Master's Thesis of Science in Agriculture

Comparison between Analyze and Reference Starch and Sugar Contents Influencing on Feeding Value of Net Energy in Swine Diets

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Giselle Ann D. Fontamillas

Department of International Agricultural Technology

Graduate School of International Agricultural Technology

Seoul National University

Comparison between Analyzed and Reference Starch and Sugar Contents Influencing on Feeding Value of Net Energy in Swine Diets

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By
Giselle Ann D. Fontamillas

Supervised by
Prof. Byung-Chul Park

Major of International Agricultural Technology
Department of International Agricultural Technology
Graduate School of International Agricultural Technology
Seoul National University

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Approved as a qualified thesis
for the Degree of Master of Science in Agriculture
by the committee members

Chairman	**Tae Sub Park, Ph.D.**	
Member	**Byung-Chul Park, Ph.D.**	朴
Member	**Chul Sung Huh, Ph.D.**	

Abstract

A 33-day feeding trial was conducted wherein a total of 360 starter pigs (initial weight 17.70 ± 0.53 kg) were allotted to 4 dietary treatments with 3 replicates (30 pigs/pen) arranged in a 2x2 factorial design. For the main treatment, reference (CVB) and analyzed starch and sugar values were used to predict NE of feed ingredients using NE equation from the Dutch system. Furthermore, diets were designed with different NE concentrations and feed forms and were used as sub-treatment. Pellet forms were 30 kcal/kg lower NE compared to mash, then diets were fed to starter pigs from 55d to 87d to evaluate pig growth responses and implication on feed cost.

Starch contents of ingredients except in barley were higher in the analyzed treatment compared to those in the reference which consequently resulted in higher predicted NE value of the analyzed. For sugar, analyzed and reference values also varied but unlike starch, its effect on predicted NE is minimal due to its relatively small concentration except in soybean meal. These results indicated that using NE from reference values without analyzing nutrient compositions of ingredients can result in inaccurate energy contents of swine diets because such compositions can vary, which consequently affect predicted NE values.

In the growth trial, results showed that pigs fed different dietary treatments had relatively similar ADG ($p>0.05$). Starch and

sugar values (reference or analyzed) also had no significant difference ($p>0.05$) in ADFI. However, considering feed forms and energy concentrations, pigs fed mash consumed significantly higher ($p<0.05$) compared to those fed pellets. This lower ADFI with similar ADG of pigs fed pellets resulted to their significantly better feed efficiency ($p<0.05$). In terms of cost, diets formulated using analyzed values had considerably lower cost/kg feed which can be attributed to its higher starch which supplied the major energy in the experiment diets.

In conclusion, the present study suggests that accurate estimation of dietary energy contents in swine diets by analyzing the nutritional compositions including starch and sugar of ingredients can minimize diet cost without compromising animal performance. Additionally, it also demonstrated that in general, pelleting can positively affect feed efficiency potentially due to improved energy digestibility and/or nutrient utilization by the animals.

Keywords: Net Energy, Starch, Sugar, Analyzed, Reference, Feeding Value, Swine Diet

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List of Abbreviations

NE – Net energy

CVB – Centraal Veevoederbureau (Central Bureau for Livestock Feeding)

INRA – Institut National de la Recherche Agronomique (The National Institute for Agricultural Research)

NRC – National Research Council

Kcal – Kilocalorie

DM – Dry matter

MC– Moisture content

CF– Crude fiber

CP – Crude protein

DCP – Digestible crude protein

CFat – Crude fat

DCFat – Digestible crude fat

EE – Ether extract

FCH – Fermentable carbohydrates

NSP – Non-starch polysaccharides

DNSP – Digestible non-starch polysaccharides

CF_DI – Correction factor to convert the sugar content

AID – Apparent ileal digestibility

Dig P – Digestible phosphorus

SAS – Statistical analysis software

SEM – Standard error mean

ADG – Average daily gain

ADFI – Average daily feed intake

1. Introduction

1.1 Study Background

Dietary energy is required for all metabolic processes in pigs (Patience, 2009) hence in animal nutrition, energy represents an overall quality that is associated with nutrients in diets and feed ingredients (Moehn et al., 2005; Kil et al., 2013).

In commercial swine enterprise, the feed is commonly regarded as the most expensive variable inputs representing about 50% of total production cost to which energy contributes the largest proportion (Stein and Shurson, 2009; Patience, et al., 2015). Additional practical implication of dietary energy is the relationship which exists between feed efficiency of the animal and energy concentration of its diet (Patience, 2012). For instance, variation in available energy may translate to economically significant changes in feed conversion (Li et al., 2014). Therefore, it is not surprising that energy as a dietary component has received and still is continuously gaining significant attention in livestock and feed industries over the years.

To estimate dietary energy, nutritional information and concentrations of digestible nutrients in feed ingredients are used (Noblet, 2000; Noblet 2007) through several equations proposed by different energy evaluation systems (Noblet and Perez, 1993; Fairbairnet al., 1999). Such information can be extracted from the literature, collected from laboratories, obtained from other databases or generated specifically from animal studies and analyses of feeds (Gizzi and Givens, 2004).

While proximate components are readily measured, some variables, important for formulation are obtained as fixed values from feeding tables (Evans, 2013). This formulation practice is practical however, major feed ingredients used in livestock industry vary in their nutrient composition within and between individual batches due to both intrinsic and extrinsic factors which affect energy digestibility and availability (Gutiérrez-Alamo et al., 2008). Sources of variability include genetic, geographical origin, growing environment, post-harvest storage condition and technological processes (e.g. grinding, extrusion, pelleting, etc.) among others (Gizzi and Givens, 2004). For instance, within different batches of same feed material, proportion of starch, sugars and fibrous component varies (CVB, 2012). Aside from inherent dietary factors affecting variation in their energy content, different energy values are assigned to a particular diet or ingredient depending on the energy utilization by the animal and the method used to predict dietary energy (Noblet and Henry, 1993).

For these reasons, it's important to properly evaluate ingredient and diet nutrient composition because incorporating inaccurate data (under- or over- estimated values) will result to unreliable energy estimates and consequently produce inconsistent animal performance, higher levels of nutrient excretion or higher cost of production (Gizzi and Givens, 2004; Pomar et al., 2009; Kong and Adeola, 2014).

1.2 Purposes of Research

In commercial swine production, knowledge on the nutritional value, particularly of available energy content of an individual batch of feed ingredients is important for accurate diet optimization (Zijlstra et al., 1999) either for least-cost formulation or for meeting energy requirement of animals for optimum performance (Noblet 2006; Noblet 2013). Moreover, accurate energy prediction provides a better match between feed supply and animal requirements by minimizing over- or under- supply of nutrients thereby safeguards against both feed waste and suboptimal animal performance (Ramaekers, 2015).

Therefore, the present study aims to: i.) compare between analyzed and reference starch and sugar contents in predicting NE values of major energy-source ingredients used in formulating starter diets ii.) evaluate its consequent effects in terms of animal performance and diet cost and lastly iii.) investigate effect of pelleting in dietary energy and examine its growth response in starter pigs.

2. Literature Review

2.1 Dietary energy and its role in swine nutrition

Pigs require energy for all its metabolic processes mainly for maintenance, growth or production and reproduction (Patience, 2009; Holden et al., 2010). Maintenance requirements for energy include all of the basic functions required to keep the animal alive and healthy which include thermoregulation, body fluid regulation, respiration, digestion, blood flow, muscle tone, normal tissue turnover, etc. (Patience, 2009). Meanwhile, the actual energy requirement for production (protein and lipid deposition) will depend on the growth of the pig and the composition of that growth (Patience, 2009).

As a dietary component, energy is not a nutrient per se, but a quality associated with the nutrient content of feedstuffs and mixed diets (Moehn et al., 2005). It is enclosed as a chemical energy which is released by partial or complete oxidation following digestive and absorptive mechanisms in the gastrointestinal tract (Pond et al., 1995) and can only be measured in its transformation from one form to another (Velayudhan et al., 2015).

In terms of diet proportion, meeting the energy specifications of the feed represents more than 30% of the total cost of raising pig to its market weight (Patience, 2009) thus ingredients that supply energy are the main components of swine diets.

Specifically, in selecting and evaluating feed ingredients, available energy (and contribution of other nutrients) and its value as an energy source is a major factor that influences the value of that particular feed ingredient (Patience, 2009; Holden et al., 2010). Additionally, at the farm level, energy content of the diet influences the amount of feed intake voluntarily consumed by pigs (Holden et al., 2010).

2.2 Major sources of energy

Meeting the pig's requirement for energy is considerably more complex than it is for other nutrients. Dietary energy encompasses the energy produced from oxidation of proteins, lipids and carbohydrates (e.g. starch, sugar and fiber) after digestion and absorption (Patience, 2009).

Among the energy-sources, oxidation of glucose derived from starch, which is the main form of carbohydrates in cereal grains, represent the major source of dietary energy for pigs (Trottier et al., 2014; Velayudhan et al., 2015). Starch in particular, has received much attention not only for its major contribution on energy supply but also because of its influence on other nutrients (Hall, 2008).

Moreover, each nutrient source has different bio-availabilities and the metabolic pathways that transform them into useable energy are also diverse (Patience, 2012). For instance, fat is a very efficient energy source, especially if it is transformed directly to body fat in the pig. On the other hand, fiber and protein are used with much less efficiency, because a certain amount of intermediate metabolic activity is required to convert them into useable forms of energy in the body and in terms of energetic efficiency, starch is mid-way between these other groups (Patience, 2009). Thus, in terms of their energetic efficiencies different nutrients (protein, starch, fiber and fat) are utilized with varying levels of efficiency by the pig (Brafield and Llewellyn, 1982; Pond et al., 1995; Noblet and van Milgen, 2004).

2.2.1 Carbohydrates

Swine do not have a specific dietary requirement for carbohydrates, however in commercial pig production, they are important from nutritional as well as economic standpoint because quantitatively, they represent the main fraction accounting for more than 2/3rd of the dry matter of swine (& also poultry) diets therefore the largest energy contributor (60-70% of total energy intake) (Knudsen, 1997; Knudsen, 2011; NRC, 2012). Hence, properly accounting its energetic contribution in diet formulation can be important on productive performance and overall diet cost in pork production.

Carbohydrate fraction represents a diverse group of compounds and chemically, can be classified according to the degree of polymerization - into sugars (mono- and disaccharides), oligosaccharides and two broad classes of polysaccharides namely, starch and non-starch polysaccharides (NSP) (Knudsen and

Jorgensen, 2001; Cummings and Stephen, 2007). These 2 types of polysaccharides, however, have different fates and functions in the gastrointestinal tract and lead to different metabolites upon digestion. Pancreatic and mucosal enzymes in the small intestine break down the majority of starch, whereas NSP primarily are degraded by the microflora in the large intestine (Knudsen, 2011). In addition, carbohydrates within each fraction are digested or fermented to a different degree. As a consequence, the digestibility needs to be characterized for each group of carbohydrates (NRC, 2012).

2.2.1.1 Dietary Starch

Starch is a nutritionally important carbohydrate in livestock feeding that is increasingly measured and used in the formulation of their diets (Hall, 2008). It is the major dietary source of glucose and energy for monogastric animals (Regmi et al., 2010; Giuberti et al., 2012). Moreover, by weight, starch is the largest constituent in diets for monogastric animals such as pigs and poultry (Knudsen et al., 2006; Wiseman, 2006; Giuberti et al., 2014).

In terms of structure, it is composed entirely of glucose units and would be easily digestible if they readily dissolved, however, starch macromolecules are laid down within the plant in a complex form (Doucet et al., 2007; NRC, 2012). Pure starch consists predominantly of [alpha]-glucan in the form of amylose and amylopectin, embedded in a relatively hydrophobic protein network and surrounded by cell walls (Knudsen et al., 2006).

In monogastric animals, starch is mainly digested in the small intestine where it is hydrolyzed to maltose, maltotriose and isomaltose (α-dextrins) subunits by pancreatic and intestinal enzymes such as α-amylase and isomaltase (NRC, 2012; Wiseman, 2006; Shi and Noblet, 1993). Its degradation leads to the release of glucose, which is absorbed by an active absorption process that triggers the release of insulin from the pancreas (Knudsen, 2011). Meanwhile, starch disappearance from the large intestine is through microbial fermentation whose products (volatile fatty acids) are not use with the same efficiency of metabolic utilization in energy-yielding pathways as glucose (Wiseman, 2006).

In practical swine feeding, starch is mainly in the form of cereals (e.g. wheat, maize, rice, oats, barley, among others), although, it can also be found in other cereal by-products, seeds, tubers (e.g. potato, cassava) and stems (e.g. sago) (Wiseman, 2014). For instance, it was previously cited that corn is the main source of energy in practical diets or wheat is an important energy component in pig diets and this is mainly attributed to their high starch contents (Rosenfelder et al., 2013).

2.2.1.2 Sugars

In feed materials, the sugar fraction consists of enzymatically digestible and fermentative degradable sugars (CVB, 2012). Sugars are water-soluble components composed of monosaccharides and disaccharides. Monosaccharides are the simplest sugars (Knudsen et al., 2013). They can be further divided into subgroups depending on the number of carbon atoms present in the molecule. Arabinose, xylose, glucose, fructose and galactose are examples of monosaccharides (Church and Pond, 1982). Disaccharides consist of two monosaccharide molecules linked together by the release of one water molecule. Lactose from sow's' milk, sucrose from plant products and maltose found in sprouted cereals are examples of disaccharides (Church and Pond, 1982; Högberg, 2003).

For simple sugars, such as glucose, one mole releases 2.80 MJ of energy equivalent to 3.7 kcal per gram, known as the "caloric content" of sugar which for practical use is taken as 4 kcal/g (Velayudhan et al., 2015). In most feedstuffs however, monosaccharides are present in low concentrations (Knudsen et al., 2013).

2.2.1.3 Non-Starch Polysaccharides

Some fraction of carbohydrates, which is known as dietary fiber (DF) is not digested by digestive enzymes of the small intestine and becomes available as a substrate for bacterial fermentation, mainly in the large intestine (Knudsen, 2001; Noblet, 2007; Jha et al., 2010).

NSP, particularly cellulose (fiber) is a major component which can comprise up to 90% of the cell wall of plants (Grieshop et al., 2001; Jha and Berrocoso, 2015). It is composed of glucose molecules linked together by β1→4 glycosidic bonds, which the pig's digestive tract is unable to unlink them and hence is degraded by microbial fermentation in the hindgut (Knudsen, 2001). In comparison with simple sugars and starch, which need to be digested prior to the terminal ileum of monogastric animals for optimal use of these nutrients, non-starch polysaccharides (NSP) are mainly fermented by microbes in the hindgut into short-chain fatty acids (SCFA) (Knudsen, 2011).

Some energy sources with relatively high fiber when fed at excessive levels can reduce nutrient and energy digestibility hence gain and efficiency of animals (Knudsen, 2001; Noblet, 2007; Holden et al., 2010). These were demonstrated by results from previous experiments which showed that NSP negatively affected apparent digestion of protein, fat and some minerals in pigs and had indicated that NSP have a negative effect on the absorption process of these nutrients (Bakker, 1996; Bakker et al., 1998; Knudsen, 2011).

Furthermore, even though dietary fiber is partially digested, it provides negligible amounts of digestible or metabolizable energy to growing pigs due to increased endogenous protein and fat losses and negative interactions between DF and other dietary components. Meanwhile, digestive utilization of DF improves with pig's body weight where highest values are obtained in adult sows hence, consequently, DF makes a positive contribution to energy supply in adult sows therefore it is recommended to give at least two energy values for pig feeds: one for growing pigs and one for adult sows (Noblet and Le Goff, 2001).

2.2.2 Lipids (Fats and Oils)

The term 'fat' is generally used as a synonym for lipid which both describe a diverse variety of compounds that are insoluble in water, but dissolve in organic solvents. Triglycerides, phospholipids, sterols and fat-soluble vitamins are the important lipids from the nutritional point of view (Ravindran et al., 2016).

Fat molecules are made almost entirely of carbon and hydrogen, with very little O_2 (Velayudhan et al., 2015). Fats and oils contain the highest caloric density among nutrients. When metabolized yields approximately 9 kcal/g, which is 2.25 times more energy per unit of weight compared to carbohydrates in cereal grains but they are more expensive hence are included in the diet to a lesser extent (Holden et al., 2010). Therefore fats make a smaller overall contribution to total dietary energy than carbohydrates (Carter, 2010).

Fats and oils come from wide variety of sources and their concentration in feed ingredients also varies widely (Wiseman, 2016). Moreover, their composition largely differ in the type of fatty acids, the building blocks of fat, which are present. Specifically, animal fats normally contain more saturated fatty acids which are a solid at room temperature while vegetable oils largely consist of unsaturated fatty acids which are liquids at room temperature (Stahly, 1998).

The primary contribution of fats and oils in swine diets is to provide serve as concentrated source of energy (Stahly, 1998). Other benefits of this diet component include major source of essential fatty acids (Ω-3 and Ω-6), improving diet palatability, reducing dustiness and acting as lubricant for feed mill equipment (Wiseman, 2014).

Lastly, the response of pigs to dietary fat/oil additions largely depends on the animal's feed intake level, the digestibility of the fat source, and the efficiency of utilization of the fat for body maintenance and tissue growth (Stahly, 1998).

2.2.3 Protein and Amino Acids

Amino acids, or protein, may serve as an energy source if included in the diets in excess of the requirement for protein synthesis (Holden et al., 2010). Proteins are very complex molecules containing considerable amount of nitrogen (N) in addition to carbon, hydrogen, and O_2. They serve a variety of nutritional needs, but can be metabolized for energy when needed, extracting approximately 4 kcal/g, the same as from carbohydrates (Velayudhan et al., 2015). Moreover, protein usually contributes between 15 and 20% of the total energy in the diet (Carter, 2004).

2.3 Energy metabolism and utilization in pigs

In animal nutrition, efficiency of energy metabolism and utilization has been an important research focus (Holden et al., 2010). Furthermore, understanding energy supply and metabolic transformations of dietary energy in the animal is essential to adequately supply their energetic requirement for efficient pork production (Gutierrez and Patience, 2012).

Animals meet its energy requirements for normal physiological and metabolic function through the ingested energy from the diet. Dietary energy absorbed by pigs is then utilized for maintenance and/or protein or lipid retention (van Milgen and Noblet, 2003). After ingestion, energy-yielding nutrients from feed constituents (carbohydrates, fats and proteins) undergo series of catabolic reactions which involve conversion of energy from one form to another.

However, pigs do not utilize all the dietary energy contained in the feed, since energy produced from nutrient oxidation is either a retained by the animal but some will be inevitably loss through the feces, urine, (fermentation) gases or heat (Noblet and van Milgen, 2012; Kil et al., 2013). Based on these losses during the process of energy utilization, different energy values and energy systems have been defined: digestible energy (DE); metabolizable energy (ME) and net energy (NE) (Noblet and van Milgen, 2012).

Furthermore, it has been assumed that energy in pigs, is first prioritized for maintenance and energy intake in excess of the maintenance requirement is retained as protein or lipids in the body (Lizardo et al., 2002). The energy requirement for maintenance accounts for approximately 1/3 of total dietary energy utilization and the remaining 2/3 is stored as proteins or lipids in growing pigs (Black and de Lange, 1995; NRC, 1998). However, the ratio of energy utilization for maintenance or retention also depends on several factors such as growth stage and genetic background of pigs, thermal environment, and nutritional composition of the diet (Kil et al., 2013).

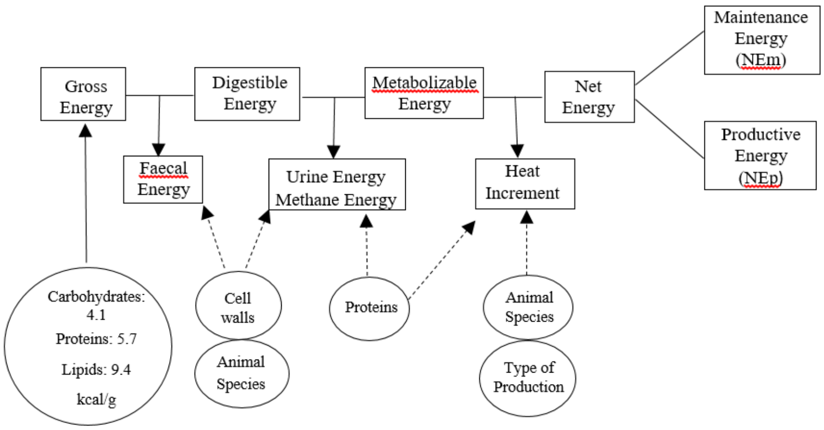


Figure 1. Schematic representation of different steps in energy utilization from feed in pigs (adapted from Sauvant et al., 2004 and Soren, 2012).

This figure represents the sequential energy loss and the pathway by which the gross energy or feed intake is converted to both maintenance energy and productive energy.

2.3.1 Energy digestibility

There are several factors affecting energy content of a diet or ingredient and its digestibility by the animal which includes diet composition, animal factors and technological processing (Noblet, 2013).

In most swine diets, the digestibility coefficient of energy (DCe) varies between 70 and 90% and variation is larger for feed ingredients (10 to 100%) (Noblet, 2013). Most of this variation is related to the presence of dietary fiber (DF) which is less digestible than other nutrients and which also reduces the apparent fecal digestibility of other dietary nutrients such as crude protein and fat (Noblet, 2007). Consequently, DCe is linearly and negatively related to the DF content of the feed (Le Goff and Noblet, 2001).

Moreover, energy digestibility is also affected by animal factors such as body weight (Garnsworthy and Wiseman, 2005; Noblet, 2007). DCe increases with increasing body weight (Noblet, 2006). Previous literature results indicate that energy digestibility of feeds is negatively affected by dietary fiber content but the negative effect is attenuated with increase in animal's body weight (Noblet, 2007). This improvement in energy digestibility with BW is mainly explained by an improved digestive utilization due to increased hindgut capacity and a subsequent reduced passage rate of digesta in the gut (Le Goff et al., 2002; Noblet, 2013). Study done by Lowell et al. (2015) comparing apparent total tract digestibility (ATTD) of nutrients in 11 diets fed to both growing pigs and gestating sows concluded that differences in digestibility of energy between gestating sows and growing pigs indicate that different energy values for gestating sows and growing pigs should be considered when formulating diets (Lowell et al., 2015). It is therefore suggested to use two energy values, one for "60 kg" pigs which can be applied to piglets and growing-finishing pigs and one for adult pigs applicable to both pregnant and lactating sows (Garnsworthy and Wiseman, 2005; Noblet, 2007).

Digestibility of energy in pig feeds can also be modified by feed processing such as pelleting and extrusion among others (Noblet, 2007). For instance, pelleting increases energy digestibility by about 1% (Noblet, 2006; Le Gall et al., 2009). However, this effect is more important for fat-rich ingredients (e.g. high-oil corn, full fat-rapeseed oil, linseed) for which pelleting improves digestibility of fat with subsequent differences in their DE value between mash and pellet forms. (Noblet, 2013).

2.4 Energy evaluation systems

An energy system is defined as a way of assigning energy values to feed ingredients using prediction equations and these predicted energy values are supposed to be additive in mixed diets and are also used to calculate the energy concentrations in mixed diets (Emmans, 1999). Essential qualities of a practical energy system is that it should be precise, should include unconventional rations and high production levels and should be simple to use and applicable in general (Velayudhan et al., 2015).

In livestock nutrition, energy systems are intended for the following purposes; to attribute energy values to a feed ingredient or a mixture of feed ingredients that could be used to estimate the amount of a given diet needed to meet the performance of the individual animal (Emmans, 1999) and to determine the requirements for maintenance, production, diet formulation and to develop feeding programs. Ultimately, the value of such a system lies in its ability to predict the performance of animals (Noblet, 2000).

Different energy values and energy systems have been defined based on the consideration of sequential energy losses during digestion and metabolism from gross energy in feeds or during the process of energy utilization known as: gross energy (GE), digestible energy (DE), metabolizable energy (ME) and net energy (NE) (Kong and Adeola, 2014; Noblet and Van Milgen, 2013).

2.4.1 Gross Energy

Gross energy (GE) or heat of combustion refers to the maximum quantity of energy present in an ingredient or ingested feed (Kil et al., 2013). It is the combustible energy ingested per day and is determined from the combustible energy density of the feed, its opportunity for ingestion, and the appetite of the animal (Soren, 2012). Additionally, it is the energy released by burning a feed or feedstuff sample in excess oxygen which is usually determined using bomb calorimetry (Velayudhan et al., 2015). Whereas in the absence of a bomb calorimeter, GE values may be estimated from the chemical composition by prediction equations (Noblet and Van Milgen, 2013).

Although GE is the most basic form in which energy can be expressed and is a property of the feed itself (Noblet and Van Milgen, 2013), this energy expression however, is rarely used in feed formulation except for computational purposes as it provides no clue about the amount of energy available for livestock production (Soren, 2012; Kil et al., 2013; Velayudhan et al., 2015).

2.4.2 Digestible Energy

Digestible Energy (DE) is the energy in feed that corresponds to its GE content minus energy losses after digestion and is calculated as GE minus the energy lost or excreted in feces (Just 1982; Velayudhan et al., 2015). It is usually measured in pigs kept in digestibility cages wherein the amount of feces (over a minimum of 5 days) is either obtained from total collection or estimated according to indigestible markers (e.g. chromic oxide, titanium dioxide, and acid insoluble ash) included in the feed (Noblet, 2007). DE can also be referred to as apparent total tract digestibility (ATTD) of GE, since it corrects for energy that is not absorbed by the pig as the feed passes along the gastrointestinal tract, but endogenous losses (e.g. digestive secretions and intestinal cell debris) are disregarded in its calculation (Patience, 2012). It is hence not a true measure of the energy values of the nutrients absorbed from the digestive tract (Velayudhan et al., 2015).

2.4.3 Metabolizable Energy

Metabolizable Energy (ME) is estimated by subtracting energy excreted in urine and gases from DE. In pigs, while energy content of feed, feces and urine can be measured with pigs kept in metabolism crates, measuring methane production is difficult and requires the pig to be housed in a respiration chamber (Noblet 2007; Noblet and Van Milgen 2013). In addition, the energy loss as methane is small in piglets and growing pigs, hence generally overlooked in ME calculation since relatively small amounts of gases are produced thus it represents only a small fraction (between 0.1% and 3%) of DE (Verstegen, 1971, Wenk, 2000; Velayudhan, Kim et al. 2015). Consequently, most ME values reported in literatures and tables ignore energy losses as methane and is therefore usually calculated as the difference between DE and urinary energy excretion (Kil et al., 2013). However, in adult pigs which diet contain higher inclusion of fiber-rich ingredients, hindgut fermentation is more important thereby increasing the importance of gaseous energy losses when ME is calculated for diets fed to pigs (Noblet, 1996; NRC, 1998). Consequently, methane production is four to five times greater than in growing pigs and thus deserves consideration in ME evaluation (Noblet and Van Milgen, 2013). Therefore, ME of diets varies with the quantities as well as characteristics of dietary fiber (Noblet, 1996; NRC, 1998).

Meanwhile, urinary energy losses represent a variable percentage of DE since energy losses in urine depend on the amount urinary N (Noblet and van Milgen, 2004). Urinary N in turn mainly depends on the amount of digestible protein thus on crude protein (CP) content of the diet (Velayudhan et al., 2015). On average, 50% of absorbed N is used for body protein synthesis and the remaining 50% of absorbed N is excreted in the urine (Sauvant et al., 2004). However, the ME value only accounts for energy losses as urinary excretion, but do not consider the energy cost for urinary excretion (Birkett and de Lange, 2001; Kil et al., 2013).

2.4.4 Net Energy

Net energy is defined as ME content minus heat increment (HI) which is the heat associated with metabolic utilization of ME and the energy cost of ingestion and digestion of the feed (Birkett and de Lange, 2001; Noblet, 2007; Kil et. al 2008). Since HI is difficult to separate from heat production, it is generally computed as the sum (estimated or measured) of fasting heat production and retained energy (Noblet, 2006; Noblet, 2007). Heat production can be measured directly through direct calorimetry or indirectly from gas exchanges through indirect calorimetry or from the comparative slaughter technique as the difference between ME intake and body energy gain (Noblet, 2013).

Measurements of DE and, to a lesser extent, ME are relatively easy and can be undertaken on a large number of feeds at a reasonable cost, the actual measurement of NE is far more complex and expensive. Hence another alternative is the use of reliable NE prediction equations that were established from measurements carried out under similar and standardized conditions (Noblet and van Milgen, 2013).

In order to calculate NE, it starts with GE value and predict sequentially the values of energy digestibility as well as the energy loss in the form of methane, urine and heat increment (Sauvant et al., 2004). However, NE value can also be calculated from DE or ME if the efficiency of ME utilization for NE (NE:ME) or that of DE utilization for NE (NE:DE) is known (de Lange, 2008; Kil et al., 2013).

Moreover, NE values for diets and feed ingredients are affected by energy evaluation systems (Noblet and van Milgen, 2004). The hierarchy between feeds or feed ingredients is dependent on the energy system with an over-estimation of protein-rich feeds and under-estimation of starch and/or fat-rich feeds in DE or ME systems (Noblet, 2007). NE system is also describe as the energy available from feed ingredients for the synthesis and retention of proteins and fats or the energy available to the animal for maintenance and production (Velayudhan et al., 2015). Hence it is considered to provide closer estimates (Payne and Zijlstra, 2007) and better predictors of the "true" energy value of feeds and of performance of pigs (Noblet, 2000; Garnsworthy and Wiseman, 2005). Therefore, as one of its potential advantages, NE system may reduce feed cost if this system can be used to more correctly rank feed ingredients in terms of energy values (Patience and Beaulieu, 2005).

2.5 Net energy systems and prediction equations

Methods for estimating the energy value are required. One method that consists of direct measurement on pigs can be undertaken, but the delay in response is long and the cost too high. In vitro methods have also been proposed (Eggum and Boisen, 1991; Van der Meer and Perez, 1992), but their accuracy and reproducibility remain insufficient. The best compromise is then to relate the energy value of a diet to its chemical characteristics, assuming that the sources of the feedstuffs do not significantly affect prediction responses (Noblet and Perez, 1993).

The NE systems currently in use are French and Dutch systems that are based on the digestible nutrient content in feed ingredients and mixed diets (Moehn et al., 2005). These digestible nutrient contents (also DE or ME contents) are used to predict the net energy content in complete diets using regression equations that were derived from the combination of digestibility and respiration (measurement of heat production) experiments (Moehn et al., 2005; Kil et. al, 2013).

Another NE concept is from the Danish called potential physiological energy (PPE) was proposed by Boisen and Verstegen (1998) for estimating the NE value of pig feeds (Using Net Energy for Diet Formulation: Potential for the Canadian Pig Industry; Velayudhan et al., 2015). It is based on the combination of in vitro digestion methods for estimating nutrient and bio-chemical coefficients for evaluating ATP potential production from the nutrients at the cellular level of pigs (Stewart, 2005; Noblet, 2006; Velayudhan et. al, 2015).

All published NE systems combine the utilization of ME for maintenance and for growth by assuming similar efficiencies for maintenance and energy retention (Noblet, 2006 Lohmann Information; Noblet, 2007). Lastly, these proposed NE prediction equations are applicable to ingredients and compound feeds at any stage of pig production (Noblet, 2006. Recent advances in energy evaluation of feeds for pigs).

2.5.1 French System

The NE content of feedstuffs based on French system has been estimated using equations proposed by Noblet et al. (1994) and applied in the INRA and AFZ feeding tables (Sauvant et al., 2004) with 61 diets (Noblet, 2006). Energy digestibility and energy losses in feces, urine and gases were measured in respiratory chambers and heat production were measured using indirect calorimetry. The average daily FHP for growing pigs was determined by extrapolating total heat production to zero ME intake using regression analysis. The

NE values of each diet were then calculated as sum of FHP and retained energy in pigs (Kil et. al, 2013). A total of 11 regression equations were developed for predicting dietary NE content which can determine a correct hierarchy among feeds for both growing pigs and pregnant or lactating sows (Noblet et al., 1994a; Velayudhan et. al, 2015). All of these equations are based on information available in many feed tables and are applicable to single ingredient and compound feeds at any stage of pig production (Noblet, 2006). Components of digestible nutrients in the equations were later modified and 3 equations were used and in practice the NE given in the tables is the average of the 3 NE values obtained using those modified equations (Sauvant et al., 2004).

2.5.2 Dutch System

The system from the Netherlands has been adapted from the equations proposed by Schiemann et al (1972). It was developed by Central Bureau Livestock Feeding (CVB) using a variation of one of NE prediction equations developed by the French system (Stewart, 2005).

Both systems considered similar digestible nutrients in the equations such as digestible crude protein (dCP), digestible crude lipids (dCL) and digestible carbohydrates. The latter is subdivided into fractions: starch, sugar, crude fiber, neutral and acid detergent fiber, organic residue and possibly other fractions (Using Net Energy for Diet Formulation: Potential for the Canadian Pig Industry).

However, the Dutch system separates total digestible carbohydrates (i.e., starch and sugar) into an enzymatically-digestible fraction and a fermentable fraction owing to differences in energetic utilization of carbohydrates between the small and the large intestine of pigs (Kil et al., 2013; Velayudhan et al., 2015). For the Dutch system in particular, the following were considered important for determining the NE value for pigs: chemical composition of feed materials, faecal digestibility of crude protein, crude fat and non-starch polysaccharides (NSP), ileal digestibility of starch and digestibility (enzymatical and fermentative) of sugars, and the equation for the calculation of NE according to this system (CVB Feed Table, 2012).

Both the Dutch (CVB) and the French (Sauvant et al. 2004) have published extensive feed tables that list the common and 'exotic' feedstuffs for swine, their nutrient composition and estimates of their net energy contents. Nevertheless, the limitation of such tables is that they generally only show the mean for a feedstuff, whereas in practice there is a large variability in the nutrient composition (protein, lipid, type and quality of carbohydrate), and hence energy content between batches of the same feedstuff (Moehn et al., 2005).

2.5.3 Danish System

Aside from the above NE systems, Boisen and Verstegen (1998) proposed a new concept called Potential Physiological Energy (PPE) which is based on theoretical biochemical utilization of energy (i.e ATP) by pigs (Kil et al., 2013). It estimates the energy yielding potential of feed ingredients based on the oxidation of nutrients used for synthesis of ATP and in vitro digestibility methods (Szabó and Halas, 2013). The PPE of different nutrients are not influenced by their actual utilization for oxidation or deposition and therefore the contributions of the PPE from feed ingredients are additive in diets (Boisen, 2007).

2.6 Pelleting

One of the primary purposes of processing is to reduce anti-nutritional factors that affect nutrient utilization and subsequent animal performance, while at the same time not causing inadvertent destruction of other needed dietary components (NRC, 2012). In swine feed production, various processing methods have been studied for decades and variable results have been reported on its effect on improving nutrient digestibility or pig performance.

Among the available technological processing applied in feed production, the scope of this present study specifically focuses on pelleting and its subsequent effect on dietary energy and growth performance.

2.6.1 Pelleting Process

Starch consumed by the livestock industry are still fed largely untreated and/or in raw forms (Knudsen et al., 2006). Also, a conventional diet based on corn and soybean meal fed to pigs is usually provided in a mash form and in most cases, processing other than grinding and mixing is not used. However, feed processing technologies such as grinding and pelleting (also expansion, extrusion, , use of enzymes or chemical treatments) may be used to solubilize some of the cell wall fractions of plant-based ingredients and therefore, increase nutrient availability (Rojas and Stein, 2017).

Feed pelleting can be defined as conversion of finely ground mash feed into dense, free flowing pellets or capsules, in a process that involves steam injection (moisture and heat) and mechanical pressure (Farahat, 2015).

Pelleted feeds have been defined as “agglomerated feeds formed by extruding individual ingredients or mixtures by compacting and forcing through die openings by any mechanical process”. It agglomerates ingredients that have different particle sizes, densities, and flowability (Feed processing to maximize feed efficiency).

Pellets are produced by combining the mixed feed with steam in a conditioner to increase the moisture and temperature of the mash. The mash is retained and mixed in the conditioner which retention time depends on the number and design of conditioners above the pellet mill. The conditioned mash is then pressed through a ring die, which forms the pellet to a specific diameter (Feed processing to maximize feed efficiency).

Lastly, Stark (2015) outlined the factors that affect pellet quality in feeds with corresponding approximations on their degree of impact and these include: diet formulation (40%), conditioning (20%), particle size (20%), cooling (5%), die specification (15%).

2.6.2 General advantages of feed pelleting

Benefits of pelleting have been discussed previously among which are the following: a) least-cost formulation - nutritionists can formulate least cost diets with ingredients that have poor flow characteristics, b) particle size reduction - grains can be reduced to less than 600 microns without affecting the handling characteristics of the finished feed and c) feed conversion is improved - due to enhanced palatability, reduced wastage, and the potential for improved nutrient utilization due to heat treatment of the ingredients (Stark, 2012). Other benefits of feeding pelleted diets include increase feed density, decrease feed dustiness, better mechanical handling of feed on the feed lines, and destruction of feed-borne pathogens.

The effect of pelleting diets on pig performance is variable, but overall it gain and feed efficiency are improved by approximately 6% (Hancock and Behnke, 2001). Although the observed improvement in feed conversion from feeding pellets may be confounded with the reduced particle size of the grain, the overall improved performance of pelleted diets has been well documented (Stark, 2012).

2.6.3 Effect of pelleting in dietary energy

Pelleting increases energy digestibility of feeds by about 1% (Skiba et al., 2002; Le Gall et al., 2009). However, for some feeds, the improvement can be more important and depends on the chemical and physical (particle size) characteristics of feeds (Skiba et al., 2002).

In a specific situation presented in table from the review of Noblet and van Milgen (2013), for high-oil corn (75g oil/kg), pelleting increased DE content by approximately (0.45 MJ or 107.55 kcal per kg). Similarly for coarsely ground full-fat rapeseed, the DE values were improved from 10.0 (mash) to 23.5 MJ DE/kg DM after pelleting, (Skiba et al., 2002; Noblet and Van Milgen, 2013). The improvement in energy digestibility was mainly due to an improved digestibility of fat provided by maize or full-fat rapeseed. Consequently, the energy values of these ingredients depend greatly on the technological treatment (Skiba et al., 2002).

In addition, previous research has demonstrated that mechanical and/or thermal processing of feed grains prior to feeding can greatly alter starch digestion potential, due to changes in physico-chemical starch characteristics (Svihus et al., 2005; Anguita et al., 2006).

Sauvant et al. (2004) concluded that, in general, pelleting improves energy and nutrient digestibilities which is in agreement with previous data, they however stated that, literature data are insufficient to propose, for all the materials used in pig feeding, an energy value that takes into account the different types of processing such as pelleting.

2.7 Variability in nutrient composition of feed ingredients

Understanding potential causes, implications and solutions to address variation in nutrient composition of ingredients used for livestock feeds is essential for efficient pork production. In particular, presence of substantial variation on both chemical composition and nutritional attributes may have different effects when fed to animals (Gizzi and Givens, 2004).

Study from Cowieson (2015) on the variation in chemical composition of 59 corn samples showed variability in terms of starch, CP, fiber, oil and AA contents. Similar observations were reported by Lee et al. (2016) in a study conducted to determine nutrient variability of cereal grains from different origins where particularly in corn, all nutrients concentrations evaluated were different and also in study by Li et al. (2014) wherein 100 corn samples were investigated in which chemical composition particularly fiber, fat and starch varied greatly.

Numerous data had shown that nutrient composition of feed ingredients are variable, but methods are available to reduce the potential implication of such variation. Reducing variation in nutrient composition of diets can lower feed costs, improve animal health, and/or increase production (Weiss and St-Pierre, 2009).

2.7.1 Sources of variability

The nutrient composition of grains and by-products used in livestock industry however have variability in their nutrient composition due to both intrinsic and extrinsic factors. Such variability is influenced by the plant's genetics (hybrid, variety, etc.), geographical origin, environment/growing conditions (drought, climate, soil fertility, etc), and technological processes (e.g. grinding, extrusion, pelleting, etc.) applied to it. Because of these reasons, it is important to "properly" evaluate their nutrient composition because imprecise data have deleterious implication to animal production from the nutritional, economical as well as environmental points of view (Gizzi and Givens, 2004; Lee et al., 2016).

Feed grains rich in starch that are commonly fed to livestock animals include corn, wheat, barley, rice and oats which also serve as their primary energy-source. These grains may contain starch from 40% (oat) to 80% (rice) of their dry matter (DM) 1 and concentration may vary depending on several factors (Giuberti et al., 2012).

Among nutritional value, the digestible organic matter (e.g. proteins, fats and oils, carbohydrates) are the ones most frequently represented in databases and used to predict energy supply from feed ingredients and complete diets (Gizzi and Givens, 2004). Although balanced with regard to essential nutrients, cereal based diets, vary widely in chemical composition and accounted for 90% of the variation in the chemical composition of the diets used in practice (Just, 1982).

2.7.1.1 Intrinsic factors

One source of variability is from intrinsic factors. Each feed has particular chemical and nutritional characteristics which distinguish it from other feeds. However, the same feed can also be derived from different cultivars or influenced by its geographical origin. Moreover, an identical raw material may have been processed in a variety of ways to produce very different products (Gizzi and Givens, 2004).

For instance rice bran, a by-product of rice grain production from different rice varieties, processing methods and regions have different DE and ME content due to their variable chemical composition (Shi et al., 2015). Another example is in the case of wheat wherein the year of production or growing conditions can have a dramatic effect on its chemical composition (Ball et al., 2013). Similar findings were cited by Wan et al. (2009) for the large variation in the chemical composition of wheat by-products because of varied wheat (soft vs. hard) sources (Kim et al., 2005) and due to difference in processing techniques (e.g. fixed-system technique vs. setting-changed system) (Li and Posner, 1989). Meanwhile, if ingredients have consistent nutrient specifications, variability in their digestibility due to various reasons is another consideration when predicting energy value of ingredients used to formulate swine diets (Evans, 2013).

2.7.1.2 Extrinsic factors and data source

When assembling a database it is necessary to make sure that the real variability arising from the intrinsic characteristics of the feedstuffs is correctly recognized in order not to affect the quality of the data.

In describing the nutritional value and predicting the energy of diets, information on the composition of a feed ingredients is acquired through chemical analysis which commonly includes parameters such as dry matter, protein, fiber fractions, organic matter and fat contents. Meanwhile, the nutritional value of a feedstuff is assessed from animal experiments (e.g. in vivo digestibility/in situ degradability, etc.) and provides information on how feedstuffs are digested and metabolized by the animal (Gizzi and Givens, 2004).

An important limitation of databases is related to the type and quality of the data they make available to users. When balancing for nutrients obtained from file values only, be aware of the method used to obtain the information (Evans, 2013). This is because in general, the diversity of analysis methods adopted by different laboratories is responsible for most of the extrinsic variability found in databases (Barber, 1983). Additionally, a change in analytical methods or laboratories may also result in a sudden shift in one or more nutrient values. Hence, it is safe to compare or mean parameters only if they have been grouped according to the method of analysis used to obtain them (Gizzi and Givens, 2004).

2.7.2 Implication of nutrient variability in dietary energy

It is reported that the starch, CP, and fiber among the proximate composition of wheat are the most variable components according to different varieties, growing locations, and climate, which in turn causes variability of ME value of wheat by-products (Kim et al., 2005; Wan et al., 2009). Furthermore, apparent metabolizable energy (AME) value of corn in poultry can vary by more than 2MJ/kg (478 kcal/kg) from batch to batch making a "generic" energy value for corn inaccurate (Leeson et al., 1993; Cowieson, 2005). Another study done by Lee, J.Y. et.al (2016) concluded that nutrient and energy contents of cereals (corn, wheat and barley) from various origins were different therefore such variations should be considered when formulating animal diets.

A precise knowledge of nutrient composition of feedstuffs is essential in order to match the energy supply from the diet with the energy required by animals (Kong and Adeola, 2014). Additonally, when nutrient compositions are more consistent, diets can be formulated to more closely match animal requirements which can potentially result to reduce feed costs or improve animal performance. Hence, accurately estimating energy value of feeds is important to produce nutritionally balanced compound feeds for optimizing pig production and minimizing feed cost (Gizzi and Givens, 2004; Lee et al., 2016).

3. Materials and Methods

3.1 Experimental Diets

3.1.1 Chemical Analysis

Before the preparation of diets, wheat, corn, soybean mean, barley and rice bran samples were ground in a lab mill to pass through 1 mm screen and then analyzed for dry matter, crude protein, crude fiber, ether extract, starch and sugar including minerals (Ca and P). All samples were analyzed in quadruplicate.

Dry matter analysis of feed ingredients was performed by drying in an oven at 135 °C for 2 h (AOAC 2007; method 930.15) while crude protein (CP) was determined using the Kjeldahl method with a conversion factor of 6.25 (AOAC 2007; method 990.03). Crude fat content was determined by Soxhlet apparatus extraction using petroleum ether according to AOAC 920.39. Crude fiber (CF) content was determined according to AOAC 962.09 and ash according to AOAC 942.05.

3.1.2 Analysis of total starch and sugar contents

To determine 'analyzed' total starch (TS) content, a commercially available AMG/α-AMYLASE/HK enzyme assay kit from Megazyme International Ltd. (Wicklow, Ireland) (K-TSHK kit according to AOAC 996.11) was used.

The amount of NADPH formed in this reaction is stoichiometric with the amount of D-glucose. It is the NADPH which is measured by the increase in absorbance at 340 nm. Values were used to calculate for starch content based on the calculator (Megazyme Mega-Calc^{TM}) provided by the enzyme assay supplier.

Briefly, samples were ground through a 1.0 mm screen and 100.0 mg of sample was added to a test tube. Next, 0.2 mL of ethanol solution (80%, vol/vol) was added into the tube and mixed to wet the sample. Next, 3.0 mL of thermostable α-amylase was immediately added, and the tubes were boiled for 6 min and stirred at 2-min intervals. Tubes were then placed in a 50°C bath to rest for 5 min. Next, 0.1 mL of amyloglucosidase was added into each tube. Tubes were then stirred and incubated for 30 min and then filled to a volume of 10 mL with distilled water followed by centrifugation at 1,800 × g for 10 min at room temperature. Next, 1.0 mL of aliquots from the supernatant was diluted to10 mL with distilled water. Then, 0.1 mL of this diluted solution was placed into a clean test tube. Glucose oxidase/peroxidase reagent (3 mL) was added to each tube and incubated at 50°C for 20 min. For blanks, 0.1 mL of water was used instead of 0.1 mL of diluted solution, and the other added reagents were all the same. Samples were read for absorbance at 340 nm. Analysis was conducted in quadruplicate and the average value was calculated.

Reducing sugar content in same feed ingredients was likewise determined using Luff-Schoorl Method. This procedure determines the content of reducing sugar in feed (present in the 40% ethanol soluble fraction) after inversion and expresses reducing sugar as glucose.

3.1.3 NE prediction and digestibility coefficients

Prediction equations for the NE of feed ingredients were established using data obtained from the chemical composition and digestibility of nutrients (Kil et. al, 2013). Similarly, in this study, energy-containing crude nutrients and chemical compositions of 5 major feed ingredients were used in the formulation of four starter diets.

For the treatment diets, components such as ash, crude protein (CP), calcium (Ca), phosphorous (P), ether extract (EE), crude fiber (CFIber), dry matter (DM), starch and sugar concentrations were all analyzed using above mentioned methods. On the other hand, for the control diets, same analyzed contents were used except that starch and sugar values were directly obtained from CVB (2012) feeding tables according to specific product sheet of each individual ingredient.

To calculate for the NE of the major ingredients, NE equation based on Dutch CVB (Centraal Veevoederbureau; Central Bureau for Livestock Feeding, 2012) NE system was used in all diets used in the feeding trial as follows:

$$NE\ (kcal/kg) = (2.58 \times DCP) + (8.63 \times DCFat) + (3.27 \times Starch_e) + (2.96 \times Sug_e) + (2.29 \times FCH)$$

where:

NE = net energy (kcal/kg DM), DCP = digestible CP (g/kg DM), DEE = digestible ether extract (g/kg DM), $Starch_{am}$ = enzymatically digestible starch (g/kg DM), Sug_e = enzymatically digestible sugar (g/kg DM), and FCH = DNSP + Sta_f + CF_DI * Sug_f)

To calculate for the digestible concentrations of DM, CP, EE, sugar and starch, the digestibility coefficients of each nutrient were obtained from CVB (2012) according to individual feed ingredient's 'product sheet'. These coefficients were not obtained by performing actual digestibility trial, rather CVB digestible coefficients were applied in both control and treatment diets. It is important to have reliable data on the digestibility of energy and of nutrients for the prediction of NE content which is one of the most limiting factors for predicting energy values of pig feeds (Noblet and van Milgen, 2004;Velayudhan et. al, 2015). Same digestibility coefficients were used in all experiment diets. Predicted NE calculated from CVB equation is shown in Tables 1A and 1B for control (reference) and treatment (analyzed) diets respectively. Digestible amino acids (AID) and phosphorus (dig P) concentrations were set similarly in all diets.

Table 1A. Predicted net energy of major ingredients using reference starch and sugar values.

Coefficient	Component	Formula for NE				
		corn	wheat	SBM	Wheat Bran	Barley
2.58	DCP=%CP*DCCP/100	157.38	232.20	1091.34	241.12	170.45
8.63	DCFat=%CFat*DCCFat/100	233.01	25.89	79.40	168.54	86.99
3.27	Starche	1981.62	1821.39	26.16	451.26	1621.92
2.96	Sugare	32.56	47.36	198.32	128.46	56.24
2.29	FCH=DNSP+STAf+CF_Di*Sugf)	191.77	234.96	525.91	421.65	266.12
NE,kcal/kg		**2596.34**	**2361.80**	**1921.13**	**1411.03**	**2201.71**

Table 1B. Predicted net energy of major ingredients using analyzed starch and sugar values.

Coefficient	component	Formula for NE				
		corn	wheat	SBM	Wheat Bran	Barley
2.58	DCP=%CP*DCCP/100	157.38	232.2	1091.3	241.12	170.45
8.63	DCFat=%CFat*DCCFat/100	233.01	25.89	79.4	168.54	86.99
3.27	Starche	2153.9	2005.8	35.316	608.22	1612.1
2.96	Sugare	32.833	50.027	216.23	128.46	56.24
2.29	FCH=DNSP+STAf+CF_Di*Sugf)	176.26	217.64	535.95	418.72	239.13
NE,kcal/kg		**2753.4**	**2531.6**	**1958.2**	**1565.1**	**2164.9**

3.1.4 Formulation of experimental diets

Four dietary treatments consisted of 2 mash and 2 pellet diets were formulated to contain energy and other nutrients that meet or exceed the nutrient requirements recommended by the National Research Council (2012) for starter pigs. Amino acid ratio and other nutrient specifications were closely maintained in all diets.

Diets were formulated to contain same type of ingredients but NE content were predicted using different reference source of starch and sugar values (CVB vs. analyzed).

Control diets were formulated with ingredients which NE were predicted using starch and sugar values from CVB (2012) while for treatment diets, analyzed values were used. Both control and treatment diets were presented in mash and pellet form with pellet containing 30 kcal lower NE than the mash form.

The ingredient composition and analyzed nutritional values of the diets are presented in Tables 2 and 3 respectively.

Table 2. Ingredient composition (%) of experiment diets (as-fed basis).

Diet	Control		Treatment	
NE Prediction	Reference	Analyzed	Reference	Analyzed
Feed Form	Mash		Pellet	
Ingredients		%		
Corn	48.35	30.00	44.43	30.00
Wheat	20.00	37.08	25.00	37.93
Barley	3.00	5.00	3.00	5.00
Soybean Meal	17.08	14.33	16.41	14.11
Wheat Bran	2.50	5.00	2.50	5.00
Mixed Animal Fat	3.43	2.34	2.99	1.73
Molasses	2.00	2.50	2.00	2.50
MDCP	0.74	0.77	0.73	0.70
Limestone	1.09	1.08	1.10	1.11
Salt	0.40	0.40	0.40	0.40
L-Lysine HCl	0.50	0.56	0.51	0.56
DL-Methionine	0.18	0.19	0.18	0.19
L-Tryptophane	0.05	0.05	0.05	0.05
L-Threonine	0.17	0.20	0.18	0.20
Choline Cl	0.05	0.05	0.05	0.05
Phytase	0.07	0.07	0.07	0.07
Vitamin Premix	0.05	0.05	0.05	0.05
Mineral Premix	0.34	0.34	0.34	0.34
Total	**100.00**	**100.00**	**100.00**	**100.00**

*Provided the following quantities of vitamins per kg of complete diet: Vitamin A, 12000 IU; vitamin D3, 2400 IU; thiamin, 1.0 mg as thiamine mononitrate; riboflavin, 4.0 mg; pyridoxine, 3.3 mg 76 as pyridoxine hydrochloride; vitamin B12, 40 mg; D-pantothenic acid, 16 mg as calcium pantothenate; niacin, 20 mg; folic acid, 1.0 mg; biotin, 0.1 mg; choline, 835mg as choline chloride. Vitamin K3, 5.6 mg. Provided the following quantities of minerals per kg of complete diet: Cu, 104 mg as copper sulfate; Fe, 220 mg as iron sulfate; I, 1.24 mg as potassium iodate; Mn, 65 mg as manganese sulfate; Se, 0.50 mg as sodium selenite; Zn, 67 mg as zinc sulfate; Co, 0.68 mg as cobalt sulfate.

Table 3. Analyzed nutrient analysis of experiment diets (as-fed basis).

Diet		Control		Treatment	
NE Prediction		Reference	Analyzed	Reference	Analyzed
Feed Form		Mash		Pellet	
Nutrient	Unit	Values			
Moisture	%	12.01	12.13	11.48	11.56
C Protein	%	14.90	15.12	15.41	15.01
C Fat	%	5.36	3.84	4.69	4.11
C Fiber	%	2.64	3.38	2.69	2.91
Ash	%	4.31	4.64	4.59	4.49
Ca	%	0.70	0.77	0.82	0.83
P	%	0.44	0.50	0.47	0.47
dig P*	%	0.30	0.30	0.30	0.30
ai Lys*	%	0.940	0.940	0.940	0.940
ai M+C*	%	0.564	0.564	0.564	0.564
ai Thr*	%	0.555	0.555	0.555	0.555
ai Trp*	%	0.169	0.169	0.169	0.169
Sugar	%	5.27	6.64	5.65	4.40
Starch	%	47.36	43.59	46.04	45.18
NE*	kcal	2475.00	2475.00	2445.00	2445.00

*These values were calculated rather than analyzed

3.2 Growth Trial

3.2.1 Animals and Experimental Design

A 33-day feeding trial arranged in a 2 × 2 factorial design was conducted in a commercial swine farm, wherein a total of 360 starter pigs (initial weight 17.70 ± 0.53 kg) were fed with experimental diets from 55 to 87 days of age to determine their growth performance in response to feeding with diets formulated using similar crude nutrient contents but were different in terms of the starch and sugar values to predict NE concentration of major-ingredients (CVB or analyzed value) and in different feed forms (mash or pellet) containing 30 kcal lower NE in pellet compared to mash.

Male and female pigs were separated in pens (15 heads each) but shared the same feeder which was considered as one replicate. Pigs then were group weighed and were randomly allotted to one of four dietary treatments with 3 replicates having 30 pigs per replicate. For the duration of trial, pigs were allowed ad libitum access to feed and water and at the same time the feed allocation was increased gradually in keeping with pig's greater body weight. In terms of environment, same housing condition and management were provided for all the animals used in the experiment.

3.2.2 Measurements and Calculations

To determine the effect of dietary treatments on growth performance of pigs, BW (initial and final) and daily feed intake (considering retained feed in feeder) within each treatment group were recorded at the end of the 33-day feeding period. At the conclusion of the experiment, Average Daily Gain (ADG), Average Daily Feed Intake (ADFI), and feed efficiency (G:F) for each pig were calculated and summarized for each treatment.

3.3 Statistical Analysis

Treatments were arranged in a 2 × 2 factorial design and data were analyzed as completely randomized design using the PROC MIXED procedure (SAS Inst. Inc., Cary, NC). Pen was the experimental unit in both studies. When significant interactions ($P < 0.05$) were observed, LSD were used to evaluate the means. Results were considered significant at $P \leq 0.05$.

4. Results and Discussion

4.1 Comparative Starch and Sugar Contents of Major Feed Ingredients

Nutritional value of feed ingredients (e.g. cereal grains) is determined foremost by chemical composition (Noblet and Perez, 1993; Fairbairn et al., 1999b) and results of chemical analyses may be used to predict energy value using prediction equations (Zijlstra et al., 1999).

In this study the major feed ingredients used to formulate experiment diets were analyzed for their chemical composition including starch and sugar contents. Figure 2 shows the comparison between analyzed starch content of 5 feed ingredients relative to their corresponding value from CVB (2012) table.

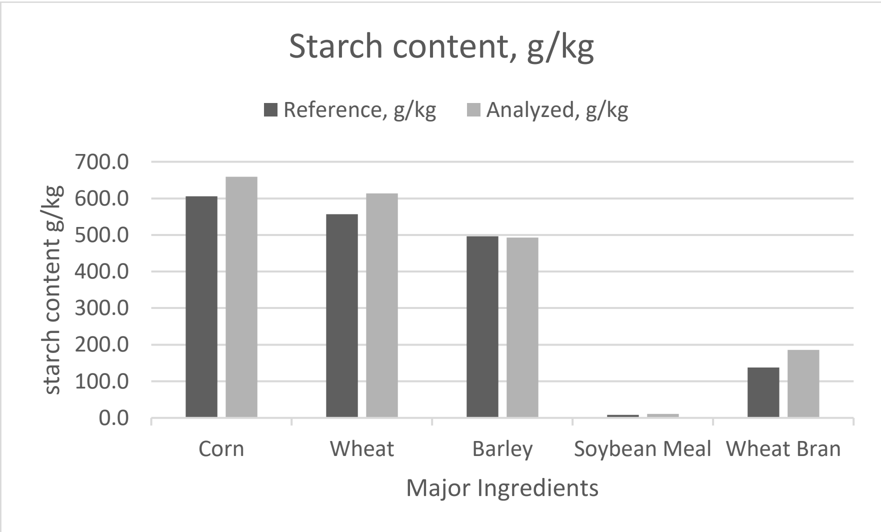


Figure 2. Comparative total starch content of major feed ingredients based on reference (CVB) vs. analyzed value.

Except for barley with relatively similar analyzed and reference (CVB) values, all major energy-source ingredients used to formulate the experiment diets had higher analyzed starch contents compared to those values obtained from CVB (2012). In addition, result demonstrated that when using the CVB 'mean values', the particular batch of major energy-source ingredients used in our study were under-estimated for their actual starch contents. These observations conformed to data from previous literatures (Leeson et al., 1993; Cowieson, 2005; Kim et al., 2005; Wan et al., 2009; Faba and Sola-Oriol, 2016) wherein analyzed chemical composition including starch and sugar varied from published values or from feeding tables.

For instance, the difference in analyzed starch of corn (52.70 g/kg) and wheat (56.40 g/kg) with their corresponding CVB mean values can be attributed to factors such as cultivar, fertilizer application and soil condition for corn while also cultivar, hulling process and weather for wheat as cited by Lee et al. (2016). Additionally, in terms of environmental influences, similar contributing factors were stated by Wenk (1998) which include soil, climate, altitude, fertilizer etc. as determinants for the nutrient and energy contents of feedstuffs as well as their availability for animal utilization.

Same ingredients were analyzed for their individual sugar contents. Figure 3 shows the comparative sugar content of 5 major ingredients based on their feeding table (CVB) and analyzed value.

Result indicated that analyzed sugar content present in each batch of ingredient varies with reference values but in comparison to starch, its implication in predicted dietary NE was relatively lesser due to its lower energy contribution except in soybean meal.

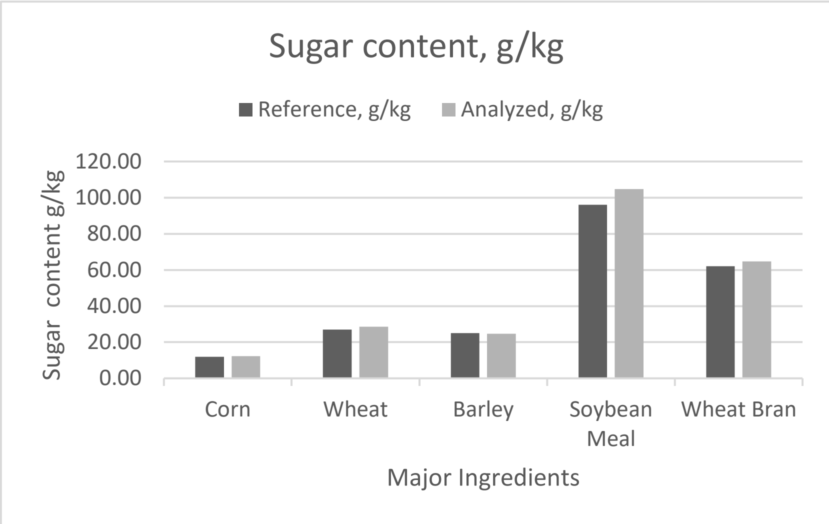


Figure 3. Comparative sugar content of major feed ingredients based on reference (CVB) vs. analyzed value.

4.1.1 Effect in predicted net energy

In using NE prediction equation, it is assumed that chemical composition and nutrient digestibility of feed ingredients can be obtained from tabulated values (Kil et al., 2013) which is still currently practiced when formulating diets for commercial farms or for feed producers. While ingredients presented in feeding tables (CVB, INRA, NRC, NSNG, etc.) have a fixed composition and a corresponding energy value, composition of ingredients that are available in industry can be variable (especially for by-products) with expected variations in energy values (Noblet, 2006) as likewise demonstrated in Figure 4.

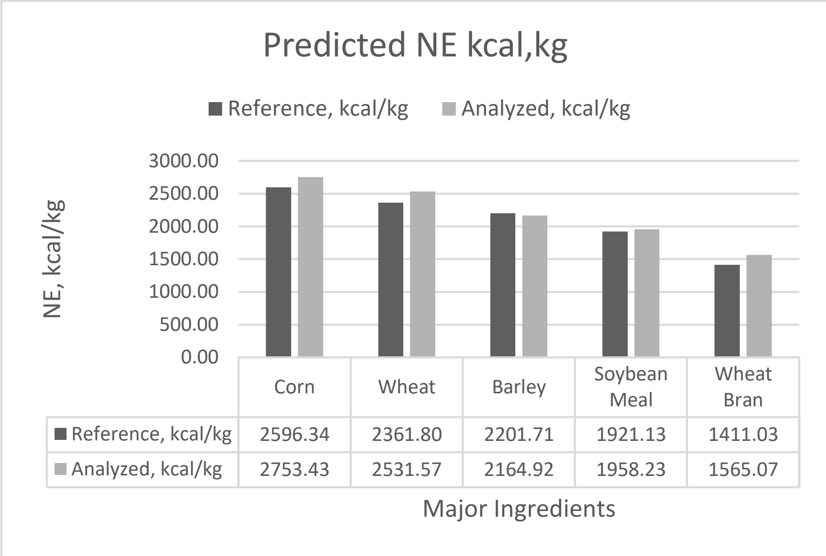


Figure 4. Net energy of Ingredients Predicted from different Starch and Sugar Values (Reference vs. Analyzed).

Starch is the major energy-yielding component in swine diets (Wiseman, 2006). In this particular feeding trial, starch-rich ingredients such as corn and wheat comprised the largest proportion, accounting for approximately 65% of the formulated diets. Similarly, these grains are the principal ingredients used in most commercial swine feed (Li et al., 2014) which serve as the basic energy source (usually accounts about 60% energy contribution) and is mainly attributed for their high starch contents (Holden et. al, 2010; Lee et al., 2016).

In this study, data showed higher analyzed (except for barley) relative to reference starch values in almost all the major ingredients particularly in corn, wheat and wheat bran. Consequently, the higher analyzed relative to reference values, resulted to the higher NE level of feed. This likewise demonstrated the linear relationship between starch and sugar concentrations and predicted NE content of ingredients using the CVB proposed equation.

In addition, our data revealed that when the nutrient content particularly starch in ingredients with high inclusion percentage in diets is under-estimated (or can also be over-estimated in other case), energy value of such ingredient is likewise under-estimated. This result agreed to data presented by Gutiérrez-Alamo et al. (2008) in wheat where they indicated that carbohydrates constitute up to 80% of the total dry matter of the wheat kernel and variation in their composition (starch vs. non starch polysaccharides) has a large impact on its nutritional value.

Furthermore, a larger gap can be observed when for instance CVB (2012) NE value of corn (2581.0 kcal/kg) and wheat (2343.0 kcal/kg) are compared to the calculated NE (2753.4 and 2531.6 kcal/kg respectively) from analyzed nutrient values. In feed mill practice, this finding is particularly relevant when animal nutritionist or feed formulators utilize only NE from table or book values when formulating diets due to time or resource limitation.

Meanwhile, in terms of sugar content, difference between analyzed and CVB value did not cause significant effect in predicted energy as compared to that of starch due to their lower concentrations relative to the latter.

Considering the above discussions, knowledge of the nutritional value, and of available energy content in particular, by performing real-time analysis rather than using fixed values for a specific batch of an ingredient is important for accurate formulation of diets for pigs (Zijlstra et al., 1999).

4.2 Effect in Animal Growth Performance

When formulating diets, in order to prevent unforeseen reductions in performance or additional feed cost as potential consequences of inaccurate energy estimation, determining the chemical composition present in feed ingredients including starch and sugar contents help minimize variability between calculated and analyzed energy values (Li et al., 2014).

Table 4. Growth performance of starter pigs as affected by different starch and sugar values to predict NE and effect of pelleting in reduced dietary NE.

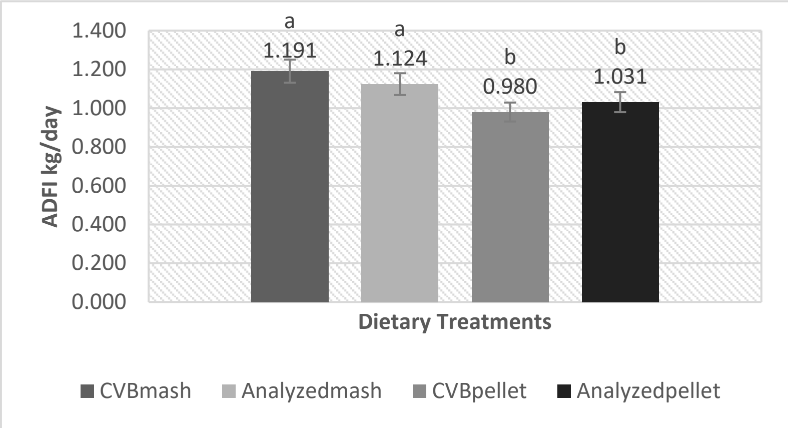
NE Prediction	Reference	Analyzed	Reference	Analyzed	SEM
Diet Form	mash		pellet		
Feeding Days	33 days				
Ave. Initial Wt. (kg)	17.667	17.656	17.689	17.689	-
Ave. Final Wt. (kg)	36.279	36.053	35.907	36.061	-
Weight Gain (kg)	18.612	18.397	18.219	18.372	0.4693
ADG (kg)	0.564	0.557	0.552	0.557	0.0142
Total Feed Intake (kg)	39.315[a]	37.095[a]	32.348[b]	34.010[b]	0.7001
ADFI (kg)	1.191[a]	1.124[a]	0.980[b]	1.031[b]	0.2130
Gain:Feed	0.474[a]	0.496[a]	0.563[b]	0.540[b]	0.0517
Mortality (%)	4.444	5.556	10.000	8.889	-

Means with different superscripts are different at $P < 0.05$.

Several previous studies have been conducted to evaluate the effect of mash compared to pelleted diets in animal performance or response of pigs to different dietary energy concentrations. In my knowledge, no previous studies have been conducted similar to the set up in this study, wherein the growth response of starter pigs were compared using different feed forms and at the same time containing different energy level.

4.2.1 Effect in feed intake

The energy level in diets were set to contain 30 kcal/kg NE difference between mash (2475 kcal/kg) and pellet (2445 kcal/kg) form.



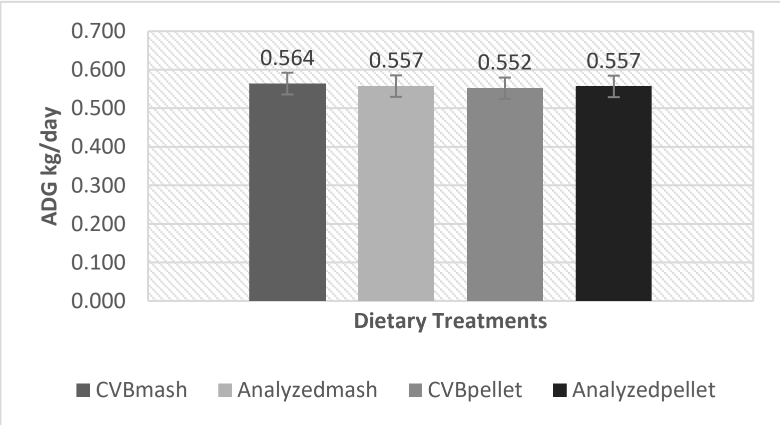
Means with different superscripts are different at $P < 0.05$

Figure 5. Average Daily Feed Intake (ADFI) of starter pigs-fed with different dietary treatments.

Predicted NE × feed form with different NE interactions ($P <$ 0.05) were observed for ADFI. When comparing the main effect of starch and sugar content in average daily feed intake (ADFI), result showed that analyzed or CVB starch and sugar values did not affect ($P < 0.05$) ADFI of starter pigs. however, when comparing the effect of different feed forms containing different energy concentrations, pigs fed pellet diet with lower energy level had significantly lower ADFI compared to mash with 30 kcal higher energy irrespective of starch and energy values used.

Energy density in the diet influences voluntary feed intake because pigs have tendency to consume feed until they satisfy their energy requirements (Nyachoti et al., 2004) hence the correlation between feed intake and dietary energy. Using this rationale, the relatively similar ADFI ($P < 0.05$) of pigs when comparing the effect of starch and sugar content indicated that when values obtained in CVB were used to formulate a similar NE of diet, it potentially under-estimated the actual energy contribution from energy-source ingredients. Hence in spite of the 'higher values' of analyzed starch content used to predict NE of ingredients, it apparently provided relatively similar energy density in the formulated compound diet as shown by the pigs' similar feed intake response.

4.2.2 Effect in Weight Gained



Means with different superscripts are different at $P < 0.05$.

Figure 6. Average Daily Gain (ADG) of starter pigs-fed with different dietary treatments.

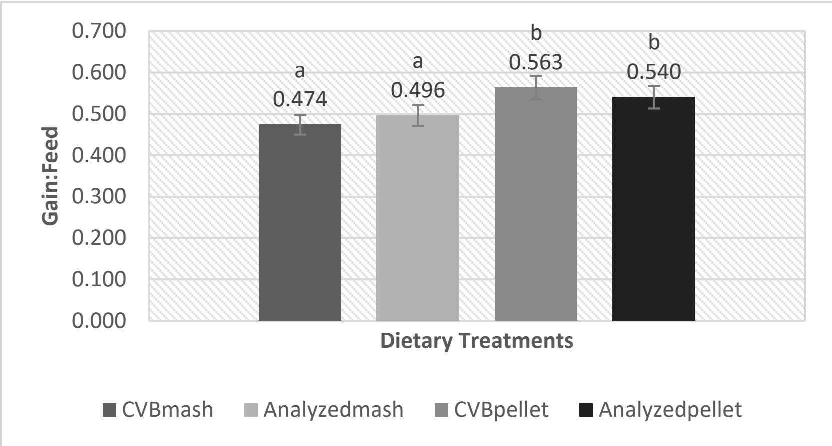
Result showed no significant difference in terms of average daily gain among starter pigs fed with experiment diets. Considering the interaction effect, it also showed no significant difference at $P <$ 0.05 which means that ADG was neither affected by different starch and sugar values nor feed form with different energy concentrations.

The similar ADG among treatments could be associated with the adjustment of pigs in their feed intake or can also be explained by the formulation design due to diet optimization. In order to meet the target NE level of experiment diets, with the use of formulation software, diets were optimized considering both price and chemical composition among others (Kersten et al., 2005) hence resulted to different raw material inclusion levels, in response to varying starch and sugar content of the ingredients in this case.

Applying the concept of formulation optimization (with the use of linear programming formulation software) to formulate 2 similar NE levels for mash (2475 kcal/kg) and for pellet (2445 kcal/kg) diets, the lower CVB starch in particular hence under-estimated NE value (as shown in figures 2 and 3) in all ingredients (except for barley), resulted to the higher inclusion levels of 'mixed animal fat' to compensate for the lower predicted NE in CVB values. Fat is used as a highly-concentrated or as an alternative energy source in pigs diets (Stahly, 1998).

In further details, the difference in starch and sugar hence NE of feed ingredients, were accounted through the inclusion of more 'mixed animal fat' in the control compared to treatment diets (2.99% vs. 1.73% in pellets and 2.34% vs. 3.43%). Through diet optimization, both control and treatment diets have equal content NE across mash and pellet forms hence when diets were fed to pigs, weight gained was not affected by the treatment. The discussion in the similar ADG in response to energy concentration and feed form will be addressed in succeeding section.

4.2.3 Effect in Feed Efficiency (Gain:Feed)



Means with different superscripts are different at $P < 0.05$.

Figure 7. Gain:Feed of starter pigs-fed with different dietary treatments.

Given today's high feed costs and environmental considerations, there is a considerable emphasis placed on the improvement of feed efficiency in pigs to propose optimized and sustainable pork production systems (INRA 2014). A common and simple definition of feed efficiency in the scientific literature is body weight gain per unit of feed consumed (Patience et al., 2015).

Among many other factors, feed efficiency can be influenced by providing accurate energy supply or by manipulating energy concentration of the diet (Patience, 2012).

In the present study, in terms of interaction effect, predicted NE by feed form and energy concentration interaction was not significant (P = 0.116) for gain:feed. Considering the main treatment effect (predicted NE using different starch and sugar values) animals did not significantly differ (P < 0.05) in feed efficiency among treatments. It was however significantly affected by the diet form despite reduction of energy in pellet diets.

Our result is in agreement to a similar research where variability of feed ingredients was studied to evaluate its effect on productivity of fattening pigs (Faba and Solà-Oriol, 2016). A feed formulation that was not adjusted to account for ingredient variability showed a difference of 2.5 additional kg feed to the ration that was adjusted in response to variable nutrient (CP and Cfiber) and ME of ingredients used. Their data showed that when these variabilities were not accounted in formulating the diet, it resulted to a reduced feed efficiency. This can be associated to a possible mismatch between the predicted formulation matrices and actual energy content of the main ingredients. Meanwhile, in the design of our experiment diets, as previously described, the variability in NE was adjusted to meet the designed NE, hence showing relatively same gain:feed of starter pigs fed dietary treatments irrespective of starch and sugar values used.

4.3 Economic Analysis in terms of Diet Cost

To consider overall productivity in commercial pork production, the cost of mixed feeds used (often comprise 50% of the entire production costs) is important. Hence it is critical to be able to implement ways to reduce feed costs (Kersten et al., 2005). Furthermore, when balancing rations, one of the goals is to 'mix' feeds as economic as possible.

Table 5. Cost per kg feed of experiment diets (won/kg).

Dietary Treatment	Feed Cost, won/kg*	Feed cost to produce 1 kg gain**
$Reference_{mash}$	339.31	716.506
$Analyzed_{mash}$	310.16	625.331
$Reference_{pellet}$	336.26	596.901
$Analyzed_{pellet}$	305.99	566.658

*won/kg feed based on prevailing ingredient market price when the formulations were prepared

**computed as FCR (Feed/Gain) x Feed Cost/kg

In this experiment, price/kg feed as compared in Table 5, showed that when all nutrient values including sugar and starch were analyzed to predict NE of ingredient to formulate starter diets, feed costs were reduced. This is in agreement with discussion from Noblet et al., 1994 which stated that an accurate estimation of both energy requirements for pigs and feed energy values may reduce the feed costs in pig production (Noblet et al., 1994). In economic points of view, variation in nutrient content of feed ingredients (e.g. corn) has the potential to greatly affect profits in pig production (Li et al., 2014). Likewise, Beaulieu and Engele (2013) stated that costs are also associated with inefficient utilization of nutrients due to 'over-formulation' (or growth and even health consequences due to 'under-formulation').

Reduction in feed cost in present experiment can be attributed to the higher starch values of ingredients that constitute the largest proportion of the diet (e.g. corn and wheat). Particularly, in this circumstance, it meant that nutrients' 'actual' energetic contribution were under-estimated when starch and sugar values for each ingredient were acquired from reference value (CVB). Hence in this study, it was clearly demonstrated that under-estimating ingredients' energy values has direct implication on feed cost due to increasing the nutrient costs of animal feeds. It should also be noted that the potential cost of inaccurate estimate in energy value of feed increases, with the cost of ingredients (Beaulieu and Engele, 2013). Meaning, depending on the prevailing market prices, the extent of additional cost in feed could go higher when prices of 'under-estimated' ingredients become more expensive.

In addition, information on the energy value of diets for pigs is of great importance to pig producers as an assessment guide for the price and production potential of the diets (Just et al., 1984). Furthermore, (though it was not demonstrated in the formulation design of present experiment), another way that inaccurate energy estimation can potentially result to higher feed cost is due to limiting the inclusion level of ingredients with energy value not well defined or due to raising safety margins relative to designed nutrient levels (de Lange et al., 2005). The formulation practice of increasing safety margins, to account for potential variation of predicted nutrient from actual content of ingredients, adds cost to the final ration due to increasing nutrient cost (Beaulieu and Engele, 2013).

Furthermore, it was previously stated that failure to get the initial correct nutrient or energy values will ultimately be reflected in a higher cost of production for feed or pork producers (Gizzi and Givens, 2004;). In feed cost table, diets formulated with analyzed values had lower cost which is attributed to the higher overall NE contribution accounted from higher starch contents. Meanwhile, comparing cost between mash and pellet forms, the slight reduction in cost of pellet diets were due to 30 kcal lower energy level set for these diets compared to mash (2445 vs. 2475 kcal/kg).

Therefore, if not in terms of growth performance, another possible consequence in failing to get the analyzed or measured nutritional composition of the different ingredients correctly will ultimately be reflected in a higher feed cost.

Meanwhile as pelleting process also contributes to additional cost in feed because it requires approximately 50% of the power consumption in feed mill the cost of pelleting was not incorporated in the cost/kg comparison presented in our study.

4.4 Effect of pelleting in diets with reduced energy concentration

4.4.1 Effect in feed intake

Result showed interaction ($P < 0.05$) between predicted NE using different sugar and starch values and feed form with different energy concentration in terms of ADFI. This means that effect of predicted NE in feed intake depends on feed form and energy concentration of diets.

Meanwhile, evaluating the treatment effect of pelleting in diets with reduced energy concentrations, pigs-fed mash diet with higher NE had significantly ($P < 0.05$) consumed more feed compared to those fed lower NE in pellet form.

It was previously stated that feeding pelleted feed to pigs immediately after weaning is used as reasonable approach in swine industry, because pigs fed pellets may achieve a higher feed intake in the first one week after weaning than pigs fed mash (Zijlstra et al., 2009). Result from study of Steidinger et al. (2000), pelleting improved feed intake of weanling pigs compared with those provided with diets in mash form.

In contrast, other research indicates that feeding in the form of pellets versus mash may reduce feed intake of pigs immediately after weaning, while resulting in equal growth (Medel et al., 2003). Similar to the findings of Medel et al. (2003), considering only the effect of feed form, our study observed that pigs fed pellet diet consumed less feed intake having equal ADG with pigs fed mash feeds.

On the other hand, when only considering the effect of energy concentration in feed intake, our study did not conform to previous studies. A research investigating the effect of dietary NE content on feed intake (and performance) of pigs housed individually, over the entire experiment, ADFI decreased with increasing NE concentrations or in other words, when dietary energy concentrations are decreased, pigs are reported to respond by increasing ADFI (Quiniou and Noblet, 2012). Likewise, in feeding trials conducted in both research facility and commercial farm set-ups by Beaulieu et al. (2014), similar results were observed that increasing DE content in feed, decreased overall feed intake. Furthermore, Lee et al. (2015) from which experiment diets were presented in mash form, stated that ADFI was decreased when NE was increased from 9 MJ/kg to 12 MJ/kg in early finishing gilts. Meanwhile, Smit et al. (2016) evaluated feeding reduced net energy (NE) levels to growing-finishing pigs, and observed that for the entire trial, reducing NE by 0.1 Mcal/kg (−1) linearly increased ($P < 0.001$) their average daily feed intake. This similar observed response associated with reduced dietary available energy content, could be explained by the pig's attempt to maintain energy intake by eating more feed, until feed intake is limited by physical feed intake capacity or other environmental factors (Nyachoti et al., 2004).

The contradicting ADFI result of our study is in reference to previous studies comparing either pelleted vs. mash or in terms of different concentrations of dietary energy. However, the design of our present experimental treatment is combination of different feed form having different energy level. Our result indicated that pelleting diet with 30 kcal/kg lower NE significantly ($P < 0.05$) reduced feed intake of pigs. This could be associated to the apparent improvement in energy density of pellet since pelleting increases energy digestibility by about 1% (Noblet, 2006).

Furthermore as described above, pigs are known to adjust their feed intake containing variety of energy concentrations to maintain a constant daily energy intake (Quinou and Noblet, 2013) or until they satisfy their energy requirements (Nyachoti et al., 2004). Hence in the particular diets used in our experiment, pelleting apparently did not only compensate the 30 kcal/kg reduction in its NE but may also have increased energy density of diets to more than what was deducted (30 kcal), hence a possible explanation of the lower feed consumed in pellet diets. Other potential rationale could also be attributed to reduced feed wastage which was not properly accounted since the experiment was done in a commercial farm set-up.

Use of steam and pressure are the principles behind the pelleting technology. Steam increases the temperature of the feed and the steamed ingredients are subsequently pelleted to a determined pellet size using pressure (Zijlstra et al., 2009; Rojas and Stein, 2017).

4.4.2 Effect in ADG

No predicted NE × diet form with different NE concentration interactions ($P < 0.05$) were observed for ADG. In evaluating the effect of diet form with different NE concentration in ADG, result showed that weight gained of animals fed pellet diets was similar to those fed with mash and despite the 30 kcal/kg reduction in its energy content, it did negatively affect ADG.

If considering the feed form *per se*, our result was not consistent with numerous studies wherein they reported an improvement in ADG compared to the same diets that were in mash form using different growth stage of animals (i.e nursery, growing, finishing) (Skoch et al., 1983; Stark, 1994; Wondra et al., 1995; Potter et al., 2010; Miller, 2012; Myers et al., 2013; Myers et al., 2014). These research demonstrated that pigs fed pelleted diets tended to have improved ADG compared with pigs presented with mash diets however, the magnitude of the improvement was inconsistent between trials (Potter et al., 2010).

Correlating the above discussion on feed intake, our study observed that pigs fed pellet diet with reduced NE consumed less feed intake yet provided equal ADG with pigs fed mash feeds. Similar with its effect on feed intake, result in ADG could also be associated with improved energy digestibility in diets subjected to pelleting. Additionally, it could also be attributed to improved nutrient utilization (e.g. starch) due to heat treatment of the ingredients (Miller, 2012).

The apparent improvement in energy digestibility in pelleted diets (Wondra et al., 1995) could also be attributed in the starch of cereals grains that was more likely digested in the small intestine due to the gelatinization hence better nutrient utilization by the pigs (Rojas and Stein, 2017). Feed processing technologies such as pelleting may also be used to solubilize some of the cellulose and hemicellulose fractions that form the cell wall of plants in the ingredients. Consequently, this may have a positive effect on energy digestibility, and nutrient availability, therefore, also on pig growth performance and carcass composition (Rojas and Stein, 2017).

As repeatedly discussed above, that pelleting in general, improves energy and nutrient digestibilities. However, literature data are insufficient to propose, for all the materials used in pig feeding, energy values that take into account the different types of processing such as pelleting in particular (Sauvant et al., 2004).

4.4.3 Effect in Feed efficiency

No predicted NE × diet form with different NE concentration interactions ($P < 0.05$) were observed for gain:feed. In the present study, when evaluating effect of pelleting the diet with reduced energy result showed significant difference in feed efficiency.

Pelleting diets has been shown to be an effective feed processing method to improve feed efficiency in nursery and finishing pigs (Stark et al., 1993). Wondra et al. (1995) demonstrated that pelleted diets via conventional dry feeders increased in G:F of 4 to 6%

compared pigs fed mash diets. Diets fed to growing and finishing pigs based on corn and wheat middlings that were pelleted increased the G:F as well as digestibility of GE (Skoch et al., 1983). Likewise, only in another expression of performance (in terms of F:G), Potter et. al. (2010) found that feeding pelleted diets improved F:G from 5% to 8% in finishing pigs fed with corn-soybean meal-based diet under university research conditions. Contrary to these findings, research conducted by Hanrahan (1984) did not show an improvement in feed conversion and Myers et. al (2013) did not observe consistent improvements in G:F in pigs fed pelleted diets via dry feeders, and G:F actually worsened in most phases. However according to their observation, such response could be a result of the poor pellet quality (a high proportion of fines) resulting in pigs sorting through and wasting feed (Myers et al., 2013) which appeared to be not the case of our present study, as shown by the higher feed consumption in mash forms compared with pellets.

The relatively similar weight gained but lesser feed consumed in pellet diets, lead to better efficiency in pigs fed pellet diet hence our data indicated that pelleting provides a positive benefit in terms of feed efficiency. Lastly, in addition to improved energy digestibility and nutrient utilization, feed efficiency can be further improved by pelleting since cereal grains can be ground finely (< 500 micron) and included in a pelleted diet as compared to a mash containing a larger particle size (Miller, 2102).

5. Conclusion

Animal nutrition and feed science are among the central themes of livestock production. These fields of science entail provision of adequate, physiologically-balanced nutrition that meets animal requirements of animals considering their health, productivity, fertility and overall well-being.

To help attain this, feed producers require rapid and accurate methods for evaluating the nutritional value of feeds such as dietary energy. Measurements with animals have interest only in research or for calibration purposes as they are cost and labor intensive to perform, whereas the use of values in feeding tables predicted from equations give a reasonable estimate of the nutritional value of ingredients. Carbohydrates, mainly starch constitute the largest proportion of swine diets hence is the most abundant energy source in typical swine diets supplying approximately 60% of the total NE in typical corn-soybean meal swine diets. However, available feed ingredients in the market's supply chain have variability in terms of their nutritional composition and such variability can influence the predicted dietary energy. In order to account for the inherent and extrinsic nutrient variabilities present within, between and among feed ingredients, chemical and nutrient composition including starch and sugar, need to be accurately measured rather than simply acquiring values directly from reference feeding tables, in order to accurately match the energy requirement of pigs for more efficient pork production.

The present study demonstrated that analyzing the composition of feed ingredients to predict NE of diets including starch and sugar, provided similar growth response in starter pigs with a considerably cheaper diet cost. Also, accounting for the variability in starch and sugar contents to match the target energy concentration of a diet, reduced the costs of nutritional inputs (through minimizing potential over- or under-estimation) without compromising growth performance of animals.

Moreover, findings on the significantly positive effect of pelleting in feed efficiency despite reduction in its energy concentration compared to mash form diet, indicated that pelleting increases energy digestibility and potentially improves nutrient utilization thereby improving feed efficiency of animals. In this study, 30 kcal/kg reduction in energy concentration in pellet feeds compared to mash, to be used as a formulation strategy in commercial feed production, appeared to be reasonable. However, all animal production aspects (animal, dietary, environment factors as well as pig management, pork price, etc.) should first be carefully considered before implementing in practical level. Also, different energy concentrations should be further investigated in future studies to establish more conclusive data.

As an overall conclusion, this study suggests to predict NE of diets by regularly analyzing incoming ingredients for their nutrient compositions including starch and sugar rather than merely using ‘mean values’ from feeding tables in order to prevent unforeseen reductions in growth performance or incurring additional feed cost as potential consequences of inaccurate energy estimation. Such recommendation is also relevant when database has not been updated for certain period of time. Additionally, by-products where the process involved to produce them may have a significant impact on their corresponding feeding values making them highly variable, may require more frequent analyses.

6. References

Anguita, M., Gasa, J., Martín-Orúe, S. M., & Pérez, J. F. 2006. Study of the effect of technological processes on starch hydrolysis, non-starch polysaccharides solubilization and physicochemical properties of different ingredients using a two-step in vitro system. Animal Feed Science and Technology, 129(1): 99-115.

Ball, M. E. E., Owens, B., & McCracken, K. J. 2013. The effect of variety and growing conditions on the chemical composition and nutritive value of wheat for broilers. Asian-Australasian journal of animal sciences, 26(3): 378.

Boisen S. 2007. New concept for practical feed evaluation systems. Research Centre Foulum; Denmark. DJF Animal Science No. 79.

Boisen, S., & Verstegen, M. W. 1998. Evaluation of feedstuffs and pig diets. Energy or nutrient-based evaluation systems? II. proposal for a new nutrient-based evaluation system. Acta Agriculturae Scandinavica A—Animal Sciences, 48(2): 95-102.

Cowieson, A. J. 2005. Factors that affect the nutritional value of maize for broilers. Animal Feed Science and Technology, 119(3): 293-305.

CVB Feed Table 2011. Chemical Compositions and Nutritional Values of Feed Materials. 2012. Product Board Animal Feed CVB. NL 2700 AX Zoetermeer.

D.E. Velayudhan, I.H. Kim and C.M. Nyachoti. 2015. Characterization of Dietary Energy in Swine Feed and Feed Ingredients: A Review of Recent Research Results. Asian Australas. J. Anim. Sci. 28:1-13.

De Lange, C. F. M., and H. Birkett. 2005. Characterization of useful energy content in swine and poultry feed ingredients. Canadian journal of animal science 85.3: 269-280.

Doucet, F. J. 2007. Physicochemical Changes to Starch Structure During Processing of Raw Materials and Their Implications for Starch Digestibility in Newly-weaned Piglets. Recent advances in animal nutrition, 2006(1): 313-330.

Evans, E. 2013. How to deal with feed ingredient variability. WATTAgNet.com. www.wattagnet.com/articles/16078-how-to-deal-with-feed-ingredient-variability.

Fairbairn, S. L., Patience, J. F., Classen, H. L., & Zijlstra, R. T. 1999. The energy content of barley fed to growing pigs: characterizing the nature of its variability and developing prediction equations for its estimation. Journal of animal science, 77(6): 1502-1512.

Firkins, J. L., Eastridge, M. L., St-Pierre, N. R., & Noftsger, S. M. 2001. Effects of grain variability and processing on starch utilization by lactating dairy cattle. Journal of Animal Science, 79 (E-Suppl), E218-E238.

Giuberti, G., Gallo, A., Moschini, M., & Masoero, F. 2015. New insight into the role of resistant starch in pig nutrition. Animal Feed Science and Technology, 201, 1-13.

Giuberti, G., Gallo, A., Masoero, F., Ferraretto, L. F., Hoffman, P. C., & Shaver, R. D. 2014. Factors affecting starch utilization in large animal food production system: A review. Starch-Stärke, 66(1-2): 72-90.

Giuberti,G., Gallo,A., Cerioli,C., Masoero,F. 2012. In vitro starch digestion and predicted glycemic index of cereal grains commonly utilized in pig nutrition. Anim. FeedSci. Technol. 174: 163–173.

Gizzi, G., & Givens, D. I. 2004. Variability in feed composition and its impact on animal production. FAO Animal Production and Health Paper, 39-54.

Grieshop, C. M., Reese, D. E., & Fahey Jr, G. C. 2001. Nonstarch polysaccharides and oligosaccharides in swine nutrition. Swine nutrition, 2: 107-130.

Gutierrez-Alamo, A., De Ayala, P. P., Verstegen, M. W. A., Den Hartog, L. A., & Villamide, M. J. 2008. Variability in wheat: factors affecting its nutritional value. World's poultry science journal, 64(1): 20-39.

Hall, M. B. 2008. Determination of starch, including maltooligosaccharides, in animal feeds: Comparison of methods and a method recommended for AOAC collaborative study. Journal of AOAC International, 92(1): 42-49.

Huang, Q., Shi, C. X., Su, Y. B., Liu, Z. Y., Li, D. F., Liu, L. and Lai, C. H. 2014. Prediction of the digestible and metabolizable energy content of wheat milling by-products for growing pigs from chemical composition. Animal Feed Science and Technology, 196: 107-116.

INRA (Institut National de la Recherche Agronomique). 2004. Tables of composition and nutritional value of feed materials, Sauvant, D., J-M. Perez and G. Tran, Eds. Wageningen Academic Publishers, The Netherlands and INRA, Paris, France.

Jha, R., & Berrocoso, J. D. 2015. Dietary fiber utilization and its effects on physiological functions and gut health of swine. animal, 9(9): 1441-1452.

Just, A. 1982. The net energy value of balanced diets for growing pigs. Livestock Production Science, 8(6): 541-555.

Just, A., Jørgensen, H., & Fernández, J. A. 1984. Prediction of metabolizable energy for pigs on the basis of crude nutrients in the feeds. Livestock Production Science, 11(1): 105-128.

Kersten, J., Rohde, H.R. & Nef, E. 2005. Principles of Mixed Feed Production. Components, Processes, Technology. Mixed Feed Library. Agrimedia GmbH. Germany. p 13-29.

Kil, D. Y., Kim, B. G., & Stein, H. H. 2013. Feed energy evaluation for growing pigs. Asian-Australasian journal of animal sciences, 26(9): 1205.

Kim, J. C., Simmins, P. H., Mullan, B. P., & Pluske, J. R. 2005. The digestible energy value of wheat for pigs, with special reference to the post-weaned animal. Animal Feed Science and Technology, 122(3): 257-287.

Knudsen, K. E. B. 1997. Carbohydrate and lignin contents of plant materials used in animal feeding. Animal feed science and technology, 67(4): 319-338.

Knudsen, K. E. B., Lærke, H. N., & Jørgensen, H. 2013. Carbohydrates and carbohydrate utilization in swine. In Sustainable Swine Nutrition (pp. 109-137). Wiley-Blackwell.

Knudsen, K. E. B., Lærke, H. N., Steenfeldt, S., Hedemann, M. S., & Jørgensen, H. 2006. In vivo methods to study the digestion of starch in pigs and poultry. Animal feed science and technology, 130(1): 114-135.

Kong, C., & Adeola, O. 2014. Evaluation of amino acid and energy utilization in feedstuff for swine and poultry diets. Asian-Australasian journal of animal sciences, 27(7): 917.

Lammers, P. J., & Honeyman, M. S. 2009. Minimizing Starch Consumption by Finishing Pigs: Demonstrated and Theoretical Approaches. Animal Industry Report, 655(1): 83.

Lee, J., Nam, D. S., & Kong, C. 2016. Variability in nutrient composition of cereal grains from different origins. SpringerPlus, 5(1): 419.

Leeson, S., Yersin, A., & Volker, L. 1993. Nutritive value of the 1992 corn crop. Journal of Applied Poultry Research, 2(3): 208-213.

Lewis, L. L., Stark, C. R., Fahrenholz, A. C., Bergstrom, J. R., & Jones, C. K. 2015. Evaluation of conditioning time and temperature on gelatinized starch and vitamin retention in a pelleted swine diet. Journal of animal science, 93(2): 615-619.

Li, Q., Zang, J., Liu, D., Piao, X., Lai, C., & Li, D. 2014. Predicting corn digestible and metabolizable energy content from its chemical composition in growing pigs. Journal of animal science and biotechnology, 5(1): 11.

Li, Y. Z., & Posner, E. S. 1989. An experimental milling technique for various flour extraction levels. Cereal Chem, 66(4): 324-328.

Lluis Faba and David Sola-Oriol.2016. Variability in feed manufacture, A factor to be considered in the efficiency of fattening. https://www.pig333.com.

Lowell, J. E., Liu, Y., & Stein, H. H. 2015. Comparative digestibility of energy and nutrients in diets fed to sows and growing pigs. Archives of animal nutrition, 69(2): 79-97.

M. L. Potter , S. S. Dritz , M. D. Tokach, J. M. DeRouchey, R. D. Goodband, and J. L. Nelssen. Effects of Meal or Pellet Diet Form on Finishing Pig Performance and Carcass Characteristics.

Medel, P., Latorre, M. A., De Blas, C., Lázaro, R., & Mateos, G. G. 2004. Heat processing of cereals in mash or pellet diets for young pigs. Animal Feed Science and Technology, 113(1): 127-140.

Miller, T. G. 2012. Swine feed efficiency: influence of temperature.

Myers, A. J., Goodband, R. D., Tokach, M. D., Dritz, S. S., DeRouchey, J. M., & Nelssen, J. L. 2013. The effects of diet form and feeder design on the growth performance of finishing pigs. Journal of animal science, 91(7): 3420-3428 (Abstr.).

Noblet, J. 2000. Digestive and metabolic utilization of feed energy in swine: Application to energy evaluation systems. Journal of Applied Animal Research, 17(1): 113-132.

Noblet, J. 2006. Energy Evaluation of Feeds for Pigs: Consequences on Diet Formulation and Environment Protection. Lohmann Information Vol. 41 p. 38-50.

Noblet, J. 2006. Recent advances in energy evaluation of feeds for pigs. Recent advances in animal nutrition, 39, 1.

Noblet, J. 2007. Net energy evaluation of feeds and determination of net energy requirements for pigs. Revista Brasileira de Zootecnia, 36: 277-284.

Noblet, J. 2007. Recent developments in net energy research for swine. Adv Pork Prod, 18(18), 149-156.

Noblet, J. 2013. Energy evaluation of pig feeds with emphasis on net energy. In 12. BOKU-Symposium Tierernährung (p. np).

Noblet, J. 2013. Use of net energy vs metabolizable energy in swine and poultry. In Paper presented at the Southeast Asian Feed Technology and Nutrition Workshop (Vol. 3, p. 7).

Noblet, J., & Henry, Y. 1993. Energy evaluation systems for pig diets: a review. Livestock Production Science, 36(2): 121-141.

Noblet, J., & Jaguelin-Peyraud, Y. 2007. Prediction of digestibility of organic matter and energy in the growing pig from an in vitro method. Animal feed science and technology, 134(3): 211-222.

Noblet, J., & Perez, J. M. 1993. Prediction of digestibility of nutrients and energy values of pig diets from chemical analysis. Journal of animal science, 71(12): 3389-3398.

Noblet, J., Fortune, H., Dupire, C., & Dubois, S. 1993. Digestible, metabolizable and net energy values of 13 feedstuffs for growing pigs: effect of energy system. Animal Feed Science and Technology, 42(1-2): 131-149.

Nozière, P., Ortigues-Marty, I., Loncke, C., & Sauvant, D. 2010. Carbohydrate quantitative digestion and absorption in ruminants: from feed starch and fibre to nutrients available for tissues. Animal, 4(7): 1057-1074.

NRC. 1998. Nutrient Requirements of Swine. 10th ed. National Academy Press, Washington, DC.

NRC. 2012. Nutrient Requirements of Swine. 11th ed. Natl. Acad. Press, Washington, DC.

Nyachoti CM, Zijlstra RT, de Lange CFM, Patience JF. 2004. Voluntary feed intake in growing-finishing pigs: A review of the main determining factors and potential approaches for accurate predictions. Can J Anim Sci. 84:549–566.

Patience, J. F. 2012. The influence of dietary energy on feed efficiency in grow-finish swine. In Feed efficiency in swine (pp. 101-129). Wageningen Academic Publishers.

Patience, J. F., Rossoni-Serão, M. C., & Gutiérrez, N. A. 2015. A review of feed efficiency in swine: biology and application. Journal of animal science and biotechnology, 6(1): 33.

Peter Ramaekers. 2015. Net energy system for gestating and lactating sows.https://www.pig333.com/nutrition/net-energy-system-for-gestating-and-lactating-sows-1-2_9914/.

Pomar, C., Hauschild, L., Zhang, G. H., Pomar, J., & Lovatto, P. A. 2009. Applying precision feeding techniques in growing-finishing pig operations. Revista Brasileira de Zootecnia, 38(SPE): 226-237.

Potter, M. L., S. S. Dritz, M. D. Tokach, J. M. DeRouchey, R. D. Goodband, J. L. Nelssen, and J. A. Barnes. 2010. Effects of meal or pellet diet form on finishing pig performance and carcass characteristics. J. Anim. Sci. 88 (E-Suppl. 3) 181 (Abstr.).

Ravindran, V., Tancharoenrat, P., Zaefarian, F., & Ravindran, G. 2016. Fats in poultry nutrition: Digestive physiology and factors influencing their utilisation. Animal Feed Science and Technology, 213: 1-21.

Regmi, P. R., Matte, J. J., Van Kempen, T. A. T. G., & Zijlstra, R. T. 2010. Starch chemistry affects kinetics of glucose absorption and insulin response in swine. Livestock Science, 134(1): 44-46.

Rosenfelder, P., Eklund, M., & Mosenthin, R. 2013. Nutritive value of wheat and wheat by-products in pig nutrition: A review. Animal Feed Science and Technology, 185(3): 107-125.

Shi, C. X., Liu, Z. Y., Shi, M., Li, P., Zeng, Z. K., Liu, L., & Li, D. F. 2015. Prediction of digestible and metabolizable energy content of rice bran fed to growing pigs. Asian-Australasian journal of animal sciences, 28(5): 654.

Skoch, E. R., S. F. Biner, C. W. Deyoe, G. L. Allee, and K. C. Behnke. 1983. Effects of pelleting conditions on performance of pigs fed a corn-soybean meal diet. J. Anim. Sci. 57:922–928.

Smit, M. N., Landero, J. L., Young, M. G., & Beltranena, E. 2016. Feeding diets with reduced net energy levels to growing-finishing barrows and gilts. Canadian Journal of Animal Science, 97(1): 30-41.

Stark, C. R., K. C. Behnke, J. D. Hancock, S. L. Traylor, and R. H. Hines. 1994. Effect of diet form and fines in pelleted diets on growth performance of nursery pigs. J. Anim. Sci 72, no. Suppl 1: 214.

Stark, C.R. 1994. Pellet Quality I. Pellet quality and its effects on swine performance. PhD Dissertation, Kansas State University, Manhattan, KS.

Stark, CR. 2012. Feed processing to maximize feed efficiency. In Feed efficiency in swine (ed. JF Patience), pp. 131-151. Wageningen Academic Publisher, Wageningen.

Statistical Analysis System Institute, Inc. 2009. SAS/STAT users guide, Version 8. SAS Institute Inc., Cary, NC.

Steidinger, M.U., R.D. Goodband, M.D. Tokach, S.S. Dritz, J.L. Nelssen, L.J. McKinney, B.S. Borg, J.M. Campbell. 2000. Effects of pelleting and pellet conditioning temperatures on weanling pig performance. J. Anim. Sci. 78: 3014-3018.

Stein, H. H., & Shurson, G. C. 2009. Board-invited review: The use and application of distillers dried grains with solubles in swine diets. Journal of animal science, 87(4): 1292-1303.

Svihus, B., Uhlen, A. K., & Harstad, O. M. 2005. Effect of starch granule structure, associated components and processing on nutritive value of cereal starch: A review. Animal Feed Science and Technology, 122(3): 303-320.

Szabó, C., & Halas, V. 2013. Shortcomings of the energy evaluation systems in pigs: a review. Agriculturae Conspectus Scientificus, 78(3): 153-158.

Trottier, N. L., Johnston, L. J., & de Lange, C. F. M. 2015. Applied amino acid and energy feeding of sows. In The gestating and lactating sow (pp. 99-106). Wageningen Academic Publishers.

van Kempen, T. A., Regmi, P. R., Matte, J. J., & Zijlstra, R. T. 2010. In vitro starch digestion kinetics, corrected for estimated gastric emptying, predict portal glucose appearance in pigs. The Journal of nutrition, 140(7), 1227-1233.

van Milgen, J., & Noblet, J. 2003. Partitioning of energy intake to heat, protein, and fat in growing pigs. Journal of Animal Science, 81(14_suppl_2), E86-E93.

van Milgen, J., Noblet, J., & Dubois, S. 2001. Energetic efficiency of starch, protein and lipid utilization in growing pigs. The Journal of nutrition, 131(4): 1309-1318.

Velayudhan, D. E., Kim, I. H., & Nyachoti, C. M. 2015. Characterization of dietary energy in swine feed and feed ingredients: A review of recent research results. Asian-Australalasian journal of animal sciences, 28(1): 1.

Wan, H. F., Chen, W., Qi, Z. L., Peng, P., & Peng, J. 2009. Prediction of true metabolizable energy from chemical composition of wheat milling by-products for ducks. Poultry science, 88(1): 92-97.

Weiss, W. P., & St-Pierre, N. R. 2009. Impact and management of variability in feed and diet composition. In Tri-State Dairy Nutrition Conf. Proc., Fort Wayne, Indiana. Michigan State University, East Lansing (pp. 83-96).

Wiseman, J. 2006. Variations in starch digestibility in non-ruminants. Animal Feed Science and Technology, 130(1): 66-77.

Wiseman, J. 2014. Energy Sources for Non-Ruminant Livestock feeds. https://www.researchhate.net/publication.242364101.

Wondra, K. J., Hancock, J. D., Behnke, K. C., Hines, R. H., & Stark, C. R. 1995. Effects of particle size and pelleting on growth performance, nutrient digestibility, and stomach morphology in finishing pigs. Journal of Animal Science, 73(3): 757-763.

Zijlstra, R. T., Lange, C. D., & Patience, J. F. 1999. Nutritional value of wheat for growing pigs: chemical composition and digestible energy content. Canadian Journal of Animal Science, 79(2): 187-194.

요약

본 연구의 사양 실험은 33 일 간 진행하였고 2 x 2 factorial 디자인이 사용되었다. 총 360 마리의 돼지 (개시 체중 17.70 ± 0.53 kg)를 4 종류의 사료 처리구에 3 반복 (1 반복당 30 마리)으로 배치하였다. Dutch system 의 NE 방정식을 사용하여 사료 원료의 NE 값을 예측하는데 이용된 참고 값 (CVB)과 분석한 전분 및 당 값을 주처리 효과로, 상이한 에너지 농도와 사료 형태를 부처리 효과로 하여 시험설계를 하였다. 펠렛 (pellet) 형태의 사료는 메시 (mash) 형태의 사료보다 30 kcal/kg 낮은 정미에너지를 가지도록 설계되었고, 성장 성적과 사료 비용을 평가하기 위하여 55 일부터 87 일까지 젖먹이 돼지에게 급여하였다.

보리를 제외한 대부분 사료원료의 분석된 전분함량은 참조 값과 비교하여 높았으며, 그 결과 더 높은 NE 예측 값을 나타냈다. 당의 경우, 분석 값과 참조 값은 상이하였으나, 대두박을 제외하고는 전분과는 달리 그 농도가 상대적으로 낮았기 때문에 NE 예측 값에 미치는 영향이 적었다. 이러한 결과는 원료사료의 실제 영양소 성분은 참고 값과 다를 수 있으므로 원료사료의 영양소 성분에 대한 측정 없이 NE 참고 값을 사용하면 양돈 사료의 에너지 함량을 부정확하게 측정할 수 있다는 것을 나타낸다.

사양 실험에서 다른 처리구의 사료를 섭취한 돼지들은 유사한 ADG 를 나타냈다. ADFI 의 경우, 참고 값과 분석 값의 처리구 사이에서도 유의적인 차이가 없었으나, 사료 형태와 에너지 농도를 고려하였을 때, 메시 사료를 섭취한 돼지는 펠렛 사료를 섭취한 돼지에

비하여 유의적으로 (P<0.05) 많은 사료를 섭취하였다. 펠렛 사료 처리군의 낮은 ADFI 와 유사한 ADG 는 유의적으로 (P<0.05) 높은 사료 효율을 가지게 하였다. 사료 비용에 있어서는 분석 값을 사용한 사료 처리구가 매우 낮은 비용을 보였고, 이것은 전분이 실험사료에서 주요한 에너지 소스로 이용되었기 때문으로 생각된다.

결과적으로, 본 실험은 원료사료의 전분과 당을 포함한 영양 성분의 분석을 통해 돼지 사료의 정확한 에너지 가치에 대한 평가가 이뤄질 때, 가축생산성에 대한 저해 없이 사료비용을 최소화 할 수 있다는 것을 시사하고 있다. 추가적으로, 펠렛팅 (pelleting)은 돼지의 에너지 소화율 및/또는 영양소 이용률 개선으로 사료 효율에 긍정적인 영향을 미칠 수 있음을 보여주고 있다.

주요어: 정미 에너지, 전분, 당,분석치, 참고치, 사료가치, 양돈사료

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