06; AOAC, 2005) on a Soxtec 2050 automated analyzer (FOSS North America, Eden Prairie, MN). The concentration of total lipids in diets and feces was measured after acid hydrolysis followed by ether extraction (method 996. 01; AOAC, 2005). Diets and fecal samples were analyzed for concentrations of chromium (Fenton and Fenton, 1979). The crude fiber concentration in diets was measured using the Weende method (method 962.09; AOAC, 2005). Diet samples were also analyzed for ash (method 942.05; AOAC, 2005).

Calculations

The apparent total tract digestibility (**ATTD**) of energy, CP, and acid-hydrolyzed ether extract in diets fed to each treatment group was calculated according to Chastanet et al. (2007). Total amount of energy, protein, and lipids in each pig at harvest was calculated from the sum of the energy, protein, and lipids in the blood, viscera, and carcass. 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). Energy retention was also calculated from protein gain and lipid gain (Ewan, 2001).

Lipid gain from non-lipid nutrients was calculated from the difference between the lipid gain and the intake of digestible lipid, assuming that all digested lipids were incorporated into body lipids without being utilized for ATP synthesis (Chwalibog et al., 1992). The standardized total tract digestibility (**STTD**) of lipids was used to calculate the amount of digested lipids. The STTD of lipids was calculated from the ATTD of lipids after correction for basal endogenous losses of lipids (9 g/kg DM intake, Boisen, 2007).

The daily operational NE requirement for maintenance for each pig was calculated by multiplying the mean metabolic body weight ($kg^{0.6}$) by 128 kcal for growing pigs and 219 kcal for finishing pigs (Kil et al., unpublished data). The NE for each diet was then calculated from the sum of energy retention and total operational NE requirement for maintenance (Ewan, 2001). The NE of SBO and CWG were subsequently calculated using the difference method by subtracting the NE contribution from the basal diet from the NE of the diets containing SBO or CWG (de Goey and Ewan, 1975).

Statistical Analyses

All data were analyzed using the MIXED procedure (SAS Inst. Inc., Cary, NC) with the individual pig as the experimental unit. Homogeneity of the variances was verified using the UNIVARIATE procedure of SAS. The residual vs. the predicted plot procedure was used to analyze for outliers. One finishing pig was identified as an outlier and this pig was excluded from the analysis. Diet was the main effect in the model. The LSMEANS procedure was used to calculate mean values. Orthogonal polynomial contrasts were used to determine linear and quadratic effects of the inclusion rate of SBO on growth performance, nutrient digestibility, carcass measurements, and retention of protein, lipids, and energy at each stage of growth. The interaction between lipid level and stage of growth or between lipid source and stage of growth for the NE of diets or lipids was analyzed. However, the interaction was not significant for any of the calculated values for NE of diets or lipids, and therefore, was omitted in the final analysis. An alpha-value of 0.05 was used to assess significance among means.

RESULTS

Pig Performance and Nutrient Digestibility

Final BW, ADG, and ADFI for growing pigs were not affected by dietary level or source of lipids, but a trend for an increase in G:F (linear, $P = 0.08$) was observed as the level of dietary lipids increased (Table 5.3).The ADG and G:F for finishing pigs increased (linear, $P < 0.05$) with increasing level of dietary lipids, but was not affected by lipid source. A trend for greater ($P = 0.06$) ADFI was observed for finishing pigs fed diets containing 10% SBO compared with finishing pigs fed diets containing 10% CWG. For both growing and finishing pigs, the ATTD of energy increased (linear, $P < 0.01$) as the level of dietary lipids increased. The ATTD of acid-hydrolyzed ether extract also increased (linear and quadratic, $P < 0.01$) with lipid level. The ATTD of CP was not affected by lipid level for growing pigs, but a trend for an increase (linear, $P = 0.09$) in ATTD of CP by increasing lipid level was observed for finishing pigs. The ATTD of acid-hydrolyzed ether extract tended to be greater ($P = 0.07$) for growing pigs fed diets containing 10% SBO than growing pigs fed diets containing 10% CWG.

Carcass Composition and Retention of Energy, Protein, and Lipids

In the growing phase, live BW, hot carcass weight, and dressing percentage were not influenced by dietary level or source of lipids (Table 5.4). The weight of total digesta-free body DM increased (linear, $P < 0.05$), but the concentration of protein in the digesta-free body DM decreased (linear, $P < 0.01$) as the level of dietary lipids increased. The concentration of lipids and energy in the digesta-free body DM was greater ($P < 0.01$) for pigs fed the diet containing 10% CWG than for pigs fed the diet containing 10% SBO. Total amount of energy, lipid gain:protein gain, and measured energy retention increased (linear, $P < 0.05$) with increasing level of lipids, but protein gain was not affected by the level of dietary lipids. A trend for an increase (linear, $P = 0.07$) in lipid gain was observed as the level of dietary lipids increased. Lipid gain, lipid gain:protein gain, and calculated energy retention was greater ($P < 0.01$) for pigs fed the diet containing 10% CWG than for pigs fed the diet containing 10% SBO. Measured energy retention also tended to be greater ($P = 0.06$) for pigs fed the diet containing 10% CWG than pigs fed the diet containing 10% SBO.

In the finishing phase, hot carcass weight increased (linear, $P < 0.05$) with increasing level of dietary lipids, but that was not the case for live weight and dressing percentage (Table 5.5). Live weight, hot carcass weight, and dressing percentage were not affected by lipid source. Likewise, the weight of the digesta-free body DM and the concentration of lipids and energy in the digesta-free body DM were not influenced by dietary level or source of lipids. However, the concentration of protein in the digesta-free body DM decreased (linear, $P < 0.01$) with increasing level of dietary lipids and pigs fed the diet containing 10% CWG had greater ($P < 0.05$) concentration of protein in the digesta-free body DM than pigs fed the diet containing 10% SBO.

Total amount of protein, lipids, and energy, protein gain, and lipid gain were not affected by dietary level or source of lipids, but lipid gain:protein gain increased (linear, $P < 0.05$) with increasing level of dietary lipids. A trend for an increase (linear, $P = 0.05$) in measured energy retention was also observed as the level of dietary lipids increased, but the calculated energy retention was not influenced by the level or source of dietary lipids.

Based on the data for ADFI and STTD of lipids, the amount of body lipid gain from digested lipids or from non-lipid nutrients was calculated (Table 5.6). The STTD of lipids increased (linear and quadratic, $P < 0.01$) with lipid level. Total amount of digested lipids also increased (linear, $P < 0.01$) as the level of dietary lipids increased. The amount of lipid gain from non-lipid nutrients decreased (linear, $P < 0.01$) with increasing level of dietary lipid for growing and finishing pigs. Lipid gain from non-lipid nutrients for growing pigs fed the diet containing 10% CWG was greater ($P < 0.01$) than for growing pigs fed the diet containing 10% SBO.

NE of Diets and Dietary Lipids

For growing pigs, no difference among treatment groups in initial body energy was observed, but the final amount of energy, energy retention, and NE intake increased (linear, $P < 0.05$) as the level of dietary lipids increased (Table 5.7). The final amount of energy in the digesta-free body was greater ($P < 0.05$) for pigs fed the diet containing 10% CWG than for pigs fed the diet containing 10% SBO, and energy retention and NE intake tended to be greater ($P = 0.06$) for pigs fed the diet containing 10% CWG than for pigs fed the diet containing 10% SBO.

The NE of diets increased (linear, $P < 0.01$) as dietary SBO increased (1,762, 1,889, and 2,036 kcal/kg for diets containing 0, 5, and 10% SBO). The NE of the diet containing 10% CWG (2,158 kcal/kg) tended to be greater (*P* = 0.05) than the NE of the diet containing 10% SBO. The difference in values for the NE of SBO was not significant when SBO was included at 5% (4,301 kcal/kg) or at 10% (4,509 kcal/kg) in diets, but the NE of CWG (5,727 kcal/kg) tended to be greater (*P* = 0.05) than the NE of SBO.

For finishing pigs, no difference in initial or final amount of body energy was observed, but a trend for an increase (linear, *P* = 0.06) in energy retention and in NE intake was observed as the level of dietary lipids increased. However, energy retention and NE intake were not affected by lipid source. The NE of diets increased (linear, *P* < 0.05) as the level of dietary lipids increased (2,303, 2,483, and 2,545 kcal/kg for diets containing 0, 5, and 10% SBO). The NE of diets containing 10% CWG (2,703 kcal/kg) was not different from the NE of diets containing 10% SBO. The NE of SBO included at 5% (5,904 kcal/kg) was not different from the NE of SBO included at 10% (4,729 kcal/kg) and the NE of CWG (6,307 kcal/kg) was not different from the NE of SBO.

There was no interaction between lipid level and stage of growth or between lipid source and stage of growth, and therefore, the main effects of lipid level, lipid source, and stage of growth on NE of diets and lipids were calculated (Table 5.8). The NE of diets increased (linear, *P* < 0.01) with increasing level of SBO (2,032, 2,186, and 2,292 kcal/kg for diets containing 0, 5, and 10% SBO). The NE of the diet containing 10% CWG (2,431 kcal/kg) was greater (*P* < 0.05) than NE of the diet containing 10% SBO. The average NE of diets was greater (*P* < 0.01) for finishing pigs (2,509 kcal/kg) than for growing pigs (1,961 kcal/kg) regardless of the dietary level or source of lipids. The NE of SBO included at 5% (5,102 kcal/kg) was not different from the NE of SBO included at 10% (4,619 kcal/kg), but the NE of CWG (6,017 kcal/kg) was greater ($P < 0.05$) than the NE of SBO. Stage of growth had no influence on the NE of dietary lipids.

DISCUSSION

The composition of fatty acids in SBO and CWG corresponds to published values (NRC, 1998; Engel et al., 2001). The fatty acid composition of CWG used in this experiment is also similar to the fatty acid composition in fat from pigs or poultry (Jørgensen and Fernández, 2000).

Pig Performance and Nutrient Digestibility

The observation for improved G:F for growing and finishing pigs as a result of increasing level of dietary lipids agrees with previous observations (Pettigrew and Moser, 1991; Øverland et al., 1999; de la Llata et al., 2001). It was unexpected that the level of dietary lipids did not influence ADFI for growing or finishing pigs because pigs often reduce feed intake as the dietary energy concentration increases (Pettigrew and Moser, 1991; de la Llata et al., 2001). The reason for this observation may be that dietary energy concentration is not the only factor that determines feed intake (Black, 1995; Giles et al., 1998; Nyachoti et al., 2004). Other factors such as the number of pigs in a pen (Gomez et al., 2000; Hyun and Ellis, 2001), ambient temperature, health status of pigs, and physical properties of feed (Whittemore et al. 2001; Nyachoti et al., 2004) may also affect feed intake of pigs.

The increase in ATTD of energy with increasing levels of dietary lipids for both growing and finishing pigs may be a result of the decreased concentration of crude fiber in diets containing lipids. Lipids have greater energy concentration than other ingredients, which also may have contributed to this observation. The increased ATTD of lipids with increasing levels of dietary lipids was expected because the supplemental lipids are liquid, and lipids supplied in a liquid form have a greater digestibility than lipids supplied in an intact form (Kil et al., 2007). The relative effect of endogenous losses on the ATTD of lipids decreases as the concentration of dietary lipids increases, which also leads to a greater measured value for ATTD of lipids at high level of dietary lipids (Jørgensen et al., 1993; Kil et al., 2007).

Saturated lipids may be less digestible than unsaturated lipids (Wiseman et al., 1990; Powles et al., 1994; Scheeder et al., 2003), but we were not able to verify this observation because the ATTD of lipids was similar for pigs fed diets containing SBO or CWG. The reason for this discrepancy may be that the CWG used in this experiment was less saturated than tallow used in previous experiments (Wiseman et al., 1990; Powles et al., 1994; Scheeder et al., 2003).

Carcass Composition and Retention of Energy, Protein, and Lipids

The protein gain in growing (161 g/d) and finishing pigs (171 g/d) fed the basal diet is slightly greater than the values reported by Quiniou et al. (1996) who suggested that the potential maximum for protein gain is 151 g/d for growing and finishing pigs allowed free access to feed. The increase in lipid gain:protein gain and in energy retention that was obtained for growing and finishing pigs as the level of dietary lipids increased was a result of increased lipid gain with no change in protein gain, which is an often observed response to increased levels of dietary lipids (Stahly, 1984).

The decrease in body lipid gain from non-lipid nutrients with increasing level of dietary lipid has been previously reported (Chwalibog and Thorbek, 1995).

Calculations based on ADFI and the STTD of lipids showed that growing pigs fed the diet containing 10% SBO absorbed 226 g of lipids/d, but gained 176 g of lipids/d, which indicates that some of the digested SBO was utilized for ATP synthesis rather than being directly incorporated into body lipids (Chwalibog and Thorbek, 1995). This observation agrees with Jakobsen et al. (2001) who reported increased oxidation of digested lipids in growing pigs when the level of dietary rapeseed oil was greater than 8%. This observation indicates that the NE of lipids may decrease with high inclusion rate in diets because the lower energetic efficiency of utilizing digested lipids for ATP synthesis than for body lipids (Black, 1995).

NE of Diets and Dietary lipids

The values for NE of diets for growing and finishing pigs measured in this experiment are lower than values calculated from the NE of each ingredient (Sauvant et al., 2004). The reason for this difference may be that the value for the assumed maintenance requirement used by Sauvant et al. (2004) is greater than the values used in the present experiment. Different methodologies to measure energy retention also affect the NE of diets. Energy retention may be greater if it is measured by indirect calorimetry, which was used by Sauvant et al. (2004), compared with measurements based on the comparative slaughter method, which was used by this experiment (Quiniou et al., 1995; Reynolds, 2000).

An increase in the NE of diets containing increased levels of dietary lipids has been observed in other experiments (Just, 1982) and is caused by the greater NE concentration in lipids compared with corn and soybean meal. Increasing levels of dietary lipids also increase the digestibility of AA (Cervantes-Pahm and Stein, 2008) and may decrease the proportion of digested energy in the hindgut of pigs where the absorbed energy has a lower efficiency compared with energy absorbed in the small intestine (Just, 1982; Noblet et al., 1994a).

The greater NE of the diet containing 10% CWG than for the diet containing 10% SBO may be a consequence of increased utilization of dietary energy for lipid gain because the energetic efficiency for lipid gain is greater than for maintenance and for protein gain (Just et al., 1983; Black, 1995). Pigs fed the diet containing 10% CWG gained more lipids than pigs fed the diet containing 10% SBO (on average 361 vs. 340 g/d, respectively). The SBO contains more unsaturated fatty acids than CWG, and therefore, may increase the maintenance requirement for pigs because unsaturated fatty acids may increase the oxidative stress in pigs (López Bote et al., 2001).

The greater NE of diets for finishing pigs than for growing pigs regardless of the dietary level or source of lipids is a consequence of finishing pigs having a greater digestibility of energy and nutrients (Noblet and Shi, 1994) and a greater potential for lipid gain than growing pigs (de Greef et al., 1994).

The values for NE of SBO are lower than the value for NE of dietary lipids that was suggested by Sauvant et al. (2004) and also lower than the value of rapeseed oil estimated by Noblet et al. (1994b) and Jørgensen et al. (1996). One reason for the different estimates of NE in SBO among experiments may be that different estimates for the maintenance requirement and different methodologies to measure energy retention were used.

There was no effect of inclusion rate of dietary lipid on the NE of SBO although the ATTD for acid hydrolyzed ether extract was greater when 10% rather than 5% SBO was included in the diet. However, at the low inclusion rate, the majority of the absorbed lipids may be directly incorporated into body lipids, which has an energetic efficiency of 90% (Black, 1995). When the greater amount of SBO was included in the diet, a greater proportion of the absorbed lipids may be oxidized to ATP, which has an energetic efficiency of 66% (Black, 1995). Therefore, the results of this experiment suggest that the increased ATTD of acid hydrolyzed ether extract at high inclusion rates is negated by a reduced efficiency of utilization, and therefore, the inclusion rate of dietary lipids has little influence on the NE of dietary lipids.

Dietary SBO may increase the rate of turnover of triacylglyceride in adipose tissue because of increased susceptibility to oxidation in body tissue (López Bote et al., 2001) and more rapid incorporation into body lipids (Karola et al., 2002) compared with fatty acids from CWG. Polyunsaturated fatty acids in SBO may also increase the rate of β-oxidation via the activation of carnitine palmitoyl transferase (Gavino and Gavino, 1991) and increased activity of lipoprotein lipase in muscle (Shimomura et al., 1990), and therefore, may be more rapidly oxidized than saturated fatty acids in the body (Cunnane, 2004; Kloareg et al., 2007; Mitchaothai et al., 2008). Therefore, a greater proportion of fatty acids in SBO may be utilized for ATP synthesis than fatty acids in CWG. As a consequence, the NE of dietary lipids containing saturated fatty acids may be greater than the NE of dietary lipids containing unsaturated fatty acids, which may be the reason why the NE of CWG was greater than the NE of SBO.

There were no interactions between lipid level and stage of growth or between lipid source and stage of growth. This observation indicates that the effect of lipid level or lipid source on the NE of diets and lipids is not influenced by the stage of growth.

In conclusion, results from this experiment indicate that the NE of diets increases as the level of dietary lipids increases and the NE of diets containing CWG is greater than the NE of diets containing SBO. The NE of diets is also greater for finishing pigs than for growing pigs regardless of the level or source of lipids. The NE of lipids is not affected by the inclusion rates of lipid in diets, but the NE of CWG is greater than the NE of SBO. Stage of growth has no influence on the NE of lipids.

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Table 5.1. Analyzed composition of soybean oil and choice white grease (as-fed basis)

Composition	Soybean oil	Choice white grease
GE, mcal/kg	9.38	9.41
Acid ether extract,[1] %	98.9	98.4
Total M.I.U.,[2] %	0.93	1.33
Moisture, %	0.51	0.44
Insoluble impurities, %	0.14	0.32
Unsaponifiable matter, %	0.28	0.57
Fatty acids, % of sample		
Myristic (C14:0)	0.0	2.0
Palmitic (C16:0)	11.0	22.0
Palmitoleic (C16:1)	0.0	2.0
Stearic (C18:0)	5.0	12.0
Oleic (C18:1)	24.0	39.0
Linoleic (C18:2)	50.0	15.0
Linolenic (C18:3)	7.0	1.0
Saturated fatty acids, %	17.0	38.0
Polyunsaturated fatty acids, %	58.0	17.0
Monounsaturated fatty acids, %	24.0	43.0
Peroxide value, meq/kg fat	5.3	4.0

[1] Acid ether extract = acid hydrolyzed ether extract.

[2] Total of moisture, insoluble impurities, and unsaponifiable matter.

Table 5.2. Composition of experimental diets[1] (as-fed basis)

	Growing pigs				Finishing pigs			
Item	Basal	5% SBO	10% SBO	10% CWG	Basal	5% SBO	10% SBO	10% CWG
Ingredient, %								
Ground corn	67.55	64.17	60.80	60.80	78.94	74.98	71.05	71.05
Soybean meal, 47.5%	29.00	27.55	26.10	26.10	18.00	17.10	16.20	16.20
Soybean oil	-	5.00	10.00	-	-	5.00	10.00	-
Choice white grease	-	-	-	10.00	-	-	-	10.00
Dicalcium phosphate	1.40	1.33	1.26	1.26	1.00	0.95	0.90	0.90
Ground limestone	0.82	0.78	0.74	0.74	0.90	0.86	0.81	0.81
L-Lysine HCl	0.17	0.16	0.15	0.15	0.10	0.10	0.09	0.09
Vitamins premix[2]	0.17	0.16	0.15	0.15	0.17	0.16	0.15	0.15
Minerals premix[3]	0.39	0.37	0.35	0.35	0.39	0.37	0.35	0.35
Cr_2O_3	0.50	0.48	0.45	0.45	0.50	0.48	0.45	0.45

Table 5.2 (Cont.)

Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Energy and nutrients[4]								
DM, %	88.44	89.39	89.35	89.99	87.62	86.78	87.83	89.02
GE, mcal/kg	3.87	4.12	4.38	4.38	3.81	4.05	4.36	4.39
ME, mcal/kg	3.29	3.55	3.80	3.76	3.31	3.56	3.82	3.77
CP, %	19.08	17.67	17.34	17.53	15.78	15.26	14.23	14.29
SID Lys,[5] %	1.06	1.00	0.95	0.95	0.73	0.69	0.65	0.65
Ether extract, %	2.77	7.75	11.47	12.04	3.53	6.08	10.33	12.24
Acid ether extract,[6] %	3.24	8.57	13.70	13.10	4.67	8.55	13.15	14.62
Crude fiber, %	2.04	1.97	1.90	1.92	1.91	1.71	1.67	1.62
Ash, %	5.75	5.29	4.90	5.03	4.65	4.22	4.27	4.37
Ca, %	0.72	0.69	0.65	0.65	0.64	0.61	0.57	0.57
Bioavailable P, %	0.28	0.27	0.25	0.25	0.21	0.20	0.19	0.19

Table 5.2 (Cont.)

[1] Basal = basal diet; 5% SBO = diet containing 5% soybean oil; 10% SBO = diet containing 10% soybean oil; 10% CWG = diet containing 10% choice white grease.

[2] Vitamin premix provided the following quantities of vitamins per kilogram of complete diet: 6,608 IU of vitamin A as retinyl acetate; 680 IU of vitamin D as cholecalciferol; DL-α-tocopheryl acetate, 88 mg; menadione sodium bisulfite complex 4 mg; riboflavin, 9 mg; vitamin B_{12}, 35 μg; D-Ca-pantothenic acid, 24 mg; niacin, 33 mg; and choline chloride, 324 mg.

[3] Mineral premix provided the following quantities of mineral per kilogram of complete diet: Fe, 90 mg ($FeSO_4 \cdot H_2O$); Zn 100 mg (ZnO); Mn 20 mg (MnO); Cu 8mg ($CuSO_4 \cdot H_2O$); I, 0.35 mg (CaI_2); Se, 0.3 mg (Na_2SeO_3); and NaCl, 3 g.

[4] Values for ME, SID Lys, Ca, and bioavailable P were calculated from NRC (1998); all other values were analyzed.

[5] SID Lys = standardized ileal digestible lysine.

[6] Acid ether extract = acid hydrolyzed ether extract.

Table 5.3. Effects of dietary soybean oil and choice white grease on growth performance and apparent total tract digestibility (ATTD) of energy and nutrients of growing and finishing pigs[1]

	Dietary treatment[2]				Lipid level			Lipid source	
						P-value[3]			
	Basal	5% SBO	10% SBO	10% CWG	SEM	L	Q	SEM	*P*-value[4]
Growing pigs									
Initial BW, kg	22.19	22.06	22.31	22.56	0.678	0.90	0.82	0.679	0.50
Final BW, kg	49.44	50.00	50.69	52.19	1.450	0.55	0.97	1.436	0.47
ADG, kg	0.973	0.998	1.014	1.058	0.037	0.45	0.93	0.047	0.15
ADFI, kg	1.887	1.879	1.872	1.980	0.072	0.88	0.99	0.071	0.30
G:F, kg/kg	0.517	0.531	0.543	0.533	0.010	0.08	0.88	0.011	0.56
ATTD,[5] %									
Energy	81.04	83.06	84.05	84.06	0.523	<0.01	0.44	0.578	0.99
CP	77.96	78.37	78.47	79.67	0.789	0.65	0.87	0.766	0.29

Table 5.3 (Cont.)

Acid ether extract[6]	33.19	74.20	82.35	80.52	1.427	<0.01	<0.01	0.656	0.07
Finishing pigs									
Initial BW, kg	85.56	84.56	85.71	83.13	2.245	0.96	0.68	1.980	0.36
Final BW, kg	127.88	130.31	135.64	127.81	3.380	0.11	0.72	4.062	0.18
ADG, kg	1.209	1.307	1.427	1.277	0.054	0.01	0.87	0.080	0.19
ADFI, kg	3.701	3.561	3.858	3.274	0.156	0.47	0.24	0.207	0.06
G:F, kg/kg	0.326	0.368	0.375	0.388	0.014	0.02	0.29	0.015	0.54
ATTD,[5] %									
Energy	82.66	85.10	87.08	86.74	0.464	<0.01	0.68	0.420	0.57
CP	79.36	81.21	81.60	82.22	0.928	0.09	0.51	0.617	0.47
Acid ether extract[6]	49.13	73.11	82.10	81.93	1.231	<0.01	<0.01	0.949	0.90

[1] Data are least squares means of 32 observations for growing pigs and 31 observations for finishing pigs.

[2] Basal = basal diet; 5% SBO = diet containing 5% soybean oil; 10% SBO = diet containing 10% soybean oil; 10% CWG = diet containing 10% choice white grease.

Table 5.3 (Cont.)

[3] *P*-values for linear (L) and quadratic (Q) effects are for the effects of lipid level in diets among Basal, 5% SBO, and 10% SBO.

[4] *P*-value for lipid source is based on contrast analyses between 10% SBO and 10% CWG.

[5] ATTD = apparent total tract digestibility.

[6] Acid ether extract = acid hydrolyzed ether extract.

Table 5.4. Effects of dietary soybean oil and choice white grease on carcass composition and retention of energy, protein, and lipid in growing pigs[1,2]

						Lipid level				
		Dietary treatment[4]					*P*-value[5]		Lipid source	
Item	ISG[3]	Basal	5% SBO	10% SBO	10% CWG	SEM	L	Q	SEM	*P*-value[6]
Live wt, kg	19.43	46.68	47.33	48.58	50.13	1.350	0.33	0.86	1.221	0.39
Hot carcass wt, kg	16.05	37.23	38.55	39.00	40.33	1.151	0.29	0.76	1.094	0.41
Dressing percentage, %	82.83	79.78	81.47	80.22	80.45	0.643	0.63	0.08	0.400	0.70
Total DF body[7]										
DF BW, kg	19.12	44.67	45.72	46.75	48.34	1.269	0.26	0.99	1.147	0.34
DF body DM, kg	5.62	15.49	16.25	17.25	18.34	0.565	0.04	0.86	0.566	0.20
Protein, g/kg	576	505	484	444	430	10.9	<0.01	0.45	11.0	0.38
Lipids, g/kg	262	358	389	371	465	10.9	0.40	0.08	13.6	<0.01
Energy, mcal/kg	5.81	6.24	6.33	6.38	6.72	0.052	0.07	0.75	0.060	<0.01

Table 5.4 (Cont.)

Total protein, kg/pig	3.24	7.81	7.85	7.63	7.84	0.275	0.65	0.70	0.190	0.45
Total lipids, kg/pig	1.48	5.56	6.34	6.44	8.54	0.350	0.09	0.43	0.417	<0.01
Total energy, mcal/pig	32.65	96.67	102.96	110.03	123.37	4.061	0.03	0.94	4.369	<0.05
Protein gain, g/d	-	161.3	163.5	154.2	160.3	7.97	0.54	0.57	5.62	0.46
Lipid gain, g/d	-	144.8	173.3	176.1	250.5	11.68	0.07	0.38	14.92	<0.01
Lipid:protein,[8] g/g	-	0.91	1.07	1.14	1.57	0.076	0.04	0.67	0.092	<0.01
MER,[9] mcal/d	-	2.27	2.50	2.74	3.20	0.122	0.01	0.98	0.157	0.06
CER,[10] mcal/d	-	2.28	2.56	2.54	3.28	0.133	0.19	0.36	0.154	<0.01

[1] Data are least squares means.

[2] n = 16 for initial slaughter group, n=8 for all other treatments.

[3] ISG = initial slaughter group.

[4] Basal = basal diet; 5% SBO = diet containing 5% soybean oil; 10% SBO = diet containing 10% soybean oil; 10% CWG = diet containing 10% choice white grease.

Table 5.4 (Cont.)

[5] *P*-values for linear (L) and quadratic (Q) effects are for the effects of lipid level in diets among Basal, 5% SBO, and 10% SBO.

[6] *P*-value for lipid source is based on contrast analyses between 10% SBO and 10% CWG.

[7] Total digest-free body = chilled carcass + empty viscera + blood.

[8] Lipid:protein = the ratio of daily lipid gain to daily protein gain.

[9] MER = measured energy retention.

[10] CER = calculated energy retention (calculated from protein and lipid gain as 5.66 and 9.46 kcal/g for protein and lipid, respectively).

Table 5. 5. Effects of dietary soybean oil and choice white grease on carcass composition and retention of energy, protein, and lipid in finishing pigs[1,2]

						Lipid level				
		Dietary treatment[4]					*P*-value[5]		Lipid source	
Item	ISG[3]	Basal	5% SBO	10% SBO	10% CWG	SEM	L	Q	SEM	*P*-value[6]
Live wt, kg	82.89	122.58	126.18	131.03	123.38	3.262	0.07	0.87	4.146	0.20
Hot carcass wt, kg	-	108.63	112.50	118.74	111.75	2.949	0.02	0.73	3.574	0.18
Dressing percentage, %	-	88.63	89.18	90.66	90.61	0.875	0.11	0.65	0.392	0.93
Total DF body[7]										
DF BW, kg	80.56	118.76	122.40	127.27	119.76	3.182	0.07	0.87	3.990	0.19
DF body DM, kg	32.92	55.90	56.98	61.33	56.41	2.129	0.08	0.52	2.277	0.14
Protein, g/kg	399	346	326	299	333	8.0	<0.01	0.75	10.3	0.03
Lipids, g/kg	503	568	583	561	581	10.0	0.57	0.12	10.3	0.18
Energy, mcal/kg	6.89	7.25	7.22	7.24	7.26	0.058	0.90	0.73	0.051	0.79

Table 5.5 (Cont.)

Total protein, kg/pig	13.12	19.30	18.55	18.28	18.70	0.623	0.25	0.74	0.601	0.62
Total lipids, kg/pig	16.57	31.84	33.24	34.45	32.82	1.522	0.23	0.96	1.658	0.49
Total energy, mcal/pig	227.1	405.5	411.4	444.1	409.5	17.25	0.12	0.51	17.84	0.18
Protein gain, g/d	-	171.5	154.6	141.9	165.3	13.80	0.13	0.90	14.34	0.25
Lipid gain, g/d	-	430.7	476.2	504.2	472.1	36.09	0.15	0.84	39.90	0.57
Lipid:protein,[8] g/g	-	2.52	3.19	3.89	2.95	0.376	0.02	0.98	0.469	0.17
MER,[9] mcal/d	-	5.02	5.27	6.11	5.32	0.384	0.05	0.51	0.403	0.18
CER,[10] mcal/d	-	5.05	5.38	5.57	5.40	0.364	0.30	0.87	0.392	0.76

[1] Data are least squares means.

[2] n = 16 for initial slaughter group, n=8 for Basal, 5% SBO and 10% CWG; n=7 for 10% SBO.

[3] ISG = initial slaughter group.

[4] Basal = basal diet; 5% SBO = diet containing 5% soybean oil; 10% SBO = diet containing 10% soybean oil; 10% CWG = diet containing 10% choice white grease.

Table 5.5 (Cont.)

[5] *P*-values for linear (L) and quadratic (Q) effects are for the effects of lipid level in diets among Basal, 5% SBO, and 10% SBO.

[6] *P*-value for lipid source is based on contrast analyses between 10% SBO and 10% CWG.

[7] Total digest-free body = chilled carcass + empty viscera + blood.

[8] Lipid:protein = the ratio of daily lipid gain to daily protein gain.

[9] MER = measured energy retention.

[10] CER = calculated energy retention (calculated from protein and lipid gain as 5.66 and 9.46 kcal/g for protein and lipid, respectively).

Table 5. 6. Lipid gain from digested lipids and non-lipid nutrients in growing and finishing pigs[1]

					Lipid level				
	Dietary treatment[2]					*P*-value[3]		Lipid source	
Items	Basal	5% SBO	10% SBO	10% CWG	SEM	L	Q	SEM	*P*-value[4]
Growing pigs									
Dietary lipids, g/kg	32.4	85.7	137.0	131.0					
ADFI, kg	1.887	1.879	1.872	1.980	0.072	0.88	0.99	0.071	0.30
STTD of lipids,[5] %	57.76	83.59	88.22	86.70	1.427	<0.01	<0.01	0.656	0.12
Digested lipids,[6] g/d	35.3	134.8	226.0	224.9	5.64	<0.01	0.55	7.967	0.93
Lipid gain, g/d	144.8	173.3	176.1	250.5	11.68	0.07	0.38	14.92	<0.01
Lipid gain from non-lipid nutrients,[7] g/d	109.5	38.5	-49.9	25.6	8.67	<0.01	0.42	11.42	<0.01
Finishing pigs									
Dietary lipids, g/kg	46.7	85.5	131.5	146.2					
ADFI, kg	3.701	3.561	3.858	3.274	0.156	0.47	0.24	0.207	0.06

Table 5.6 (Cont.)

STTD of lipids,[5] %	66.02	82.24	88.11	87.41	1.231	<0.01	<0.01	0.949	0.60
Digested lipids,[6] g/d	114.1	250.4	446.9	419.3	14.68	<0.01	0.09	26.73	0.46
Lipid gain, g/d	430.7	476.2	504.2	472.1	36.09	0.15	0.84	39.90	0.57
Lipid gain from non-lipid nutrients,[7] g/d	316.6	225.8	57.3	52.8	33.03	<0.01	0.32	24.57	0.90

[1] Data are least squares means of growing pigs (n=32) and finishing pigs (n=31).

[2] Basal = basal diet; 5% SBO = diet containing 5% soybean oil; 10% SBO = diet containing 10% soybean oil; 10% CWG = diet containing 10% choice white grease.

[3] *P*-values for linear (L) and quadratic (Q) effects are for the effects of lipid level in diets among Basal, 5% SBO, and 10% SBO.

[4] *P*-value for lipid source is based on contrast analyses between 10% SBO and 10% CWG.

[5] STTD of lipids = standardized total tract digestibility of lipids which was calculated from the apparent total tract digestibility of lipids after correction for basal endogenous losses of lipids (9 g/kg DM intake, Boisen, 2007).

[6] Digested lipids = Average daily feed intake (kg/d) × dietary concentration of lipids (g/kg) × STTD of lipids (%) × 0.01.

Table 5.6 (Cont.)

[7] Lipid gain from non-lipid nutrients = total amount of lipid gain (g/d) – total intake of digested lipids (g/d). Digested lipids are assumed 100% incorporated into body lipids (Chwalibog et al., 1992).

Table 5.7. Net energy of diets and dietary lipids in growing and finishing pigs[1]

	Dietary treatment[2]				Lipid level			Lipid source	
						P-value[3]			
Item	Basal	5% SBO	10% SBO	10% CWG	SEM	L	Q	SEM	*P*-value[4]
Growing pigs									
Initial body energy, mcal	33.20	33.02	33.39	33.76	1.014	0.90	0.82	1.017	0.50
Final body energy, mcal	96.67	102.96	110.03	123.37	4.061	0.03	0.94	4.369	<0.05
Energy retention, mcal	63.47	69.94	76.64	89.61	3.407	0.01	0.98	4.387	0.06
Total ONE$_m$,[5] mcal	29.33	29.53	29.76	30.20	0.487	0.54	0.98	0.401	0.45
Total NE intake, mcal	92.79	99.47	106.40	119.81	3.789	0.02	0.98	4.542	0.06
Total feed intake, kg	52.83	52.60	52.40	55.45	2.005	0.88	0.99	1.994	0.30
NE of diets, kcal/kg	1,762	1,889	2,036	2,158	39.7	<0.01	0.83	41.0	0.05
NE of lipids,[6] kcal/kg	-	4,301	4,509	5,727	467.3	0.76	-	410.4	0.05
Finishing pigs									

Table 5.7 (Cont.)

Initial body energy, mcal	229.80	227.12	230.21	223.26	6.03	0.96	0.68	5.32	0.36
Final body energy, mcal	405.54	411.43	444.07	409.53	17.25	0.12	0.51	17.84	0.18
Energy retention, mcal	175.74	184.31	213.86	186.28	13.43	0.05	0.51	14.09	0.18
Total ONE$_{m}$,[5] mcal	124.25	124.64	126.52	123.07	1.91	0.40	0.74	1.98	0.23
Total NE intake, mcal	299.98	308.95	340.38	309.34	14.60	0.06	0.51	15.77	0.17
Total feed intake, kg	129.53	124.63	135.03	114.60	5.46	0.47	0.24	7.25	0.06
NE of diets, kcal/kg	2,303	2,483	2,545	2,703	77.7	0.03	0.52	70.4	0.13
NE of lipids,[6] kcal/kg	-	5,904	4,729	6,307	1,016.9	0.41	-	703.9	0.13

[1] Data are least squares means of 32 observations for growing pigs and 31 observations for finishing pigs.

[2] Basal = basal diet; 5% SBO = diet containing 5% soybean oil; 10% SBO = diet containing 10% soybean oil; 10% CWG = diet containing 10% choice white grease.

[3] *P*-values for linear (L) and quadratic (Q) effects are for the effects of lipid level in diets among Basal, 5% SBO, and 10% SBO.

[4] *P*-value for lipid source is based on contrast analyses between 10% SBO and 10% CWG.

Table 5.7 (Cont.)

[5] Total operational NE requirement for maintenance is calculated by multiplying the mean metabolic BW (kg$^{0.6}$) of each pig by 128 and 219 kcal for growing and finishing pigs, respectively (Kil et al., 2009a) and the number of days on experiments (28 d for growing pigs and 35 d for finishing pigs).

[6] NE of lipids = SBO included at 5%, SBO included at 10%, and CWG included at 10%; The NE of SBO and CWG were calculated using the difference method by subtracting the NE contribution from the basal diet from the NE of the diets containing SBO or CWG (De Goey and Ewan, 1975).

Table 5. 8. Effects of dietary level or source of lipids on NE of diets and dietary lipids fed to growing and finishing pigs[1]

	Lipid level[2]					Lipid source[3]				Lipid level[2]			Lipid source[3]		
				Stage[4]				Stage[4]			*P*-value[5]			*P*-value[6]	
kcal/kg	0% SBO	5% SBO	10% SBO	G	F	10% SBO	10% CWG	G	F	SEM	Level[7]	Stage	SEM	Source	Stage
NE of diets,[8]	2,032	2,186	2,292	1,896	2,444	2,292	2,431	2,097	2,625	41.8	<0.01	<0.01	39.1	0.02	<0.01
NE of lipids,[9]	-	5,102	4,619	4,405	5,317	4,619	6,017	5,118	5,518	540.1	0.55	0.22	391.4	0.02	0.46

[1] Data are least squares means of 24 observations for growing pigs and 23 observations for finishing pigs.

[2] Lipid level = 0, 5, and 10% soybean oil (SBO).

[3] Lipid source = 10% soybean oil (10% SBO) or 10% choice white grease (10% CWG).

[4] Stage of growth = growing pigs (G) and finishing pigs (F).

[5] *P*-values for the effects of lipid level and stage of growth on NE of diets and lipids. No interaction was observed between lipid level and stage of growth.

[6] *P*-values for the effects of lipid source and stage of growth on NE of diets and lipids. No interaction was observed between lipid source and stage of growth.

[7] Linear effect of lipid level on the NE of diets was significant ($P < 0.01$).

Table 5.8 (Cont.)

[8] NE of diets containing 0, 5, or 10% SBO or 10% CWG.

[9] NE of lipids = SBO included at 5%, SBO included at 10%, CWG included at 10%.

CHAPTER 6

EFFECTS OF DIETARY LIPIDS ON NET ENERGY OF CORN IN DIETS FED TO GROWING AND FINISHING PIGS

ABSTRACT

An experiment was conducted to measure the effect of dietary lipids on the NE of corn in growing and finishing pigs and to determine if the effect of dietary lipids on the NE of corn is affected by the stage of growth. Forty eight growing (initial BW: 27 kg) and 48 finishing (initial BW: 86 kg) barrows were used and within each stage of growth, pigs were allotted to 8 outcome groups of 6 barrows according to BW. Within each outcome group, pigs were randomly allotted to 1 of 6 treatment groups. Two treatment groups at each stage of growth served as an initial slaughter group. The remaining pigs were assigned to 4 different diets and slaughtered at the conclusion of the experiment. A low lipid basal diet containing corn, soybean meal, and no added lipids and a high lipid basal diet containing corn, soybean meal, and 8% soybean oil were formulated. Two additional diets were formulated by mixing 25% corn and 75% of the low lipid basal diet or 25% corn and 75% of the high lipid basal diet. Results showed that supplemental lipids had no effect on ADG, ADFI, and G:F of growing pigs, but improved ($P < 0.01$) G:F for finishing pigs. The addition of corn increased ($P < 0.05$) ADFI but decreased ($P < 0.05$) G:F for growing pigs, but there was no effect of the addition of corn on ADG, ADFI, and G:F for finishing pigs. For growing pigs, supplemental corn tended to increase ($P < 0.10$) lipid gain:protein gain and energy retention but dietary lipids had no effect on lipid gain:protein gain or energy retention. For finishing pigs, lipid gain, lipid gain:protein gain, and energy retention were not influence by the addition of dietary lipids or corn. For growing and finishing pigs, the NE of diets containing supplemental lipids was greater ($P < 0.01$) than the NE of diets containing no supplemental lipids. No effect of additional corn on the NE of diets was observed. The NE of corn in the diet containing supplemental lipids (2,053kcal/kg) was not different from the NE of corn in the diet containing no supplemental lipids (2,197 kcal/kg). The NE of corn was greater ($P < 0.05$) for finishing pigs (2,607 kcal/kg) than for growing pigs (1,643 kcal/kg). In conclusion, addition of dietary lipids to diets fed to growing or finishing pigs increases the NE of the diets. The NE of corn is not affected by the presence of lipids in the diet, but the NE of corn is greater for finishing pigs than for growing pigs.

Keywords: corn, dietary lipids, NE, pig, stage of growth

INTRODUCTION

Corn is an important ingredient as an energy source for swine diets in North America. Therefore, an accurate assessment of the energy value of corn is essential. Starch, which is the major energy-containing nutrient in corn, can be metabolized to ATP or used for the synthesis of fatty acids and subsequently stored as body lipids. The energetic efficiencies for these 2 metabolic pathways are different (Black, 1995), but DE and ME systems do not account for these differences in the metabolism of starch (Noblet, 2007). It is, therefore, possible that NE systems are more accurate in estimating the energy value of corn than DE and ME systems because NE systems consider the efficiency of energy utilization (Noblet et al., 1994a).

If pigs are fed high amounts of dietary lipids, it is likely that most of the starch in corn is utilized for ATP synthesis instead of being converted to body lipids, but if no lipids are included in the diets, some of the starch in corn will be used for fatty acid synthesis (Jakobsen and Thorbek, 1993). The theoretical energetic efficiency of metabolizing glucose to ATP is 68%, while the efficiency of using glucose for fatty acid synthesis is 74% (Black, 1995). Based on these efficiencies, it is expected that the NE of corn is lower if high amounts of lipids are added to the diets than if no lipids are used. It is also expected that the impact of dietary lipids on the NE of corn may depend on the BW of pigs because finishing pigs retain more lipids than growing pigs (de Greef et al., 1994). However, no experiments have been conducted to investigate these hypotheses.

The objective of this experiment was to test the hypothesis that the NE of corn fed to pigs is greater in diets containing no added lipids than in diets containing a high amount of lipids. A second objective was to determine if the effect of dietary lipids on the NE of corn is influenced by the BW of pigs.

MATERIALS AND METHODS

Animals, Housing, and Experimental Design

The experiment was approved by the Institutional Animal Care and Use Committee at the University of Illinois. Forty eight growing and 48 finishing barrows that were the offspring of line 337 sires mated to C-22 females (Pig Improvement Company, Hendersonville, TN) were used. The average initial BW of the growing pigs was 27.33 ± 2.49 kg and the average initial BW of the finishing pigs was 85.99 ± 3.00 kg. All pigs used in the experiment were selected based on BW and ADG during a 2-wk pre-experimental period. Within each stage of growth, pigs were allotted to 8 outcome groups of 6 barrows according to BW. Within each outcome group, pigs were randomly allotted to 1 of 6 treatment groups. Two randomly chosen treatment groups at each stage of growth served as an initial slaughter group and all pigs in these 2 treatment groups were harvested at the start of the experiment. The other 4 treatment groups at each stage of growth were assigned to 4 dietary treatments in a 2 × 2 factorial arrangement with 2 levels of supplemental lipids in the diet (0% or 8%) and with 2 levels of supplemental corn (0 or 25%). Within each stage of growth, all pigs fed the 4 dietary treatments were slaughtered at the conclusion of the experiment.

Pigs were housed individually in 0.9 × 1.8 m pens in an environmentally controlled building. Pens were equipped with a feeder, a nipple waterer, and a fully-slatted concrete floor. The experimental period was 28 d for growing pigs and 35 d for finishing pigs.

Dietary Treatments

Commercial corn was obtained and analyzed for chemical composition (Table 6.1). Four diets for growing pigs and 4 diets for finishing pigs were prepared (Table 6.2). A low lipid basal diet containing corn, soybean meal, and no added lipids and a high lipid basal diet containing corn, soybean meal, and 8% soybean oil were formulated within each stage of growth. Two additional diets were formulated by mixing 25% corn and 75% of the low lipid basal diet (as-is basis) or 25% corn and 75% of the high lipid basal diet (as-is basis). Chromic oxide (0.40%) was included as an inert marker in both basal diets. Vitamins and trace minerals were also included in the basal diets to exceed the estimated nutrient requirements (NRC, 1998) for pigs at each stage of growth. No antibiotic growth promoters were used and all diets were provided in a meal form. Pigs were allowed ad libitum access to feed and water during the entire experimental period. The procedure for collecting data, the experimental periods, chemical analyses, and calculation of growth performance, nutrient digestibility, carcass composition, and retention of protein, lipids, and energy were similar to the procedures described previously (Kil et al., unpublished data).

Statistical Analyses

All data were analyzed using the MIXED procedure (SAS Inst. Inc., Cary, NC) with the individual pig as the experimental unit. Homogeneity of the variances was verified using the UNIVARIATE procedure of SAS. The residual vs. the predicted plot procedure was used to identify outliers. The model included the effect of dietary lipids, supplemental corn, and the interaction between dietary lipid and supplemental corn within each stage of growth. The interaction for the ATTD of acid hydrolyzed ether extract in growing pigs was significant ($P < 0.05$), while no significant interaction for other measurements was observed. For values for the NE of supplemental corn, the model included the effect of dietary lipids, stage of growth and the interaction between dietary lipid and stage of growth but no interaction was significant. If there was no interaction, the interaction terms were omitted from the final analyses and only main effects were presented. The LSMEANS procedure was used to calculate mean values. An alpha-value of 0.05 was used to assess significance among means.

RESULTS

Pig Performance and Nutrient Digestibility

One finishing pig fed the diet containing high lipid and supplemental corn became sick and had to be removed from the experiment. All other pigs remained healthy throughout the experiment. Inclusion of dietary lipids had no influence on the final BW, ADG, ADFI, and G:F for growing pigs, but improved ($P < 0.01$) G:F for finishing pigs (Table 6.3). The addition of corn increased ($P < 0.05$) ADFI, and decreased ($P < 0.05$) G:F for growing pigs. However, there was no effect of the addition of corn on ADG, ADFI, and G:F for finishing pigs. A trend for an increase ($P = 0.06$) in the ATTD of energy as a result of the addition of dietary lipids was observed in growing pigs, but the ATTD of energy decreased ($P < 0.01$) with the addition of corn. For finishing pigs, the ATTD of energy also increased ($P < 0.05$) with the addition of dietary lipids, but decreased ($P < 0.05$) with the addition of corn. The ATTD of CP for both growing and finishing pigs was not affected by the addition of dietary lipids, but decreased ($P < 0.05$) with the addition of corn. The addition of corn had no effect on the ATTD of acid hydrolyzed ether extract in growing pigs in the absence of supplemental lipids, but the addition of corn decreased the ATTD of acid hydrolyzed ether extract in the presence of supplemental lipids, leading to a significant interaction ($P < 0.05$). For finishing pigs, the addition of dietary lipids increased ($P < 0.01$) the ATTD of acid hydrolyzed ether extract but the addition of corn decreased ($P < 0.05$) the ATTD of acid hydrolyzed ether extract.

Carcass Composition and Retention of Energy, Protein, and Lipids

In the growing phase, there was no effect of the addition of dietary lipids or corn on live BW, hot carcass weight, dressing percentage, or the weight of the total digesta-free body DM (Table 6.4). The addition of dietary lipids decreased ($P < 0.05$) the concentration of protein in the digesta-free body DM, but did not influence the concentration of lipids and energy. The addition of corn increased ($P < 0.05$) the concentration of lipids and energy in the digesta-free body DM. Protein gain was not affected by the addition of dietary lipids or corn. There was a trend for greater (*P* = 0.06) lipid gain for pigs fed the diets containing supplemental corn than for pigs fed the diets containing no supplemental corn. The addition of corn also tended to increase (*P* < 0.10) the lipid gain:protein gain and measured energy retention. The addition of corn also increased (*P* < 0.05) the calculated energy retention. However, there was no effects of dietary lipids on lipid gain, lipid gain:protein gain, or energy retention.

In the finishing phase, addition of dietary lipids or corn had no influence on live BW, hot carcass weight, dressing percentage, or the weight of total digesta-free body DM (Table 6.5). The concentration of energy in the digesta-free body was greater (*P* < 0.05) for pigs fed diets containing supplemental corn than for pigs fed diets containing no supplemental corn. Protein gain, lipid gain, lipid gain:protein gain, and energy retention were not affected by the addition of dietary lipids or corn.

NE of Diets and Corn

For growing pigs, no difference among dietary treatments in final body energy and energy retention was observed, but the addition of corn tended to increase (*P* < 0.10) energy retention and NE intake (Table 6.6). The NE of diets containing supplemental lipids (1,787 kcal/kg) was greater (*P* < 0.01) than the NE of diets containing no supplemental lipids (1,642 kcal/kg). The addition of corn had no influence on the NE of diets, and supplemental dietary lipids had no effect on the NE of corn.

For finishing pigs, the addition of dietary lipids or corn had no effects on final body energy or energy retention, but the NE of diets containing supplemental lipids

(2,604 kcal/kg) was greater ($P < 0.01$) than the NE of diets containing no supplemental lipids (2,373 kcal/kg). The NE of diets was not influenced by the addition of corn, and supplemental dietary lipids also had no effect on the NE of corn.

No interaction between dietary lipids and stage of growth was observed for the NE of corn and therefore, the main effects of dietary lipids and stage of growth on the NE of corn were calculated (Table 6.7). The NE of corn in the diet containing no supplemental lipids (2,197kcal/kg) was not different from the NE of corn in the diet containing supplemental lipids (2,053 kcal/kg). The NE of corn was greater ($P < 0.01$) for finishing pigs (2,607 kcal/kg) than for growing pigs (1,643 kcal/kg).

DISCUSSION

The chemical composition of corn used in the present experiment agrees with published values (Adeola and Bajjalieh, 1997; NRC, 1998). Small differences in chemical composition of the corn used for growing and finishing pigs may be a result of the natural variability among corn varieties and variation in the chemical analysis within laboratory (Cromwell et al., 1999).

Pig Performance and Nutrient Digestibility

The improvement in G:F for finishing pigs as a result of the addition of dietary lipids is caused by the increase in ADG but decrease in ADFI and this result agrees with previous observations (Pettigrew and Moser, 1991; Kil et al., unpublished data). The decrease in G:F for growing pigs but no change in G:F for finishing pigs as a consequence of supplemental corn may be related to the concentration of CP in the diet. Kerr et al. (1995) reported that the diets containing low CP but supplemental AA increased feed intake but decreased G:F for growing pigs, while they observed no effect on feed intake and G:F for finishing pigs. The increase in lipid gain by supplemental corn may also contribute to a reduction in G:F for growing pigs (de Lange et al., 2001).

The increase in ATTD of energy by the addition of dietary lipids for growing and finishing pigs agrees with our previous observation (Kil et al., unpublished data). The reason for the decrease in ATTD of energy by supplemental corn for growing and finishing pigs may be a consequence of increased feed intake in pigs fed diets containing supplemental corn, which leads to a reduction in energy digestibility (Haydon et al., 1984; Chastanet et al., 2007). The observation that the ATTD of lipids increased with the addition of dietary lipids, but decreased with supplemental corn for growing and finishing pigs was expected because supplemental lipids are more digestible than the lipids in corn (Kil et al., 2007) and the influence of endogenous losses on the ATTD of lipids is greater at low levels than at high levels of dietary lipids (Jørgensen et al., 1993). This may also explain why supplemental corn decreased the ATTD of CP. Supplemental corn decreased the concentration of dietary CP by diluting the CP in the basal diet, and therefore, increased the effect of endogenous losses on the ATTD of CP in diets (Fan and Sauer, 1997).

Carcass Composition and Retention of Energy, Protein, and Lipids

The values for protein gain for growing pigs (147 g/d) and finishing pigs (194 g/d) fed the low lipid basal diet were slightly different from the values for pigs fed a similar diet in our previous experiment (Kil et al., unpublished data). One explanation for this difference may be that the chemical composition of the diets and the feed intake were different between 2 experiments.

An increase in lipid gain and lipid gain:protein gain as the level of dietary lipids increases has been reported (Stahly, 1984; Kil et al., unpublished data). In this experiment, however, no effect of the addition of dietary lipids on lipid gain or lipid gain:protein gain for growing or finishing pigs was observed. Jørgensen et al. (1996) also reported that increasing levels of rapeseed oil did not affect the lipid gain for growing pigs. The reason for these conflicting observations is unknown, but it may be related to the difference in the levels or sources of lipids and other components in the diet and the variation in genotype of pigs among experiments.

The reason for the tendency for increased lipid gain and energy retention in growing pigs fed diets containing supplemental corn may be that increased intake of starch increases plasma concentrations of insulin and glucose, which have a stimulatory effect on de novo lipogenesis in pigs (Kersten, 2001; Martinz-Puig et al., 2006). The decreased concentration of CP in the diet by supplemental corn may also increase lipid gain and energy retention by reducing energy losses during N metabolism (Henry, 1985; Le Bellego et al., 2001; Noblet et al., 2001). However, this effect was not observed in finishing pigs, which may be a result of the fact that supplemental corn did not increase the feed intake for finishing pigs as it did for growing pigs.

NE of Diets and Corn

The values for NE of the diets in growing pigs were lower than values calculated from the NE of each ingredient published by Sauvant et al. (2004). This result was expected because the value (128 kcal/kg $BW^{0.6}$) for the maintenance of growing pigs used in the present experiment was lower than the value (179 kcal/kg $BW^{0.6}$) used by Sauvant et al. (2004). However, values for NE of diets fed to finishing pigs were also lower than the calculated NE of the diets although the value (218 kcal/kg $BW^{0.6}$) for maintenance of finishing pigs in this experiment was greater than the value used by Sauvant et al. (2004). The reason for this observation may be that energy retention measured by indirect calorimetry method tends to be greater than energy retention measured by the comparative slaughter method used in this experiment (Quiniou et al., 1995; Reynolds, 2000).

An increased NE of diets with increasing levels of dietary lipids has been observed in other experiments (Just, 1982; Kil et al., unpublished data) and is a consequence of the fact that the NE of lipids is greater than the NE of corn and SBM. Inclusion of lipids in the diet may also increase the digestibility of energy and AA (Cervantes-Pahm and Stein, 2008), and may increase the amount of energy absorbed in the small intestine and reduce the amount of energy absorbed in the hindgut (Kil et al., unpublished data). The efficiency of energy absorbed in the hindgut is lower than the efficiency of energy absorbed in the small intestine (Just, 1982; Noblet et al., 1994a). There is no influence of supplemental corn on the NE of the diets, which is likely a consequence of the fact that the NE of the basal diet was similar to the NE of supplemental corn.

It was unexpected that the NE of supplemental corn was not affected by the presence or absence of lipids in the diets because the energetic efficiency of starch is lower for ATP synthesis (68%) than for de novo lipogenesis (74%, Black, 1995). In diets containing high amounts of lipids, it was expected that more starch in corn would be utilized for ATP synthesis rather than for de novo lipogenesis, which should decrease the energetic efficiency and subsequently decrease the NE of corn. Possible explanations for this observation is that the addition of dietary lipids may increase the digestibility of energy and nutrients in corn by reducing gastric emptying (Gentilcore et al., 2006) and the passage rate of digesta (Valaja and Silijander-Rasi, 2001), which may compensate for the reduction in the energetic efficiency of the utilization of corn. In addition, small difference (6%) in the theoretical efficiency of the utilization of corn between ATP synthesis and de novo lipogenesis may be too small to be detected in an experiment with live animals.

The greater NE of supplemental corn in finishing pigs than in growing pigs is in agreement with Noblet et al. (1994b) who reported that the NE of cornstarch for pigs at 100 kg was greater than for pigs at 45 kg. The reason for this observation may be that for finishing pigs, more starch in corn is utilized for de novo lipogenesis than in growing pigs because finishing pigs have a greater potential for lipid gain than growing pigs (Leat, 1983; de Greef et al., 1994). This observation may also be explained by greater digestibility of energy and nutrients in corn for finishing pigs than for growing pigs (Noblet and Shi, 1994). The lack of interaction for the NE of corn between the addition of dietary lipids and stage of growth indicates that the effect of dietary lipids on the NE of corn is similar at both stages of growth.

In conclusion, results from this experiment indicate that dietary lipids increase the NE of diets. The NE of corn is greater for finishing pigs than for growing pigs but the NE of corn is not influenced by dietary lipids.

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Table 6.1. Chemical analyses of supplemental corn used at each stage of growth (as-fed basis)

Composition	Growing pigs	Finishing pigs
DM, %	86.49	84.86
GE, mcal/kg	3.87	3.83
CP, %	8.67	9.05
Ether extract, %	3.74	2.34
Acid ether extract,[1] %	3.89	4.52
Crude fiber, %	1.44	1.56
Total starch,[2] %	64.80	62.20
Ash, %	1.32	1.46
Particle size,[3] µm	701	770

[1] Acid ether extract = acid hydrolyzed ether extract.

[2] Total starch was measured by the method of EEC (1999).

[3] Particle size was determined using American Society of Agricultural Engineers procedures (ASAE, 1983).

Table 6.2. Composition of experimental diets (as-fed basis)

	Growing pigs				Finishing pigs			
Diets[1]:	LLB	LLC	HLB	HLC	LLB	LLC	HLB	HLC
Ingredient, %								
Ground corn	65.61	74.21	55.53	66.65	85.32	88.99	75.04	81.28
Soybean meal, 47.5%	28.11	21.08	30.27	22.70	9.85	7.39	12.25	9.19
Soybean oil	-	-	8.00	6.00	-	-	8.00	6.00
Dicalcium phosphate	1.95	1.46	1.95	1.46	1.34	1.01	1.35	1.01
Ground limestone	1.00	0.75	1.00	0.75	0.74	0.55	0.72	0.54
L-lysine HCl	0.60	0.45	0.55	0.42	0.51	0.38	0.45	0.34
DL-methionine	0.17	0.13	0.17	0.13	0.04	0.03	0.04	0.03
L-threonine	0.26	0.19	0.26	0.19	0.14	0.11	0.14	0.10
L-tryptophan	0.07	0.05	0.06	0.04	0.05	0.04	0.04	0.03
L-valine	0.06	0.05	0.06	0.04	0.02	0.02	0.01	0.01
L-isoleucine	-	-	-	-	0.04	0.03	0.02	0.01
Salt	0.12	0.09	0.12	0.09	0.12	0.09	0.12	0.09
Vitamins[2]	0.13	0.10	0.13	0.10	0.13	0.10	0.13	0.10
Minerals[3]	0.47	0.35	0.47	0.35	0.47	0.35	0.47	0.35
Sodium bicarbonate	0.73	0.55	0.73	0.55	0.59	0.44	0.59	0.44
Potassium carbonate	0.31	0.23	0.31	0.23	0.24	0.18	0.24	0.18
Cr_2O_3	0.40	0.30	0.40	0.30	0.40	0.30	0.40	0.30
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Energy and nutrients[4]								

Table 6.2 (Cont.)

DM, %	87.67	86.98	89.07	88.23	87.24	86.76	88.05	88.07
GE, mcal/kg	3.81	3.79	4.21	4.15	3.79	3.78	4.12	4.10
ME, mcal/kg	3.19	3.25	3.59	3.55	3.25	3.29	3.65	3.59
CP, %	20.43	17.54	20.20	17.08	12.09	11.36	12.31	11.67
Lys, %	1.48	1.18	1.48	1.18	0.91	0.75	0.91	0.75
Ether extract, %	2.17	2.42	8.65	7.10	1.94	2.24	8.17	7.60
Acid ether extract,[5] %	4.03	4.31	9.93	8.70	4.36	4.26	10.77	8.88
Crude fiber, %	2.05	1.92	1.90	1.83	1.61	1.55	1.58	1.51
Ash, %	5.92	4.90	6.64	5.09	95.18	96.15	95.08	95.88
Ca, %	0.90	0.68	0.90	0.68	0.62	0.47	0.62	0.47
Bioavailable P, %	0.43	0.33	0.43	0.33	0.30	0.23	0.30	0.23

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[1] LLB = basal diet containing no supplemental lipids; LLC = 75% LLB + 25% corn; HLB = basal diet containing 8% soybean oil; HLC = 75% HLB + 25% corn.

[2] Vitamin premix provided the following quantities of vitamins per kilogram of complete diet: 6,608 IU of vitamin A as retinyl acetate; 680 IU of vitamin D as cholecalciferol; DL-α-tocopheryl acetate, 88 mg; menadione sodium bisulfite complex 4 mg; riboflavin, 9 mg; vitamin B_{12}, 35 μg; D-Ca-pantothenic acid, 24 mg; niacin, 33 mg; and choline chloride, 324 mg.

[3] Mineral premix provided the following quantities of mineral per kilogram of complete diet: Fe, 90 mg ($FeSO_4·H_2O$); Zn 100 mg (ZnO); Mn 20 mg (MnO); Cu 8mg ($CuSO_4·H_2O$); I, 0.35 mg (CaI_2); Se, 0.3 mg (Na_2SeO_3); and NaCl, 3 g.

Table 6.2 (Cont.)

[4] Values for ME, Lys, Ca, and bioavailable P were calculated from NRC (1998); all other values were analyzed.

[5] Acid ether extract = acid hydrolyzed ether extract.

Table 6.3. Effects of additional dietary lipids and corn on growth performance of growing and finishing pigs and apparent total tract digestibility (ATTD) of energy and nutrients[1]

	Added lipids[2]		Added corn[3]			*P*-value[4]	
Items	-	+	-	+	SEM	Lipids	Corn
Growing pigs							
Initial BW, kg	27.34	27.34	27.38	27.31	0.636	1.00	0.95
Final BW, kg	54.00	55.22	54.09	55.13	1.031	0.41	0.49
ADG, kg	0.952	0.996	0.954	0.993	0.025	0.23	0.28
ADFI, kg	2.012	2.023	1.906	2.129	0.069	0.91	0.03
G:F, kg/kg	0.475	0.500	0.508	0.468	0.012	0.13	0.02
ATTD,[5] %							
Energy	82.01	83.35	83.99	81.38	0.493	0.06	<0.01
CP	79.38	79.62	82.28	76.72	0.781	0.83	<0.01
Acid ether extract[6,7]							
0% lipids	-	-	47.23	47.50	0.836		
8% lipids	-	-	74.94	70.11	-		
Finishing pigs							
Initial BW, kg	85.34	85.97	85.56	85.75	0.789	0.57	0.86
Final BW, kg	129.78	133.85	132.13	131.50	1.558	0.07	0.78
ADG, kg	1.270	1.368	1.330	1.307	0.037	0.07	0.66
ADFI, kg	3.907	3.681	3.748	3.839	0.097	0.10	0.50
G:F, kg/kg	0.326	0.372	0.357	0.341	0.007	<0.01	0.11

Table 6.3 (Cont.)

ATTD,[5] %							
Energy	83.41	84.64	84.54	83.51	0.330	0.01	0.03
CP	76.35	77.97	78.67	75.64	0.794	0.15	0.01
Acid ether extract[6]	43.79	70.56	58.95	55.40	1.007	<0.01	0.02

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[1] Data are least squares means of 32 observations for growing pigs and 31 observations for finishing pigs.

[2] Supplementation of soybean oil (+); No supplementation of soybean oil (-).

[3] Additional corn in the diet (+); No additional corn in the diet (-).

[4] *P*-values for main effects of dietary lipids and additional corn. No interaction was observed between supplemental dietary lipids and the addition of corn.

[5] ATTD = apparent total tract digestibility.

[6] Acid ether extract = acid hydrolyzed ether extract.

[7] The interaction between supplemental dietary lipids and the addition of corn was significant ($P < 0.05$).

Table 6.4. Effects of additional dietary lipids and corn on carcass compositions and total amount of energy, protein, and lipids in growing pigs[1]

		Added lipids[2]		Added corn[3]			*P*-value[4]	
Items	ISG[5]	-	+	-	+	SEM	Lipids	Corn
Live wt, kg	26.65	51.26	52.31	51.18	52.40	0.997	0.46	0.39
Hot carcass wt, kg	21.16	41.76	42.40	41.56	42.60	0.809	0.58	0.37
Dressing percentage, %	79.35	81.48	81.06	81.22	81.32	0.319	0.35	0.83
Total DF body[6]								
DF BW, kg	25.47	49.16	50.33	49.09	50.40	0.939	0.38	0.33
DF body DM, kg	7.46	16.58	17.78	16.67	17.69	0.517	0.11	0.17
Protein, g/kg	584	514	480	509	485	11.9	< 0.05	0.17
Lipids, g/kg	282	359	355	337	376	12.4	0.83	0.03
Energy, mcal/kg	5.94	6.30	6.33	6.22	6.42	0.059	0.72	0.03
Total protein, kg/pig	4.35	8.48	8.42	8.40	8.50	0.152	0.75	0.64
Total lipids, kg/pig	2.11	5.99	6.43	5.70	6.71	0.372	0.41	0.07
Total energy, mcal/pig	44.34	104.72	113.23	104.07	113.88	4.108	0.15	0.10
Protein gain, g/d	-	147.3	144.9	144.1	148.1	3.41	0.62	0.41
Lipid gain, g/d	-	138.6	154.2	128.3	164.4	12.82	0.40	0.06
Lipid:protein,[7] g/g	-	0.95	1.06	0.89	1.12	0.093	0.39	0.09
MER,[8] mcal/d	-	2.15	2.46	2.13	2.48	0.134	0.12	0.07
CER,[9] mcal/d	-	2.14	2.28	2.03	2.39	0.124	0.45	< 0.05

[1] Data are least squares means of 32 observations.

[2] Supplementation of soybean oil (+); No supplementation of soybean oil (-).

[3] Additional corn in the diet (+); No additional corn in the diet (-).

Table 6.4 (Cont.)

[4] *P*-values for main effects of dietary lipids and additional corn. No interactions between dietary lipids and additional corn were observed for all measurements.

[5] ISG = initial slaughter group.

[6] Total digest-free body = chilled carcass + empty viscera + blood.

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

[8] MER = measured energy retention.

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

Table 6.5. Effects of additional dietary lipids and corn on carcass compositions and total amount of energy, protein, and lipids in finishing pigs[1]

		Added lipids[2]		Added corn[3]			P-value[4]	
Items	ISG[5]	-	+	-	+	SEM	Lipids	Corn
Live wt, kg	84.01	125.85	129.73	127.79	127.79	1.416	0.06	0.99
Hot carcass wt, kg	71.35	106.17	109.07	108.20	107.04	1.439	0.16	0.57
Dressing percentage, %	84.93	84.37	84.10	84.71	83.76	0.461	0.67	0.15
Total DF body[6]								
DF BW, kg	81.44	124.91	128.60	126.91	126.60	1.463	0.08	0.88
DF body DM, kg	33.42	58.12	59.80	58.67	59.26	0.975	0.22	0.67
Protein, g/kg	401	343	327	340	331	7.5	0.12	0.42
Lipids, g/kg	497	575	554	554	574	8.6	0.09	0.11
Energy, mcal/kg	6.90	7.29	7.28	7.21	7.36	0.042	0.88	0.02
Total protein, kg/pig	13.40	19.86	19.55	19.86	19.54	0.346	0.52	0.52
Total lipids, kg/pig	16.66	33.50	33.14	32.56	34.08	0.908	0.78	0.24
Total energy, mcal/pig	230.70	424.11	435.43	423.14	436.40	8.364	0.34	0.26
Protein gain, g/d	-	190.3	178.7	189.4	179.5	9.6	0.39	0.47
Lipid gain, g/d	-	489.0	475.1	460.8	503.2	25.10	0.70	0.24
Lipid:protein,[7] g/g	-	2.70	2.75	2.54	2.91	0.206	0.85	0.20
MER,[8] mcal/d	-	5.63	5.90	5.58	5.95	0.220	0.38	0.24
CER,[9] mcal/d	-	5.70	5.51	5.43	5.78	0.230	0.54	0.29

[1] Data are least squares means of 31 observations.

[2] Supplementation of soybean oil (+); No supplementation of soybean oil (-).

[3] Additional corn in the diet (+); No additional corn in the diet (-).

Table 6.5 (Cont.)

[4] *P*-values for main effects of dietary lipids and additional corn. No interactions between dietary lipids and additional corn were observed for all measurements.

[5] ISG = initial slaughter group.

[6] Total digest-free body = chilled carcass + empty viscera + blood.

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

[8] MER = measured energy retention.

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

Table 6.6. Net energy of diets and supplemental corn in growing and finishing pigs[1]

	Added lipids[2]		Added corn[3]			*P*-value[4]	
Items	-	+	-	+	SEM	Lipids	Corn
Growing pigs							
Initial body energy, mcal	44.39	44.39	44.44	44.34	1.033	1.00	0.95
Final body energy, mcal	104.72	113.23	104.07	113.88	4.108	0.15	0.10
Energy retention, mcal	60.33	68.84	59.63	69.54	3.758	0.12	0.07
Total ONE_m,[5] mcal	32.26	32.42	32.23	32.45	0.417	0.78	0.71
Total NE intake, mcal	92.59	101.26	91.86	101.99	4.003	0.14	0.08
Total feed intake, kg	56.33	56.64	53.35	59.61	1.923	0.91	0.03
NE of diets, kcal/kg	1,642	1,787	1,725	1,704	30.9	<0.01	0.64
NE of corn,[6] kcal/kg	1,677	1,608	-	-	212.2	0.82	-
Finishing pigs							
Initial body energy, mcal	227.10	228.78	227.68	228.19	2.099	0.57	0.86
Final body energy, mcal	424.11	435.43	423.14	436.40	8.364	0.34	0.26
Energy retention, mcal	197.01	206.65	195.45	208.21	7.709	0.38	0.24
Total ONE_m,[5] mcal	126.87	128.32	127.53	127.67	0.806	0.21	0.90
Total NE intake, mcal	323.88	334.98	332.98	335.88	8.118	0.33	0.26
Total feed intake, kg	136.76	128.82	131.20	134.38	3.378	0.10	0.51
NE of diets, kcal/kg	2,373	2,604	2,470	2,506	38.7	<0.01	0.51
NE of corn,[6] kcal/kg	2,716	2,493	-	-	277.4	0.57	-

[1] Data are least squares means of 32 observations for growing pigs and 31

observations for finishing pigs.

[2] Supplementation of soybean oil (+); No supplementation of soybean oil (-).

Table 6.6 (Cont.)

[3] Additional corn in the diet (+); No additional corn in the diet (-).

[4] *P*-values for main effects of dietary lipids and additional corn. No interactions between dietary lipids and additional corn were observed for all measurements.

[5] Total operational NE requirement for maintenance is calculated by multiplying the mean metabolic BW ($kg^{0.6}$) of each pig by 128 and 219 kcal for growing and finishing pigs, respectively (Kil et al., 2009a) and the number of days on experiments (28 d for growing pigs and 35 d for finishing pigs).

[6] NE of supplemental corn in the diet containing no supplemental soybean oil or in the diet containing supplemental soybean oil. The NE of supplemental corn was calculated using the difference method by subtracting the NE contribution from each basal diet containing 0 or 8% soybean oil from the NE of the diets containing 25% supplemental corn (de Goey and Ewan, 1975).

Table 6.7. Effect of dietary lipids and stage of growth on the NE of corn fed to growing and finishing pigs[1]

	Added lipids[2]		Stage of growth[3]			*P* – value[4]	
Items	-	+	G	F	SEM	Lipids	Stage
NE of corn, kcal/kg	2,197	2,053	1,643	2,607	169.9	0.55	<0.01

[1] Data are least squares means of 16 observations for growing pigs and 15 observations for finishing pigs.

[2] Supplementation of soybean oil (+); No supplementation of soybean oil (-).

[3] Stage of growth = growing pigs (G) and finishing pigs (F).

[4] *P*-values for main effects of dietary lipids and stage of growth. No interaction between dietary lipids and stage of growth was observed for the NE of corn.

CHAPTER 7

COMPARISON OF NET ENERGY VALUES FOR DIETS AND INGREDIENTS FED TO PIGS IN NORTH AMERICA AND VALUES PREDICTED FROM EUROPEAN ENERGY SYSTEM

ABSTRACT

The objective of this study was to compare net energy values for diets and ingredients measured in North America (NE_{NA}) and values predicted from 3 European energy systems. The NE_{NA} of 16 diets and 7 ingredients were measured in growing and finishing pigs at the University of Illinois, at the University of Missouri, and at the Prairie Swine Centre. All diets were formulated based on corn and soybean meal, but some of the diets also contained soybean oil (SBO), choice white grease (CWG), soybean hulls (SBH), wheat middlings (WM), or low-oligosaccharide soybean meal (SBM-LO). The French NE system (NE_{INRA}) and the Dutch NE system (NE_{CVB}) are based on the concentrations of digestible nutrients, and therefore, the concentrations of digestible nutrients in the 16 diets and 7 ingredients were measured at each location and were used for predicting energy values for diets and ingredients. The potential physiological energy values (PPE) for diets and ingredients that are used in Danish energy system were also measured. All chemical analyses needed in the prediction equations for the European energy systems followed the procedures specified by each system. Results showed that values for NE_{NA} of most diets fed to growing pigs were lower ($P < 0.05$) than values predicted from NE_{INRA} and NE_{CVB}. However, values for NE_{NA} of most diets fed to finishing pigs were more comparable with values predicted from NE_{INRA} and NE_{CVB}. In general, values for NE_{NA} were closer to PPE values than to NE_{INRA} and NE_{CVB} values. The measured NE_{NA} values for all ingredients fed to growing pigs were also lower ($P < 0.05$) than values predicted from NE_{INRA} and NE_{CVB}. However, for finishing pigs no differences in values for corn, SBH, WM, SBM, and SBM-LO among NE_{NA}, NE_{INRA}, and NE_{CVB} were observed. For both growing and finishing pigs, the measured NE_{NA} values for SBO and CWG were lower ($P < 0.01$) than values predicted from NE_{INRA} and NE_{CVB}. The values for NE_{NA} of SBO and CWG were also lower than the PPE values of SBO and CWG. In conclusion, values for NE_{INRA} and NE_{CVB} of diets and ingredients fed to growing pigs were greater than the values measured in North America but NE_{INRA} and NE_{CVB} predicted values for finishing pigs that were closer to NE_{NA} values than the values for growing pigs. All the European energy systems predict greater energy values of lipids than the measured energy values of lipids in North America.

Keywords: European energy systems, NE, North America, pig, potential physiological energy

INTRODUCTION

Energy is the most expensive component in swine diets. In North America, diets have typically been formulated based on DE or ME systems. However, DE and ME systems may have limitations because these systems do not consider the efficiency of utilization of metabolized energy (de Lange and Birkett, 2005).

Currently, France and the Netherlands use NE systems to overcome the limitations of DE and ME systems. These systems estimate the NE of diets and ingredients from the concentrations of digestible nutrients. Demark has implemented a system for estimating energy values of diets and ingredients based on in vitro digestibility of nutrients and theoretical energy values of digestible nutrients when utilized for ATP synthesis (Boisen, 2007). This system is called the potential physiological energy system (**PPE system**).

European NE systems have been criticized because they sometimes predict greater efficiencies of nutrient utilization for NE than theoretical possible and they also fail to account for the change in energetic efficiencies associated with increased lipid retention as pigs mature (Whittemore, 1997; de Lange and Birkett, 2005). The NE values measured under a specific condition may not always be applicable to other conditions (Boisen, 2007). For the PPE system, it is a concern that this system relies on theoretical efficiencies of nutrient utilization and not on values that are measured in pigs (Noblet and van Milgen, 2004).

Recently, the NE of several diets and ingredients was determined in North America (Hinson et al., unpublished data; Kil et al., unpublished data; Patience et al., unpublished data; Stewart et al., unpublished data), but it is not known how well these values compare with energy values predicted from the European energy systems. The objective of this work, therefore, was to compare the NE values for diets and ingredients measured in North America (**NE_{NA}**) and the energy values predicted from 3 European energy systems.

MATERIALS AND METHODS

Data from North America

The NE_{NA} of 16 diets and 7 ingredients were measured in both growing and finishing pigs at the University of Illinois, Urbana (**UIUC**), at the University of Missouri, Columbia (**MO**), or at the Prairie Swine Centre Inc., Saskatoon (**PSC**). All diets were formulated based on corn and soybean meal, but some of the diets also contained soybean oil (**SBO**), choice white grease (**CWG**), soybean hulls (**SBH**), wheat middlings (**WM**), or low-oligosaccharide soybean meal (**SBM-LO**). Details for diet formulations and experimental procedures have been reported (Hinson et al., unpublished data; Kil et al., unpublished data; Patience et al., unpublished data; Stewart et al., unpublished data). Briefly, the comparative slaughter procedure was used to estimate energy retention in growing and finishing pigs (de Goey and Ewan, 1975; Kil et al., unpublished data). The NE for each diet was then calculated from the sum of energy retention and the total NE requirement for maintenance, which was measured in a separate experiment (Kil et al., unpublished data). The NE values of ingredients were calculated using the difference method by subtracting the NE contribution from a basal diet from the NE of the diet containing each ingredient (de Goey and Ewan, 1975).

All diets contained an indigestible marker and fecal samples from pigs fed all diets were collected via weekly grab sampling. The apparent total tract digestibility of energy, OM, CP, ether extract, and acid-hydrolyzed ether extract was then calculated for all diets according to Chastanet et al. (2007). The concentrations of digestible energy and nutrients in diets were calculated from multiplying the concentration of energy and nutrients in the diet by the apparent total tract digestibility of energy and nutrients in the diet. The concentrations of digestible energy and nutrients in each ingredient were determined using the difference method (Adeola, 2001).

All chemical analyses for diets, ingredients, and samples of feces were conducted in one laboratory. The DM of diets and fecal samples was determined by oven drying at 135°C for 2 h (method 930.15; AOAC, 2005). The GE of diets and feces were measured using an adiabatic bomb calorimeter (Model 6300, Parr Instruments, Moline, IL). The concentration of N in diets and feces was measured using the combustion method (method 990.03; AOAC, 2005) and CP was calculated as N × 6.25. The concentration of ether extract in diets was determined using the ether extraction method (method 2003.06; AOAC, 2005). The concentration of total lipids in diets and feces was measured after acid hydrolysis followed by ether extraction (method 996. 01; AOAC, 2005). Diet and fecal samples were also analyzed for ash (method 942.05; AOAC, 2005). The concentration of total starch in the diet was measured using the Ewers polarimetric method (EEC, 1999) and also using the enzymatic method (ISO, 2004). Total free sugars were measured by the Luff-Schoorl method (BIPEA, 1976). The crude fiber concentration in diets was measured using the Weende method (method 962.09; 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 ileal digestible carbohydrates, ileal digestible CP, fermentable carbohydrate, and enzyme indigestible ileal DM in all diets and ingredients were also measured using in vitro procedures (Boisen, 2007). The ileal digestible crude fat was calculated from the fatty acid composition in the diet (Boisen, 2007).

European Energy Systems

The French NE system (**$\mathbf{NE_{INRA}}$**; Noblet et al., 1994; Sauvant et al., 2004) was developed from experiments using growing pigs fed 61 diets containing different ingredients and varying nutrient composition (Noblet et al., 1994). Regression equations were then developed to predict the NE of diets or ingredients from concentrations of digestible nutrients, assuming that the energetic utilization of each dietary component is independent of other components in the diet (Bakker, 1996). The NE_{INRA} is based on the following equations:

$$NE2 = 2.892\ DCP + 8.365\ DEE + 3.418\ ST + 2.844\ SU + 2.055\ Dres$$

$$NE4 = 0.703\ DE + 1.58\ EE + 0.47\ ST - 0.97\ CP - 0.98\ CF,$$

where NE = net energy (kcal/kg DM), DCP = digestible CP (g/kg DM), DEE = digestible ether extract (g/kg DM), ST = starch (g/kg DM), SU = sugar (g/kg DM), Dres (g/kg DM) = digestible OM – digestible CP – digestible ether extract – ST – SU, DE = digestible energy (kcal/kg DM), EE = ether extract (g/kg DM), CF = crude fiber (g/kg DM). The average NE values from the above 2 equations are used to predict the values for NE_{INRA} (Sauvant et al., 2004).

The Dutch NE system (**NE_{CVB}**; Blok, 2006) was developed with similar principles and methods as those used to develop NE_{INRA} and the NE_{CVB} was based on measurements of nutrients in diets and ingredients from Noblet et al. (1994). However, in calculating NE values for NE_{CVB}, total carbohydrates (i.e., starch and sugar) are separated into an enzymatically digestible fraction and a fermentable fraction. The NE_{CVB} is based on the following equation:

$$NE = 2.796\ DCP + 8.542\ DEE\text{–}acid + 3.380\ ST\text{-}Am\text{-}e + 3.042\ SU\text{-}e + 2.328\ FCH,$$

where NE = net energy (kcal/kg DM), DCP = digestible CP (g/kg DM), DEE-acid = digestible ether extract using acid hydrolysis (g/kg DM), ST-Am-e = enzymatically digestible starch (g/kg DM), SU-e = enzymatically digestible sugar (g/kg DM), FCH = fermentable carbohydrate (g/kg DM), being the fermentable starch + fermentable sugar + DNSP. The DNSP (g/kg DM) = digestible OM – digestible CP – DEE-acid –

ST-Am-e – 0.95× total sugar (0.95 = correction factor for disaccharides in feed ingredients).

The PPE system is based on measurements of in vitro digestibility of nutrients and calculation of the PPE that is defined as the potential energy value for ATP production when all digestible nutrients are oxidized (Boisen, 2007). The theoretical efficiency of starch utilization for ATP synthesis (67%) is considered a standard and the efficiencies of other digestible nutrients for ATP synthesis are determined relative to the efficiency of starch (Boisen, 2007). The PPE system is based on the following equation:

$$\text{PPE} = 2.37 \times \text{RDCP} + 7.58 \times \text{RDCF} + 2.80 \times \text{EDC} + 1.67 \times \text{FERMC} - 0.67 \times \text{EIDMi},$$

where PPE = potential physiological energy (kcal/kg DM), RDCP = in vitro ileal digestible CP, RDCF = ileal digestible crude fat that is calculated from the fatty acid composition of the diet; EDC = in vitro ileal digestible carbohydrates; FERMC = in vitro fermentable carbohydrate; EIDMi = in vitro enzyme undigested ileal DM.

Statistical Analysis

All data were analyzed using the MIXED procedure (SAS Inst. Inc., Cary, NC) with pig as the experimental unit. The NE values for diets and ingredients were compared among NE_{NA}, NE_{INRA}, and NE_{CVB} using an ANOVA. Only 1 value for PPE of each diet and ingredient was available because PPE values were measured only for a diet or an ingredient, and therefore, a statistical comparison between NE_{US} and PPE could not be conducted. The NE values for ingredients were also compared between growing pigs and finishing pigs using a t-test. An alpha-value of 0.05 was used to assess significance among means.

RESULTS

Diets

For growing pigs, values for NE_{NA} of most diets were lower (*P* < 0.01) than values predicted from NE_{INRA} and NE_{CVB} (Table 7.1). Values for NE_{NA} and NE_{CVB} of the diet containing supplemental AA were greater (*P* < 0.01) than the value predicted from NE_{INRA}, but for 11 of the 16 diets, no difference between NE_{INRA} and NE_{CVB} was observed. The average value for NE_{NA} of all diets (2.099 mcal/kg DM) was lower (*P* < 0.01) than the average value predicted from NE_{INRA} (2.635 mcal/kg DM) or NE_{CVB} (2.701 mcal/kg DM). For 15 of the 16 diets, values for PPE were closer to the measured NE_{NA} values, but lower than the values predicted from NE_{INRA} and NE_{CVB}.

For finishing pigs, NE_{INRA} and NE_{CVB} predicted greater (*P* < 0.05) values than measured NE_{NA} values for 7 and 9 of the diets, respectively, but for the remaining diets, the values predicted from NE_{INRA} and NE_{CVB} were not different from the measured values for NE_{NA}. Values for 3 of the 16 diets predicted from NE_{CVB} were greater (*P* < 0.05) than values predicted from NE_{INRA}. The average value for NE_{NA} of the 16 diets (2.638 mcal/kg DM) was lower (*P* < 0.01) than the average value for NE_{INRA} (2.764 mcal/kg DM) and NE_{CVB} (2.814 mcal/kg DM). The values for PPE of 13 of the 16 diets were lower than the values for NE_{NA}.

Ingredients

For growing pigs, the measured values for NE_{NA} of all ingredients were lower (*P* < 0.05) than the values predicted from NE_{CVB}. The NE_{NA} values for 8 of the 9 ingredients were also lower than the values predicted from NE_{INRA} (Table 7.2). The values for NE_{INRA} of SBO and CWG were also lower (*P* < 0.01) than the values for

NE_{CVB} but all other ingredients, no differences between NE_{INRA} and NE_{CVB} were observed. The average value for NE_{NA} of all ingredients (2.543 mcal/kg DM) was lower ($P < 0.01$) than the average value for NE_{INRA} (4.070 mcal/kg DM) or NE_{CVB} (4.493 mcal/kg DM). The values for PPE of most ingredients were numerically greater than the values for NE_{NA}, but lower than the values predicted from NE_{INRA} and NE_{CVB}. The average value for PPE of all ingredients was also greater than the average measured value for NE_{NA} (3.467 vs. 2.543 mcal/kg DM, respectively).

For finishing pigs, the measured values for NE_{NA} of SBO and CWG were lower ($P < 0.01$) than the value predicted from NE_{INRA} and NE_{CVB}, but for all other ingredients, no differences between the measured and the predicted values were observed. Likewise, the average measured value for NE_{NA} of all ingredients (3.351 mcal/kg DM) was not different from the average values predicted from NE_{INRA} (3.736 mcal/kg DM) or NE_{CVB} (3.981 mcal/kg DM). With the exception of SBO, CWG, and WM, all values for PPE were lower than the values for NE_{NA}, but the average value for PPE of all ingredients was close to the average measured value for NE_{NA} (3.464 vs. 3.351 mcal/kg DM, respectively).

The 2 values for NE_{NA} of corn were greater ($P < 0.05$) for finishing pigs (3.201 and 2.938 mcal/kg DM) than for growing pigs (1.939 and 1.859 mcal/kg DM), but for the remaining ingredients, no differences in NE_{NA} values between growing and finishing pigs were observed. Likewise, with the exception of SBO, no differences between growing and finishing pigs were observed for values predicted from NE_{INRA} and NE_{CVB}.

DISCUSSION

Diets

The lower values for NE_{NA} than values predicted from NE_{INRA} and NE_{CVB} may be a consequence of the different methodologies that were used to measure energy retention because the comparative slaughter method often yields values for energy retention that are lower than when measurements are based on indirect calorimetry (Quiniou et al., 1995; Reynolds, 2000). In addition, pigs used to measure NE_{NA} values were allowed free access to the diet, while pigs that were used for NE_{INRA} and NE_{CVB} were fed a restricted amount of diet. Pigs that are restricted in their feed intake have a greater digestibility of energy compared with pigs that are allowed ad libitum access to feed (Haydon et al., 1984; Chastanet et al., 2007). Therefore, the prediction equations for NE_{INRA} and NE_{CVB} may overestimate the energy value of diets consumed by pigs that are allowed free access to the diet.

The values for NE_{NA} of most diets fed to finishing pigs were more comparable to the values for NE_{INRA} and NE_{CVB} than values for growing pigs. One possible reason for this observation is that the NE_{INRA} and NE_{CVB} equations (Noblet et al., 1994; Sauvant et al. 2004; Blok, 2006) were developed using heavier pigs (initial BW of approximately 45 kg) than the growing pigs used to measure NE_{NA} values. Therefore, the efficiencies of nutrient utilization for NE in NE_{INRA} and NE_{CVB} equations may be closer to the efficiencies for finishing pigs than for growing pigs, which may explain why the values predicted from NE_{INRA} and NE_{CVB} are closer to NE_{NA} values for finishing pigs than for growing pigs. The effect of feed intake on the digestibility of energy and nutrients may also be less pronounced for finishing pigs than for growing pigs (Kil et al., unpublished data), and therefore, the equations used to predict the values for NE_{INRA} and NE_{CVB} may more accurately predict the energy values of diets for finishing pigs than for growing pigs.

The reason for the greater values for NE_{CVB} than for NE_{INRA} for some diets is that in the prediction of values for NE_{CVB}, the concentration of lipids in diets and feces is analyzed using the acid hydrolyzed ether extract method, while values for NE_{INRA} are predicted based on concentration of lipids in the diet that is analyzed via the ether extraction method. As a consequence, a greater concentration of lipids in the diet is used in the prediction of NE_{CVB} than in the prediction of NE_{INRA}.

Although PPE values for most diets were more comparable to the values for NE_{NA} of diets than the values predicted from NE_{INRA} and NE_{CVB}, it is difficult to compare the values directly because NE systems consider energy retention in the body as GE, while the PPE system predicts the potential ATP production from digestible nutrients in the diet (Boisen, 2007). However, the PPE values of diets increased with increasing levels of dietary lipids but decreased as the levels of fiber or CP in the diet increased, indicating that the effects of dietary components on PPE values are similar to effects on values for NE_{NA}, NE_{INRA}, and NE_{CVB}.

Ingredients

The measured NE_{NA} values for all ingredients fed to growing pigs were lower than the values predicted from NE_{INRA} and NE_{CVB}. This difference is likely a consequence of the fact that smaller pigs were used to measure values for NE_{NA} than the pigs used to generate the prediction equations for NE_{INRA} and NE_{CVB}. The biggest differences were observed for fibrous ingredients fed to growing pigs, which is likely a result of the lower fermentation capacity in young pigs compared with older pigs

(Noblet and van Milgen, 2004). This difference in fermentation capacity may be one of the reasons for the lower values for $\mathrm{NE}_{\mathrm{NA}}$ of diets fed to growing pigs compared with the values predicted from $\mathrm{NE}_{\mathrm{INRA}}$ and $\mathrm{NE}_{\mathrm{CVB}}$.

For both growing and finishing pigs, the measured $\mathrm{NE}_{\mathrm{NA}}$ values for SBO and CWG were much lower than the values predicted from $\mathrm{NE}_{\mathrm{INRA}}$ and $\mathrm{NE}_{\mathrm{CVB}}$. The $\mathrm{NE}_{\mathrm{INRA}}$ and $\mathrm{NE}_{\mathrm{CVB}}$ assumes that 90% of the energy in digested lipids is retained in NE regardless of the level of dietary lipids (Noblet et al., 1994) and this efficiency is the same as the theoretical efficiency of energy utilization of digested lipids for body lipid retention (Black, 1995). However, not all digested lipids are incorporated into body lipids because some digested lipids are utilized for ATP synthesis (Chwalibog and Thorbek, 1995; Kil et al., unpublished data), which has an energetic efficiency of 66% (Black, 1995). This may be one of the reasons why the values for SBO and CWG predicted from $\mathrm{NE}_{\mathrm{INRA}}$ and $\mathrm{NE}_{\mathrm{CVB}}$ of dietary lipids were much greater than the values for $\mathrm{NE}_{\mathrm{NA}}$.

The observation that the measured $\mathrm{NE}_{\mathrm{NA}}$ values for CWG were greater than the values for SBO may be a consequence of unsaturated fatty acids being more prone to oxidation for ATP than saturated fatty acids (Cunnane, 2004; Kloareg et al., 2007). However, this difference is not taken into account when $\mathrm{NE}_{\mathrm{INRA}}$ and $\mathrm{NE}_{\mathrm{CVB}}$ predict the values for dietary lipids because $\mathrm{NE}_{\mathrm{INRA}}$ and $\mathrm{NE}_{\mathrm{CVB}}$ account for only the digestibility of lipids. The final utilization of digestible lipids for ATP synthesis or incorporation of digested lipids into body lipids, which may depend on the fatty acid composition of dietary lipids (Shimomura et al., 1990; Kil et al., unpublished data), is not accounted for in the values predicted from $\mathrm{NE}_{\mathrm{INRA}}$ and $\mathrm{NE}_{\mathrm{CVB}}$. The $\mathrm{NE}_{\mathrm{INRA}}$ and $\mathrm{NE}_{\mathrm{CVB}}$ may, therefore, overvestimate the NE for unsaturated fatty acids than saturated fatty acids.

The biggest difference between NE_{NA} and PPE was also observed for dietary lipids. The reason for this observation may be that the PPE system predicts the PPE value of dietary lipids from the fatty acid composition of lipids, assuming that the digestibility of fatty acids is constant (90%) and all digested lipids are retained as body lipids (Boisen, 2007). This assumption, however, may be over-simplified because the digestibility of fatty acids may be influenced by fatty acid composition and other components in the diet (Stahly, 1984; Jørgensen et al., 1992; Kil et al., 2007), and some of the digested lipids may be utilized for ATP synthesis instead of being retained as body lipids (Kloareg et al., 2005; Kil et al., unpublished data). The PPE values represent the theoretical energy values of SBO and CWG and the PPE values for SBO and CWG were lower than the predicted values for NE_{INRA} and NE_{CVB}, which further indicates that NE_{INRA} and NE_{CVB} for dietary lipids may be overestimated.

In conclusion, NE values for diets and ingredients predicted from NE_{INRA} and NE_{CVB} were greater than the values measured in North America but NE_{INRA} and NE_{CVB} may more accurately predict the NE values of diets and ingredients fed to finishing pigs than to growing pigs. Values for NE_{NA} were closer to PPE values than to NE_{INRA} and NE_{CVB}. The European energy systems predict a greater energy value of dietary lipids than the measured energy value of dietary lipids, which is likely a consequence of these systems assuming that all dietary lipids are incorporated into body lipids.

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Table 7.1. Comparison of NE values (NE_{NA}, mcal/kg DM) measured in North America and energy values (mcal/kg DM) predicted from the French (NE_{INRA}), the Dutch (NE_{CVB}), and the Danish (PPE) energy systems for diets fed to growing and finishing pigs[1,2]

Diet number	Diets[3]	Growing pigs						Finishing pigs					
		NE_{NA}	NE_{INRA}	NE_{CVB}	PPE	SEM	*P* –value	NE_{NA}	NE_{INRA}	NE_{CVB}	PPE	SEM	*P* –value
1	Corn-SBM	1.867^{x}	2.538^{y}	2.592^{y}	2.210	0.023	<0.01	2.664^{x}	2.703^{xy}	2.781^{y}	2.402	0.027	0.02
2	75% Diet 1 + 25% Corn	1.894^{x}	2.564^{y}	2.730^{z}	2.306	0.024	<0.01	2.791	2.698	2.765	2.368	0.059	0.52
3	Corn-SBM-8% SBO	2.035^{x}	2.905^{y}	2.935^{y}	2.414	0.030	<0.01	2.972^{x}	3.038^{x}	3.128^{y}	2.570	0.025	<0.01
4	75% Diet 3 + 25% Corn	1.996^{x}	2.840^{y}	2.885^{y}	2.479	0.049	<0.01	2.936	3.025	3.037	2.551	0.030	0.06
5	Corn-SBM	1.992^{x}	2.557^{y}	2.549^{y}	2.236	0.032	<0.01	2.628	2.691	2.653	2.186	0.050	0.68
6	95% Diet 5 + 5% SBO	2.113^{x}	2.882^{y}	3.069^{z}	2.483	0.017	<0.01	2.861	2.930	2.989	2.507	0.035	0.06
7	90% Diet 5 + 10% SBO	2.279^{x}	3.121^{y}	3.154^{y}	2.716	0.034	<0.01	2.898^{x}	3.231^{y}	3.243^{y}	2.798	0.064	<0.01
8	90% Diet 5 + 10% CWG	2.398^{x}	3.133^{y}	3.136^{y}	2.758	0.025	<0.01	3.037^{x}	3.288^{y}	3.415^{z}	2.972	0.026	<0.01
9	Corn-SBM	2.120	2.338	2.318	1.519	0.117	0.36	2.760	2.656	2.718	2.428	0.079	0.65

Table 7.1 (Cont.)

10	70% Diet 9 + 30% SBH	1.537^{x}	2.059^{y}	2.091^{y}	2.189	0.104	<0.01	2.273	2.147	2.183	1.836	0.091	0.61
11	70% Diet 9 + 30% WM	1.709^{x}	2.247^{y}	2.301^{y}	2.031	0.070	<0.01	2.324	2.266	2.273	2.147	0.108	0.92
12	Corn-SBM	2.221^{x}	2.639^{y}	2.724^{z}	2.463	0.030	<0.01	2.382^{x}	2.737^{y}	2.760^{y}	2.520	0.055	<0.01
13	75% Diet 12 + 25% SBM	2.059^{x}	2.568^{y}	2.650^{y}	2.316	0.043	<0.01	2.303^{x}	2.672^{y}	2.731^{y}	2.335	0.048	<0.01
14	75% Diet 12 + 25% SBM-LO	2.146^{x}	2.551^{y}	2.684^{z}	2.276	0.036	<0.01	2.405^{x}	2.600^{y}	2.735^{z}	2.339	0.044	<0.01
15	Corn-SBM-AA	2.687^{y}	2.572^{x}	2.724^{y}	2.254	0.020	<0.01	2.372^{x}	2.782^{y}	2.828^{y}	2.408	0.067	<0.01
16	Corn-SBM	2.539^{x}	2.640^{y}	2.666^{y}	2.287	0.030	0.02	2.678^{x}	2.850^{y}	2.869^{y}	2.368	0.032	<0.01
	Mean	2.099^{x}	2.635^{y}	2.701^{y}	2.309	0.028	<0.01	2.638^{x}	2.764^{y}	2.814^{y}	2.421	0.028	<0.01

$^{x-z}$Values within a row lacking a common superscript letter are different ($P < 0.05$).

[1] Data are mean of 7 or 8 observations.

[2] NE_{NA} values for ingredients from previous experiments (Hinson et al., 2009; Kil et al., 2009b,c; Patience et al., 2009; Stewart et al., 2009); Values for NE_{INRA} = the average of NE values predicted from the equations (Sauvant et al., 2004); Values for NE_{CVB} were predicted from the Dutch equation (Blok, 2006); Values for PPE = potential physiological energy values measured by the method of Boisen (2007).

Table 7.1 (Cont.)

[3] SBO = soybean oil; CWG = choice white grease; SBH = soybean hulls; WM = wheat middlings; SBM = conventional soybean meal; SBM-LO = low oligosaccharide soybean meal.

Table 7.2. Comparison of NE values (NE_{NA}, mcal/kg DM) measured in North America and energy values (mcal/kg DM) predicted from the French (NE_{INRA}), the Dutch (NE_{CVB}), and the Danish (PPE) energy systems for ingredients fed to growing and finishing pigs[1,2]

	Growing pigs						Finishing pigs					
Ingredients[3]	NE_{NA}	NE_{INRA}	NE_{CVB}	PPE	SEM	*P* – value	NE_{NA}	NE_{INRA}	NE_{CVB}	PPE	SEM	*P* – value
Corn in low lipid diet[4]	1.939^{x}	2.622^{y}	2.713^{y}	2.541	0.0957	<0.01	3.201	2.698	2.685	2.528	0.2419	0.25
Corn in high lipid diet[4,5]	1.859^{x}	2.600^{y}	2.657^{y}	2.541	0.1990	0.02	2.938	2.997	2.817	2.528	0.1242	0.59
5% SBO[6,7]	4.301^{x}	8.022^{y}	9.118^{z}	6.791	0.2903	<0.01	5.904	6.251	6.955	6.791	0.5838	0.45
10% SBO[7]	4.509^{x}	7.359^{y}	8.810^{z}	6.791	0.2832	<0.01	4.729^{x}	7.082^{y}	7.458^{y}	6.791	0.5605	<0.01
10% CWG	5.727^{x}	7.556^{y}	8.183^{z}	6.720	0.2114	<0.01	6.307^{x}	7.784^{y}	8.468^{z}	6.720	0.2168	<0.01
SBH	0.168^{x}	1.421^{y}	1.515^{y}	0.330	0.3435	0.02	1.125	0.934	1.064	0.330	0.2998	0.90
WM	0.760^{x}	2.015^{y}	2.151^{y}	1.573	0.2289	<0.01	1.371	1.379	1.606	1.573	0.3553	0.87
SBM	1.634^{x}	2.439^{y}	2.516^{y}	1.989	0.1711	<0.01	2.150	2.531	2.615	1.989	0.1913	0.21

Table 7.2 (Cont.)

SBM-LO	1.990^{x}	2.389^{xy}	2.523^{y}	1.929	0.1421	0.04	2.554	2.292	2.449	1.929	0.1740	0.57
Mean	2.543^{x}	4.070^{y}	4.493^{y}	3.467	0.3071	<0.01	3.351	3.736	3.981	3.464	0.2982	0.32

[x-z] Values within a row lacking a common superscript letter are different ($P < 0.05$).

[1] Data are mean of 7 or 8 observations.

[2] NE_{NA} values for ingredients from previous experiments (Hinson et al., 2009; Kil et al., 2009b,c; Patience et al., 2009; Stewart et al., 2009); Values for NE_{INRA} = the average of NE values predicted from the equations (Sauvant et al., 2004); Values for NE_{CVB} were predicted from the Dutch equation (Blok, 2006); Values for PPE = potential physiological energy values measured by the method of Boisen (2007).

[3] Corn included in the diet containing low lipid; corn included in the diet containing high lipid; SBO = soybean oil; CWG = choice white grease; SBH = soybean hulls; WM = wheat middlings; SBM = conventional soybean meal; SBM-LO = low oligosaccharide soybean meal.

[4] Values of NE_{NA} for finishing pigs were greater ($P < 0.05$) than for growing pigs.

[5] Valuee of NE_{INRA} for finishing pigs were greater ($P < 0.05$) than for growing pigs.

Table 7.2 (Cont.)

[6] Valuee of NE_{INRA} for growing pigs were greater ($P < 0.05$) than for finishing pigs.

[7] Valuee of NE_{CVB} for growing pigs were greater ($P < 0.05$) than for finishing pigs.

GENERAL CONCLUSION

Liquid fat induces a lower endogenous loss of fat and has a greater apparent and true digestibility than intact fat at the end of the ileum and over the entire intestinal tract. No difference in true digestibility of fat between at the end of the ileum and over the entire intestinal tract indicates that there is no net absorption of fat in the large intestines of pigs. Purified form of NDF has little influence on apparent and true digestibility of fat.

The efficiency of DE utilization for NE (NE:DE) and operational NE requirement for maintenance (ONE_m) are greater for finishing pigs than for growing pigs. Experimental location also influences the NE:DE and ONE_m. The significant interaction between stage of growth and locations for ONE_m indicates that ONE_m depends on both stage of growth and experimental locations.

The NE of diets increases with increasing levels of dietary lipids. The NE of lipids is not affected by the level of dietary lipids. The NE of choice white grease is greater than the NE of soybean oil, indicating that the NE of lipids containing unsaturated fatty acids may be lower than the NE of lipids containing saturated fatty acids. The stage of growth has no impact on the NE of lipids.

The NE of corn is not affected by the absence or presence of lipids in the diet. However, the NE of corn is greater for finishing pigs than for growing pigs.

The NE values of diets and ingredients predicted from the French and the Dutch NE systems are greater than the NE values measured in North America, but those NE systems have a greater predictability for NE values of diets and ingredients fed to finishing pigs than to growing pigs. European energy systems predict greater energy values of lipids than the measured energy values of lipids in North America.

AUTHOR'S BIOGRAPHY

Dong Yong Kil was born on the 13th of Febrary, 1976 in Seoul, South Korea. He graduated Daeil Foreign Language High School in 1994. He pursued his bachelor and master degrees at Seoul National University, South Korea. He then worked as a research and teaching assistant for 2 years in Agricultural Sciences department at Korea National Open University. In 2005, he attended graduate school as a Ph.D. student from the summer of 2005 to spring of 2006 at the South Dakota State University in Brookings, SD. He eventually moved to the University of Illinois at Urbana-Champaign with his advisor, Dr. Hans Stein. He spent 2 and half years on finishing his Ph. D. program. He got happily married Hae Sun Park in 2004 and has two lovely daughters, Dayeon (Amy) and Dawon (Angie).