DETERMINATION OF THE METABOLIZABLE ENERGY CONCENTRATION OF CORN AND SORGHUM VARIETIES FOR GROWING PIGS

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TABLE OF CONTENTS

LIST OF TABLES

Table Page

Chapter I

Chapter II

Chapter III

Table Page

Chapter IV

Chapter V

Chapter VI

Table Page

Chapter VII

Chapter VIII

LIST OF FIGURES

Figure Page

Chapter I

Chapter II

APPENDIX TABLES

Table Page

Table Page

Table Page

Table Page

Introduction

Cereal grains are the primary ingredients within swine diets in the United States. In fact, they typically comprise greater than 50% of swine diets. This is because they are commonly produced, easily transported across the country, easily handled by processors, and palatable to swine. The most important reason is that they are usually the most economical source of metabolizable energy.

Because pigs consuming feed ad libitum typically consume to the amount which meets their energy requirements, the energy content and availability from cereals is critically important. More important, however, is the knowledge of the energy concentration within the specific cereal grains being utilized in swine diets. This is because other nutrients (i.e., lysine, calcium, phosphorus) must be formulated at the proper ratio to energy in order that pigs consuming to meet their energy requirements also meet all of their other nutrient requirements.

The priorities are different for the grain producer and the swine nutritionist concerning the "quality" of a cereal grain for their specific enterprise. For example, grain producers typically use seed cost, production cost, and expected grain yields in a given environment to select the type and specific hybrid or variety propagated. Swine nutritionists are interested in the grain's available energy content for pigs, concentration of essential amino acids, the lack of anti-nutritional compounds or toxins, and the consistency of the nutrient composition. Trying to deal with the priorities of the opposite sector, the grain producer or swine nutritionist can face some economic difficulties if premiums are not available. Some swine producers are thus purchasing "identity-preserved" grains from contract grain producers to meet their needs for producing pork for specific markets. In this scenario, the grain producer receives a premium for his grain, and the swine producer receives premiums for pork.

The type of cereal grain utilized in a specific geographic location is primarily due to the agronomic conditions that result in local grain production and availability. In the United States, corn is the most widely used cereal grain in swine diets due to its vast production and availability. However, in the southern portion of the U.S., the utilization of grain sorghum in swine diets is a possibility. This is because grain sorghum is more drought resistant than corn and consequently more readily produced in these areas. Thus, the accessibility of grain sorghum in the southern U.S. may allow it to be a cheaper energy source for swine diets, as compared with the cost of transportion of corn from the Corn Belt. More importantly, many studies have shown that the nutritional value of sorghum for pigs is similar to corn. However, because the primary emphasis in sorghum production is its agronomic characteristics versus its nutrient content, grain sorghum has a reputation of being highly variable in chemical composition.

Not only may genotype affect the variation in nutrient contents of cereal grains, but environment also may have an integral affect along with genotype × environment interactions. Thus, large variations in nutrient composition exist among cereal grains and even within a specific cereal grain. In fact, with the development of new hybrids and varieties of grains, this diversity will certainly increase.

Thus, the topic of this thesis was to determine the metabolizable energy content of several varieties or hybrids of corn and sorghum when fed to growing pigs through the use of energy and nitrogen balance experiments. As well, the variation in the nutrient content of several grain sorghum samples were evaluated.

Chapter I

Literature Review

Energy in feedstuffs

When organic molecules undergo oxidation, energy is produced. In living cells, when the organic molecules that comprise feedstuffs are oxidized through metabolism, energy is produced. This energy can then be either released as heat from the animal or retained for use in powering the animal's metabolic processes. Feedstuffs can have varying levels of energy content based upon the chemical composition of the feedstuff and how it is utilized by the animal. Determining the energy values of feedstuff utilized in swine feeding is very tedious and difficult. Initially, energy values of feedstuffs for swine were calculated from total digestible nutrients (TDN) or were derived from research on chicks. Prediction equations were also developed to calculate the energy value of feedstuffs based entirely from their chemical composition. Presently, the most widely used system for evaluating energy content in feedstuffs is by the energy partitioning system (Figure 1.1).

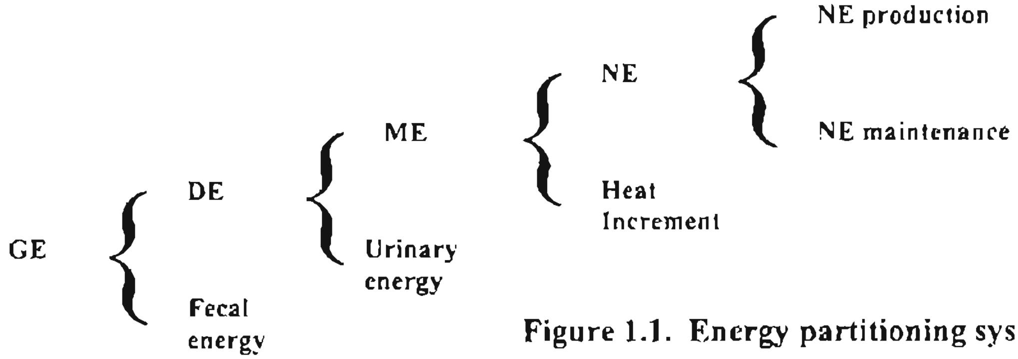


Figure 1.1. Energy partitioning system.

In this method, energy is expressed as calories (cal), kilocalories (kcal), or megacalories (Mcal) of gross energy, digestible energy, metabolizable energy, or net energy. The NRC (1998) also states that energy can also be expressed as joules (J), kilojoules (KJ), or megajoules (MJ), (1 Mcal = 4.184 MJ ; 1 MJ = 238.8459 kcal). Other measurements of energy sometimes utilized are BTUs and therms. These are related to one another as one therm is comprised of approximately 10^5 BTUs. Thus, one BTU is equal to 0.2519958 kilocalories, while one therm is equal to 25,199.68 kilocalories.

Gross energy (GE) of a substance is the energy produced when that substance is combusted. The quantity of chemical energy present in a food or feedstuff is measured by converting it into heat energy, and determining the heat produced. In application, the gross energy can be determined through combustion in a bomb calorimeter. According to NRC (1998), the proportions of carbohydrate, fat, and protein determine the GE. Water and minerals contribute no usable energy, carbohydrates provide 3.7 to 4.2 kcal/g, protein provides 5.6 kcal/g, and fat provides 9.4 kcal/g (NRC, 1998). Whittemore (1993) reports gross energy values for carbohydrates, protein, and fat as 17.5 MJ/kg, 23.6 MJ/kg, and 39.3 MJ/kg, respectively.

Dietary GE intake minus the GE of the excreted feces produces a value termed digestible energy (DE) (NRC, 1998). Because collection of feces is the only procedure required, Farrell (1978) and Morgan and Whittemore (1982) propose digestible energy to be the value of choice to evaluate feedstuff energy. The DE measurement does give a straightforward view of energy in feed (Whittemore, 1993). This straightforward nature of digestible energy determination makes it very appropriate for describing the characteristics of pig rations (Robinson et al., 1965). The determination of energy value of feeds by DE measurement, rather than GE, ME, or NE, has been found to be useful because it is readily found through the use of simple experimental techniques and has also shown consistent relationships with pig performance (Whittemore, 1993). However, DE is apparent, not true, because fecal endogenous energy is not considered (NRC, 1998). Robinson et al. (1965) suggested that testing individual ingredients for their energy value may give values for each feedstuff, but the values found may be subject to modification when fed with other ingredients. The associative effects of feeds are easily demonstrated but are very unpredictable (Robinson et al., 1965).

Metabolizable energy (ME) is defined as digestible energy minus the gross energy of urinary and gaseous losses. The energy release through gaseous losses is very difficult to measure and the actual amount of energy in gaseous loss is very small. In fact, the energy from gaseous loss is usually between 0.1 and 3.0 percent of DE (Shi and Noblet, 1993). For these reasons, gaseous loss energy is typically ignored. Because ME determination accounts for energy losses in the urine, it is a more sensitive indicator of an animal's physiological state and this implies the need to determine ME values for each physiological state (Wiseman et al., 1982).

Net energy (NE) is the difference between metabolizable energy and heat increment (HI) (NRC, 1998). Heat increment is the heat produced by the digestion and metabolism of nutrients of an animal's diet and by fermentation in the intestinal tract. Normally, heat increment is waste energy, but it can be used to maintain body temperature in environments colder than thermoneutral. Net energy, in general, is the energy that is available for maintenance and production by the animal. Because the evaluation of net energy requires the measurement of heat production, it is very difficult to measure; however, NE is the best indication of the energy available to an animal for maintenance and production (Noblet et al., 1994). Whittemore (1993) suggested that net energy is influenced to such a great extent by the activities of the animal itself that a single NE value cannot be accurately or properly assigned to a feedstuff.

Noblet et al. (1993) determined that DE is overestimated in feeds that contain high amounts of protein and fiber, but is underestimated in feeds which contain more starch or fat ingredients. They emphasized the benefit of adopting a NE system for estimating the energy value of ingredients as it provides an evaluation of the dietary energy content which is closer to the "true" value.

Comparing energy evaluation systems

Several studies have been conducted to examine the relationship between DE, ME, and TDN. Total digestible nutrient (TDN) is the sum of digestible protein, digestible ether extract, and digestible carbohydrate. Some relationships between TDN and DE have been observed. Robinson et al. (1965) determined that digestible energy values of various cereal grains agreed well with total digestible nutrient values for the same cereals. The average ratio of DE to TDN for various feedstuffs was 44.2 (Robinson et al., 1965), which agrees very closely with the value of Swift (1957) who proposed that 1 gram of TDN was equal to 4.5 kcal digestible energy. However, Morgan et al. (1975) showed that TDN was most closely related to ME and least closely related to DE. Morgan et al. (1975) evaluated nineteen feedstuffs and found that the average ME was 95.3% of DE for all feedstuffs and ME of cereal grains was 97.4% of DE. Farrell (1979) proposed a simple calculation, ME is often thought to be 94 to 97 percent of DE, with an average of 96 percent. May and Bell (1971) suggested that the most meaningful ME values for feedstuffs could be obtained by calculating ME as 98% of DE. Diggs et al. (1965) found that ME averaged 94.8% of DE for cereal grains. According to Morgan et al. (1975), the disadvantage of this approach is that it ignores the fact that the ME:DE ratio of a diet will vary according to its composition. Adeola and Bajjalieh (1997) found that for high-oil corn and normal corn the average ME value was 98.4% of DE.

Metabolizable energy values are sometimes assessed a correction factor for nitrogen gained or lost from the body. This correction factor is derived from evaluating the GE of urine per gram of urinary nitrogen. It is based on the fact that a proportion of the ME that is retained as protein is biologically unavailable to the animal when catabolized for energy (Wiseman et al., 1982). For this reason, uncorrected ME values are thought to overestimate the energy–yielding potential of feedstuffs (Wiseman et al., 1982). This correction to nitrogen equilibrium may be valid for mature animals but is not valid for growing pigs that retain considerable amounts of nitrogen (NRC, 1998). The corrected metabolizable energy value reflects the energy potentially available to the animal, irrespective of its metabolic status (Robinson et al., 1965). Some of the correction factors used were 6.77 kcal/g (Diggs et al., 1959;1965) and 9.17 kcal/g or 38.4 MJ/g of (Morgan et al., 1975; Wiseman et al., 1982) urinary nitrogen. Metabolizable energy can be corrected to zero nitrogen retention (ME_{N0}) and also corrected to 30% nitrogen retention (ME_{N30}) (Morgan et al., 1975; Wiseman et al., 1982). Metabolizable energy corrected to zero nitrogen balance (ME_{N0}) takes into account the energy of the nitrogen retained, but on the other hand, it has been criticized for underestimating the energy value of feedstuffs because it assumes that there will be no net energy stored from the retained nitrogen (Wiseman et al., 1982). In order to achieve a value that is somewhere between the uncorrected ME value and the ME_{N0} value, Morgan et al. (1975) proposed that a correction of ME to a positive level of nitrogen retention (30%) would be more appropriate. With the small size of the ME_{N30} correction, there may be little difference between ME_{N30} and ME and may have limited practical significance (Wiseman et al., 1982). It is also apparent that nitrogen retention is not highly variable among various diets (Diggs et al., 1965). The adjusted ME value for corn reported by Diggs et al. (1965) was in reasonable agreement with the ME value reported by Garrigus and Mitchell (1935).

A study was performed by Wiseman et al. (1982) to determine variation in energy values of corn samples when fed to growing gilts. Data illustrated that variability in DE values between different corn samples was small, and it is unlikely that there is considerable intra-species variation. The DE values of the corn samples ranged from 16.05 to 16.47 MJ/kg. A significant correlation existed between DE and ME. There was little improvement in accuracy with the use of ME_{N30} when compared to ME since similar standard errors were obtained from both values.

Techniques used in determining energy composition of feedstuffs fed to pigs

When determining the digestible or metabolizable energy concentration of feedstuffs for pigs, several different methods can be applied. In most methods, pigs from the same contemporary group are placed into individual metabolism crates that allow for the separate collection of urine and feces as well as the measurement of feed intake. From that point, the actual methodology may differ. Two general methods that can be utilized are the quantitative feed and feces (total collection) method or some type of index (marker) method. The total collection method requires the accurate measurement of feed intake, fecal excretion, and if desired, urine output. Indigestible markers are added to the feed to signify the initiation and termination of excreta collection. This method allows for the analysis of total excreta associated with a given amount of consumed feed. The calculation for percentage digestibility using the total collection method is as follows.

$$\text{Digestibility, \%} = 100 \times \left[\frac{\text{amount of component consumed} - \text{amount of component voided in feces}}{\text{amount of component consumed}} \right]$$

The index (marker) method for measurement of digestibility is less labor intensive than the total collection method since measurements of feed intake and quantitative collection of excreta is avoided due to the use of index compounds. These compounds must be: easily to analyze chemically, nonabsorbable, nonessential, nontoxic, completely inert (indigestible), regularly and completely voided into the feces, and uniformly mixed with the feed and feces (Adeola, 2001). Some examples of insoluble markers used are: chromic oxide, titanium dioxide, ferric oxide, and acid-insoluble ash. Thus, shorter, less structured collection periods are utilized. The feed and fecal samples are analyzed for the index compounds and the percentage of digestibility is calculated as follows.

$$\text{Digestibility} = 100 - \left[100 \times \left(\frac{\text{concentration of index compound in feed} \times \text{concentration of component in feces}}{\text{concentration of index compound in feces} \times \text{concentration of component in feed}} \right) \right]$$

Yet another method utilized is grab sampling of group-housed animals. This comprises using an indigestible marker and collecting fecal grab samples for a portion of the animals in a pen as a representative sample. For this method, acid-insoluble ash is often used as the indigestible marker.

Experiments have been conducted to compare the effectiveness of each of these methods for accurate digestibility research. Adeola et al. (1986) performed a study to compare the chromic oxide index method to the total collection method in determining the energy digestibility of corn and triticale. The chromic oxide method and the total collection method provided similar estimates of energy digestibility for corn; however, the chromic oxide index underestimated the energy digestibility of triticale, possibly due to the passage rate of the marker being affected by the viscosity of the triticale contents of the gut. Kavanagh et al. (2001) conducted an experiment to evaluate chromic oxide, titanium dioxide, and acid-insoluble ash markers for the calculation of digestibility and compared them to the total collection method. Energy digestibility as determined by acid-insoluble ash and chromic oxide did not differ from total collection. However, the digestibility estimate for the titanium dioxide method was lower than the estimate from total collection. Kavanagh et al. (2001) also used acid-insoluble ash to examine the reliability of grab sampling as a technique for measuring digestibility in group-housed pigs as compared with total collection. Energy digestibility was similar for total collection and grab sampling which indicates that grab sampling offers a rapid and reliable alternative to the tedious individual metabolism crate method.

When determining the energy value of individual feedstuffs, several methods can be utilized. One method is to conduct a short-term experiment using a diet that contains essentially one ingredient. Another procedure is to compare diets with and without the test ingredient. A basal diet can also be used with added amounts of the feedstuff of interest added and determine the response from the added energy. Finally, another method is to place ingredients into nylon bags and place them in the duodenum of surgically prepared pigs and then measure the residue in the bags (Ewan, 2001).

Certain variables have been of concern when performing balance experiments to determine the energy value of an individual feedstuff. Some of these include the percentage of the test ingredient in the diet and ingredient interactions in formulated diets, level of feed intake, and length of collection period implemented. De Goey and Ewan (1975a) reported that digestible energy and metabolizable energy concentrations of diets fed to pigs were not significantly affected by level of feed intake when the levels evaluated were 2, 3, 4, and 5% of body weight. However, Nelson et al. (1975) conducted a balance study with broilers and determined that dry matter intake affected the ME content of the diet with a correlation coefficient of 0.98. Lassiter et al. (1956) tested the accuracy of using 3-, 5-, and 7-day collection periods in a balance experiment and concluded that, following an adjustment period of sufficient length, a 7-day collection period offered little advantage over a 5-day collection period.

From these numerous factors to consider, it is evident that varying approaches may be conducted in determining the metabolizable energy concentration of feedstuffs by experimentation. However, in general, it seems that the total collection method, when using individually-housed pigs, may be slightly more accurate than the index methods. In addition, although several schools of thought suggest varying approaches for diet formulation when evaluating a single nutrient, it is possible that dry matter feed intake, no matter what feeding method used, may affect available energy concentrations.

Structure and composition of corn

The corn (Zea mays) kernel is classified botanically as a caryopsis, which means it has a dry, indehiscent, single-seeded fruit of which the mature ovary wall (pericarp) does not separate naturally from the seed. These features are characteristic of all cereal grains (Watson, 1987). There are numerous genetic types of corn which are categorized by kernel characteristics. These include: flint, pop, floury, dent, waxy, sweet, amylose, opaque, and high-oil. Flint corn has a rounded crown and the hardest kernels due to the presence of a large and continuous volume of corneous, or horny, endosperm. Popcorn is a small flint type. Floury corn has a rounded or flat crown but contains virtually all floury or soft endosperm. This type of corn is more extensively damaged during handling and artificial drying. Fines that are produced and the formation of stress cracks results in an increased susceptibility to insect and mold damage as the fines prevent air flow for drying and storing the grain. Dent corn is the most commercially used corn type in the United States. It has a depressed crown which forms as the maturing kernel dehydrates. This "dent" is formed as the rigidity of the cylinder of corneous endosperm prevents the central core of floury endosperm from shrinking uniformly during drying causing an indentation to be formed on the crown (Watson, 1987).

Dent corns of the United States were developed in precolonial North America from natural hybridization between northern flint and southern flour corns (Watson, 1987). Because corn was developed as a hybrid cross, it can exhibit significant differences in the ratio of corneous to floury endosperm induced by environmental and heritable influences (Hamilton et al., 1951). These factors specifically include moisture differences between fields, temperature, and soil nitrogen supply and uptake. The endosperms of dent and flint corn carry dominant genes and normal amounts of starch with normal starch properties. However, numerous recessive mutant genes can alter starch composition, such as waxy and amylose extender (Watson, 1987). Waxy maize starch was observed to be made up of highly elongated irregular particles approximately 100 angstroms in diameter and several hundred angstroms long (Yamaguchi et al., 1979).

Table 1.1 displays the chemical composition of yellow dent corn grain as summarized and reported by NRC (1998).

Table 1.1. Chemical composition of yellow dent corn grain.[ab]

Protein %	Fat %	NDF %	ADF %	Calcium %	Phosphorus %
8.3	3.9	9.6	2.8	0.03	0.28

[a] Adapted from NRC (1998)
[b] Data reported on 89% DM basis

The corn kernel is a seed and therefore contains a complete embryo and all of the structural, nutritional, and enzymatic apparatus required to initiate embryo growth and development. The four major structural components of the kernel include the germ, endosperm, pericarp (hull or bran), and the tip cap (Figure 1.2).

The germ is composed of the embryo and the scutellum and is the innermost portion of the kernel. The germ lies embedded in endosperm tissue in such a manner that only the scutellum is in contact with it. The germ comprises about 10-12% of the kernel dry weight, which is a greater proportion of the seed than is the case in other common

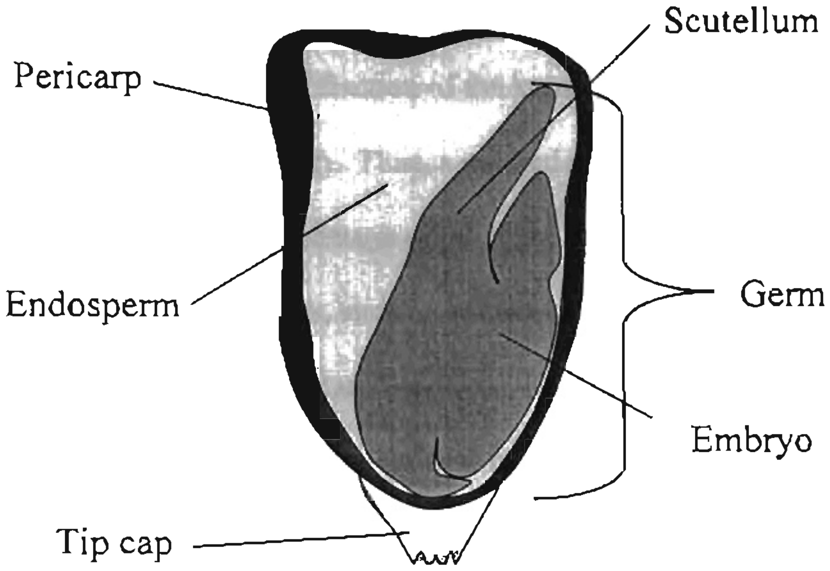


Figure 1.2. Diagram of external and internal structural components of a corn kernel.

cereal grains (Wolf et al., 1952c). The germ contains approximately 22% of the total kernel protein and nearly 80% of the minerals (Table 1.2).

Table 1.2. Individual nutrient composition in kernel fractions as a percentage of total kernel composition (DM basis).[ab]

	Starch	Protein	Oil	Ash	Sugar
Endosperm	98.0	74.8	14.5	16.5	28.2
Germ	1.4	22.4	83.7	79.7	70.2
Pericarp	0.5	2.0	1.1	2.9	1.0
Tip cap	0.1	0.8	0.7	0.9	0.7

[a] Adapted from Earle et al., 1946
[b] Based upon analysis of 11 corn varieties with 4 replications per variety.

The germ is also the major depository of lipids in the seed since about 83% of the total kernel lipids are contained in the germ (Earle et al., 1946). This is due to the fact that oil occurs in the cytoplasm of the cells of both the scutellum and the embryonic axis.

Because the cells of the scutellum are not only richer in oil than the embyonic axis cells, but also comprise a much larger fraction of the kernel, most of the oil is obtained from the scutellum (Wolf et al., 1952c). Thus, a marked positive correlation exists between the percentage of germ and the percentage of oil in the corn kernel (Hopkins et al., 1974). Thus, as the oil content increases, such as in high-oil corn, the percentage of endosperm decreases causing a decrease in starch content. The protein and amino acid content is also slightly higher for high-oil corn because of the larger germ portion.

The endosperm is made up of elongated cells packed with starch granules embedded into a continuous protein matrix within the individual cells (Wolf et al., 1952b). The endosperm, the main storage compartment of the kernel, constitutes about 82 to 84% of the dry weight of the kernel and is 86-89% starch by weight (Earle et al., 1946). This is the area of the corn kernel that products such as corn grits, corn meal, and corn flakes are made from and from which starch and corn gluten are separated. The starchy endosperm can be of two types, floury and corneous (horny). Starch granules are less readily released from the corneous endosperm than from the floury endosperm cells due to the greater thickness of the proteinaceous matrix in the horny endosperm (Wolf et al., 1952b). Dry grinding of floury endosperm causes breakage across the cell contents, releasing some free starch granules and producing a rough surface with many exposed starch granules and very little starch granule damage. Corneous endosperm breaks more along cell wall lines but also across cells, with little release of starch granules but with much granule damage (Watson, 1987).

The endosperm contains about 98% of the starch of the kernel as well as about 74% of the total protein (Table 1). In the endosperm of young kernels, sugar, in the form of sucrose, is stored in the vacuole of the endosperm cells until needed for starch synthesis (Boyer and Shannon, 1987). Boyer et al. (1977) observed major and minor gradients in physiological age of endosperm cells in all kernels of six different maize genotypes. During kernel development, the cells in the central crown region of the endosperm begin starch synthesis and accumulation first, while the lower endosperm cells of the kernel begin this process much later. Another minor cell maturity gradient forms as the central endosperm cells mature earlier than the peripheral cells (Boyer et al., 1977). Thus, in physiologically young endosperm cells, sugar content is high and starch content is low. As the proportion of cells synthesizing starch increases, sugar content of the kernel declines and starch increases (Creech, 1965). As a result, the mature endosperm consists of approximately 86% starch and less than 1% sugar (Table 1.3) on a dry matter basis (Inglett, 1970). As for carbohydrate content of the corn seed, while starch makes up about 72% of the kernel, sugars such as sucrose, glucose, and fructose amount only to about 1-3% (Watson, 1987).

Table 1.3. Average composition whole grain and dissected fractions of corn (DM basis).[a]

		% composition				
Fractions	% of kernel	Starch	Protein	Lipid	Sugar	Ash
Whole grain	----	71.5	10.3	4.8	2.0	1.4
Endosperm	82.3	86.4	9.4	0.8	0.6	0.3
Germ	11.5	8.2	18.8	34.5	10.8	10.1
Bran	5.3	7.3	3.7	1.0	0.3	0.8
Tip cap	0.8	5.3	9.1	3.8	1.6	1.6

[a] Adapted from Inglett, 1970

Starch granules are made up of two glucan polymers, amylose and amylopectin. Amylose is an essentially linear molecule of glucose units linked by α-1,4 linkages while amylopectin is a branched molecule composed of linear regions of α-1,4-linked glucose units with α-1,6-linked branch chains. Amylose makes up about 25-30% of the starch in corn while amylopectin constitutes 70-75% (Boyer and Shannon, 1987). The physical properties of starch granules are important in determining their biological and economic value. Some of these important features are: starch granule morphology, amylose content, crystallinity, gelatinization temperature, and digestibility, all of which are altered by different endosperm genotypes (Boyer and Shannon, 1987).

The pericarp (hull or bran) is the outermost membrane structure of the corn seed and is comprised of all tissues exterior to the seed coat. The pericarp makes up 5-6% of the kernel dry weight. It is divided into four layers of cells, each type having its own specific characteristics (Wolf et al., 1952a). The tip cap is the remnant of the tissue connecting the kernel to the cob and is the smallest fragment of the kernel.

Many gene mutations that occur in corn have been observed to affect endosperm carbohydrate components. Some of these mutated genes include: waxy (*wx*), dull (*du*), sugary-1, (su_1), sugary-2 (su_2), amylose-extender (*ae*), shrunken-1 (sh_1), shrunken-2 (sh_2), brittle-1 (bt_1), brittle-2 (bt_2), and sugary enhancer (*se*). The waxy mutant contains mostly amylopectin starch, nearly 100%, and only a trace of amylose (Sprague et al., 1943). No amylose was formed in *wx* seeds whether in sugary or non-sugary endosperms (Kramer and Whistler, 1949). The *wx* gene also increases sugars and water-soluble polysaccharides alone and with a su_1 background (Andrew et al., 1944). Conversely, Cameron (1947) reported that su_1 and *du* interact to increase the amylose content of the endosperm starch; however, the water-soluble polysaccharides were increased and total starch was reduced. The su_1 gene increased water-soluble polysaccharides to over 30%

(Dvonch et al., 1951). The su_2 gene resulted in amylose content of 36% as compared to 22% for normal starchy endosperms (Kramer and Whistler, 1949). Dvonch et al. (1951) reported that *du*, su_1, and su_2 interact to increase the amylose content to about 53%, but endosperm starch decreased and water-soluble polysaccharides increased. Dunn et al. (1953) also observed the *du*, su_1, and su_2 gene interaction in which amylose was 77% of total starch, but starch content of the seed decreased to 9% and water-soluble polysaccharides increased.

Specific genotypic combinations of genes *ae*, *du*, su_1, su_2, and *wx* have been reported to result in endosperm amylose contents that varied from none to over 70% (Kramer et al., 1958). The *ae*, when expressed in corn, increased the amylose portion of starch to 61% as compared to 27% in normal dent corn (Kramer et al., 1958). The *ae* gene resulted in increased amylose, increased sugars, and decreased starch content and when combined with *wx* or *du wx*, these trends are even more dramatic (Creech, 1965). Creech (1965) suggests that *ae* and *wx* are in separate pathways of starch synthesis in which *ae* is associated with a metabolic block between the sugars and the branched chain polysaccharides and *wx* is associated with a block between the sugars and the straight chain polysaccharides.

The shrunken-1 gene (sh_1), was first described by Hutchison (1921) in which large indentations on the sides and crown of the kernel reduced starch content of the endosperm. The sh_2 gene causes mature endosperms to be highly collapsed, opaque and brittle and have a weight that is 75% of that of normal endosperms (Laughnan, 1953). Shrunken-2 kernels contained a high concentration of sugars which resulted in a corresponding decrease in endosperm starch (Laughnan, 1953). Cameron and Teas

(1954) reported two other mutations, brittle-1 (*bt_1*), and brittle-2 (*bt_2*) which caused a reduction in endosperm starch content without accumulation of water-soluble polysaccharides as well as increased sugar content. Dickinson et al. (1983) found that the *se* gene increased sucrose and maltose levels and decreased starch content. Creech and McArdle (1966) observed that all the known mutant corn genotypes had less starch content than normal genotypes.

In a long-term experiment conducted at the Illinois Agricultural Experiment Station, the original population in 1896 was used to initiate four selection lines. These lines were selected for: high protein (HP), low protein (LP), high oil (HO), and low oil (LO). Following 70 generations of selection (Table 1.4), the means of the selected variables were 215, 23, 341, and 14% of the means of the original population for the respective selection lines (Dudley et al., 1974). These data indicate that selection for nutrient composition of corn is successful. Significant differences among the last six generations indicate that selection had not exhausted genetic variation and further

Table 1.4. Composition of corn lines after 70 generations of selection.[a]

Strain	% Oil	% Protein	% of original pop. for selected variable	# of S.D. from mean of original pop. for selected variable
Original popul.	4.69	10.9	-------	--------
High oil	16.64	14.2	215	12
Low oil	0.40	11.8	23	8
High protein	4.82	26.6	341	27
Low protein	3.10	4.4	14	10

[a] Adapted from Dudley et al., 1974

changes due to selection procedures were possible. Selection for chemical composition caused a marked change in kernel size. Kernels of the high oil and high protein lines were smaller than the other two lines. The kernels of the low oil and low protein lines were larger with a higher percentage of soft starch. Yield differences were also observed. The high protein line was consistently the lowest yielding while the low protein line was usually the highest yielding throughout the experiment (Dudley et al., 1974).

Structure and composition of grain sorghum

The mature sorghum (*Sorghum bicolor*) caryopsis or kernel is spheroidal and has typical dimensions of 4.0 mm × 2.5 mm × 3.5 mm. The weight of a sorghum kernel varies from 8 to 50 mg with an average of 28 mg. The hulls of common sorghums are tan, red, or brown, but a white-hulled sorghum also exists called kafir that generally has a smaller average kernel size than most other sorghums. Grain sorghums are known by varietal groupings such as milo, kafir, hegari, shallu, kaoliang, and feterita. The chemical composition of sorghum grain is shown in Table 1.5.

Table 1.5. Chemical composition of sorghum grain.[a][b]

Protein %	Fat %	NDF %	ADF %	Calcium %	Phosphorus %
9.2	2.9	18.0	8.3	0.03	0.29

[a] Adapted from NRC (1998)
[b] Data reported on 89% DM basis

As with most cereal grains, the sorghum caryopsis has three major structural parts. These include the germ, which is positioned toward one side and one end, the endosperm or large central mass, and the pericarp or outer covering (Figure 1.3).

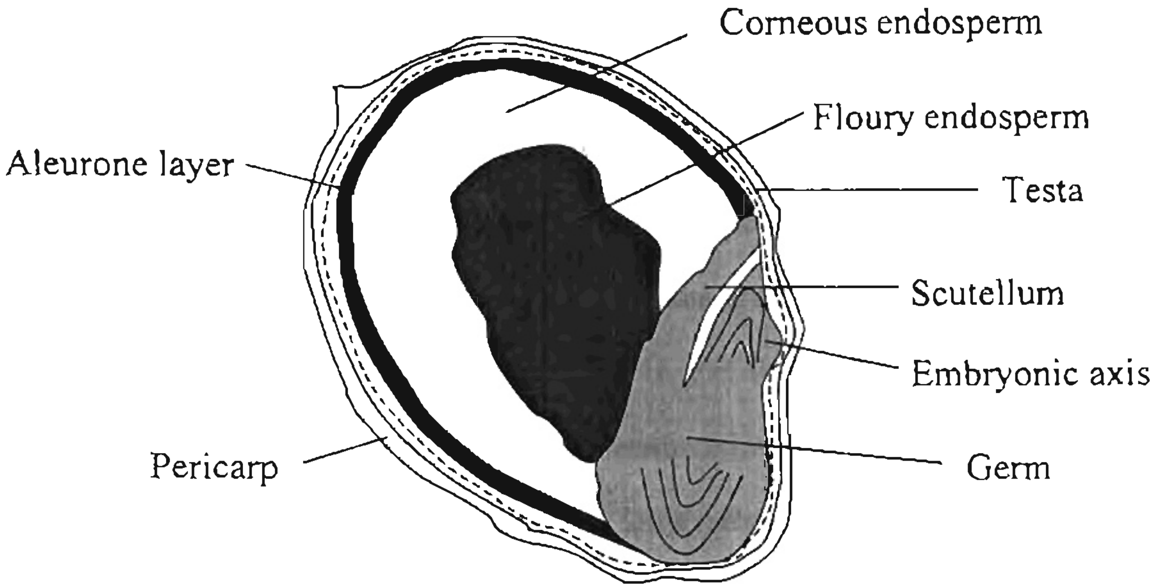


Figure 1.3. Structural components of a sorghum kernel (cross-section).

The mature germ or embryo lies at the basal portion of the kernel and consists of a primary root, a short axis, the terminal plumule, and the scutellum (Artschwager and McGuire, 1949). The scutellum makes up the majority of the germ and almost completely encompasses the embryo axis (Paulson, 1969).

The mature endosperm consists of cells filled with starch. Starch granules from sorghum are very similar to those from corn, but the diameter may reach 35 microns as opposed to a maximum of about 30 microns for corn starch (Matz, 1991). Sorghum starch also appears to have a higher number of large granules as compared with corn (Matz, 1991). The amylose content of nonwaxy sorghum starch ranges from 21 to 28% with an average of about 25%, while the waxy varieties have 1 to 2% amylose content (Matz, 1991).

Endosperm cells that store starch are further divided into an outer corneous (horny) region and an inner floury (starchy) region. Bidwell et al. (1922) observed that for a sample of milo sorghum, the horny endosperm made up about 55% of the kernel while the starchy endosperm was about 29% of the weight of the kernel. The starchy endosperm was higher in ether extract, carbohydrates, starch, crude fiber and ash as compared with horny endosperm, but possessed nearly half the protein content found in horny endosperm (Bidwell et al., 1922). Thus, sorghum grain has both hard and soft endosperm, similar to the endosperm of corn. Hoseney et al. (1974) evaluated the characteristics of these types of endosperm by electron microscopy. They observed that the soft endosperm is characterized by relatively large intergranular air spaces, is essentially round, and is covered with a thin layer of protein. Additionally, the hard endosperm is characterized by a tightly packed structure with no air spaces, the starch granules are polygonal, and they are covered with a thin protein matrix. The opaque appearance of the soft endosperm is caused by air spaces diffracting light, and the hard endosperm is translucent because it has no air spaces. Air spaces in the soft endosperm result in a less dense material; thus, kernels with predominantly soft endosperm are less dense than hard kernels (Hoseney et al., 1974).

The proportions of the type of endosperm, corneous or floury, varies among varieties and even among kernels of the same variety (Freeman, 1970). Sorghum generally has the lowest starch digestibility among all cereal grains due to the hard peripheral endosperm layer being resistant to digestion (Rooney and Pflugfelder, 1986). The presence of a waxy gene in sorghum appears to have an alteration in the distribution of protein in the endosperm where the peripheral endosperm area is not as dense nor as thick in the waxy and heterowaxy genotypes compared to the nonwaxy genotype (Sullins et al., 1974). Thus, the starches of the waxy and heterowaxy genotypes are more susceptible to digestion (Rooney and Pflugfelder, 1986). Waxy sorghum varieties contain essentially all amylopectin as the form of starch (Wall and Blessin, 1970).

The seed coat of sorghum consists of the fused pericarp and testa. The testa is the inner layer of the inner integument and is conspicuous because of its yellow or brown color (Artschwager and McGuire, 1949).

Because birds are everpresent pests wherever sorghum is grown, sorghum varieties have been bred for resistance to birds due to the formation polyphenols, or tannins, in the seed causing these sorghums to be bitter tasting. Tannins are naturally-occurring substances formed in the seed as a result of its physiological reactions. A large portion of the polyphenols of high tannin sorghums is found in the testa layer (Blakely et al., 1979). Tannin content of sorghum is influenced by pericarp color, presence of testa, extent of testa, plant color, and the environment during development (Maxson et al., 1972). The presence or absence of a pigmented testa in a mature kernel is controlled by two genes, B_1 and B_2 (Blakely et al., 1979). Sorghums can be classified by their level of tannin concentration. High tannin sorghums are the bird-resistant sorghums and low tannin sorghums are the nonbird-resistant sorghums. In some varieties, the testa layer is missing (Hoseney et al., 1974).

Although high-tannin sorghum varieties have a benefical effect of reducing yield losses caused by bird damage, when fed to animals, these compounds may have antinutritional effects. Some of these adverse effects may include reduced decreased feed intake, reduced weight gain, and even decreased nutrient digestibility.

Kersting et al. (1961) observed changes in chemical composition of sorghum kernels during development. Nitrogen content decreased until ten days after pollination and then remained quite constant at 2 to 3% of dry matter. Total sugars decreased rapidly and starch increased rapidly after pollination to the point that total sugars were about 1 to 2% during the majority of the growing season and starch content ranged from 64 to 79% of total kernel weight through the remainder of the development (Kersting et al., 1961).

When measured as a portion of the entire dry kernel, the endosperm fraction comprises 80.0 to 84.6%, the germ makes up 7.8 to 12.1%, and the pericarp constitutes 7.3 to 9.3% (Hubbard et al., 1950). These are remarkably similar to those proportions of corn determined by Earle et al. (1946). Hubbard et al. (1950) also determined the concentrations of ash, protein, oil, and starch for the whole sorghum kernel as well as its fractional parts (Table 1.6).

Table 1.6. Composition of whole grain sorghum and sorghum fractions (DM basis).

	Starch %	Protein %	Oil %	Ash %
Whole Grain	73.8	12.3	3.6	1.65
Endosperm	82.5	12.3	0.6	0.37
Germ	13.4	18.9	28.1	10.36
Pericarp	34.6	6.7	4.9	2.02

Adapted from Hubbard et al. (1950).

Using the numbers in Table 4, Hubbard et al. (1950) calculated the proportion of the total nutrients existing in each specific kernel fraction (Table 1.7).

Table 1.7. Proportion of the total of the indicated nutrient existing in the specific fraction.

	Starch %	Protein %	Oil %	Ash %
Endosperm	94.4	80.9	13.2	20.6
Germ	1.8	14.9	76.2	68.6
Pericarp	3.8	4.0	3.8	10.8

Adapted from Hubbard et al. (1950).

The composition of sorghum grain, in many aspects, is similar to that of corn. In general, most varieties of sorghum contain no vitamin A activity and the bioavailability of many other vitamins appears to be low (Matz, 1991). A general perception is that a wide variation in vitamin content exists among different cultivars (Matz, 1991).

Heller and Seiglinger (1944) evaluated 28 sorghum varieties grown in three different years for their nutrient content. The average dry matter concentrations of protein, fat, ash, calcium, and phosphorus were: 11.4, 3.01, 1.68, 0.02, and 0.33 %, respectively.

One general reputation of grain sorghum from a nutritional standpoint is the presence of a large variation in chemical composition among different varieties. Variations in nutrient content cause difficulties in nutritional evaluation of sorghum and complicate the calculation of suitable formulations of rations. Smith and Stephenson (1960) found significant variations in fat, ash, methionine, and lysine content of eleven sorghum samples. Miller et al. (1964) analyzed sorghum samples grown in three separate years in the same locations. They reported a wide variation in protein content with a range of 5.9% to 12.8% on a DM basis. Location and variety or hybrid were found to result in significant differences in the protein content of the sorghums. Cohen and

Tanksley, Jr. (1973) evaluated four sorghums of varying endosperm and starch types and observed that their protein content ranged from 10.5% to 15.0%.

Waggle et al. (1966) evaluated the nutritive value of high protein versus low protein sorghums. All of the essential amino acids except leucine and phenylalanine make up a smaller percentage of the protein in high protein sorghums as compared with low protein sorghums. This, coupled with the fact that rats fed the low protein sorghums had higher growth rates, indicates that the nutritive value of the protein of low protein sorghum grain was superior to that of a high protein sorghum grain. However, Waggle et al. (1967) evaluated three sorghum varieties, a low protein, an intermediate protein, and a high protein sorghum. They determined that the distribution of the amino acids was not affected by protein level and their amino acid compositions were similar. Additionally, when the three sorghum varieties were fed in diets containing equal grain and equal soybean meal, the diet containing the high-protein sorghum resulted in the highest growth rate of broilers while the low-protein sorghum produced the least growth.

Factors affecting energy concentration or availability of feedstuffs

Available energy values of feeds should be considered species specific for swine as compared with poultry due to physiological and energy utilization differences. For example, the available energy in the high energy feeds, such as starch, dextrose, corn, oats, wheat, and milo is about the same for the chick and the pig. However, other feedstuffs such as wheat bran, alfalfa meal, dried whey, and soybean meal have less energy value for the chick when compared to the pig (Diggs et al., 1965). Variations in analytical procedures also affect the results that are obtained.

Gross energy of feedstuffs is dependent on the proportions of carbohydrate (3.7 kcal/kg glucose, 4.2 kcal/kg starch), fat (9.4 kcal/kg), protein (5.6 kcal/kg), minerals (0 kcal/kg), and water (0 kcal/kg). So, if the composition of a feedstuff is known, the gross energy can be calculated fairly accurately (Ewan, 2001). The major sources of energy in cereal grains are starch, lipid, and protein while nonenergy-yielding components such as water, ash, indigestible fiber, and chemically bound protein or carbohydrates reduce the available energy concentration of a feedstuff by dilution. Ether extract is correlated positively with metabolizable energy while crude fiber and ash are correlated negatively with ME. As oil content of grain increases, the net energy content increases because, not only does oil have a gross energy concentration nearly twice that of starch, but the heat increment of fat is lower than that for starch.

Noblet et al. (1993) reported that the digestibility of energy of diets was negatively affected by their neutral detergent fiber (NDF) content in which energy digestibility would decrease 1.1% for every 1% increase in NDF. Noblet and Perez (1993) determined the digestibility of energy in diets was highly dependent on the dietary fiber and mineral contents. Digestible (Noblet and Le Goff, 2000) and metabolizable energy (De Goey and Ewan, 1975b) concentrations were reduced by increasing levels of fiber in the diet. Grains that are high in fiber content would have low DE and ME values for growing pigs as these grains are more bulky and the growing pig has a limited feed intake capacity. On the other hand, older pigs, with their larger capacity for feed intake would perform well on high fiber grains (Sauber and Owens, 2001).

As more varieties or hybrids are developed to match environmental conditions or to resist predator dangers, the nutrient composition of these grains are becoming more variable which has a major impact on their nutritional value. Not only does variability exist among grains and varieties within grains, but the techniques and accuracy of analysis may vary. For the majority of nutrients analyzed for in corn and soybean meal, the variability among labs was as great or greater than the variability in nutrient composition among the sources of corn and soybean meal (Cromwell et al., 1999). Considerable variation among laboratories was reported for analysis of dry matter, crude protein, calcium, phosphorus, selenium, neutral detergent fiber, and amino acids for wheat middlings (Cromwell et al., 2000).

Particle size is another factor that may affect the energy values of some cereal grains. Particle size reduction is thought to improve digestibility and gain/feed as the resulting greater surface area allows the digestive enzymes to be in more contact with the feedstuffs. Owsley et al. (1981) showed improved energy digestibility as particle size decreased for sorghum fed to pigs. Healy et al. (1994) also showed low apparent digestibilities of hard endosperm sorghum when the particle sizes were 700 micrometers and 500 micrometers. Furthermore, Ohh et al. (1983) reported that energy digestibility increased as particle size decreased for corn and sorghum fed to pigs. Wondra et al. (1995) determined that pigs fed corn ground to 400 micrometers were more efficient and had greater digestibilities of gross energy than pigs fed corn ground to 800 micrometers. Healy et al. (1994) observed that pigs fed corn responded to particle size reduction more than pigs fed sorghum. Gross energy digestibilities were greater for corn than for the sorghums and GE digestibility improved linearly for corn and sorghum as mean particle size was reduced (Healy et al., 1994). Decreasing the variation in particle size also quadratically increased apparent digestibilities of GE and linearly increased GE intake (Wondra et al.,1995).

Environment during production of cereal grains such as soil fertility, growing conditions, yield, and maturity can drastically affect their composition. Heller and Sieglinger (1944) observed, for sorghum grains, that in years of drought and high temperature, not only did yield decrease, but the protein level in the grain increased at the expense of starch and fat. Hamilton et al. (1951) reported that corn grown continuously year after year on a soil type that is naturally productive, but with no replenishing of nutrients to the soil resulted in the production of kernels that were 26% smaller than kernels of well-nourished corn. The germ of the kernel was small and thus accounted for 17% less of the kernel than normal. As a result, the nutrients largely concentrated in the germ, oil and phosphorus, were present in lower than normal concentrations. The entire kernel was 30% lower in protein content than corn in optimum conditions. The changes in total protein content are primarily due to changes in endosperm protein content, mainly zein (Hamilton et al., 1951).

Genetic differences in varieties or hybrid cereal grains can affect nutrient composition. The lipid content of corn is influenced mainly by genetics, but fertility has a limited effect unless nutrients are severely restricted (Dudley et al., 1974). Genetic × environment interactions, genetics × environment × processing interactions, and even more complex interactions such as genetic × environment × processing × pig differences may exist (Sauber and Owens, 2001).

Certain strains of sorghums carry bitter-flavored tannins in the testa layer under the seed coat. These can form complexes with free amino groups and decrease the protein digestibility of the grain. Lizardo et al. (1995) evaluated six sorghum varying in tannin content and observed that gross energy digestibility was reduced by high tannin sorghum diets fed to weanling pigs possibly due to a decrease in digestive enzyme activity. For endosperm texture, Cohen and Tanksley, Jr. (1973) reported a greater energy digestibility for pigs fed intermediate texture endosperm sorghums as compared with pigs fed the two extreme endosperms, corneous and floury.

Another factor that may affect the energy availability of grains is the presence of enzyme inhibitors. Some varieties of corn contain typsin inhibitors or amylase inhibitors which will decrease the starch digestibility of the grain and reduce the DE and ME concentration to pigs (Sauber and Owens, 2001).

Corn and sorghum grains, having more corneous endosperm than other cereal grains, have as much as 50% of their endosperm protein composed of gliadin (zein in corn, kafrin in sorghum). These insoluble proteins adhere starch granules together reducing the enzymatic access to these granules. Fine grinding can improve the accessibility of starch to the digestive enzymes (Sauber and Owens, 2001).

Heat processing of grains may decrease their energy digestibility by altering the starch form. In flaking or extruding processes, amylopectin that is melted and not rapidly cooled will crystallize or harden to form resistant starch that is not digestible by amylase.

Through genetics or selection, the energy content of cereal grains may be modified by increasing the oil or starch content or increasing the availability of these components. Because varieties with modified traits require identity preservation, swine producers desiring such varieties may need to personally produce them or contract with grain producers or traders to obtain the desired grain with a specific trait of interest

(Sauber and Owens, 2001). The modifications of these grains by selection for these mutations occurring in the plant genome itself results in what is termed non-genetically modified varieties (non-GM). These may be important in the future if the increasing public concern about genetically modified (GM) crops hinders the use of the GM technologies.

Corn versus sorghum

Corn and sorghum are a couple of the high energy sources that can be utilized in swine diets. While corn has been more widely used in swine feeding and research studies about corn are more numerous, sorghum is certainly an energy source that is predominant in certain agricultural areas and in some areas is beginning to be used more in swine production. In the United States, the principal use of grain sorghum is for animal feed, which accounts for about 90% of the amount which is harvested in the nation (Matz, 1991). Grain sorghum is more drought resistant than corn and has a longer planting season, which allows it to be double-cropped. With the possible increased use in areas where sorghum is more accessible and more economically productive than corn, evaluation of the energy values of sorghum is important and comparisons to the energy values of corn is imperative when finding its true economic value for use in swine rations.

Patil et al. (1998) quantified the starch in feed ingredients into fractions termed rapidly digestible (RDS), slowly digestible (SDS), and resistant (RS). It was determined that the RDS, SDS, and RS fractions of corn were 37.1, 15.6, and 25.2 % of total dry matter, while the same fractions for sorghum were 29.2, 13.9, and 36.2 %, respectively.

This indicates that sorghum contains more resistant starch and less rapidly digestible starch as compared with corn.

Some comparable performance studies have shown sorghum to equal or excel the levels of corn when fed to pigs. Loeffel (1957) reported that pigs fed milo had slightly better gains than those receiving shelled maize. Another study by Peo and Hudman (1958) reported that the greatest daily live weight gains could be achieved with rations containing one-third maize and two-thirds milo. Robinson et al. (1965) showed that 120-200 lb pigs had lower average daily gain when fed milo as compared with those fed maize. Feeding milo also resulted in significantly lower loin eye muscle areas and lower percentage of lean compared to feeding maize (Robinson et al., 1965). Hale (1986) determined there were no significant differences in weight gain, average daily gain, feed consumed, or feed:gain ratio between pigs fed corn diets and those fed grain sorghum diets. In broilers, no significant differences between corn or sorghum for growth and feed conversion were observed (Smith and Stephenson, 1960; Ozment et al., 1963; Stephenson et al., 1967). In an experiment conducted by Kemmerer and Heywang (1965), three sorghum varieties were determined to be inferior to corn for their nutritive value in chick diets, while two other sorghum varieties were reported to be equal to corn. Thayer et al. (1957) conducted five growing chick experiments and concluded that the majority of the 15 grain sorghum varieties tested were equal to corn for growth performance and feed efficiency in the birds.

Many studies have evaluated the nutrient composition comparison of corn and sorghum. Table 1.8 presents the nutrient composition of corn and sorghum as reported by NRC (1998). These values indicate similar chemical composition of corn and

Table 1.8. Composition of corn and sorghum grains[a][b].

Nutrient	Corn	Sorghum
Crude protein	8.3	9.2
Crude fat	3.9	2.9
Neutral detergent fiber	9.6	18.0
Acid detergent fiber	2.8	8.3
Calcium	0.03	0.03
Phosphorus	0.28	0.29
Lysine	0.26	0.22
Methionine	0.17	0.17
Threonine	0.29	0.31
Tryptophan	0.06	0.10
Arginine	0.37	0.38
Histidine	0.23	0.23
Isoleucine	0.28	0.37
Leucine	0.99	1.21
Phenylalanine	0.39	0.49
Valine	0.39	0.46

[a] From NRC (1998)
[b] Reported on a 89% DM basis.

sorghum. The only distinct difference in these values is the higher fiber content of sorghum as compared with corn.

Douglas et al. (1990) determined that the proteins of sorghum contained higher concentrations of alanine, asparagine, glutamine, leucine, isoleucine, phenylalanine, tyrosine, and valine as compared with corn. However the sorghum proteins, as compared with corn, had lower concentrations of arginine, glycine, and histidine. The ether extract of corn was 1 to 2% higher than the sorghums. The sorghums contained higher levels of acid detergent fiber (ADF). However, ash, calcium, phosphorus, and neutral detergent fiber (NDF) were relatively similar among the sorghums and corn (Douglas et al., 1990). Hale (1986) studied grain sorghum hybrids and found that their gross energy contents were similar to corn and also stated that some of the new grain sorghum hybrids may be equivalent to corn as a feed grain for swine.

In 1959, the National Research Council publication contained no DE or ME values for feeds used in swine production and very few published energy values existed that were more precise than the total digestible nutrients values (Diggs et al., 1965). Most of the studies with pigs and energy had dealt with more fibrous feeds such as alfalfa meal prior to this time; however, Garrigus and Mitchell (1935) had reported that ground yellow corn contained 3,791 kcal/g of metabolizable energy (Diggs et al., 1965). Diggs's studies at this time were performed to determine descriptive information on the available energy value of some more common feeds for swine.

When evaluating gross energy levels of corn and sorghum, Lin et al. (1987) found that their GE values were equal. On the other hand, Morgan et al. (1975), Just et al. (1983), and Robinson et al. (1965) found higher energy values for corn than sorghum. The uncorrected metabolizable energy concentrations (DM basis) determined by Morgan et al. (1975) were 3,940 kcal/kg for corn and 3,890 kcal/kg for sorghum. Diggs et al. (1965) found slightly higher energy values for sorghum than corn with DE being 3,760 and 3,670 kcal/kg (DM basis) for sorghum and corn, respectively; the ME content was 3,670 and 3,640 kcal/kg. Douglas et al. (1990) reported that of eight sorghum samples tested for ME content in chicks, five had similar ME concentrations as compared with corn. Sorghum grain is approximately equal to corn as a calorie source for most classes of livestock, although the differences in contents of protein, oil, and vitamin A must be considered (Matz, 1991).

Evaluation of the energy concentration of corn

Harmon et al. (1969) evaluated 16 corn samples grown each year for two consecutive years and determined that their gross energy content ranged from 4,425 to 4,645 kcal/kg on a dry matter basis. Many studies have been conducted to determine the energy concentration of corn in the form of digestible energy, metabolizable energy, some form of adjusted ME, and even net energy. In order to accomplish these goals, varying procedures have been implemented. These include either the total collection method or the chromic oxide index method for the analysis of DE or ME.

In this section, experiments will be discussed in which the total collection method was utilized. Summaries of the procedures utilized in these experiments (Table 1.9) and their energy determinations (Table 1.10) are also presented. Wiseman et al. (1982) evaluated four samples of corn for their energy concentration and reported that the average DE and uncorrected ME values (DM basis) were 3,876 and 3,792 kcal/kg, respectively. Keys and DeBarthe (1974) determined the digestibility of the starch, amylose and amylopectin, in corn grain was 98% in the pig. Cornejo et al. (1973) reported that the DE, ME, and ME_n concentrations of corn were 3,796, 3,745, and 3,560 kcal/kg (DM basis). These data indicated that ME was 98.7% of DE, while ME_n was 95.1% of ME. Miller and Ku (1979) determined the ME concentration of corn was 3,820 kcal/kg and the corrected ME_n value was 3,700 kcal/kg (DM basis). De Goey and Ewan (1975b) determined the ME, ME_n, and NE concentrations of corn to be 3,730, 3,549, and 2,617 kcal/kg.

Young et al. (1977) conducted a series of metabolism experiments in which several diets that contained various ratios of two or more feed ingredients were fed to growing pigs. After energy concentrations of the diets were determined, the data were subjected to multiple regression analysis with the percents of ingredients as the independent variables and DE or ME of the diets as the dependent variable. From these data, the DE for corn was approximately 3,955 kcal/kg while the ME was 3,857 kcal/kg (DM basis). Noblet et al. (1993) conducted a large experiment consisting of 17 diets containing 13 feedstuffs and performed a total collection procedure when feeding these diets to 45 kg boars. The DE, ME, and NE of these ingredients were calculated by regression of nutritive values of diets on levels of inclusions of ingredients. For corn, the DE, ME, and NE concentrations were 3,776, 3,650, and 2,966 kcal/kg (DM basis). This study serves as a large portion of the data summarized for energy content of feedstuffs by NRC (1998).

The differences in energy values of high-lysine corn compared to normal corn as well as differences between dry, high-moisture, and reconstituted corn have been evaluated. Asche et al. (1986), however, reported there were no differences in digestible energy and metabolizable energy values between normal corn and high-lysine corn. Asche et al. (1986) also reported that digestible and metabolizable energy values were higher for dry stored corn than for high-moisture corn and reconstituted corn. They also concluded that high-moisture storage improved energy balance of normal corn and reconstitution improved energy balance of high-lysine corn.

Other varieties of corn with higher than normal oil content have been recently developed. In order to fully evaluate the significance of oil concentration, the utilization of energy in high-oil corn varieties must be known. Kim et al. (1999) determined that high-oil corn had higher gross energy, crude protein, crude fat, lysine, and methionine than normal corn. They also reported DE and ME values for normal corn being 3,891 and 3,806 kcal/kg (DM basis), while those concentrations for high-oil corn were 4,069 and 3,970 kcal/kg. Of twenty-one samples evaluated, the variation in ME concentration was about 5% between the corns (Kim et al., 1999). As stated by Adeola and Bajjalieh (1997), the use of high-oil corn versus typical fat addition could potentially lessen the difficulty of lack of uniform mix with other ingredients, limited storage time, and slowed feed flow from feed storage bins and feeders.

Young pigs are known to not consume enough energy to achieve their growth potential due to a limited digestive capacity. If energy density of a feedstuff could be increased while maintaining the same level of intake, it would certainly benefit the performance of young pigs. This is another way in which high-oil corns could be beneficial. Adeola and Bajjalieh (1997) compared the energy values of three varieties of high-oil corn (TC1, TC2, and X122) and a control normal corn. The control corn was lower in DE and ME than the high-oil varieties and one of the high-oil varieties (TC1) was higher in DE than the other two high-oil varieties. The DE values for the control, TC1, TC2, and X122 corns were 3,796, 4,103, 3,886, and 3,935 kcal/kg (DM basis) while the ME concentrations were 3,739, 4,035, 3,830, and 3,878, respectively. Gastric emptying rate can be delayed and rate of passage of digesta can be reduced with an increase in dietary fat. The slower movement results in an increased retention time, which might provide nutrients more time for digestion (Adeola and Bajjalieh, 1997).

Other corn varieties with specific characteristics are being analyzed for their available energy content for pigs. The apparent gross energy digestibility for high-lysine, high-oil corn was similar to that of high-oil corn (O'Quinn et al., 1999). Growing pigs fed high-lysine corn had a higher starch digestibility than pigs fed a normal corn (Andersen et al., 2000). Spencer et al. (2000) conducted an experiment comparing genetically modified low-phytate corn and normal corn in 20-kg barrows and reported no differences in energy digestibility with all treatments averaging approximately 90%.

Yet another type of corn termed Quality Protein Maize (QPM) has been studied over the last several years. QPM retains the protein quality of conventional opaque-2 corn but also has improved growing traits, such as higher yields and less susceptibility to fungal and insect damage. Food corn is another cereal that has been evaluated for its nutritional value in pigs. It was developed to have large kernels to increase yields and is primarily used to produce products for human consumption. Both of these corn products were evaluated in a study by Sullivan et al. (1989) and were compared to normal feed corn. Feeding QPM to starter and grower pigs resulted in greater performance than food and feed corns. Food corn and QPM had higher gross energy, digestible energy, and metabolizable energy content than feed corn.

Several experiments utilized the chromic oxide index procedure to evaluate either ileal and/or fecal digestibilities of gross energy in corn (Tables 1.9, 1.10). O'Quinn et al. (2000) compared the GE ileal digestibilities of high-oil corn and high-oil, high-lysine corn in diets formulated to be isolysinic, isocaloric, and isofibrous. They determined that apparent ileal GE digestibility of high-oil corn and high-lysine, high-oil corn were similar. In another experiment evaluating other varieties of corn, energy digestibilities seemed to be similar for food corn, quality protein maize (QPM), and feed corn (Sullivan et al., 1989). Fecal gross energy digestibilities were higher for QPM than for opaque-2 corn (Burgoon et al., 1992). However, the apparent fecal digestibility of gross energy was similar for QPM and normal corn at 89% (Burgoon et al., 1992). Rosa et al. (1977) reported that opaque-2 corn had a 5.6% lower digestible energy content than normal corn for pigs. Corns with double mutants (*sugary-1*, *opaque-2*) and (*waxy*, *opaque-2*) had similar energy digestibility as normal corn (Rosa et al., 1977).

Ewan (personal communication) summarized several experiments that reported energy contents of corn and determined average GE, DE, and ME values to be 4,489, 3,961, and 3,840 kcal/kg (DM basis). These data were used in formulation of estimates of energy values of corn by NRC (1998).

Evaluation of the energy concentration of sorghum

The initial portion of this section will include the evaluation of those experiments in which the total collection method was utilized to determine the digestible energy or metabolizable energy content of sorghum grains. The summarized procedures (Table 1.9) of these experiments along with their determined energy values (Table 1.11) are presented herein.

Batterham et al. (1980) evaluated sorghum to assess any variation in DE content between different cultivars and to attempt to relate any variation found to their physical and chemical composition. Eight cultivars of sorghum were selected from different regions of Australia and included both dry land and irrigated production. There appeared to be no relationship between the physical and chemical composition of the sorghums and area of production and there were also few significant correlations between DE content and the physical and chemical composition of the sorghums (Batterham, 1980). Digestible energy content, on the other hand, was influenced by GE, density, and fiber as indicated by regression analysis. The DE of the sorghums ranged from 3,368 to 3,559 kcal/kg (as-fed basis) with an average of 3,439. The small variation in DE between the various cultivars of sorghum demonstrates that average energy values of cereal grains vary little between countries or systems of expression (Batterham, 1980; Morgan et al., 1975). Sauber and Owens (2001) reviewed several experiments and calculated a weighted variation of 8% for DE of sorghum for pigs.

Cohen and Tanksley, Jr. (1973) evaluated four sorghum grains, with three endosperm textures and two starch types, for their energy content. The intermediate texture endosperm appeared to have a 5.35% advantage in digestible energy over the floury texture. However, starch type, either normal or waxy, did not affect DE or ME values of the sorghums (Cohen and Tanksley, Jr., 1973). Nelson et al. (1975) conducted a broiler experiment to evaluate the ME concentration of 12 sorghum varieties differing in tannin content, endosperm color, and starch texture. The range in ME concentration of the sorghums was from 3,180 to 3,920 kcal/kg (DM basis). Neither endosperm color nor starch texture appeared to influence the ME content. However, tannin content of the sorghums was negatively correlated to ME content by a coefficient of -0.64. Additionally, the GE content of the sorghums was not correlated to the analyzed ME content (Nelson et al., 1975).

Keys and DeBarthe (1974) reported that the percentage of gross energy of diets containing 70% sorghum digested by pigs was 72.6%, which was less than the GE digestibilities of diets containing corn, wheat, and barley. They also determined that grain sorghum starch, amylose and amylopectin, were 94% digestible in the pig gastrointestinal tract.

Phillips and Ewan (1977) concluded that average daily gain increased linearly with the addition of sorghum to a basal diet and there was an improvement in feed:gain ration, although not significant. However, although not significant, metabolizable energy increased with the addition of sorghum. As sorghum was added to the basal diet, daily energy gain increased linearly and empty body energy increased.

When comparing the NE values of corn and sorghum, Phillips and Ewan (1977) determined the NE of sorghum to be 2290 kcal/kg and De Goey and Ewan (1975b) reported that corn contains 2330 kcal/kg. Morrison (1956) stated that the NE of sorghum is about 88% of the NE of corn.

The different levels of tannin in sorghum are thought to cause differences in energy digestibility and energy values of sorghum. Cousins et al. (1981) conducted a study comparing sorghums of low tannin concentrations with sorghums of high tannin concentration. Corn was also compared to the two types of sorghum. All of the grains were grown in the same field so as to eliminate any differences in nutrient availability in the soil. Growing-finishing pigs were used in two experiments; one consisting of 25 kg pigs and in the other, pigs were fed from 20 to 94 kg. Gross energy digestibilities as well as digestible energy and metabolizable energy contents of the low tannin sorghums were significantly higher than the high tannin sorghums. In a basic growth study, gains were not affected by diet, but feed consumption was 9% higher and feed efficiency was 10% poorer for pigs fed high tannin sorghum versus those fed low tannin sorghum. Performance was similar for animals fed the low tannin sorghums and those fed corn.

Stephenson et al. (1967) evaluated the performance of broilers fed different sorghum varieties and reported that there were no differences in average daily gain and feed efficiency between brown sorghum strains and yellow sorghum strains. The chromic oxide index method has also been used to estimate the ileal or fecal digestibilities of the gross energy contained in sorghum grains. Lin et al. (1987) found that corn and sorghum had similar gross energy digestibilities when measured at both the end of the small intestine and over the total digestive tract. The amount of dietary gross energy digested in the large intestine was similar for corn and sorghum at about 7% (Lin et al., 1987). Corn and low tannin sorghums had similar digestibilities in 50 kg pigs (Cousins et al., 1981). Cao et al. (1999) determined the digestibility of gross energy for pigs was less for waxy sorghums than soft, medium, and hard endosperm sorghums. The hard sorghums were also more digestible than the medium hardness sorghums (Cao et al., 1999).

Dean et al. (2000) compared the nutrient digestibilities of bronze-pericarp and white-pericarp sorghums and concluded that their nutrient digestibilities were similar. For ileal cannulated pigs, Cousins et al. (1981) also found that digestibility of gross energy for the low tannin sorghums was significantly higher than for the high tannin sorghums, whether measured at the end of the small intestine or over the total digestive tract. The estimated ME concentrations for these varieties ranged from 3,788 to 3,834 kcal/kg (DM basis). The range of the ME content of sorghum grain samples fed to chicks was 3,185 to 3,692 kcal/kg (DM basis) with a mean of 3,516 kcal/kg (Douglas et al., 1990).

Ewan (personal communication) submitted recommended energy values, based on previous experiments, to NRC (1998) which were utilized in their summary of the energy

values of sorghum. These values for GE, DE, and ME were: 4,456 3,842,
kcal/kg (DM basis).

Prediction of ME concentration of feedstuffs

Noblet and Perez (1993) determined the DE and ME content of 11
diets fed to growing pigs along with their proximate analysis in order to f
prediction equations for feedstuffs fed to pigs. The best equations develo
following predictors combined into a linear model: ash, ether extract, cru
NDF. From these equations, the DE and ME values of diets could be acc
predicted (R^2=0.92) from their chemical composition. In a followup stud
(1994), evaluated 616 diets for their proximate analysis, DE, ME, and NE
order to develop equations to predict the energy contents of feedstuffs. T
combination of chemical characteristics for prediction of DE, ME, and N
of feedstuffs for pigs were: digestible crude protein, digestible ether extr
content, sugar content, digestible hemicellulose, digestible ADF, and the
between organic matter and the other nutrients considered. For the NE e
including these variables, the R^2 value was 0.96. These data by Noblet et
by NRC (1998) in setting energy values of feedstuffs. Ozment et al. (196
energy predictions equations based upon the composition of nitrogen-fre
nitrogen, and fat to determine the ME values of four sorghum varieties.

Table 1.9. Summary of methods of swine experiments determining energy values of corn and sorghum.

Total collection method experiments:

Investigators	Collection period	Intake level	Wt. of pigs	% test ingred. in diet
Diggs et al. (1965)	6 d	Fed twice daily	15.4 kg	------
Robinson et al. (1965)	5 d	Scale fed; <*ad lib*	54 kg	97.5
Cohen & Tanksley, Jr (1973)	(4 periods) 7 d ea.	*ad lib*; twice daily	22-25 kg	79.1
Cornejo et al. (1973)	4 d	Scale fed; <*ad lib*	43-49 kg	97.5
Keys & DeBarthe (1974)	5 d	15 g/kg BW/day	-----	70.0
De Goey & Ewan (1975)	7 d	3% of BW	5.4 kg	0, 1.0, 2.0
Morgan et al. (1975)	7 d	Scale fed twice/d	45-70 kg	45.0 (corn), 50.0 (sorg)
Phillips & Ewan (1977)	(4 periods) 7 d ea.	*ad libitum*	5.1 kg	0, 1.0, 2.0
Miller & Ku (1979)	3 d	Fed twice daily	8-10 kg	0, 30.0, 60.0
Batterham et al. (1980)	(2 periods) 7 d ea.	Scale fed once/d	20 kg	76.5
Cousins et al. (1981)	(5 periods) 5 d ea.	equal restr., twice/d	25 kg	89.0
Wiseman et al. (1982)	7 d	*ad libitum*	25 kg	50.0
Asche et al. (1986)	5 d	90% lowest *ad lib*	29-35 kg	76.0-80.0
Lin et al. (1987)	5 d	3-3.25% of BW	39-55 kg	97.1
Sullivan et al. (1989)	4 d	3.5% of BW	35 kg	93.8
Noblet & Perez (1993)	10-11 d	500 cal ME/g BW^{60}	43 kg	Variable (30 diets)
Noblet et al. (1993)	10-11 d	573 cal ME/g BW^{60}	35 kg	11.0-30.0 (11 diets)
Noblet et al. (1994)	11 d	540 cal ME/g BW^{60}	35 kg	19.0-28.0 (12 diets)
Adeola & Bajjalieh (1997)	5 d	4.3% of BW	25 kg	97.0, 79.0
Kim et al. (1999)	5 d	6.6% of BW	19 kg	97.2
Noblet & Le Goff (2000)	10 d	2.0 kg/d	65 kg	Variable (9 diets)
Spencer et al. (2000)	5 d	800 g/d	20 kg	78.0

Chromic oxide index

Investigators	% Cr_2O_3	Intake level	Wt. of pigs	% test ingred. in diet
Keys & DeBarthe (1974)	0.15	15 g/kg BW/d	-----	70.0
Cousins et al. (1981)	0.30	equal restr., twice/d	45 kg	91.0
Lin et al. (1987)	0.25	3-3.25% of BW	39-55 kg	97.1
Sullivan et al. (1989)	0.25	3.5% of BW	35 kg	93.8
Burgoon et al. (1992)	0.25	Equal; twice/d	73 kg, 97 kg	97.0
Healy et al. (1994)	0.25	*ad libitum*	18.3 kg	58.9
Anderson et al. (2000)	0.25	Twice daily	40 kg	96.6
O'Quinn et al. (2000)	0.20	4.5% of BW	20 kg	61.6, 87.0

Table 1.10. **Summary of energy values of corn grains for pigs determined by several experiments (DM basis).**

Investigators	# samples	GE	DE	ME	ME_n	NE
Diggs et al. (1965)	2	4,480	3,835	3,765	3,660	-----
Robinson et al. (1965)	1	-----	4,028	-----	3,783	-----
Harmon et al. (1969)	16	4,501	-----	-----	-----	-----
	16	4,584	-----	-----	-----	-----
Cornejo et al. (1973)	1	4,403	3,796	3,745	3,560	-----
De Goey & Ewan (1975)	2	4,448	3,854	3,730	3,549	2,617
Morgan et al. (1975)	1	4,510	4,020	3,940	3,840	-----
Young et al. (1977)	3	-----	3,953	3,843	-----	-----
	3	4,570	3,957	3,870	-----	-----
Miller & Ku (1979)	2	-----	------	3,820	3,695	-----
Cousins et al. (1981)	1	4,510	-----	-----	-----	-----
Wiseman et al. (1982)	4	4,463	3,876	3,792	3,722	-----
Lin et al. (1987)	1	4,510	3,910	3,830	-----	-----
Sullivan et al. (1989)	3	4,540	-----	-----	-----	-----
Burgoon et al. (1992)	5	4,554	4,041	-----	-----	-----
Noblet et al. (1993)*	10	-----	3,776	3,650	-----	2,966
Healy et al. (1994)	1	4,320	3,909	-----	-----	-----
Adeola & Bajjalieh (1997)	8	4,644	3,930	3,870	-----	-----
Kim et al. (1999)	18	4,465	3,891	3,806	-----	-----
	3	4,714	4,069	3,970	-----	-----
Noblet & Le Goff (2000)	1	-----	4,156	-----	-----	-----
Summaries of energy values:						
Ewan (personal comm.)*	Summary	4,489	3,961	3,840	3,786	2,692
NRC (1998)*	Summary	-----	3,961	3,843	-----	2,691

*Ewan's summary and Noblet et al. (1993) were used in development of NRC (1998) data.

Table 1.11. Summary of energy values of sorghum for pigs determined by several experiments (DM basis).

Investigators	# samples	GE	DE	ME	ME_n	NE
Diggs et al. (1965)	1	4,530	3,760	3,670	3,550	-----
Robinson et al. (1965)	1	-----	3,843	-----	3,634	-----
Cohen & Tanksley (1973)	4	4,367	3,719	3,685	3,593	-----
Morgan et al. (1975)	1	4,420	3,970	3,890	3,770	-----
Batterham et al. (1980)	8	4,547	3,942	-----	-----	-----
Cousins et al. (1981)	4	4,510	-----	-----	-----	-----
Lin et al. (1987)	1	4,530	3,940	3,850	-----	-----
Healy et al. (1994)	2	4,280	3,811	-----	-----	-----
Summaries of energy values:						
Ewan (personal comm.)*	Summary	4,456	3,842	3,793	3,661	2,560
NRC (1998)*	Summary	-----	3,798	3,753	-----	2,534

*Ewan's summary was used in development of NRC (1998) data.

It is evident that several similarities as well as differences exist between corn and sorghum for structural composition, growth and development, and nutrient value when fed to animals, specifically pigs. Genetically, selection of varieties of grains for desired nutrient content has been exhibited, and thus, the development of newer, more specialized grain varieties or hybrids will certainly expand the range in nutrient composition within a grain type. Additionally, due to the many factors that may affect the nutrient and energy content of corn and sorghum grains, the variability expressed may not only be a function of genetics, but will include environmental effects as well as interactions. As shown by the data in this chapter, the available energy content of corn and sorghum has been variable. Some of the earlier projects determined sorghum was equal or even greater than corn for metabolizable energy content, however, most of the more recent findings determine that corn is superior to sorghum for ME when fed to pigs. However, due to the aforementioned variability in grain varieties, some crossover in energy values of corn and sorghum may exist depending on the varieties utilized in diets for pigs.

Chapter II

General Procedures

All experiments (Table 2.1) discussed in the following chapters were conducted as energy and nitrogen balance studies by use of the total collection method. All pigs used in these experiments were supplied by the Oklahoma State University Research and Teaching Swine Farm. Experiment 1 was conducted to determine the metabolizable energy concentration of casein for growing pigs. Eight barrows (6 Yorkshire, 2 Hampshire × Yorkshire), with an average initial weight of 30.6 kg, were allowed a 3-d adjustment period followed by a 4-d total collection. This experiment served as useful information in order to conduct the following studies. Experiment 2 determined the energy and nitrogen balance of three corn hybrids by utilizing eight sets of three littermate barrows (18 Yorkshire, 6 Landrace × Yorkshire) initially weighing 25.6 kg. These pigs underwent a 7-d adjustment period to the diets and chambers and then were used in a 5-d collection period. Experiment 3 was performed with the objective to evaluate the energy and nitrogen balance of four corn grains fed to growing pigs. In this experiment, six sets of four littermate barrows (12 Yorkshire, 8 Landrace × Yorkshire, 4 Hampshire × Yorkshire), initally averaging 27.5 kg, were allowed a 7-d adjustment period followed by a 5-d collection of feces and urine. In Experiment 4, twelve sets of three littermate Yorkshire barrows, with an average initial weight of 25.9 kg, were utilized to determine the energy and nitrogen balance of three grain types (mill-run corn, mill-run red sorghum, and an identity-preserved white endosperm sorghum) fed to growing pigs. Pigs were allowed a 5-d adjustment period followed by a 4-d collection period in this study.

Table 2.1. Summary of the design of the four experiments.

Exp.	No. pigs	Initial wt.	No. trts	No. reps	Adjustment(d)	Collection(d)
1	8	30.6 kg	2	4	3	4
2	24	25.6 kg	3	8	7	5
3	24	27.5 kg	4	6	7	5
4	36	25.9 kg	3	12	5	4

Pigs were individually housed in metabolism chambers, which were composed of 12.5-mm thick plexi-glass. The outside dimensions of the chambers were 0.80 × 1.22 m and the total pig space measured 0.75 × 1.05 m. The elevated chamber floor consisted of galvanized mesh flooring. Under the floor, a wire screen served to collect fecal excreta. Beneath this screen was a stainless steel pan which was graduated toward a 8-mm center hole. This allowed urine to flow into a plastic urine collection pan, in which 10 mL of HCl was deposited prior to each day's urine collection in order to prevent the loss of nitrogen by ammonia volitilization. A stainless steel self-feeder and nipple waterer were present in each chamber. Thus, pigs were allowed *ad libitum* access to water, and in each of the experiments, an effort was made to equalize feed intake within each replicate (block).

Length of adjustment periods and collection periods varied with each experiment depending upon the type of diet consumed by the pigs prior to experimentation in relation to the type of experimental diets analyzed. Adjustment periods were utilized for the purpose of the pigs' adaptation to the chambers as well as to the experimental diets. On d

0 of the collection period, feeders were emptied and 0.20% chromic oxide as a fecal marker, was mixed with that day's ration for each pig and the fee of the collection period began. Urine collection began four hours followin feeding. Fecal collection began at the sight of the marker in the feces, whi typically 18-36 hours following consumption depending on pig size and in During the collection period, total feed consumption and feed wastage wer measured. Fecal samples were collected daily, placed in plastic bags, weig stored in a -20°C freezer. Total urine volume was measured daily and a 1(was collected from each pig per day and stored in a -20°C freezer. On the the collection period, feeders were emptied, which signified the ending of t feeding portion of the experiment, and chromic oxide was again added to tl ration for each pig. Urine collection ended four hours following feeding o and fecal collection ceased at the visibility of the marker in the feces.

Sample processing. In Experiments 1, 3, and 4, total fecal samples were t dried in a forced-air oven at 50°C for 96 hours. Then they were allowed to for 24 hours and weighed. In Exp. 2, total fecal samples were freeze-dried Freezemobile 12SL, Gardiner, NY) for approximately 7 days and then wei total dried feces were ground through a 1-mm screen in a Wiley mill (Stan No.3, Arthur H. Thomas Co., Philadelphia, PA) and stored for subsequent

Urine samples were allowed to thaw at room temperature and were into one 100 mL sample per pig based on the daily percentage of the total u for the entire collection period. These composite subsamples were then stored at –20°C until further analyses.

Multiple grain samples were taken and composited prior to the mixing of the diets, and multiple diet samples were taken following mixing. They were then ground to pass through a 1-mm screen by a Wiley mill according to AOAC (1990) procedures and stored until laboratory analyses were performed.

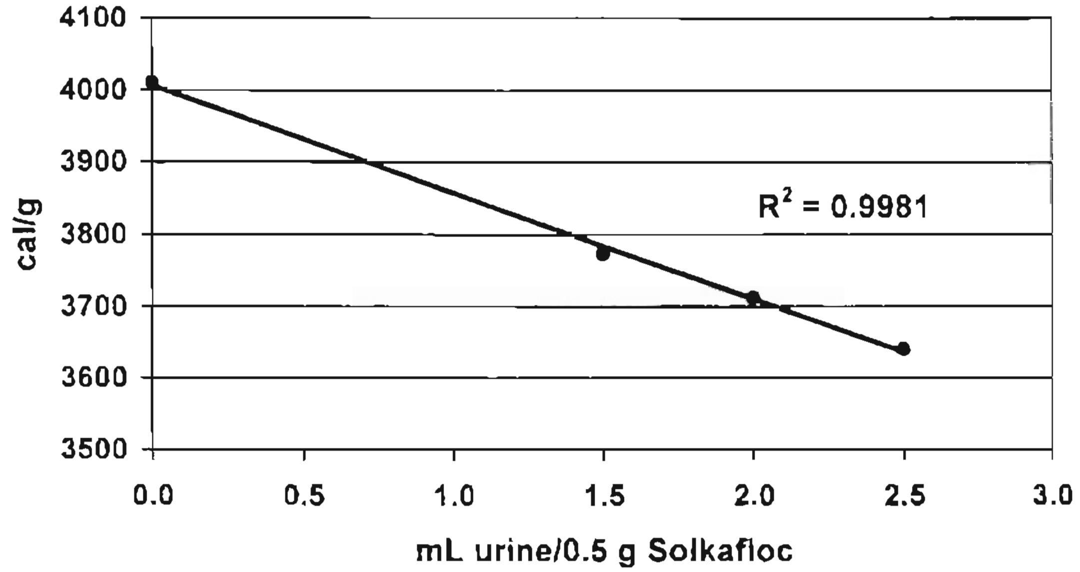
Feed and fecal analysis. Dry matter content was determined for grains, diets, and feces by drying for 24 hours at 100° C according to AOAC (1990) procedures. Gross energy was determined for 1.0 g samples of grains, diets, and feces by bomb calorimetry (Parr 1261 Isoperibol Calorimeter, Moline, IL). Nitrogen content of the diets, grains, and feces (Exp. 1, 3, 4) were determined by analysis of 0.5 g samples by Kjeldahl methodology (Foss Tecator, 2400 Kjeltec Analyzer Unit, 2020 Digestor, Hoganas, Sweden). For Exp. 2, nitrogen content of fecal samples was determined by combustion method (LECO NS2000, St. Joseph, MI). Ash content of the grains was determined by placing samples into a 500° C muffle furnace (Sybron, Dubuque, IA) for four hours according to AOAC (1990). Ether extract composition was determined by a modified procedure of AOAC (1990). Acid detergent fiber contents of grains were determined by ANKOM procedure (ANKOM 200/220 Fiber Analyzer, ANKOM Tech., Fairport, NY). Neutral detergent fiber content of grains was determined by use of a modified procedure of Moore et al. (1987) using an ANKOM 200/220 Fiber Analyzer.

Amino acid, calcium, phosphorus, and starch analyses of selected grains were performed by the University of Missouri Experiment Station Chemical Laboratories

(Columbia, MO). Amino acid analysis was performed using post-column derivitization (Beckman 6300 Amino Acid Analyzer). Calcium, phosphorus, and starch analyses were determined according to AOAC (1990) procedures.

Urine analysis. Nitrogen content of 1.0 mL urine samples was determined by Kjeldahl methodology. For urine gross energy analysis, a procedure was developed and validated through several preliminary tests using varying concentrations of urine added to various amounts of Solkafloc®. Those factors that were evaluated were the absorption of urine in a given amount of cellulose, differing lengths of drying times, and consistency of gross energy values. Figure 2.1 indicates the gross energy concentrations resulting from the addition of 1.5, 2.0, and 2.5 mL of urine to 0.5 grams of Solkafloc®. The value at 0 mL added urine is based upon six replications, while the other three data points are based upon four replicates each. Because the gross energy of the urine was lower than the gross energy of Solkafloc®, the combination of the two substances was a weighted average of each substance's gross energy content. Due to the high R-square for the treatment levels tested, specific additions of urine to Solkafloc® equally lowered the gross energy of the mixture. As well, further calculation to determine the gross energy of the urine in each of the mixtures resulted in very similar energy concentrations. From these results, each of the three levels of urine inclusion equally measured gross energy of the urine. However, because the addition of 2 grams of urine to 0.5 grams of Solkafloc® formed the easiest handling, most consistent pellet, this level of inclusion was determined the most optimum and used throughout the following experiments.

Figure 2.1. Gross energy of Solkafloc/urine mixtures



The specific procedure utilized for the determination of urine gross energy is as follows. First, Solkafloc® samples, a cellulose product, were dried at 100°C for 24 hours to achieve a dry matter state and were weighed prior to and following drying. A 2 mL subsample of each composited urine sample was added to approximately 0.5 g of dry Solkafloc®. This wet mixture was weighed and then dried at 50° C (Exp. 1, 2) or 100° C (Exp. 3, 4) for 24 hours. The samples were then weighed, which allowed for calculation of dry matter content of the urine samples. Each sample was pelleted and later combusted to determine gross energy in a bomb calorimeter. Because the gross energy determined was for the Solkafloc®/urine mixture, calculations were made to determine the actual gross energy of the urine portion. Several pure Solkafloc® samples per sample set were combusted to determine gross energy for a standard in calculations. The following are calculations conducted throughout the analysis for the gross energy content of urine samples.

1. Determine DM of Solkafloc®

   (Dry Solkafloc® ÷ as-is Solkafloc®)

2. Determine dry urine weight

   (Dry urine + Solkafloc®) – dry Solkafloc®

3. Determine % Solkafloc® and % urine in pellet

   (dry Solkafloc® ÷ dry urine/Solkafloc®) * 100 = % Solkafloc® in pellet

   (dry urine ÷ dry urine/ Solkafloc®) * 100 = % dry urine in pellet

4. Determine GE of dry Solkafloc®

   GE as-is ÷ (% DM ÷ 100)

5. Determine GE of Solkafloc® portion of pellet

   GE of Solkafloc® * (% Solkafloc® in pellet ÷ 100)

6. Determine GE concentration of urine

   (GE of pellet – GE of Solkafloc®) ÷ (% urine in pellet ÷ 100)

Chapter III

Experiment 1

Determination of the metabolizable energy concentration of casein for growing pigs

Abstract: Eight Yorkshire barrows, with an average initial weight of 30.6 kg, were utilized in an energy and nitrogen balance experiment to determine the metabolizable energy (ME) content of casein. Pigs were individually housed in metabolism chambers and allotted to two dietary treatments based upon weight and litter in a randomized complete block design. The two corn-based (90%) dietary treatments contained either sand (4.15%) or casein (6.14%). L-lysine HCl was added to each diet in order to make the diets isolysinic and to meet NRC requirements. The two diets also were formulated to contain similar digestible amino acid concentrations of methionine, threonine, tryptophan, isoleucine, valine, cystine, and histidine. Pigs had *ad libitum* access to water and an effort was made to equalize feed intake within replicate. A 3-d adjustment period to the chambers and diets was followed by a 4-d total collection of feces, urine, and feed wastage. Data are reported on a DM basis unless otherwise noted. Gross energy concentrations of the sand (S) and casein (C) diets were 4,168 and 4,454 kcal/kg. Average daily feed intake was similar ($P > 0.10$) for pigs fed the two diets. Thus, GE intake was greater ($P < 0.09$) for pigs fed C as compared to those fed S. However, daily fecal and urine dry matter excretions were similar ($P > 0.10$). Fecal energy concentrations (kcal/kg) were greater ($P < 0.01$) for pigs consuming C than those fed S,

but fecal energy excreted (kcal/d) was similar ($P > 0.10$). The resulting DE concentrations were 3,669 and 3,959 with the S being lower ($P < 0.10$) than the C. Urine energy concentration (kcal/kg) and excretion (kcal/d) were higher ($P < 0.09$) for pigs fed C vs pig fed S. Thus, the ME concentrations of S and C were 3,615 and 3,895 kcal/kg with S slightly lower ($P = 0.11$) as compared with C. However, efficiencies of energy utilization, measured as DE:GE, ME:DE, and ME:GE, were not different ($P > 0.10$) for the two diets. Assuming that the difference in energy content of the diets was entirely due to the inclusion of casein, the percentage of casein in the diet could be utilized to calculate the ME concentration of casein. Thus, because the portion of casein (6.14%) in diet C supplied 280 kcal/kg of that diet's ME, these results indicate that the ME concentration of casein for growing pigs was approximately 4,560 kcal/kg.

Introduction

Future experiments in our lab will be conducted to determine the metabolizable energy concentrations of various grain varieties or hybrids. In the following experiments, we were interested in providing diets to pigs that met their nutrient requirements. Thus, instead of feeding a entirely grain diet with added crystalline amino acids, we wanted to formulate diets with supplemented protein, i.e., casein. Investigators have observed that crystalline amino acids and casein are essentially 100% digestible when fed to pigs (Kies et al., 1986; Chung and Baker, 1992); and thus, any fecal energy could be attributed to the grain in our proposed diets. However, in order to determine the resulting ME content of the grain within these diets, the ME provided to the diet by casein would have to be subtracted.

On the other hand, few studies have been conducted to determine the metabolizable energy concentration of casein for pigs. Of the published values that are available, the variation in ME concentrations of casein is quite large. For example, published ME concentrations range from 5,201 kcal/kg (Just et al., 1983) to a low of 2,984 kcal/kg (NRC, 1972a) on a dry matter basis. Other values determined within this range, on a DM basis, include 3,045 (NRC, 1972b) and 4,334 kcal/kg (Heartland Lysine, 1996). Ewan (personal comm.) summarized analyzed ME concentrations of casein and determined an average ME content of 3,883 kcal/kg. Ewan's summary was utilized by the National Research Council to derive at a value of 3,885 kcal/kg, DM basis (NRC, 1998). This experiment was conducted to determine the metabolizable energy concentration of casein fed to growing pigs for use in further experimentation.

Materials and Methods

Eight Yorkshire barrows, with an average initial weight of 30.6 kg, were allotted by weight within litter to two dietary treatments in a randomized complete block design with four replicates per treatment. Pigs were allowed a 3-d adjustment period to the chambers and experimental diets before the 4-d total collection of feces, urine, and feed wastage was performed. Pig weights were weighed on d 0 and 4 of the collection period to monitor weight gains. Water was offered *ad libitum* and an effort was made to equalize feed intake within replicate.

Dietary treatments. Both diets (Table 3.1) were formulated to contain 90% corn and have a calculated composition of 0.98% digestible lysine, 0.70% calcium, and 0.60%

phosphorus. Because of this similar desired chemical composition, the amount of the test and control ingredients (casein and sand, respectively) along with crystalline amino acids, dicalcium phosphate, and limestone were slightly variable. The control diet contained 4.15% sand and the treatment diet contained 6.14% casein. Not only were the diets isolysinic, but also they contained similar concentrations of digestible amino acids (threonine, methionine, cystine, tryptophan, isoleucine, valine, and histidine; Table 3.2).

Table 3.1. Composition of diets (as-fed basis).

	Diet[a]	
Ingredient, %	Sand	Casein
Corn	90.00	90.00
Sand	4.15	----
Casein, dried	----	6.14
L-lysine HCl	1.05	0.50
DL-methionine	0.30	0.14
L-threonine	0.40	0.19
L-tryptophan	0.14	0.08
L-isoleucine	0.37	0.10
L-valine	0.38	0.03
L-histidine	0.17	----
L-cystine	0.03	----
Dicalcium phosphate	1.88	1.61
Limestone	0.58	0.66
Salt	0.25	0.25
Vit/TM mix[b]	0.30	0.30

[a] Diets were formulated to contain 0.98% digestible lysine, 0.70% calcium, and 0.60% phosphorus.

[b] Supplied per kilogram of complete diet: Fe, 120 mg; Zn, 120 mg; Mn, 24 mg; Cu, 12 mg; I, 0.36 mg; Se, 0.30 mg; vitamin A, 6615 IU; vitamin D_3, 662 IU; vitamin E, 40 IU; vitamin K (as menadione), 4.4 mg; riboflavin, 6.6 mg; d-pantothenic acid, 30 mg; niacin, 40 mg; vitamin B_{12}, 33 μg; folic acid, 2.0 mg; choline, 144 mg; and biotin, 265 μg.

Table 3.2. Chemical composition of diets (as-fed basis).

	Diet	
Ingredient, %	Sand	Casein
Calculated analysis		
ME, kcal/kg	3,078	3,295
Crude protein, %	9.73	13.79
Total lysine, %	1.06	1.08
Digestible lysine, %	0.98	0.98
Digestible threonine, %	0.58	0.58
Digestible meth+cyst, %	0.60	0.59
Digestible tryptophan, %	0.18	0.18
Digestible isoleucine, %	0.56	0.56
Digestible valine, %	0.66	0.66
Digestible histidine, %	0.34	0.34
Calcium, %	0.70	0.70
Phosphorus, %	0.60	0.60
Available phosphorus, %	0.38	0.33
Analyzed values		
GE, kcal/kg	3,686	3,932
Crude protein, %	9.46	13.11
Nitrogen, %	1.51	2.10

Chemical analyses. Diet, fecal, and urine sample preparation and analyses for DM, nitrogen, and gross energy were conducted as described in the general procedures in Chapter II.

Statistical Analysis. Data were analyzed as a randomized complete block design using analysis of variance procedures as described by Steel et al. (1997). The model contained the effects of block (rep), treatment, and block × treatment, which served as the error term. A single degree of freedom contrast was used to test the effect of sand versus casein. Pig served as the experimental unit.

Results

Energy. Data are reported on dry matter basis unless otherwise stated. Average daily feed intake was similar ($P > 0.10$) for pigs fed the two dietary treatments (Table 3.3). However, because the casein diet was 286 kcal/kg greater in gross energy concentration, gross energy intake (kcal/d) was greater ($P < 0.09$) for pigs fed the casein diet as compared with those fed the sand diet. Fecal dry matter excretion (g/d) was similar ($P > 0.10$) for pigs fed either of the experimental diets, but fecal gross energy concentration (kcal/kg) was greater ($P < 0.01$) for pigs consuming the casein diet versus those fed sand. However, fecal gross energy excretion (kcal/d) was similar ($P > 0.10$) for pigs consuming the two diets. When subtracting the fecal energy excreted per day from the daily gross energy intake, the resulting DE consumed per day was greater ($P < 0.07$) for pigs fed the casein diet in contrast to those fed sand. Digestible energy concentration of the casein diet was greater ($P < 0.10$) than the sand diet at 3,959 and 3,669 kcal/kg, respectively. Urine dry matter excretion (g/d) was similar ($P > 0.10$) for pigs fed the two treatments. However, urine gross energy concentration (kcal/kg) was greater ($P < 0.02$) for pigs fed casein than those fed sand. As well, urine gross energy excreted (kcal/d) was greater ($P < 0.09$) for pigs consuming the casein diet versus those fed the sand diet. After subtraction of urine gross energy excreted per day from the daily digestible energy consumed, the resulting metabolizable energy consumed per day was greater ($P < 0.07$) for pigs fed the casein diet versus those fed the sand diet. On a concentration basis, the ME content of the two diets was 3,615 and 3,895 kcal/kg for the sand and casein diets, respectively. The sand diet was slightly ($P = 0.11$) lower than the casein diet. Despite differences in available energy concentrations between the two diets, energy utilization by pigs was similar (P > 0.10) as determined by DE:GE, ME:DE, and ME:GE.

Table 3.3. Energy balance for pigs fed sand and casein (DM basis)[a].

	Diet				P<:
Trt:	Sand	Casein	SE	CV	S vs C
GE (diet), kcal/kg	4,168	4,454			
ADF, g/d	877	1,108	57.0	11.6	0.14
GE Intake, kcal/d	3,672	4,934	241	11.3	0.09
Daily fecal excr, g/d	110.2	111.5	18.5	34.0	0.97
Fecal GE, kcal/kg	3,773	4,652	38.9	1.82	0.01
Fecal GE excreted, kcal/d	437	551	75.5	30.8	0.46
Daily urine excr, g/d	21.3	27.7	2.20	18.1	0.22
Urine GE, kcal/kg	2,227	2,549	28.2	2.36	0.02
Urine GE excreted, kcal/d	48.5	70.5	4.29	14.6	0.09
DE, kcal/d	3,235	4,384	184	9.68	0.07
DE, kcal/kg	3,669	3,959	58.3	3.04	0.10
ME, kcal/d	3,187	4,313	180	9.62	0.07
ME, kcal/kg	3,615	3,895	59.8	3.17	0.11
DE:GE, %	88.03	88.88	1.35	3.06	0.74
ME:DE, %	98.53	98.40	0.06	0.13	0.32
ME:GE, %	86.73	87.46	1.39	3.18	0.78

[a] Least squares means of 4 individually-penned pigs per treatment.

Nitrogen. Nitrogen intake (g/d) was greater (P < 0.03) for pigs fed the casein diet versus those fed sand. Conversely, fecal nitrogen excreted (g/d) was similar (P > 0.10) for pigs fed the two diets. Thus, the amount of nitrogen absorbed (g/d) was greater (P < 0.01) for those pigs consuming the casein diet as compared with those fed sand. However, nitrogen absorption, as a percent of intake, was similar (P > 0.10) for pigs fed the two experimental diets. Urine nitrogen excretion (g/d) was greater (P < 0.07) in those pigs fed casein versus those consuming sand. The amount of nitrogen retained (g/d) was greater (P > 0.01) for pigs fed casein versus sand. Despite this difference, nitrogen retention, as a percent of intake, was similar (P > 0.10) for pigs consuming casein and sand. The ratio of nitrogen retained to nitrogen absorbed was only slightly greater (P = 0.13) for pigs fed casein as compared with those fed sand.

Table 3.4. Nitrogen balance for pigs fed sand and casein (DM basis)[a].

	Diet				P<:
Trt:	Sand	Casein	SE	CV	S vs C
N Intake , g/d	15.38	26.32	1.06	10.1	0.03
Fecal N excr, g/d	3.34	3.96	0.69	38.9	0.63
N absorbed, g/d	12.04	22.34	0.56	6.44	0.01
N absorption, %	78.28	85.02	2.90	7.02	0.29
Urine N excr, g/d	3.08	4.58	0.25	12.7	0.07
N retained, g/d	8.96	17.76	0.50	7.30	0.01
N retention, %	57.51	67.59	3.25	10.3	0.20
N retained: N absorbed, %	73.42	79.46	1.43	3.73	0.13

[a] Least squares means of 4 individually-penned pigs per treatment.

ME of casein. Calculations were made to determine the metabolizable energy concentration of casein. First of all, the assumption was made that the casein and crystalline amino acids added to the diets were 100% digestible (Kies et al., 1986; Chung and Baker, 1992) and that the crystalline amino acids provided relatively small amounts of energy to the diets. Thus, any differences seen in metabolizable energy between the two diets could be attributed to casein. Because the ME concentrations of the sand and casein diets were 3,615 and 3,895 kcal/kg, the 280 kcal/kg difference represents the proportion of the metabolizable energy of the casein diet provided casein. As casein was added at 6.14% of the diet, dividing the 280 kcal/kg by .0614 equals 4,560, which is the metabolizable energy concentration of casein for growing pigs.

Discussion

Baker et al. (1968) reported that up to 20% dietary sand did not affect energy consumption or weight gain. As well, sand was not retained in the gastrointestinal tract of pigs fed sand-containing diets. Utilization of the nondiluent (nonsand) portion of the diet was not affected in group-fed pigs.

In our experiment, sand was used in place of casein in the control diet to serve as an energy-free substance in order that the percentage of corn, as well as the nutrient composition, of the two diets was similar. As in agreement with Baker et al. (1968), when sand was added at 4.15% of the diet, average daily feed intake was not significantly affected. However, numerically, pigs fed the sand diet consumed less than those fed the casein diet.

Although experiments reporting metabolizable energy values of casein for pigs are limited, the ME concentration of casein found in this experiment (4,560 kcal/kg DM) was similar to the value published by Heartland Lysine (1996) of 4,334 kcal/kg DM. However, our determined ME concentration was lower than the value published by Just et al. (1983). On the other hand, the ME content we determined for casein was higher than those reported in other studies (NRC, 1972a; NRC, 1972b; Ewan, personal comm.; NRC, 1998).

Because the nitrogen concentration of the casein diet was higher than that of the sand diet, nitrogen intake (g/d) was also higher for pigs consuming the casein diet. However, fecal nitrogen excretion was similar for pigs fed the two dietary treatments. This was probably due to the fact that the difference in nitrogen concentration of the two diets was due to the addition of casein, which was nearly completely digested. When assuming that the crystalline amino acids in both diets were 100% digestible and assuming limited endogenous nitrogen losses, the nitrogen in the feces of pigs fed the sand diet could be attributed to nitrogen from corn. Thus, because the only difference in the two diets was the presence of casein, the nitrogen in the feces of pigs fed the casein diet could be attributed to nitrogen from corn as well as nitrogen from casein.

The difference in nitrogen intake for the two diets was 10.94 g/d, and the difference in nitrogen absorbed was 10.30 g/d, with the differences being from nitrogen provided by casein. Because these values are similar indicates that the nitrogen from casein was almost entirely digested. In fact, when dividing the difference in nitrogen intake (10.94 g/d) by the nitrogen absorbed (10.30), the digestibility of nitrogen from casein was 94.1%. This is similar to the 93.0% and 91.4% apparent nitrogen digestibilities of casein as reported by Kies et al. (1986) and Chung and Baker (1992), respectively.

Conversely, the amount of nitrogen (g/d) excreted in the urine was greater for pigs fed the casein diet versus those fed the sand diet. This may indicate that although almost all of the nitrogen provided by casein was absorbed, a portion of the nitrogen was excreted in the urine. In fact, the difference in nitrogen retained for the two diets, 8.80 g/d, is attributed to the addition of casein, the division of this difference in nitrogen retained by the difference in nitrogen intake (10.94 g/d) indicates that the retention of nitrogen provided by casein was 80.4%. The presence of casein as a source of readily retained nitrogen may thus explain the numerical difference in nitrogen retention, as a percentage of intake, for the two diets.

Implications

The metabolizable energy content of casein, as determined in this experiment, 4,560 kcal/kg (DM basis). This value will be used in the following experiments, of similar size pigs, to subtract out the portion of metabolizable energy of the diets that i attributed to casein. The knowledge of this ME concentration in a specific weight rar of pigs will provide a more accurate measurement of the ME contributed by casein in diet versus assuming a previously published value. This will also allow us to utilize casein-supplemented diets in order to evaluate the ME content of specific grain variet or hybrids while adequately meeting the pigs' amino acid requirements. Because we also determined that the nitrogen from casein was almost entirely digestible, any nitr excreted in the feces of pigs could be attributed to the grain source.

Chapter IV

Experiment 2

Determination of the metabolizable energy concentration of three corn hybrids fed to growing pigs

Abstract: Eight sets of three littermate barrows (initial wt = 25.6 kg) were utilized to determine the ME concentration of three commercially available corn hybrids. The hybrids (A, B, and C) were grown in the same location during the same year, and they were ground to a common particle size prior to mixing the experimental diets. The experimental diets (A, B, and C; 1.0% Lys) consisted of each corn hybrid (90.48%) supplemented with casein (5.04%), crystalline amino acids, and mineral and vitamin sources. Pigs were housed individually in metabolism chambers and equally fed within replicate. Pigs were allowed a 7-d adjustment period to the diets followed by a 5-d collection of feces and urine. All data are reported on a DM basis unless otherwise noted. The GE concentrations (kcal/kg) of Hybrids A and B were similar (4,349 and 4,323), but it was greater for Hybrid C (4,467). The GE of the experimental diets were 4,306, 4,317, and 4,337 kcal/kg, respectively. Fecal GE excretion tended to be greater ($P < 0.11$) for pigs fed Diet C vs Diets A and B. Digestible energy for Diets A, B, and C were 3,884, 3,909, and 3,836 kcal/kg, which resulted in DE:GE of .902, .906, and .885, respectively. Urinary energy excretion was similar among treatments. The ME concentration of the three diets were 3,811, 3,838, and 3,773 kcal/kg and ME:GE was .885, .889, and .870.

The ME concentrations of the three diets were similar, but ME:GE tended to be lower ($P < 0.14$) for Diet C as compared with Diets A and B. To approximate the ME concentration of each corn hybrid, the ME provided by casein was subtracted from the ME of each experimental diet. As a result, GE and ME, on an as-fed basis, were, 3,858 and 3,523; 3,846 and 3,560; and 3,971 and 3,493 kcal/kg for Hybrids A, B, and C, respectively. Thus, ME:GE was .913, .926, and .879. These results suggest only minor differences in ME content of three corn hybrids grown in one location during the same year. However, based on these data, GE of corn is not indicative of the ME concentration as the ME:GE ratios varied with corn hybrid.

Introduction

Corn is the major cereal grain source used in swine diets in the United States. In addition, energy is the most expensive "nutrient" in swine diets. As well, the reported variability in energy concentration in feedstuffs calls for a more accurate determination of energy content of specific feedstuffs resulting in more specific diet formulation. Formulating diets using feedstuffs of known metabolizable energy concentration would be ideal. However, Cromwell et al. (1999) reported that samples of corn varied in their nutrient composition, including variations in lysine content, depending on the area of origin. With this in mind, variations in energy density may not only exist across types of feedstuffs, but also may vary within a specific feedstuff.

Many studies have reported a wide range of energy values for corn fed to pigs. For example, Noblet et al. (1993) reported a metabolizable energy concentration, on a dry matter basis, of 3,650 kcal/kg for corn, while Morgan et al. (1975) reported a value of 3,940 kcal/kg (DM basis). According to the NRC (1998), the metabolizable energy of corn is 3,843 kcal/kg (DM basis). Adeola and Bajjalieh (1997) reported a dry matter ME concentration of 3,870 kcal/kg for corn. Thus, determining the metabolizable energy for feedstuffs, or different hybrids, would allow for more specific diet formulation. The objective of this study was to determine the metabolizable energy concentration of three corn hybrids (A, B, and C).

Materials and Methods

Twenty-four barrows, initially averaging 25.6 kg body weight, were allotted to three dietary treatment with eight replicates per treatment in a randomized complete block design. The barrows were allotted based on weight, keeping average replicate weights similar and littermates spread across treatments. Three diets were formulated to contain 90.48% of one of three commercially available corn hybrids (A, B, and C; Table 4.1). The hybrids were grown in the same location during the same year, and they were ground to a common particle size prior to mixing the experimental diets. Casein (5.04%) and crystalline amino acids were added to the diets to meet or exceed amino acid requirements, and limestone and dicalcium phosphate were utilized as sources of calcium and phosphorus.

The diets were formulated to contain 1.00% total lysine, 0.80% calcium, and 0.70% phosphorus (Table 4.2). Because the only difference between the three diets was the varying corn hybrids, each diet contained the same calculated analysis values for all nutrients.

Table 4.1. Composition of diets (as-fed basis).

Ingredient	% of Diet
Corn[a]	90.48
Casein, dried	5.04
L-Lysine HCl	0.50
DL-methionine	0.17
L-threonine	0.25
L-tryptophan	0.08
L-isoleucine	0.13
L-valine	0.04
Dicalcium phosphate	2.19
Limestone	0.57
Salt	0.25
Vit/TM mix[b]	0.30

[a] Corns A, B, C, and D were added to constitute the three dietary treatments.

[b] Supplied per kilogram of complete diet: Fe, 120 mg; Zn, 120 mg; Mn, 24 mg; Cu, 12 mg; I, 0.36 mg; Se, 0.30 mg; vitamin A, 6615 IU; vitamin D_3, 662 IU; vitamin E, 40 IU; vitamin K (as menadione), 4.4 mg; riboflavin, 6.6 mg; d-pantothenic acid, 30 mg; niacin, 40 mg; vitamin B_{12}, 33 μg; folic acid, 2.0 mg; choline, 144 mg; and biotin, 265 μg.

Table 4.2. Chemical composition of diets (as-fed basis).

Measurement	units
Calculated analysis	
ME, kcal/kg	3,273
Crude protein, %	12.95
Total lysine, %	1.00
Digestible lysine, %	0.90
Digestible threonine, %	0.60
Digestible met+cys, %	0.59
Digestible tryptophan, %	0.17
Digestible isoleucine, %	0.54
Digestible valine, %	0.61
Calcium, %	0.80
Phosphorus, %	0.70

Pigs were allowed a 7-d adjustment period to the chambers and the experimental diets followed by a 5-d total collection of feces and urine. Collection procedures and sample preparation are described in Chapter II.

Chemical analyses. Analyses of the grain, diet, fecal, and urine samples for dry matter, nitrogen, and gross energy are described in the general procedures in Chapter II. Grain analysis for ash, ether extract, acid detergent fiber, neutral detergent fiber, starch, calcium, phosphorus, and amino acid concentrations are also explained in Chapter II. Table 4.3 displays the proximate analysis of the three corn hybrids along with amino acid, calcium, phosphorus, and starch composition. The three corn hybrids were lower for crude protein content as compared with values suggested by NRC (1998). Ether extract was similar to NRC (1998) values for percent crude fat. Neutral detergent fiber percentages were lower and acid detergent fiber percentages were fairly similar to NRC (1998).

Statistical analysis. Data were analyzed as a randomized complete block design using analysis of variance procedures as described by Steel et al. (1997). The model contained the effects of block (rep), treatment, and block × treatment, which served as the error term. Pre-planned non-orthogonal contrasts were used to separate treatment means. Pig served as the experimental unit

Table 4.3. Chemical composition of three corn hybrids (DM basis).

Item	Corn hybrid: A	B	C
Gross energy, kcal/kg	4,349	4,323	4,467
%			
Crude protein	7.93	7.72	7.80
Ether extract	4.32	4.21	4.47
Acid detergent fiber	3.65	4.03	4.28
Neutral detergent fiber	7.57	8.17	8.18
Starch	68.23	68.71	65.36
Ash	1.32	1.24	1.35
Calcium	0.007	0.011	0.055
Phosphorus	0.291	0.279	0.291
Lysine	0.26	0.26	0.25
Methionine	0.20	0.20	0.20
Threonine	0.26	0.27	0.28
Tryptophan	<0.04	<0.04	0.04
Arginine	0.39	0.40	0.38
Histidine	0.23	0.22	0.22
Isoleucine	0.29	0.29	0.29
Leucine	0.93	0.92	0.96
Phenylalanine	0.39	0.39	0.39
Valine	0.41	0.40	0.39

Results

All data are reported on a dry matter basis unless otherwise noted. Average daily feed intake was similar ($P > 0.10$) for pigs across all three diets (Table 4.3). Daily fecal excretion was greater ($P < 0.04$) for pigs consuming the diet containing Hybrid C as compared with pigs fed the diet containing Hybrid B. Daily urine excretion was similar ($P > 0.10$) for pigs fed all three treatments.

Energy. The gross energy concentrations of the three corn hybrids were 4,349, 4,323, and 4,467 kcal/kg, and the gross energy concentrations of the diets were 4,306, 4,317, and 4,337 kcal/kg, respectively (Table 4.4). Fecal energy concentrations were lower ($P < 0.01$) for pigs consuming the diet containing Hybrid B (4,348 kcal/kg) than pigs fed the diets containing Hybrid A (4,494 kcal/kg) and Hybrid C (4,481 kcal/kg). The diet containing Hybrid C resulted in a greater ($P < 0.03$) excretion of fecal energy by pigs as compared with those fed the diet containing Hybrid B. By subtracting the energy excreted in the feces from gross energy intake and adjusting for average daily feed intake, the resulting digestible energy concentrations were 3,884, 3,909, and 3,836 kcal/kg with the diet containing Hybrid B greater ($P < 0.09$) than the diet containing Hybrid C.

Table 4.4. Energy balance for pigs fed three corn hybrids (DM basis)[a].

Diet:	1	2	3	
Corn:	A	B	C	SE
Corn GE, kcal/kg	4,349	4,323	4,467	
GE (diet), kcal/kg	4,306	4,317	4,337	
ADF, g/d	1,037	990	1,065	3.8
GE Intake, kcal/d	4,464	4,271	4,617	161
Daily fecal excr, g/d	94.4^{bc}	88.9^{b}	114.2^{c}	7.7
Fecal GE, kcal/kg	$4,661^{b}$	$4,543^{c}$	$4,659^{b}$	27.3
Fecal GE excreted, kcal/d	438^{bc}	404^{b}	532^{c}	36.7
Daily urine excr, g/d	34.7	32.4	32.7	1.5
Urine GE, kcal/kg	2,179	2,154	2,081	43.5
Urine GE excreted, kcal/d	75.2	70.3	68.1	3.4
DE, kcal/d	4,025	3,867	4,085	140
DE, kcal/kg	$3,884^{bc}$	$3,909^{b}$	$3,836^{c}$	28.6
ME, kcal/d	3,950	3,797	4,017	139
ME, kcal/kg	3,811	3,838	3,773	28.1
DE:GE, %	90.21^{b}	90.56^{b}	88.45^{c}	.66
ME:DE, %	98.12^{b}	98.19^{bc}	98.34^{c}	.08
ME:GE, %	88.51^{bc}	88.92^{c}	86.99^{b}	.65

[a] Least squares means of eight individually-penned pigs per treatment.

[b,c] Means within a row with different superscripts differ ($P < 0.10$).

The digestible energy minus the urinary gross energy excretion, along with adjustment for average daily feed intake, resulted in metabolizable energy concentrations of 3,811, 3,838, and 3,773 kcal/kg. For each of the treatments, the digestible energy as a percentage of gross energy, was 90.21, 90.56, and 88.45%, respectively. The diet containing Hybrid C was lower in DE:GE ($P < 0.10$) as compared with the diets containing Hybrids B and A. Metabolizable energy was found to be 98.12, 98.19, and 98.34% of digestible energy for the three respective treatments. The metabolizable energy, as a percentage of gross energy, was also found to be lower ($P < 0.06$) for the diet containing Hybrid C versus the diet containing Hybrid B.

ME of corns. Metabolizable energy concentrations of the diets were corrected to metabolizable energy concentrations of the corn hybrids within the diets. From the previous experiment described in Chapter III, we determined that the metabolizable energy concentration of casein was 4,560 kcal/kg (DM basis). In order to determine the ME concentration of the corn hybrids within the experimental diets, the ME supplied by casein was subtracted from the ME of the diets, assuming that the only other ME supplied in the diet was attributed to casein. Because casein was included at 5.04% of each diet, then the ME supplied by casein was 230 kcal/kg (4560 * 0.0504), which was subtracted from the ME of each of the three diets. The remaining metabolizable energy value was then divided by the percentage of each corn hybrid in their respective diets (90.48%) to give a metabolizable energy concentration for each corn hybrid. These resulting ME concentrations were 3,958, 3,988, and 3,916 kcal/kg (Table 4.5).

Table 4.5. Metabolizable energy concentration of diets corrected to ME of grains by subtraction of ME from casein.

Code	Trt:	A	B	C
A	Diet ME, kcal/kg (DM)	3,811	3,838	3,773
B	ME provided by casein, kcal/kg (DM)[a]	230	230	230
C	Diet – Casein ME, kcal/kg (DM) (A – B)	3,581	3,608	3,543
D	Grain in Diet, %	90.48	90.48	90.48
E	Grain ME, kcal/kg (DM) (C divided by D)	3,958	3,988	3,916
F	Grain DM, %	88.27	89.78	89.85
G	Grain ME, kcal/kg (as-is) (E multiplied by F)	3,494	3,580	3,519

[a] ME of casein determined from Experiment 1 (Chapter III)

Nitrogen. The nitrogen concentration of the three grains and their respective diets is shown in Table 4.6. Given the average daily feed intake of each dietary treatment, daily nitrogen intakes were similar for the three treatments. After determining the nitrogen content of the fecal samples, fecal nitrogen excretion was greater ($P < 0.03$) for pigs fed the diet containing Hybrid C as compared with pigs fed the diet containing Hybrid B, bı the amount of nitrogen absorbed (g/d) was similar for pigs fed the three diets. On the other hand, nitrogen absorption, as a percentage of intake, was lower ($P < 0.06$) for pigs consuming the diet containing Hybrid C versus those fed the diets containing Hybrids A and B. Urinary nitrogen excretion (g/d) was similar ($P > 0.10$) for pigs fed the three diets. No differences ($P > 0.10$) were observed for the amount of nitrogen retained (g/d) and nitrogen retention, as a percentage of intake, for pigs consuming the three diets. Nitrogen retained, as a percentage of nitrogen absorbed, was also similar ($P > 0.10$) for pigs fed all three diets.

Table 4.6. Nitrogen balance for pigs fed three corn hybrids (DM basis)[a].

Diet: Corn:	1 A	2 B	3 C	SE
Grain N, %	1.290	1.249	1.269	
Grain CP, %	7.93	7.72	7.80	
Diet N, %	2.287	2.185	2.215	
Diet CP, %	14.29	13.66	13.84	
N Intake, g/d	23.69	21.62	23.59	.84
Fecal N excr., g/d	3.454^{bc}	3.129^{b}	4.332^{c}	.35
N absorbed, g/d	20.34	18.49	19.26	.70
N absorption, %	85.49^{b}	85.56^{b}	81.61^{c}	1.3
Urine N excr., g/d	4.532	4.209	4.252	.18
N retained, g/d	15.70	14.28	15.00	.65
N retention, %	66.18	66.11	63.68	1.6
N retained: N absorbed, %	77.42	77.19	77.99	1.0

[a] Least squares means of eight individually-penned pigs per treatment.

[b,c] Means within a row with different superscripts differ ($P < 0.10$).

Discussion

The three corn hybrids evaluated in this experiment had very similar metabolizable energy concentrations. However, their initial gross energy concentrations were more variable, which indicates that factors were present which affected the efficiency with which the gross energy of these corn hybrids was utilized.

Although the diet containing Hybrid C was the highest in gross energy content, it also proved to have the numerically lowest metabolizable energy concentration. The Hybrid C grain itself also calculated to have the lowest ME content of the three corns. This resulted in the diet containing Hybrid C having numerically the lowest ME to GE ratio, and was significantly lower than the diet containing Hybrid B. This variation in energy utilization efficiency may possibly be explained by the nitrogen balance of pigs fed these three experimental diets. Pigs fed the diet containing Hybrid C had the greatest fecal nitrogen excretion per day. The lower ME value for Hybrid C may be a result of the increased fecal nitrogen excretion from that dietary treatment due to the loss of energy associated with the excretion of nitrogen.

Differences in available energy content of grains can be somewhat estimated based their chemical composition. Chemical constituents of grains can have a positive or negative effect not only on the gross energy of the grain, but also on the digestible and metabolizable energy concentrations. For example, Hybrid C had a slightly higher percentage of either extract than the other two hybrids. This could indicate Hybrid C's advantage in gross energy. On the other hand, Noblet et al. (1993) reported that the digestibility of energy of diets was negatively affected by their neutral detergent fiber (NDF) content. Sauber and Owens (2001) suggest that grains that are high in fiber content would have low digestible energy and metabolizable energy values for growing pigs as these grains are more bulky and the growing pig has a limited feed intake capacity. In the present experiment, Hybrid C was the highest in acid detergent fiber content. Hybrid C and Hybrid B were similarly higher than Hybrid A for neutral detergent fiber. Thus, the higher fiber fractions for Hybrid C as compared to the other two corns may explain a portion of its lower metabolizable energy content and lower energy utilization efficiency.

Another factor that may affect the metabolizable energy content of grains is the starch content. Because starch is the main energy source in diets fed to pigs and cereal grains comprise a majority of most pig rations, any variation in starch content of grains may affect their metabolizable energy content as well as that of the diet in which they are included. Of the three corn hybrids tested in this experiment, Hybrid C had the lowest starch content at 59.0%, while Hybrids A and B had starch contents of 61.5 and 61.9%, respectively. The lower starch content of Hybrid C suggests that it contained more nonstarch components than the other two hybrids, which may explain the higher level of acid detergent fiber and ether extract in Hybrid C.

The average metabolizable energy concentration for the three corn hybrids used in this experiment is 3,954 kcal/kg. This ME concentration is higher than the metabolizable energy concentrations for corn as reported by Noblet et al. (1993), Adeola and Bajjalieh (1997), and NRC (1998) of 3,650, 3,870, and 3,843 kcal/kg (DM basis), respectively. However, the metabolizable energy concentrations determined in this experiment are similar to those determined by Morgan et al. (1975) who reported a metabolizable energy concentration for corn of 3,940 kcal/kg.

Metabolizable energy, as a percentage of gross energy, ranged from 86.99 to 88.92% for the three corn hybrids evaluated in the present experiment. The lower starch content of Hybrid C could explain the lower energy digestibility. The ME:GE determined in this experiment are higher and more efficient than those reported for corn by Kim et al. (1999) and Lin et al. (1987), but similar to the ME:GE calculated for the data reported by Morgan et al. (1975). Kim et al. (1999) analyzed 18 normal corn samples and determined the percentage of ME to GE was 85.24%, while Lin et al. (1987) determined the ME to GE of corn to be 84.92%. The metabolizable energy, as a percentage of gross energy, of corn calculated from data generated by Morgan et al. (1975) was 87.36.

Implications

This experiment indicates that variations in digestible energy concentrations, as well as nitrogen absorption, existed for diets containing the three corn hybrids evaluated. However, metabolizable energy concentrations were similar for the three corn hybrids. Based on these data, gross energy concentration of corn is not an accurate indicator of the metabolizable energy concentration as shown by the variation in metabolizable energy to gross energy ratios for the three corn hybrids. Determination of metabolizable energy concentration is needed for various hybrid grains in order to perform more specific diet formulation.

Chapter V

Experiment 3

Energy and nitrogen balance of pigs fed four corn grains

Abstract: Six sets of four littermate barrows (27.5 kg) were used to evaluate four corn grains (A, B, C, and D) in an energy and nitrogen balance experiment. Corns A and B were nearly isogenic with A being normal corn, while B was a high-oil variety. Corns C and D were also normal varieties. Pigs were housed individually and allotted to four dietary treatments based on weight and litter. Experimental diets (1.0% Lys) consisted of corns A, B, C, or D (90.48%) with casein (5.04%), crystalline amino acids, and a vitamin/mineral source. Pigs had ad libitum access to water and an effort was made to equalize feed intake within replicate. A 7-d adjustment period to the diets was followed by a 5-d collection of feces and urine. Data are reported on a DM basis unless otherwise noted. GE concentration and CP content of corns A, B, C, and D were: 4,462, 4,761, 4,594, and 4,601 kcal/kg and 8.73, 9.14, 9.47, and 9.02%, respectively. GE intakes for pigs fed diets containing A, B, C, and D were 5,452, 5,291, 5,387, and 4,965 kcal/d. However, fecal and urine GE excretions (kcal/d) were similar ($P>0.10$) across all treatments. The DE for the diets containing A, B, C, and D were 3,924, 4,186, 4,061, and 3,990 kcal/kg while ME were 3,868, 4,127, 4,006, and 3,935 kcal/kg, both varying ($P<0.04$) depending on source of corn. However, no differences ($P>0.10$) were seen in DE:GE (.886, .887, .894, and .885) or ME:GE (.874, .875, .882, and .873). Nitrogen

absorption and retention were not affected by corn source. Previously, we determined the ME of casein to be 4,560 kcal/kg and, thus, the casein in the diet (5.04%) supplied 230 kcal/kg. Subtraction of the ME provided by casein from the ME of the diets resulted in ME concentrations of 3,600, 3,842, 3,660, and 3,625 kcal/kg (as-fed basis) for corns A, B, C, and D. This correction resulted in slight differences ($P<0.10$) in ME:GE (.901, .905, .909, and .890) for the corn grains. These results indicate that although ME concentrations varied for the four corn grains, the differences observed were attributed to initial variation in GE concentration. However, nitrogen digestibility of pigs appears to be similar for the corns fed in this study.

Introduction

Due to the relatively high level of inclusion of corn as the primary energy source in diets fed for pigs, corn comprises a major percentage of the cost of swine feeds. Thus, any variability in available energy content of the corns used could have a large economic impact on producers. To manage these variabilities, determining the amount of available energy content in specific varieties of corn could allow for more specific diet formulation.

Variations in chemical composition of corn have been reported experimentally. Cromwell et al. (1999) observed variability of nutrient composition of corn samples, depending on their area of origin. Kim et al. (1999) reported that there was about a 5% (±100 kcal/kg) variation in the metabolizable energy (ME) concentrations among corn samples.

A wide range of energy values for corn have been reported by a number of studies. Kim et al. (1999) analyzed 21 corn samples and determined the average dry matter ME content to be 3,829 kcal/kg. According to NRC (1998), the metabolizable energy concentration of corn is 3,843 kcal/kg (DM basis). However, in Chapter IV, we determined the average ME content of three corn hybrids to be 3,954 kcal/kg (DM basis).

The development of new varieties of corn which are selected for certain physical or chemical traits may have an effect on the metabolizable energy content of those varieties when fed to pigs. For example, Adeola and Bajjalieh (1997) determined one normal corn variety contained 3,739 kcal/kg ME, while three high-oil corns had an average ME concentration of 3,914 kcal/kg with a range of 3,830 to 4,035 kcal/kg.

Thus, as seen by the variation in published values, the determination of metabolizable energy content of various varieties of corn would assist in more specific diet formulation. The objective of this study was to determine the metabolizable energy concentration of four corn grains (A, B, C, and D) through the use of a total collection energy and nitrogen balance experiment.

Materials and Methods

Twenty-four barrows initially averaging 27.5 kg BW were allotted in a randomized complete block design to four dietary treatments with six replicates per treatment. The barrows were allotted based on weight, keeping average replicate weights similar and littermates spread across treatments. Four diets were formulated to contain 90.48% of one of four corn grains (A, B, C, and D; Table 5.1). Corns A and B were nearly isogenic with A being normal corn, while B was a high-oil variety. Corns C and D were also normal varieties. Casein and amino acids were added to the diets to meet or exceed amino acid requirements, and limestone and dicalcium phosphate were utilized as sources of calcium and phosphorus. The four corn grains were each mixed thoroughly with the specified ingredients in a horizontal paddle mixer.

Table 5.1. Composition of diets (as-fed basis)[a]

Ingredient	**%**
Corn	90.48
Casein, dried	5.04
L-lysine HCl	0.50
DL-methionine	0.17
L-threonine	0.25
L-tryptophan	0.08
L-isoleucine	0.13
L-valine	0.04
Dicalcium phosphate	2.19
Limestone	0.57
Salt	0.25
Trace mineral/vitamin	0.30
Calculated composition (%)	
Total lysine	1.00
Calcium	0.80
Phosphorus	0.70

[a] Corns A, B, C, and D were added to constitute the four diets

[b] Supplied per kilogram of complete diet: Fe, 120 mg; Zn, 120 mg; Mn, 24 mg; Cu, 12 mg; I, 0.36 mg; Se, 0.30 mg; vitamin A, 6615 IU; vitamin D_3, 662 IU; vitamin E, 40 IU; vitamin K (as menadione), 4.4 mg; riboflavin, 6.6 mg; d-pantothenic acid, 30 mg; niacin, 40 mg; vitamin B_{12}, 33 μg; folic acid, 2.0 mg; choline, 144 mg; and biotin, 265 μg.

Pigs were housed in metabolism chambers and were allowed a 7-d adjustment period to the chambers and the experimental diets followed by a 5-d total collection of feces and urine. Pigs had *ad libitum* access to water and an effort was made to keep feed intakes similar within replicate. Collection procedures and sample preparation are described in Chapter II.

Table 5.2. Chemical composition of diets (as-fed basis).

Measurement	units
Calculated analysis	
ME, kcal/kg	3,273
Crude protein, %	12.95
Total lysine, %	1.00
Digestible lysine, %	0.90
Digestible threonine, %	0.60
Digestible met+cys, %	0.59
Digestible tryptophan, %	0.17
Digestible isoleucine, %	0.54
Digestible valine, %	0.61
Calcium, %	0.80
Phosphorus, %	0.70

Chemical analyses. Analyses of the grain, diet, fecal, and urine samples for dry matter, nitrogen, and gross energy are described in the general procedures in Chapter II. Analyses for ash, ether extract, acid detergent fiber, neutral detergent fiber, starch, calcium, phosphorus, and amino acid concentrations are also explained in Chapter II.

Table 5.3 displays the proximate analysis of the three corn hybrids along with amino acid, calcium, phosphorus, and starch composition. All four of these corn grains had very similar analyzed concentrations of crude protein, acid detergent fiber, and phosphorus as compared with the concentrations of corn grain reported by NRC (1998). However, neutral detergent fiber was lower in these corns as compared to the NRC (1998) value. The ether extract concentration of corns A and C were very similar to NRC (1998), but corn D was slightly higher and corn B, the high-oil variety, was much higher.

The amino acid profile of these four corns was similar to those suggested by NRC (1998). However, corn A was slightly lower in all amino acid concentrations as compared with the other three corn grains.

Table 5.3. Chemical composition of four corn grains (DM basis).

	Corn			
Item	**A**	**B**	**C**	**D**
Gross energy, kcal/kg	4,462	4,761	4,594	4,601
%				
Crude protein	8.73	9.14	9.47	9.02
Ether extract	3.60	7.43	4.59	5.62
Acid detergent fiber	2.55	2.62	2.78	2.53
Neutral detergent fiber	5.07	5.22	5.39	4.99
Starch	70.30	69.53	64.24	69.09
Ash	1.18	1.25	1.22	1.29
Calcium	0.009	0.008	0.017	0.008
Phosphorus	0.259	0.286	0.322	0.295
Lysine	0.21	0.28	0.30	0.31
Methionine	0.17	0.21	0.22	0.19
Threonine	0.25	0.31	0.32	0.32
Tryptophan	<0.04	<0.04	<0.04	<0.04
Arginine	0.33	0.43	0.42	0.43
Histidine	0.22	0.26	0.26	0.26
Isoleucine	0.28	0.35	0.36	0.33
Leucine	0.96	1.14	1.21	1.13
Phenylalanine	0.38	0.46	0.48	0.45
Valine	0.38	0.46	0.48	0.49

Statistical analysis. Data were analyzed as a randomized complete block design using analysis of variance procedures as described by Steel et al. (1997). The model contained the effects of block (rep), treatment, and block × treatment, which served as the error term. Pre-planned non-orthogonal contrasts were used to separate treatment means. Pig served as the experimental unit.

Results

All data are reported on a dry matter basis unless otherwise noted. Average daily feed intake was greater ($P < 0.09$) for pigs consuming the diet containing corn A as compared with the diets containing corns B and D (Table 5.4). Daily fecal excretion and urine excretion were similar ($P = 0.11$) for all treatments.

Energy. All energy balance data are reported in Table 5.4. The gross energy concentrations of the four corn grains A, B, C, and D were 4,462, 4,761, 4,594, and 4,601 kcal/kg, and the gross energy of the respective diets were 4,428, 4,718, 4,542, and 4,507 kcal/kg. Fecal energy concentration was highest ($P < 0.01$) for pigs fed the diet containing corn B and lowest ($P < 0.02$) for those fed the diet containing corn C. Because little variation was observed in daily fecal excretion, only slight differences ($P = 0.11$) were found for the amount of fecal energy excreted per day. After substracting the energy excreted in the feces from the gross energy intake and adjusting for daily feed intake, the resulting digestible energy concentrations were 3,924, 4,186, 4,061, and 3,990 kcal/kg with each of the diets containing the respective corn grains being different ($P < 0.04$) from one another. Urinary energy concentration was greater ($P < 0.08$) in pigs fed the diet containing corn B than those fed the diet containing corn D. Because little variability was observed in dry matter urine excretion, calculation for urinary energy excreted per day resulted in no differences ($P > 0.10$). Subtracting the urinary gross energy excretion from the digestible energy concentration and adjusting for feed intake resulted in metabolizable energy concentrations of 3,868, 4,127, 4,006, and 3,935 kcal/kg

for the respective diets with each of the diets being different ($P < 0.04$) from one anothe
The metabolizable energy, as a percentage of gross energy, was similar ($P > 0.10$) amon
treatments. Also, digestible energy, as a percentage of gross energy, and the content of metabolizable energy, as a percentage of digestible energy, were similar ($P > 0.10$) for a four dietary treatments.

Table 5.4. Energy balance of pigs fed four corn grains (DM basis)[a].

Diet:	1	2	3	4	
Item	A	B	C	D	SE
Grain GE, kcal/kg	4,462	4,761	4,594	4,601	
GE (diet), kcal/kg	4,428	4,718	4,542	4,507	
ADFI, g/d	1,231^{b}	1,122^{c}	1,186^{bc}	1,101^{c}	41.7
GE Intake, kcal/d	5,452	5,291	5,387	4,965	188
Daily fecal excr., g/d	128.1	116.4	120.3	115.3	4.93
Fecal GE, kcal/kg	4,675^{b}	4,904^{c}	4,580^{d}	4,692^{b}	23.6
Fecal GE excr., kcal/d	627	598	577	566	23.8
Daily urine excr., g/d	28.0	26.4	25.8	24.7	1.92
Urine GE, kcal/kg	2,528^{bc}	2,659^{b}	2,572^{bc}	2,407^{c}	85.4
Urine GE excr., kcal/d	70.2	67.6	66.6	60.0	5.15
DE, kcal/d	4,825	4,693	4,810	4,399	172
DE, kcal/kg	3,924^{b}	4,186^{c}	4,061^{d}	3,990^{e}	18.9
ME, kcal/d	4,755	4,626	4,744	4,339	170
ME, kcal/kg	3,868^{b}	4,127^{c}	4,006^{d}	3,935^{e}	19.2
DE:GE, %	88.62	88.72	89.42	88.54	.416
ME:DE, %	98.57	98.61	98.64	98.63	.110
ME:GE, %	87.36	87.48	88.20	87.32	.425

[a] Least squares means of six individually-penned pigs per treatment.
[bcde] Means within the same row with different superscripts differ $P < 0.10$.

ME of corns. The metabolizable energy concentrations of the diets were corrected to a metabolizable energy concentration of each of the respective corn grains. From the previous experiment described in Chapter III, we determined that the metabolizable energy concentration of casein for pigs was 4,560 kcal/kg (DM basis). Thus, in the present experiment, the ME supplied by casein was subtracted from the ME of the diets, assuming that the only other ME supplied in the diet was supplied by casein. Because casein was included at 5.04% of the diet, then the ME supplied by casein was 230 kcal/kg (4560 * 0.0504). After subtracting this value from the ME of each of the three diets, the resulting value was divided by the percentage of corn in the diet (90.48%), which resulted in ME of the corn grains. These dry matter metabolizable energy concentrations of the corn grains A, B, C, and D (Table 5.5) were 4,021, 4,307, 4,173, and 4,095 kcal/kg, respectively.

Table 5.5. Metabolizable energy concentration of diets corrected to ME of grains by subtraction of ME from casein.

Code	Trt:	A	B	C	D
A	Diet ME, kcal/kg (DM)	3,868	4,127	4,006	3,935
B	ME provided by casein, kcal/kg (DM)[a]	230	230	230	230
C	Diet – Casein ME, kcal/kg (DM) (A – B)	3,638	3,897	3,776	3,705
D	Grain in Diet, %	90.48	90.48	90.48	90.48
E	Grain ME, kcal/kg (DM) (C divided by D)	4,021	4,307	4,173	4,095
F	Grain DM, %	89.54	89.18	87.69	88.51
G	Grain ME, kcal/kg (as-is) (E multiplied by F)	3,600	3,842	3,660	3,625

[a] ME of casein determined from Experiment 1 (Chapter III)

Nitrogen. All nitrogen data are reported in Table 5.6. Nitrogen intake was greater ($P < 0.09$) for pigs consuming the diet containing corn C than pigs consuming diets containing corns B and D. Due to little differences ($P = 0.12$) in daily fecal nitrogen excretion, nitrogen absorption (g/d) followed the same trend as nitrogen intake. Because few differences ($P > 0.10$) were found for daily urinary nitrogen excretion, nitrogen retained (g/d) followed the same trend as nitrogen absorbed. However, nitrogen absorption and nitrogen retention, as a percentage of intake, were similar ($P > 0.10$) for the four dietary treatments.

Table 5.6. Nitrogen balance of pigs fed four corn grains (DM basis)[a].

Diet:	1	2	3	4	
Item Grain:	A	B	C	D	SE
Grain N, %	1.397	1.463	1.515	1.443	
Grain CP, %	8.73	9.14	9.47	9.02	
Diet N, %	2.221	2.268	2.389	2.326	
Diet CP, %	13.88	14.17	14.93	14.54	
N Intake, g/d	27.35[bc]	25.43[b]	28.33[c]	25.65[b]	0.961
Fecal N excr., g/d	4.330	3.961	4.485	4.400	0.223
N absorbed, g/d	23.02[bc]	21.47[b]	23.85[c]	21.25[b]	0.904
N absorption, %	84.25	84.37	84.48	82.74	0.942
Urine N excr., g/d	4.209	4.146	3.980	3.809	0.217
N retained, g/d	18.81[bc]	17.32[b]	19.87[c]	17.44[b]	0.782
N retention, %	69.12	68.49	70.62	67.78	1.08
N ret: N absorb, g:g	0.820[bc]	0.812[b]	0.836[c]	0.819[bc]	0.857

[a] Least squares means of six individually-penned pigs per treatment.
[bc] Means within the same row with different superscripts differ $P < 0.10$.

Discussion

Adeola and Bajjalieh (1997) used 20-25-kg pigs in two energy and nitrogen balance experiments with high-oil and normal corn. In one experiment, they fed corn at

97% of the diet, while in the other, they fed corn at 79% of the diet supplemented wi 18.25% soybean meal. They determined that the results of the two experiments wer similar. This gives evidence that the results of this experiment utilizing corn at 90.4 of the diet with supplemented casein could be comparable to those experiments utili corn as the only energy source. However, utilizing a protein source as an amino aci supplement may more closely meet the pigs' amino acid requirements.

In this experiment, corn B, the high-oil corn, was higher in essential amino a content, ether extract, and gross energy concentration as compared with the normal c varieties, which is similar to data reported by Adeola and Bajjalieh (1997). Kim et a (1999) also reported that high-oil corn was higher in crude protein, GE, crude fat, ly and methionine content.

The higher ether extract content of these high-oil corns is probably due to an increase in the size of the germ, as a percentage of the whole kernel. The germ is th major depository of lipids in the kernel and a marked positive correlation exists bet the percentage of germ and the percentage of oil in the corn kernel. The larger germ portion also usually results in slightly higher amino acid and crude protein content o high-oil corns (Hopkins et al., 1974).

The 6.5% variation between the ME content of these four corn grains is simi the 5% variation of 21 corn varieties reported by Kim et al. (1999). Kim et al. (199 corn varieties at 97.2% of the diet to 20-kg pigs and found that of the 18 normal vari tested, the average ME was 3,806 kcal/kg with a 5.2% variation. Conversely, the th high-oil corn varieties averaged 3,970 kcal/kg of metabolizable energy with a 1.0% variation. Adeola and Bajjalieh (1997) evaluated one normal and three high-oil cor reported the metabolizable energy concentration of the normal corn was 3,739 kcal/kg and the high-oil varieties averaged 3,914 kcal/kg. Both of these previous experiments found the ME content of high-oil corn varieties to be higher than that for normal corn varieities which is in agreement with the present study.

However, the high-oil variety examined in our experiment was higher in ME content as compared to those in other studies (Adeola and Bajjalieh, 1997; Kim et al., 1999). The normal corn variety was also higher in metabolizable energy content than previous reports (Adeola and Bajjalieh, 1997; NRC, 1998; Kim et al., 1999). In this experiment, the high-oil variety, corn B, had a ME content of 4,307 kcal/kg, while the three normal varieties averaged 4,096 kcal/kg. The average ME for the normal corn varieties is fairly similar to the average of the three corns tested in Chapter IV (3,954 kcal/kg). This increase in ME concentrations of the normal corn varieties in the present experiment could be attributed to more recent selection for newer varieties of corn with higher proportions of crude fat, starch, and subsequently energy content.

Metabolizable energy, as a percentage of digestible energy, was similar for all four corn grains in this experiment at 98.6%, which agrees with the average value of 98.4% reported by Adeola and Bajjalieh (1997).

The similar nitrogen absorption, as a percentage of intake, for the high-oil and normal varieties in this experiment are in agreement with data reported by Adeola and Bajjalieh (1997). However, Adeola and Bajjalieh (1997) reported differences in nitrogen retention, as a percentage of intake, between high-oil and normal varieties, but in the present experiment, similar nitrogen retention percentages were determined.

Implications

This study indicates that energy concentrations of the four corn grains were variable, but the nitrogen absorption and retention of pigs fed these grains was not different. Although differences were observed in energy content of the grains, the efficiency of energy utilization was not different as shown by the similarities in the metabolizable energy to gross energy ratios. From this experiment, it seems that grains higher in fat content result in higher gross energy concentrations, but the efficiency of which this energy is utilized is similar to corns containing relatively low amounts of fat. More research is needed to determine specific metabolizable energy concentrations of feedstuffs for more specific diet formulation in order to improve economic efficiency.

Chapter VI

Experiment 4

Energy and nitrogen balance of pigs fed commercial red sorghum, identity-preserved white sorghum, or corn

Abstract: An experiment was conducted to determine the ME concentration and nitrogen digestibility of one corn and two sorghum (S) samples grown within an 80-km radius during the same crop year. Twelve sets of 3 littermate barrows (25.9 kg) were housed individually and allotted randomly to 3 dietary treatments. Experimental diets (1.08% Lys) consisted of mill-run corn (C), mill-run red sorghum (RS), or a white endosperm sorghum variety (WS) (90.0%) with casein (6.14%), crystalline amino acids, and a vitamin/mineral source. Pigs were allowed a 5-d adjustment period to the diets followed by a 4-d collection of feces and urine. Data are reported on a DM basis unless otherwise noted. GE and CP concentration of the C, RS, and WS were 4,495, 4,379, and 4,420 kcal/kg, and 9.34, 10.48, and 10.50%, respectively. GE intakes for pigs fed diets containing C, RS, and WS were 5,335, 5,198, and 5,186 kcal/d. Fecal GE excretion was greater ($P<.01$) for pigs fed S versus C diets, but there was no difference between pigs fed RS and WS diets. Urinary energy excretion was similar across treatments. ME for diets containing C, RS, and WS were 3,950, 3,614, and 3,656 kcal/kg, respectively. ME concentration for the diet containing C was greater ($P<.01$) compared with the S diets, but there was no difference in ME between RS and WS diets. However, DE:GE and ME:GE tended ($P<.15$) to be greater for diets containing WS compared with RS. A previous

study found that the ME of casein was 4,150 kcal/kg (as-fed) and thus the casein in the diet (6.14%) supplied 255 kcal/kg. Subtraction of the ME from casein resulted in ME concentrations, on an as-fed basis, of 3,600, 3,325, and 3,370 kcal/kg for C, RS, and WS, respectively. Nitrogen absorption and retention were greater ($P<.02$) for pigs fed the diet containing C compared with pigs fed S. These results indicate that the digestibility of energy and nitrogen were lower in mill-run red sorghum versus mill-run corn. Also, energy and nitrogen balance was similar between pigs fed mill-run red sorghum and white sorghum.

Introduction

Cereal grains are the primary ingredients in diets fed to pigs, and thus the energy availability of these cereals is economically critical. Least-cost formulation of diets should be based on accurate estimations of available energy of the grains being utilized. Although corn is the major grain source fed to pigs in the United States, grain sorghum is more easily grown in the southern portion of the U.S. Due to the accessibility of sorghum in these regions, it may be a more economically feasible form of energy in swine diets. Diggs et al. (1965) reported the ME concentrations of corn and sorghum, on an dry matter basis, were 3,765 and 3,670 kcal/kg, respectively. Lin et al. (1987) determined ME content of corn and sorghum to be 3,830 and 3,850 kcal/kg (DM basis), respectively. According to NRC (1998), the metabolizable energy concentration, (dry matter basis) of corn is 3,843 kcal/kg, and the ME content of sorghum is 3,753 kcal/kg. Due to the variation in published energy values of sorghum, analysis of new varieties for ME content would prove useful in diet formulation.

It has been reported that the degree of pigmentation of broiler fat is controlled primarily by the level of pigment (xanthophyll) in the diet (Heiman and Tighe, 1943; Day and Williams, Jr., 1958). With this in mind, the reduced amount of pigment in white sorghums may result in a whiter colored fat tissue in pigs fed these grains as compared with grains containing larger amounts of pigmenting agents. Because buyers of exported U.S. pork will pay a premium for pork containing whiter fat, the use of these grains in swine diets is being evaluated. The objective of this study was to compare the metabolizable energy concentration of sorghum versus mill-run corn and also to compare mill-run red sorghum with an identity-preserved white sorghum through the use of a total collection energy and nitrogen balance experiment.

Materials and Methods

Initially, samples from twenty-two sorghum varieties, that were all grown within a 80-km radius of Hugoton, Kansas, during the same crop year, were obtained for nutrient analysis in order to determine variability of nutrient composition. Proximate analysis and Minolta color scores were determined for these sorghum samples.

Of these twenty-two sorghum varieties analyzed, two samples, mill-run red sorghum and a white endosperm sorghum, were selected for use in an energy and nitrogen balance experiment. In this experiment, twelve sets of three littermate barrows, initially averaging 25.9 kg body weight, were allotted in a randomized complete block design to three dietary treatments with twelve replicates per treatment. The barrows were allotted based on weight, keeping average replicate weights similar and littermates spread across treatments. Three diets (Table 6.1) were formulated to contain 90.0% of one of three grain samples (mill-run corn, mill-run red sorghum, and a white endosperm sorghum variety) grown within a 80-km radius in southwest Kansas and the Oklahoma panhandle during the same crop year. Casein and amino acids were added to the diets to meet or exceed amino acid requirements, and limestone and dicalcium phosphate were utilized as sources of calcium and phosphorus. Because equal percentages of each ingredient in the diet were the same for all three treatments, diets were formulated to contain 1.08% total lysine, 0.70% calcium, and 0.60% phosphorus (Table 6.2) to ensure that nutrient requirements were met in the sorghum diets. The three grains were each mixed thoroughly with the specified ingredients in a horizontal paddle mixer for production of the experimental diets.

Table 6.1. Composition of diets (as-fed basis).

Ingredient	%
Corn/Sorghum[a]	90.00
Casein, dried	6.14
L-lysine HCl	0.50
DL-methionine	0.14
L-threonine	0.19
L-tryptophan	0.08
L-isoleucine	0.10
L-valine	0.03
Dicalcium phosphate	1.61
Limestone	0.66
Salt	0.25
Trace mineral/vitamin[b]	0.30

[a] Corn, red sorghum, and white sorghum were added to constitute the three diets

[b] Supplied per kilogram of complete diet: Fe, 120 mg; Zn, 120 mg; Mn, 24 mg; Cu, 12 mg; I, 0.36 mg; Se, 0.30 mg; vitamin A, 6615 IU; vitamin D_3, 662 IU; vitamin E, 40 IU; vitamin K (as menadione), 4.4 mg; riboflavin, 6.6 mg; d-pantothenic acid, 30 mg; niacin, 40 mg; vitamin B_{12}, 33 μg; folic acid, 2.0 mg; choline, 144 mg; and biotin, 265 μg.

Table 6.2. Chemical composition of diets (as-fed basis).

Measurement	Units
Calculated analysis	
ME, kcal/kg	3,295
Crude protein, %	13.79
Total lysine, %	1.08
Digestible lysine, %	0.98
Digestible threonine, %	0.58
Digestible meth+cyst, %	0.59
Digestible tryptophan, %	0.18
Digestible isoleucine, %	0.56
Digestible valine, %	0.66
Calcium, %	0.70
Phosphorus, %	0.60

Chemical analyses. Analyses of the grain, diet, fecal, and urine samples for dry matter, nitrogen, and gross energy are described in the general procedures in Chapter II. Analyses for ash, ether extract, acid detergent fiber, neutral detergent fiber, starch, calcium, phosphorus, and amino acid concentrations are also explained in Chapter II. Minolta color scores were also performed on the two sorghum samples to determine their relative color differences by light reflectance (Minolta CR-300 Chromameter, DP-301 Data Processor, Minolta Camera Co., Ltd., Osaka, Japan). Three measurements were taken for each grain sample in order to calculate mean values for L*, a*, and b* for each sorghum sample.

Table 6.3 displays the proximate analysis of the three grains along with amino acid, calcium, phosphorus, and starch composition as well as Minolta color scores. These Minolta color values indicate any differences in pigment color of the two sorghum samples used in this study.

Table 6.3. Chemical composition of three grain samples (DM basis).

Item Grains:	Corn	Red Sorghum	White Sorghum
Gross energy, kcal/kg	4,495	4,379	4,420
%			
Crude protein	9.34	10.47	10.49
Ether extract	4.45	2.34	2.18
Acid detergent fiber	3.82	6.26	5.72
Neutral detergent fiber	13.95	11.02	11.13
Starch	65.38	64.71	61.38
Ash	1.47	2.82	2.47
Calcium	0.01	0.24	0.39
Phosphorus	0.28	0.25	0.28
Lysine	0.28	0.28	0.24
Methionine	0.20	0.19	0.22
Threonine	0.32	0.37	0.36
Tryptophan	<0.04	0.08	0.07
Arginine	0.44	0.42	0.40
Histidine	0.27	0.26	0.23
Isoleucine	0.32	0.42	0.42
Leucine	1.18	1.36	1.42
Phenylalanine	0.46	0.55	0.56
Valine	0.46	0.58	0.57
Minolta color scores[ab]			
L*	----	75.51	78.74
a*	----	4.06	2.81
b*	----	14.46	12.28

[a] Higher L*, a*, and b* values indicate higher degrees of luminance (lightness), redness, and yellowness, respectively.

[b] Based on three measurements per sample.

Statistical analysis. Data were analyzed as a randomized complete block design using analysis of variance procedures as described by Steel et al. (1997). The model included the effects of block (rep), treatment, and block x treatment, which served as the error term. Average daily feed intake was included as a covariate in order to equalize feed intake across treatments. Orthogonal contrasts, which consisted of corn versus the average of the two sorghums and the red sorghum versus the white sorghum, were used to test treatment means. Pig served as the experimental unit.

Results

Because the twenty-two sorghum samples were grown in essentially the same geographic location under similar environments, most of the variability observed for the varieties is likely due to genetic differences. These sorghum variety samples were analyzed for proximate analysis as well as gross energy content and Minolta color scores (Table 6.4). The Minolta color scores, L*, a*, and b,* serve as indicators of color characteristics of the sorghum grains. The L* value indicates the degree of luminance (lightness), a* indicates the degree of redness, and b* represents the degree of yellow reflectance. All analyzed nutrient concentrations of the twenty-two samples are shown in Appendix Tables 49-51.

Table 6.4. Chemical analysis of 22 sorghum samples (DM basis).

Analysis	Mean	Range	CV
Gross energy, kcal/kg	4,533	4,351 – 4,740	2.9
Nitrogen, %	1.54	1.25 – 1.91	12.2
Crude protein, %	9.62	7.82 – 11.96	12.2
Crude fat, %	2.82	1.99 – 4.21	19.7
ADF, %	5.76	4.07 – 7.28	15.8
Ash, %	1.71	1.39 - 2.82	20.3
Minolta color scores[ab]			
L*	80.74	75.51 – 84.09	2.65
a*	2.68	1.07 - 4.06	37.28
b*	13.15	9.90 – 16.60	12.86

[a] Higher L*, a*, and b* values indicate higher degrees of luminance (lightness), redness, and yellowness, respectively.

[b] Based on three measurements per sample.

All data are reported on a dry matter basis unless otherwise noted. Average daily feed intake averaged 1,207 g/d for pigs fed the three dietary treatments. Daily fecal excretion was lower ($P < 0.01$) for pigs consuming the corn diet as compared with those fed sorghum. Daily fecal excretion was greater ($P < 0.03$) for pigs fed the red sorghum as compared with white sorghum. Daily urine excretion was greater ($P < 0.05$) for pigs fed corn as compared with those fed sorghum, but it was similar ($P > 0.10$) for pigs fed the two sorghums.

Energy. All energy balance data are reported in Table 6.5. The gross energy concentrations of the corn, red sorghum, and white sorghum grains were 4,495, 4,379, and 4,420 kcal/kg, and the gross energy of the respective diets was 4,427, 4,312, and 4,301 kcal/kg. Fecal energy concentration was lower ($P < 0.01$) for pigs fed the corn diet compared with those fed sorghums, and it was greater ($P < 0.01$) for pigs fed white sorghum as compared with those fed red sorghum. However, fecal energy excretion (kcal/d) was greater ($P < 0.01$) for pigs consuming sorghum as compared with those fed corn, but little difference ($P = 0.18$) was observed between pigs fed the two sorghums. After substracting the energy excreted in the feces from the gross energy intake, the resulting digestible energy concentration of corn was higher ($P < 0.01$) than the sorghums, but only a slight difference was observed between the two sorghums ($P = 0.18$). Pigs fed sorghum had higher ($P < 0.01$) urinary energy concentration ($P < 0.01$) versus those fed corn, with no difference ($P > 0.10$) observed for pigs fed white vs red sorghum. Urinary energy excretion per day was similar for pigs fed all treatments ($P > 0.10$). Upon subtraction of urinary gross energy excretion from the digestible energy concentration, the resulting ME concentration of the corn diet was greater ($P < 0.01$) than the sorghums, but the red and white sorghum diets were similar ($P > 0.10$). Digestible energy, as a percentage of gross energy, was greater ($P < 0.01$) for the corn diet versus the sorghum diets, and the white sorghum was greater ($P < 0.10$) than the red sorghum diet. Additionally, ME, as a percentage of gross energy, of the corn diet was greater ($P < 0.01$) than sorghums, and the white sorghum diet was slightly greater ($P = 0.15$) compared with the red sorghum diet. Metabolizable energy, as a percentage of digestible energy, was similar ($P > 0.10$) for the three treatments.

Table 6.5. Energy balance of pigs fed corn and sorghum (DM basis)[a].

Diet:	1	2	3		P<:	
Item Grain:	Corn	Red Sorg	White Sorg	SE	C vs S[b]	R vs W[c]
Grain GE, kcal/kg	4,495	4,379	4,420			
GE (diet), kcal/kg	4,427	4,312	4,301			
GE intake, kcal/d	5,335	5,198	5,186	7.92	0.01	0.30
Daily fecal excr., g/d	107.2	165.2	144.3	6.22	0.01	0.03
Fecal GE, kcal/kg	4,803	4,763	5,069	26.3	0.01	0.01
Fecal GE excr., kcal/d	514	785	728	28.3	0.01	0.18
Daily urine excr., g/d	28.0	18.8	19.5	3.11	0.05	0.88
Urine GE, kcal/kg	2,320	2,672	2,766	53.2	0.01	0.23
Urine GE excr., kcal/d	65.7	50.7	55.0	8.99	0.29	0.74
DE, kcal/d	4,822	4,413	4,458	33.2	0.01	0.36
DE, kcal/kg	4,006	3,657	3,704	24.6	0.01	0.19
ME, kcal/d	4,756	4,363	4,403	32.6	0.01	0.39
ME, kcal/kg	3,950	3,614	3,656	25.0	0.01	0.26
DE:GE, %	90.51	84.8	86.12	.53	0.01	0.10
ME:DE, %	98.62	98.84	98.71	.23	0.63	0.70
ME:GE, %	89.26	83.81	85.00	.55	0.01	0.15

[a] Least squares means for 12 individually-penned pigs per treatment

[b] C vs S = corn vs average of sorghums

[c] R vs W = red sorghum vs white sorghum

ME of corns. The metabolizable energy concentrations of the diets were corrected to a metabolizable energy concentration of each of the respective grains on an as-fed basis. In a previous experiment in our lab, the ME concentration of casein for pigs was determined to be 4,560 kcal/kg (DM basis). Thus, in the present experiment, the ME supplied by casein was subtracted from the ME of the diets, assuming that the only other ME supplied in the diet was supplied by casein. Since casein was included at 6.14% of the diet, then the ME supplied by casein was 280 kcal/kg (4560 * 0.0614). After subtracting this value, the resulting value was divided by the percentage of corn in the diet (90.0%), which resulted in ME of the grains on a DM basis. These resulting dry matter metabolizable energy concentrations of the corn, red sorghum, and white sorghum grains were 4,078, 3,704, and 3,751 kcal/kg, respectively (Table 6.6).

Table 6.6. Metabolizable energy concentration of diets corrected to ME of grains by subtraction of ME from casein.

Code	Trt:	Corn	Red Sorg	White Sorg
A	Diet ME, kcal/kg (DM)	3,950	3,614	3,656
B	ME provided by casein, kcal/kg (DM)[a]	280	280	280
C	Diet – Casein ME, kcal/kg (DM) (A – B)	3,670	3,334	3,376
D	Grain in Diet, %	90.0	90.0	90.0
E	Grain ME, kcal/kg (DM) (C divided by D)	4,078	3,704	3,751
F	Grain DM, %	88.27	89.78	89.85
G	Grain ME, kcal/kg (as-is) (E multiplied by F)	3,600	3,325	3,370

[a] ME of Casein determined from Experiment 1 (Chapter III)

Nitrogen. All nitrogen data are reported in Table 6.7. Nitrogen intake (g/d) of pigs consuming the corn diet was lower ($P < 0.01$) than pigs fed the sorghum diets, but no differences ($P > 0.10$) were observed between the sorghums. Daily fecal nitrogen excretion was lower ($P < 0.01$) for pigs fed corn versus sorghum, but there was no difference ($P > 0.10$) between pigs fed the two sorghums. However, no differences ($P > 0.10$) were observed for the amount of nitrogen absorbed (g/d), but nitrogen absorption, as a percentage of intake, was greater ($P > 0.01$) for pigs consuming corn as compared with pigs fed sorghum, while no difference ($P > 0.10$) was observed between the two sorghums. Daily urinary nitrogen excretion was greater ($P < 0.05$) in pigs fed the corn diet than those fed sorghums, but pigs fed the two sorghum treatments were essentially

Table 6.7. Nitrogen balance of pigs fed corn and sorghum (DM basis)[a].

	Diet:	1	2	3			
Item	Grain:	Corn	Red Sorg	White Sorg	SE	C vs S[b]	R vs W[c]
Grain N, %		1.495	1.676	1.680			
Grain CP, %		9.34	10.48	10.50			
Diet N, %		2.425	2.608	2.611			
Diet CP, %		15.16	16.30	16.32			
N Intake, g/d		29.30	31.49	31.51	0.07	0.01	0.84
Fecal N excr., g/d		3.514	5.797	6.165	0.26	0.01	0.34
N absorbed, g/d		25.78	25.69	25.34	0.23	0.39	0.30
N absorption, %		88.17	81.68	80.85	0.68	0.01	0.40
Urine N excr., g/d		4.303	3.546	3.548	0.27	0.05	0.99
N retained, g/d		21.48	22.15	21.80	0.28	0.20	0.40
N retention, %		72.96	69.98	69.42	0.91	0.02	0.67
N ret: N absorb, g:g		0.828	0.857	0.859	0.01	0.03	0.90

[a] Least square means for 12 individually-penned pigs per treatment
[b] C vs S = corn vs average of sorghums
[c] R vs W = red sorghum vs white sorghum

the same ($P > 0.10$). Consequently, nitrogen retention (g/d) was similar ($P > 0.10$) for pigs consuming the three treatments. However, nitrogen retention, as a percentage of intake, was greater ($P < 0.02$) for pigs fed corn than those fed sorghum, but it was similar for pigs fed white and red sorghum. The proportion of absorbed nitrogen that also was retained was greater ($P < 0.03$) for pigs fed the sorghum diets as compared with pigs fed corn, but it was similar ($P > 0.10$) for pigs consuming the two sorghum treatments.

Discussion

For the twenty-two sorghum samples, nutrient composition as well as Minolta color scores were highly variable. This large degree of variability is evident from the large ranges in nutrient means and large coefficient of variation values. The mean acid detergent fiber for these 22 samples is lower than NRC (1998), and crude protein and crude fat contents are also slightly lower. As compared to the means of 28 sorghum varieties evaluated by Heller and Seiglinger (1944) for nutrient composition, our average crude protein concentration is lower, but fat and ash contents are very similar to their findings.

Our observation of a large amount of variability in all nutrient contents analyzed for these 22 sorghums agrees with several other studies. Smith and Stephenson (1960) found significant variations in fat, ash, methionine, and lysine contents of eleven sorghum samples. Miller et al. (1964) reported that the crude protein content of several sorghum samples ranged from 5.9% to 12.8% (DM basis). This is a fairly similar range to that reported herein, but our sorghums were grown in the same location during the same year, and the sorghum from the study of Miller et al. (1964) were grown in three separate years in a much larger location. Thus, differences found by Miller et al. (1964) could partially be due to environmental as well as variety differences, whereas the differences we observed are believed to be predominantly due to genetic differences. Cohen and Tanksley, Jr. (1973) analyzed four sorghum varieties of differing endosperm and starch types and determined their crude protein content ranged from 10.0% to 15.0%. This is a higher crude protein content than we observed in the present experiment.

When comparing the two sorghums, which were utilized in the balance experiment, to NRC (1998) nutrient composition for sorghum, our analyzed values are lower for neutral detergent fiber, acid detergent fiber, and ether extract. Phosphorus content of the sorghums in this study was also slightly lower than NRC (1998). However, calcium content of the two sorghums was much higher, while their crude protein contents and amino acid profiles were similar to NRC (1998).

Although, the white endosperm sorghum had lower ether extract and starch content than the mill-run red sorghum, the gross energy content of the white endosperm sorghum was slightly higher. This could possibly be explained by higher ash content and acid detergent fiber content of the mill-run red sorghum as compared with the white endosperm variety. Both sorghum samples were similar in crude protein content and amino acid profile. The Minolta color scores indicate that the white endosperm sorghum variety was lighter than the red sorghum. They also indicate that the mill-run red sorghum was indeed redder, as well as yellower, than the white endosperm sorghum variety. Although physical differences and nutrient composition differences were observed for the two sorghum varieties, the balance experiment produced similar metabolizable energy concentrations for the two varieties and similar nitrogen balance in pigs fed diets containing the two sorghum samples.

Comparing the nutrient composition of the corn sample with the two sorghum samples results in many differences. The two sorghum varieties were higher in crude protein, ash, ADF, calcium, tryptophan, isoleucine, leucine, phenylalanine, and valine than the corn sample. However, the corn, when compared with the sorghums, was higher in ether extract and NDF. The corn was also higher in starch content than the white sorghum variety, but similar to the mill-run red sorghum. Phosphorus content, as well as concentrations of the remaining essential amino acids was similar for the corn and sorghum samples. These findings agree closely with data reported by Douglas et al. (1990). They also determined that sorghum samples contained higher concentrations of isoleucine, leucine, phenylalanine, and valine as compared with corn. Douglas et al. (1990) also reported that corn had 1 to 2% higher ether extract content, and sorghums contained higher levels of ADF, both of which agree with our present experiment.

The metabolizable energy concentration of the corn grain used in this study is similar to the ME of three normal corns reported in Chapter V that averaged 4,096 kcal/kg (DM basis). However, the dry matter ME values of corn in this study are higher than those reported by Diggs et al. (1965), Lin et al. (1987), and NRC (1998) which were 3,765, 3,830, and 3,843 kcal/kg, respectively.

The sorghums analyzed in this experiment (averaged 3,728 kcal/kg) have similar ME content to the value reported by NRC (1998) of 3,753 kcal/kg. However, they are greater in ME than those reported by Diggs et al. (1965) (3,670 kcal/kg), but lower than those reported by Lin et al. (1987) (3,850 kcal/kg).

The higher metabolizable energy concentration of corn as compared to sorghum, in this experiment, agrees with Diggs et al. (1965), but is opposite of the comparison analyzed by Lin et al. (1987). The higher metabolizable energy content of corn as compared with the two sorghums could possibly be explained by gross energy and energy utilization. The initial advantage of gross energy could be due to higher starch and ether extract contents in the corn sample versus the sorghums. Pigs fed the corn diet also more efficiently utilized this gross energy as compared with pigs fed the sorghums diets as seen by metabolizable energy, as a percentage of gross energy. Both of these advantages allow the corn in this study to have a higher ME content than both of the sorghum samples evaluated.

Implications

This study indicates that when feeding grains grown in the same location during the same crop year to pigs, corn was greater in ME content, and pigs fed the corn diet were more efficient in energy utilization and had improved nitrogen balance as compared with those fed sorghum. Metabolizable energy content was similar for the mill-run red sorghum and the white endosperm sorghum variety, and pigs fed the sorghums had similar nitrogen absorption and retention. In this experiment, corn was superior to the sorghums for ME content and nitrogen utilization for pigs. However, more research is needed to determine specific metabolizable energy concentrations of different varieties of sorghum. Cost analysis should also be performed when weighing the value of corn and sorghum fed to pigs in areas were sorghum may be more accessible and purchased at a lower cost than corn.

Chapter VII

The use of proximate analysis and energy balance experiments in developing prediction equations for energy content of corn varieties

Introduction

The energy concentration of feedstuffs is very important in diet formulation. Because pigs consume feed to meet their energy requirements, formulating diets to the necessary nutrient to energy ratios is needed to properly meet the pigs' requirements. Conducting energy balance experiments to determine the digestible energy (DE) or metabolizable energy (ME) content of specific hybrids or varieties of feedstuffs prior to diet formulation would be the ideal solution. However, these methods are time consuming, economically expensive, and unpractical. Thus, a more readily available method for accurately estimating the energy concentration of feedstuffs is necessary.

Several experiments have developed equations based on nutrient composition to predict the DE and ME content of mixed diets consisting of a variety of feed ingredients (Just et al., 1984; Morgan et al., 1987; and Noblet and Perez, 1993). However, the development of equations to predict the available energy concentration of specific feedstuffs is limited. The objective of this study was to develop equations, comprised of analyzed chemical composition, to accurately predict the gross energy, digestible energy, and metabolizable energy concentration of seven corn varieties that were fed to growing pigs.

Materials and Methods

The metabolizable energy concentrations and proximate analysis of corn varieties determined in Experiments 2 (Chapter IV) and 3 (Chapter V) were utilized in order to develop prediction equations for energy content of the corn grains used in those experiments. In Exp. 2, three corn hybrids were included in diets that were fed to eight sets of three littermate barrows. In Exp. 3, four corn grains were included in four diets that were fed to six sets of four littermate barrows. Procedures for analysis were the same in both experiments. During the collection period, feed intake was recorded, and total feces and urine were collected.

Additionally, lab analyses were performed on the grains, diets, feces, and urine samples in order to determine the energy and nitrogen balance of pigs fed the seven experimental diets. Nutrient composition of the seven corn grains was determined. The analytical procedures are described in Chapter II. A portion of the analyzed nutrient compositions (Table 7.1) of the corn grains were then utilized to develop equations to predict their energy concentrations when fed to growing pigs.

Table 7.1. Energy content of seven corns for pigs and respective chemical composition (DM basis).

	Experiment 2			Experiment 3				
Item Corn:	A	B	C	A	B	C	D	CV
GE, kcal/kg	4,349	4,323	4,467	4,462	4,761	4,594	4,601	3.43
DE, kcal/kg[a]	4,030	4,057	3,977	4,074	4,363	4,225	4,147	3.21
ME, kcal/kg[a]	3,958	3,988	3,916	4,021	4,307	4,173	4,095	3.44
CP, %	7.93	7.72	7.80	8.73	9.14	9.47	9.02	8.39
EE, %	4.32	4.21	4.47	3.60	7.43	4.59	5.62	26.0
ADF, %	3.65	4.03	4.28	2.55	2.62	2.78	2.53	23.6
NDF, %	7.57	8.17	8.18	5.07	5.22	5.39	4.99	23.9
Ash, %	1.32	1.24	1.35	1.18	1.25	1.22	1.29	4.53

[a] Determined by energy balance experiments of 8 (Exp. 2) or 6 (Exp. 3) individually-penned pigs per treatment.

For determination of equations to predict the available energy content of the corns fed to pigs, multiple linear regression analysis was performed as described by Neter et al. (1996). In order to select the variable to be included into the models, the stepwise procedure was used with forward selection, backward elimination, stepwise selection, and maximum R-square improvement procedures as described by SAS Inst., Inc. (1991). For determination of GE prediction equations, the proximate analysis variables were included in the model, but for determination of DE and ME prediction equations, gross energy values were added to the variables.

Results

Because the number of observations (7 corns) was small, all procedures, forward selection, backward elimination, stepwise selection, and maximum R-square improvement procedures, resulted in similar results. However, the maximum R-square procedure was used because it examines all possible pairwise interchanges that would increase the R-square value, and thus, has a better chance of finding more nearly optimum models and produces a larger number of equations from which to select.

Table 7.2 displays the equations for predicting gross energy concentration based upon nutrient composition, as well as equations for predicting the digestible energy and metabolizable energy concentration of the seven corns based upon nutrient composition and gross energy concentration.

In order to select the single best equation for each energy value (DE or ME), the R-square values were evaluated for the relative amount of improvement with each added variable. If when adding another variable to the equation resulted in a large improvement

Table 7.2. Prediction equations for GE, DE, and ME of corn fed to pigs based upon nutrient composition (DM basis).

Equation	R^2
GE = 4016.56356 + 100.50041 (% EE)	.6865
GE = 3144.37547 + 68.71147 (% EE) + 120.29807 (% CP)	.9292
GE = 2696.25845 + 67.81482 (% EE) + 158.52344 (% CP) + 39.28901 (% ADF)	.9361
GE = 4422.89300 + 76.26617 (% EE) + 464.58542 (% ADF) – 279.02583 (% NDF) *	.9816
GE = 3680.60414 + 71.79339 (% EE) + 68.63.002 (% CP) + 405.17437 (% ADF) – 221.19455 (% NDF)	.9929
GE = 3750.62409 + 72.88908 (% EE) + 66.62929 (% CP) + 412.37239 (% ADF) – 224.23273 (% NDF) – 49.04831 (% Ash)	.9931
DE = 758.05149 + 0.74679 (GE)	.7585
DE = 1708.61282 + 0.71381 (GE) – 634.24477 (% Ash)	.8323
DE = 5203.55292 – 1210.71836 (% Ash) + 92.37836 (% EE)	.9242
DE = 4343.35538 – 823.61136 (% Ash) + 75.79892 (% EE) + 52.89495 (% CP)	.9606
DE = 3648.57968 – 952.03458 (% Ash) + 76.48496 (% EE) + 123.81714 (% CP) + 38.92442 (% NDF) *	.9863
DE = 3314.02219 – 842.64778 (% Ash) + 73.07176 (% EE) + 145.30436 (% CP) + 113.15385 (% NDF) – 138.30738 (% ADF)	.9952
DE = -426.52573 – 784.51438 (% Ash) + 80.28823 (% CP) + 336.70621 (% NDF) – 549.52366 (% ADF) + 0.99250 (GE)	.9992
ME = 436.92562 + 0.80427 (GE)	.7925
ME = 1500.59710 + 0.76736 (GE) – 709.71545 (% Ash)	.8757
ME = 5260.01205 – 1318.61689 (% Ash) + 96.04956 (% EE)	.9196
ME = 4143.52613 – 816.17472 (% Ash) + 74.53042 (% EE) + 68.65454 (% CP)	.9748
ME = 3531.27083 – 929.34477 (% Ash) + 75.13497 (% EE) + 131.15311 (% CP) + 34.30126 (% NDF) *	.9928
ME = 3308.09617 – 856.37566 (% Ash) + 72.85812 (% EE) + 145.48668 (% CP) + 83.81780 (% NDF) – 92.26128 (% ADF)	.9963
ME = -417.99794 – 796.79361 (% Ash) + 80.98215 (% CP) + 306.49218 (% NDF) – 501.87982 (% ADF) + 0.98779 (GE)	.9990

*Selected as equations that best predicted GE, ME, or DE.

in R-square, then adding that variable was beneficial. If when adding another variable to the equation resulted in a small improvement in R-square, the added variable was not significantly beneficial and was not included in the model. The time for additional proximate analysis of the grain would not improve accuracy of energy prediction at this point. Another tool that was utilized for determining the "best" equations, as described by SAS Inst., Inc (1991), was comparing the C(P) statistic, which is a measure of total squared error, to $p+1$, where p is the number of variables included in the model.

The equation deemed the "best" ($R^2 = 0.9816$) for predicting GE concentration of the seven corn grains included the percentages of ether extract, acid detergent fiber, and neutral detergent fiber as variables. The addition of crude protein content in the four-variable model and the addition of ash content in the five-variable model increased the R-square value ($R^2 = 0.9929$ and 0.9931, respectively), but the improvement was considered minimal in relation to the increase in laboratory analyses. In fact, for more easily obtainable nutrient compositions by laboratory analyses, the two-variable model which included percentages of ether extract and crude protein could predict GE relatively accurately ($R^2 = 0.9292$).

In predicting the digestible energy concentration of the seven corn grains, the equation which was found to be most optimum included the variables: percent ash, percent ether extract, percent crude protein, and percent neutral detergent fiber ($R^2 = 0.9863$). The four-variable model, adding acid detergent fiber, and the five-variable model, including ash, crude protein, NDF, ADF, and GE, revealed relatively small improvements in the R-square value ($R^2 = 0.9952$ and 0.9992, respectively). For laboratory simplicity, a few smaller variable models could predict digestible energy fairly accurately. For example, a two-variable model consisting of percentages of ash and ether extract had a R-square value of 0.9242.

For prediction of the metabolizable energy concentration of the seven corn grains, the "best" equation was a four-variable model that included percentages of ash, ether extract, crude protein, and neutral detergent fiber ($R^2 = 0.9928$). The percentage of ash had a negative coefficient, and thus, had a negative effect on ME concentration. On the other hand, ether extract, crude protein, and NDF had positive coefficients, resulting in a positive effect on metabolizable energy concentration. Two different five-variable models were determined to increase R-square, but this increase was considered to be relatively small. For more easily derived laboratory analysis, the two-variable or three-variable models could possibly be effective. The two-variable model ($R^2 = 0.9196$) included ash and ether extract, and the three-variable model ($R^2 = 0.9748$) included ash, ether extract, and crude protein.

Discussion

Analysis of many nutrients was conducted on the seven corn grains in Experiments 2 and 3, but only a portion of these nutrient compositions were utilized in forming equations to predict energy content of the grains. These were crude protein, acid detergent fiber, neutral detergent fiber, ether extract, ash, and gross energy. Analyzed calcium, phosphorus, and amino acid contents were not included in the equations. Calcium and phosphorus would be included in the ash portion, while the amino acids would comprise a portion of the crude protein.

The gross energy of feedstuffs is dependent on the proportions of carbohydrate, fat, protein, minerals, and water. Ewan (2001) suggests that if the composition of a feedstuff is known, the gross energy can be calculated fairly accurately. In this study, in fact, gross energy was predicted very accurately ($R^2 = 0.9816$) for the seven corn grains in the most optimum equation by utilizing their concentrations of ether extract, acid detergent fiber, and neutral detergent fiber.

The most optimum equation to predict DE of the corns in this study contained the variables ash, ether extract, crude protein, and NDF, and had a R-square of 0.9863. Noblet and Perez (1993) also formulated many energy prediction equations. One of their equations to predict DE also contained these same variables with a R-square of 0.92. Morgan et al. (1987) used 36 diets formulated from a pool of 33 ingredients to develop energy prediction equations. Their most effective equation for predicting DE was a four-factor model that included NDF, ether extract, crude protein, and ash, which matches the variables in our most effective DE equation.

For prediction of ME concentration, Noblet and Perez (1993) suggested several equations, one of which included the nutrients: ash, ether extract, crude protein, and neutral detergent fiber ($R^2 = 0.92$). These are the same variables that were included in the most effective ME prediction equation ($R^2 = 0.9928$) determined in the current study. However, when using the equations from Noblet and Perez (1993) in an attempt to predict the ME content of the seven corn grains in this study, their ME content was overestimated by an average of 123 kcal/kg. The high-oil corn (Exp. 3, Corn B) was underestimated by 103 kcal/kg, while the six normal corn varieties were overestimated by an average of 161 kcal/kg. A wide range in ME content of the corns in this study was determined with a standard deviation of 137 kcal/kg. However, when predicted by the equations from Noblet and Perez (1993), the ME of all seven corn grains was relatively similar with a standard deviation of 10 kcal/kg.

It is important to note that the equations of Noblet and Perez (1993) are based upon 114 mixed diets consisting of 34 different feed ingredients. This would certainly indicate that a large variation in nutrient composition of the ingredients used in their experiment as compared to only using corn in our experiment. This may explain the lack of accurate prediction of the ME of corns in this study by using these equations. Formulating equations for specific feedstuffs may result in more accurate ME prediction.

Morgan et al. (1987) also developed equations to predict ME concentration of swine diets. One of the equations they produced included the same variables as our best ME equation: ash, crude protein, ether extract, and NDF. The authors suggested that this equation would be expected to give 79% of the predictions within 119 kcal/kg and 94% within 179 kcal/kg. When inserting the nutrient composition of the seven corn grains in this study into this ME equation, the ME concentrations of the corns were overestimated by only an average of 86 kcal/kg. The range in the difference between our analyzed ME concentration and the predicted ME concentration of the corns was –7 to 140 kcal/kg.

Just et al. (1984) reported that the best equation for estimating the ME concentration of 83 individual feedstuffs (excluding those of animal origin) contained the variables: crude protein, crude fiber, nitrogen free extract (NFE), NDF, gross energy, and organic matter ($R^2 = 0.86$). Crude fiber and NFE were not determined in our laboratory analysis, but the other variables in their equation were evaluated.

The large R-square values for the determined equations, in the present experiment, indicate that predicting the energy concentrations using the proximate analysis of these seven corns was effective with high accuracy.

Implications

Although several investigators have developed equations to predict the available energy content (digestible energy, metabolizable energy, or net energy) of mixed diets, equations using proximate analysis to predict the energy concentration of specific feedstuffs are limited. This study indicates that the nutrient composition of the seven corn grains accurately predicted their analyzed digestible and metabolizable energy concentration when fed to growing pigs. Further analysis of other corn varieties for nutrient composition and ME content is needed to insert into the equations formulated in this study to verify their accuracy.

Chapter VIII

Summary

Because cereal grains are the primary ingredient in swine diets with the purpose of serving as an energy source, the metabolizable energy concentration of these grains is of great importance. More specifically, corn is the most commonly used cereal grain in swine diets in the United States. Additionally, the availability of grain sorghum in the southern portion of the U.S., due to its drought resistance, requires its evaluation as an energy source in swine diets. However, the problem associated with using grain sorghums is their large variation in nutrient composition.

With the development of newer varieties or hybrids of corn and sorghum, the large variation in nutrient composition, including ME concentration, is evident. Therefore, we conducted several experiments to evaluate specific grain hybrids or varieties in which we fed experimental diets to individually-housed pigs in order to perform energy and nitrogen balance studies.

The experimental diets we utilized in these experiments met the nutrient requirements of the growing pigs. Thus, although the diets were predominantly comprised of the specific grain being tested, they were supplemented with a protein source, casein, in order to adequately meet the amino acid requirements of the pigs. Therefore, when using this type of protein-supplemented diet, we needed to determine the metabolizable energy concentration of the added casein. For future experiments, this value would need to be subtracted from the ME of the diets in order to determine the ME of the grain within the diet.

Thus, we initially conducted an experiment, Exp. 1, to determine the metabolizable energy concentration of casein. Pigs were fed one of two diets that contained equal amounts of corn and either sand or casein added to the diet. Amino acids were added appropriately to equalize the amino acid profile between the two diets. The difference in the ME of the two diets was utilized to calculate the ME concentration of casein. From this study, the metabolizable energy concentration of casein, on a DM basis, was 4,560 kcal/kg. This value would be used throughout the remaining experiments to evaluate the ME concentration of specific grain hybrids or varieties.

Experiment 2 was an energy and nitrogen balance study with growing pigs consuming one of three dietary treatments containing one of three corn hybrids (A, B, or C) that were grown in the same location during the same year. Digestible energy concentration of the diet containing Hybrid B was the highest and the DE of the diet containing Hybrid C was the lowest. However, ME concentrations of the three diets as well as the three corn hybrids (Table 8.1) were similar. Yet, metabolizable energy, as a percentage of gross energy, varied for the three diets. The diet containing Hybrid B was the highest and the diet containing Hybrid C was the lowest. This indicates that gross energy is not an accurate indicator of metabolizable energy concentration of the three corn hybrids in this experiment.

Fecal nitrogen excretion per day varied for the three diets, and thus, nitrogen absorption, as a percentage of intake, was higher for the diets containing Hybrids A and

B versus the diet containing Hybrid C. However, urine nitrogen excretion was similar resulting in similar nitrogen retention, as a percentage of nitrogen intake.

Table 8.1. Metabolizable energy concentration and ME:GE of the ten grains analyzed in Experiments 2, 3, and 4 (DM basis).

Grain	ME, kcal/kg	ME:GE
Exp. 2 (corns)		
A	3,958	0.910
B	3,988	0.923
C	3,916	0.877
Exp. 3 (corns)		
A	4,021	0.901
B	4,307	0.905
C	4,173	0.908
D	4,095	0.890
Exp. 4		
Corn	4,078	0.907
Red sorghum	3,704	0.846
White sorghum	3,751	0.849

In Exp. 3, the energy and nitrogen balance of growing pigs fed diets containing one of four corn grains (A, B, C, and D) was evaluated. Corns A and B were nearly isogenic with A being a normal variety, while corn B was a high-oil variety. Corns C and D were also normal varieties. Digestible energy and metabolizable energy concentrations of the four diets containing the four corns were significantly different from one another. Of the corns themselves, a wide variety in ME content existed (Table 8.1), with the high-oil variety (B) having the highest ME concentration. Although differences were observed for energy content of the grains, the efficiency of energy utilization was not different as shown by the similarities in the metabolizable energy to gross energy ratios. This experiment indicates that differences in ME concentration exist in newer corn varieties. As well, the chemical composition of a corn can dramatically affect its metabolizable energy concentration when fed to pigs. More specifically, it seems that grains higher in fat content result in higher gross energy concentrations, but the efficiency of which this energy is utilized is similar to corns containing relatively low amounts of fat. Nitrogen absorption and nitrogen retention, as a percentage of intake, were similar for pigs fed all four of the dietary treatments.

Initially in Experiment 4, twenty-two sorghum varieties that were grown within a 80-km radius of Hugoton, Kansas, were analyzed for their nutrient composition. The nutrient composition as well as Minolta color scores were highly variable for these 22 samples which agrees with the typical reputation of grain sorghum in general. Of these twenty-two sorghum samples, two samples were selected for use in an energy and nitrogen balance experiment. Thus, the major portion of Exp. 4 was performed with the purpose of determining the metabolizable energy concentration and nitrogen digestibility of a mill-run corn sample, a mill-run red sorghum sample, and an identity-preserved white endosperm sorghum variety.

For energy comparison, the diet containing the mill-run corn was higher in both digestible energy and metabolizable energy concentration as compared with the average of the two sorghums. In addition, metabolizable energy, as a percentage of gross energy, was higher for the corn as compared to the two sorghums, indicating a greater energy utilization efficiency. When comparing the two sorghums, the diet containing the white endosperm sorghum was numerically higher for DE and ME concentration as well as

ME:GE, although not significant. The ME of the grains indicated that the mill-run corn sample was about 350 kcal/kg greater than the average of the two sorghum samples (Table 8.1). The identity-preserved white endosperm sorghum was only about 50 kcal/kg higher in ME concentration versus the mill-run red sorghum.

The diet containing the corn sample, although lower in crude protein content as compared with the sorghum diets, was also superior for the nitrogen balance of growing pigs. The corn diet had approximately a 7-percentage unit advantage in nitrogen absorption, as a percentage of intake, and approximately a 3-percentage unit advantage in nitrogen retention, as a percentage of nitrogen intake. However, nitrogen balance was similar for pigs fed the diets containing the two sorghum samples.

After completion of these experiments, the analyzed nutrient composition, as well as the DE and ME concentrations, of the seven corns evaluated in Experiments 2 and 3 were utilized to develop equations to predict their metabolizable energy content. The equations that were developed accurately predicted the ME content of the seven corn grains as shown by the high R-square values. The equation determined to be the most optimum for predicting metabolizable energy concentration of corn fed to pigs was: $\mathrm{ME} = 3531.3 - 929.3\ (\%\ \mathrm{Ash}) + 75.1\ (\%\ \mathrm{Fat}) + 131.2\ (\%\ \mathrm{CP}) + 34.3\ (\%\ \mathrm{NDF}),\ R^2 = 0.9928$. More experiments are needed to determine the nutrient composition and metabolizable energy concentration of more corn varieties in order to verify the accuracy of the equations developed in this study.

These experiments suggest that variations exist in the metabolizable energy concentration, energy utilization efficiency, and nitrogen balance between corn and sorghum fed to growing pigs. Additionally, energy and nitrogen balance of pigs also varied for different varieties or hybrids within grain type. It is evident that the chemical composition of the grains had a tremendous effect on the realized ME concentration of the grains when fed to pigs. Because of this relationship, analyzed nutrient composition of grain may be utilized in equations to predict its metabolizable energy concentration when fed to pigs.

Variability of the grains analyzed in these experiments was certainly evident for all variables tested. For example, the eight corns evaluated in Experiments 2, 3, and 4, had a mean ME concentration of 4,067 ± 127 kcal/kg with a coefficient of variation (CV) of 3.12%. As well, ME, as percentage of GE, ranged from 87.7 to 91.0% for the eight corn grains. Variability was also observed for other nutrient contents of the grains evaluated. For the eight corns, the CVs were greater than 20% for acid detergent fiber, neutral detergent fiber, and ether extract. Additionally, the CV values for the twenty-two sorghum samples were greater than 12% for crude protein, ether extract, acid detergent fiber, and ash content. The color scores of the 22 sorghums were also highly variable with a*, a measurement of the degree of redness, having a CV of 37%. Due to the observed variability in available energy concentration and nutrient composition of the grains evaluated, the further development of even newer grain hybrids or varieties with specific traits will certainly add to this variability. Thus, the study of other new varieties of grain is necessary in order to assess their impact on nutrient variability and to identify the characteristics of specific varieties for more efficient diet formulation.

Chapter IX

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Appendix

Means and Analysis of Variance Tables

Appendix Table 1

Pig means for average daily feed intake, gross energy intake, fecal excretion, and urine excretion (DM basis) – Experiment 1.

Pen	Trt	Rep	ADFI (g)	GE intake (kcal/d)	Fecal excr. (g/d)	Urine excr. (g/d)
2	2	1	----	----	----	----
3	1	1	1273.5	5671.67	126.11	32.2
4	2	2	935.4	3898.33	103.33	22.0
5	1	2	1065.0	4743.28	108.43	25.8
6	2	3	851.7	3549.65	135.89	21.1
7	1	3	997.0	4440.54	83.06	23.0
10	2	4	679.5	2831.92	76.87	16.2
11	1	4	1096.0	4881.29	128.47	29.7

Trt 1: Casein (diet DM % = 88.28)
Trt 2: Sand (diet DM % = 88.44)

Dashes indicate data for this pig were removed from statistical analysis due to inaccurate fecal collection.

Appendix Table 2

Analysis of variance for average daily feed intake, gross energy intake, fecal excretion, and urine excretion (DM basis) – Experiment 1.

		Mean Squares			
Source	df	ADFI (g)	GE intake (kcal/d)	Fecal excr. (g/d)	Urine excr. (g/d)
Total	6				
Error	2	13008.9617	232901.161	1368.646650	19.3620975
Repetition	3	16578.01472	317441.528	110.0929472	10.34292943
Treatment	1	79672.32667	2387969.124	2.4961500	61.12935366
C.V., %		11.57	11.25	33.98	18.12

Appendix Table 3

Pig means for fecal energy excretion (kcal/kg, kcal/d) and urine energy excretion (kcal/kg, kcal/d) (DM basis) – Experiment 1.

Pen	Trt	Rep	Fecal energy (kcal/kg)	Fecal energy (kcal/d)	Urine energy (kcal/kg)	Urine energy (kcal/d)
2	2	1	----	----	----	----
3	1	1	4992.98	629.68	2702.06	87.011
4	2	2	3943.69	407.49	2112.27	46.511
5	1	2	4894.23	530.69	2471.39	63.817
6	2	3	3738.82	508.07	2269.84	47.893
7	1	3	4858.85	403.56	2646.19	60.774
10	2	4	4115.69	316.39	2144.59	34.703
11	1	4	4972.72	638.83	2374.78	70.444

Trt 1: Casein
Trt 2: Sand

Dashes indicate data for this pig were removed from statistical analysis due to inaccurate fecal collection.

Appendix Table 4

Analysis of variance for fecal energy excretion (kcal/kg, kcal/d) and urine energy excretion (kcal/kg, kcal/d) (DM basis) – Experiment 1.

		Mean Squares			
Source	df	Fecal energy (kcal/kg)	Fecal energy (kcal/d)	Urine energy (kcal/kg)	Urine energy (kcal/d)
Total	6				
Error	2	6060.658	22819.56035	3190.2136	73.500788
Repetition	3	20380.617	2933.92850	25573.8707	123.3255602
Treatment	1	1159093.354	19394.94615	155416.5393	724.4168640
C.V., %		1.82	30.79	2.36	14.59623

Appendix Table 5

Pig means for digestible energy and metabolizable energy of diets (kcal/kg) and DE and ME intake of pigs (kcal/d) (DM basis) – Experiment 1.

Pen	Trt	Rep	DE (kcal/kg)	DE (kcal/d)	ME (kcal/kg)	ME (kcal/d)
2	2	1	----	----	----	----
3	1	1	3959.28	5041.99	3890.95	4954.98
4	2	2	3731.98	3490.84	3682.26	3444.33
5	1	2	3955.44	4212.59	3895.52	4148.77
6	2	3	3571.09	3041.58	3514.86	2993.68
7	1	3	4048.98	4036.97	3988.03	3976.20
10	2	4	3702.00	2515.53	3650.93	2480.83
11	1	4	3870.87	4242.46	3806.59	4172.01

Trt 1: Casein
Trt 2: Sand

Dashes indicate data for this pig were removed from statistical analysis due to inaccurate fecal collection.

Appendix Table 6

Analysis of variance for digestible energy and metabolizable energy of diets (kcal/kg) and DE and ME intake of pigs (kcal/d) (DM basis) – Experiment 1.

		Mean Squares			
Source	df	DE (kcal/kg)	DE (kcal/d)	ME (kcal/kg)	ME (kcal/d)
Total	6				
Error	2	13600.6711	135034.704	14306.9640	129431.942
Repetition	3	1104.9342	269774.268	1237.7160	259456.427
Treatment	1	126213.8081	1976936.361	118185.9280	1901971.643
C.V., %		3.04	9.68	3.17	9.62

Appendix Table 7

Pig means for DE as a percentage of GE, ME as a percentage of DE, and ME as a percentage of GE (DM basis) – Experiment 1.

Pen	Trt	Rep	DE:GE %	ME:DE %	ME:GE %
2	2	1	----	----	----
3	1	1	88.90	98.27	87.36
4	2	2	89.55	98.67	88.35
5	1	2	88.81	98.49	87.47
6	2	3	85.69	98.43	84.34
7	1	3	90.91	98.49	89.54
10	2	4	88.83	98.62	87.60
11	1	4	86.91	98.34	85.47

Trt 1: Casein
Trt 2: Sand

Dashes indicate data for this pig were removed from statistical analysis due to inaccurate fecal collection.

Appendix Table 8

Analysis of variance for DE as a percentage of GE, ME as a percentage of DE, and ME as a percentage of GE (DM basis) – Experiment 1.

		Mean Squares		
Source	df	DE:GE %	ME:DE %	ME:GE %
Total	6			
Error	2	7.32446667	0.01526667	7.68815000
Repetition	3	0.59466944	0.01273611	0.67012222
Treatment	1	1.09226667	0.02666667	0.79935000
C.V., %		3.06	0.13	3.18

Appendix Table 9

Pig means for nitrogen intake, fecal nitrogen excretion, nitrogen absorbed, and percentage of nitrogen absorbed (DM basis) – Experiment 1.

Pen	Trt	Rep	N intake (g/d)	Fecal N (g/d)	N absorbed (g/d)	N absorption (% of intake)
2	2	1	----	----	----	----
3	1	1	30.2549	5.0109	25.2440	83.438
4	2	2	16.0082	2.9400	13.0682	81.634
5	1	2	25.3025	3.6022	21.7003	85.763
6	2	3	14.5764	3.9147	10.6616	73.143
7	1	3	23.6876	2.5938	21.0937	89.050
10	2	4	11.6291	2.1348	9.4943	81.643
11	1	4	26.0387	4.7324	21.3063	81.826

Trt 1: Casein
Trt 2: Sand

Dashes indicate data for this pig were removed from statistical analysis due to inaccurate fecal collection.

Appendix Table 10

Analysis of variance for nitrogen intake, fecal nitrogen excretion, nitrogen absorbed, and percentage of nitrogen absorbed (DM basis) – Experiment 1.

		Mean Squares			
Source	df	N intake (g/d)	Fecal N (g/d)	N absorbed (g/d)	N absorption (% of intake)
Total	6				
Error	2	4.5227385	1.94942509	1.2713240	33.4613647
Repetition	3	8.1509906	0.48100365	5.1879600	3.56343269
Treatment	1	179.4717980	0.62655553	158.8899544	68.13466017
C.V., %		10.09	38.90	6.44	7.02

Appendix Table 11

Pig means for urinary nitrogen excretion, nitrogen retained, percentage of nitrogen retained, and retention of nitrogen as a percentage of absorbed nitrogen (DM basis) – Experiment 1.

Pen	Trt	Rep	Urinary N (g/d)	N retained (g/d)	N retention (% of intake)	Ret:Abs N (%)
2	2	1	----	----	----	----
3	1	1	4.9325	20.312	67.135	80.461
4	2	2	3.1115	9.957	62.198	76.191
5	1	2	4.5747	17.126	67.683	78.919
6	2	3	3.1216	7.540	51.728	70.721
7	1	3	3.8819	17.212	72.662	81.597
10	2	4	2.5798	6.914	59.459	72.828
11	1	4	4.7724	16.534	63.498	77.601

Trt 1: Casein
Trt 2: Sand

Dashes indicate data for this pig were removed from statistical analysis due to inaccurate fecal collection.

Appendix Table 12

Analysis of variance for for urinary nitrogen excretion, nitrogen retained, percentage of nitrogen retained, and retention of nitrogen as a percentage of absorbed nitrogen (DM basis) – Experiment 1.

		Mean Squares			
Source	df	Urinary N (g/d)	N retained (g/d)	N retention (% of intake)	Ret:Abs N (%)
Total	6				
Error	2	0.24250840	0.9898462	42.2863145	8.17482717
Repetition	3	0.10614774	3.9522009	4.7522015	2.27921169
Treatment	1	3.37620011	115.9401042	152.3491260	54.77073067
C.V., %		12.69	7.30	10.26	3.73

Appendix Table 13

Pig means for average daily feed intake, gross energy intake, fecal excretion, and urine excretion (DM basis) – Experiment 2.

Pen	Trt	Rep	ADFI (g)	GE intake (kcal/d)	Fecal excr. (g/d)	Urine excr. (g/d)
1	3	1	972.28	4216.81	107.53	29.51
2	2	1	865.65	3736.79	71.52	24.56
3	1	1	905.68	3899.72	85.66	30.43
4	3	2	992.90	4306.24	112.47	30.05
5	1	2	820.73	3533.93	73.95	28.73
6	2	2	1057.81	4566.30	91.28	28.93
7	2	3	913.65	3943.99	89.88	25.77
8	3	3	1011.77	4388.07	90.85	29.76
9	1	4	1005.62	4330.04	51.27	41.45
10	3	4	1220.46	5293.20	145.06	42.28
11	2	4	1036.70	4475.17	113.28	43.57
12	1	3	1111.64	4786.55	104.06	39.48
13	1	5	1154.07	4969.21	109.51	32.98
14	3	5	869.43	3770.76	104.43	22.85
15	2	5	935.38	4037.82	67.57	31.15
16	3	8	1143.78	4960.62	126.40	39.38
17	3	6	1194.16	5179.11	129.88	31.10
18	2	6	1078.96	4657.59	111.51	32.59
19	1	6	----	----	----	----
20	2	7	1085.86	4687.38	79.89	35.00
21	3	7	1112.43	4824.66	97.12	37.02
22	1	7	1202.68	5178.53	118.85	40.54
23	2	8	941.96	4066.22	85.85	37.53
24	1	8	946.23	4074.32	97.96	29.93

Trt 1: Corn A (diet DM % = 89.20)
Trt 2: Corn B (diet DM % = 89.15)
Trt 3: Corn C (diet DM % = 89.42)

Dashes indicate data for this pig were removed from statistical analysis due to inadequate feed intake.

Appendix Table 14

Analysis of variance for average daily feed intake, gross energy intake, fecal excretion, and urine excretion (DM basis) – Experiment 2.

		Mean Squares			
Source	df	ADFI (g)	GE intake (kcal/d)	Fecal excr. (g/d)	Urine excr. (g/d)
Total	22				
Error	13	11118.5129	207239.8139	469.89906	17.4119291
Repetition	7	18335.0069	342348.7360	201.47098	73.3045352
Treatment	2	11509.7029	240485.7932	1407.77823	10.7605445
A vs B	1	8010.9508	133868.2261	109.23356	19.1006856
A vs C	1	2847.5295	85276.7422	1426.64037	13.6726728
B vs C	1	22597.6056	479210.0625	2574.54760	0.5011224
C.V., %		10.29	10.28	22.00	12.55

Appendix Table 15

Pig means for fecal energy excretion (kcal/kg, kcal/d) and urine energy excretion (kcal/kg, kcal/d) (DM basis) – Experiment 2.

Pen	Trt	Rep	Fecal energy (kcal/kg)	Fecal energy (kcal/d)	Urine energy (kcal/kg)	Urine energy (kcal/d)
1	3	1	4762.48	512.09	2022.10	59.668
2	2	1	4602.93	329.18	2133.71	52.407
3	1	1	4803.89	411.52	1886.02	57.396
4	3	2	4734.53	532.51	2127.58	63.939
5	1	2	4751.54	351.40	2367.26	68.000
6	2	2	4518.64	412.46	2101.17	60.794
7	2	3	4433.98	398.51	1633.59	42.102
8	3	3	4625.71	420.26	1882.60	56.018
9	1	4	4664.86	239.16	2006.65	83.180
10	3	4	4691.92	680.62	1766.16	74.674
11	2	4	4721.08	534.80	2014.00	87.756
12	1	3	4607.26	479.42	1974.08	77.933
13	1	5	4736.09	518.66	2026.39	66.823
14	3	5	4625.72	483.05	2058.18	47.027
15	2	5	4354.41	294.24	2145.92	66.836
16	3	8	4753.01	600.80	2242.78	88.312
17	3	6	4501.13	584.62	2213.07	68.819
18	2	6	4550.07	507.37	2425.57	79.042
19	1	6	----	----	----	----
20	2	7	4614.01	368.63	2343.17	82.011
21	3	7	4580.39	444.86	2335.16	86.441
22	1	7	4574.65	543.71	2322.53	94.158
23	2	8	4549.68	390.59	2433.93	91.345
24	1	8	4561.64	446.88	2471.06	73.956

Trt 1: Corn A
Trt 2: Corn B
Trt 3: Corn C

Dashes indicate data for this pig were removed from statistical analysis due to inadequate feed intake.

Appendix Table 16

Analysis of variance for fecal energy excretion (kcal/kg, kcal/d) and urine energy excretion (kcal/kg, kcal/d) (DM basis) – Experiment 2.

		Mean Squares			
Source	df	Fecal energy (kcal/kg)	Fecal energy (kcal/d)	Urine energy (kcal/kg)	Urine energy (kcal/d)
Total	22				
Error	13	8843.0850	10767.1298	15145.8828	90.08135
Repetition	7	12414.70588	3692.4693	121981.0340	477.48441
Treatment	2	35261.64313	34814.0432	19606.6786	92.58355
A vs B	1	49892.69912	4143.6777	2336.1475	86.07691
A vs C	1	5.67181	31929.6777	35002.4700	179.87975
B vs C	1	54066.71301	65408.0625	21316.0000	18.92250
C.V., %		2.03	22.76	5.78	13.40

Appendix Table 17

Pig means for digestible energy and metabolizable energy of diets (kcal/kg) and DE and ME intake of pigs (kcal/d) (DM basis) – Experiment 2.

Pen	Trt	Rep	DE (kcal/kg)	DE (kcal/d)	ME (kcal/kg)	ME (kcal/d)
1	3	1	3810.35	3704.72	3748.98	3645.05
2	2	1	3936.48	3407.60	3875.94	3355.20
3	1	1	3851.46	3488.21	3788.09	3430.81
4	3	2	3800.72	3773.73	3736.32	3709.79
5	1	2	3877.68	3182.54	3794.83	3114.54
6	2	2	3926.84	4153.85	3869.37	4093.05
7	2	3	3880.58	3545.49	3834.50	3503.39
8	3	3	3921.67	3967.81	3866.31	3911.79
9	1	4	4068.01	4090.88	3985.30	4007.70
10	3	4	3779.37	4612.58	3718.19	4537.91
11	2	4	3800.89	3940.37	3716.24	3852.62
12	1	3	3874.56	4307.13	3804.45	4229.19
13	1	5	3856.41	4450.55	3798.51	4383.73
14	3	5	3781.45	3287.72	3727.36	3240.69
15	2	5	4002.19	3743.58	3930.74	3676.75
16	3	8	3811.77	4359.82	3734.56	4271.51
17	3	6	3847.47	4594.49	3789.84	4525.67
18	2	6	3846.51	4150.22	3773.25	4071.18
19	1	6	----	----	----	----
20	2	7	3977.27	4318.75	3901.74	4236.74
21	3	7	3937.14	4379.79	3859.43	4293.35
22	1	7	3853.75	4634.82	3775.46	4540.66
23	2	8	3902.10	3675.63	3805.13	3584.29
24	1	8	3833.56	3627.44	3755.40	3553.49

Trt 1: Corn A
Trt 2: Corn B
Trt 3: Corn C

Dashes indicate data for this pig were removed from statistical analysis due to inadequate feed intake.

Appendix Table 18

Analysis of variance for digestible energy and metabolizable energy of diets (kcal/kg) and DE and ME intake of pigs (kcal/d) (DM basis) – Experiment 2.

		Mean Squares			
Source	df	DE (kcal/kg)	DE (kcal/d)	ME (kcal/kg)	ME (kcal/d)
Total	22				
Error	13	6541.9275	157077.0369	6319.0446	154030.3846
Repetition	7	1612.5692	293748.0523	1953.4298	276796.7806
Treatment	2	10976.0878	100962.0479	8751.4598	101655.7500
A vs B	1	2239.6185	90627.1818	2705.7100	85405.6452
A vs C	1	8364.0012	12970.0513	5357.7100	16097.5161
B vs C	1	21323.3006	190613.0111	17358.0625	194481.0000
C.V., %		2.09	9.97	2.09	10.06

Appendix Table 19

Pig means for DE as a percentage of GE, ME as a percentage of DE, and ME as a percentage of GE (DM basis) – Experiment 2.

Pen	Trt	Rep	DE:GE %	ME:DE %	ME:GE %
1	3	1	87.86	98.39	86.44
2	2	1	91.19	98.46	89.79
3	1	1	89.45	98.35	87.98
4	3	2	87.63	98.31	86.15
5	1	2	90.06	97.86	88.13
6	2	2	90.97	98.54	89.64
7	2	3	89.90	98.81	88.83
8	3	3	90.42	98.59	89.15
9	1	4	94.48	97.97	92.56
10	3	4	87.14	98.38	85.73
11	2	4	88.05	97.77	86.09
12	1	3	89.98	98.19	88.36
13	1	5	89.56	98.50	88.22
14	3	5	87.19	98.57	85.94
15	2	5	92.71	98.21	91.06
16	3	8	87.89	97.97	86.11
17	3	6	88.71	98.50	87.38
18	2	6	89.11	98.10	87.41
19	1	6	----	----	----
20	2	7	92.14	98.10	90.39
21	3	7	90.78	98.03	88.99
22	1	7	89.50	97.97	87.68
23	2	8	90.39	97.51	88.15
24	1	8	89.03	97.96	87.22

Trt 1: Corn A
Trt 2: Corn B
Trt 3: Corn C

Dashes indicate data for this pig were removed from statistical analysis due to inadequate feed intake.

Appendix Table 20

Analysis of variance for DE as a percentage of GE, ME as a percentage of DE, and ME as a percentage of GE (DM basis) – Experiment 2.

		Mean Squares		
		DE:GE	ME:DE	ME:GE
Source	df	%	%	%
Total	22			
Error	13	3.51390366	0.05697546	3.39315593
Repetition	7	0.86293197	0.17337007	1.04632904
Treatment	2	10.01942619	0.09759286	8.21051146
A vs B	1	0.43807604	0.01681152	0.59810625
A vs C	1	11.15048894	0.18001152	8.42293206
B vs C	1	17.72410000	0.09610000	14.95755625
C.V., %		2.09	0.243	2.09

Appendix Table 21

Pig means for nitrogen intake, fecal nitrogen excretion, nitrogen absorbed, and percentage of nitrogen absorbed (DM basis) – Experiment 2.

Pen	Trt	Rep	N intake (g/d)	Fecal N (g/d)	N absorbed (g/d)	N absorption (% of intake)
1	3	1	21.541	4.570	16.970	78.782
2	2	1	18.914	2.695	16.219	85.752
3	1	1	20.710	3.206	17.504	84.519
4	3	2	21.997	4.564	17.433	79.252
5	1	2	18.767	2.873	15.894	84.691
6	2	2	23.113	2.795	20.318	87.908
7	2	3	19.963	2.700	17.263	86.474
8	3	3	22.415	2.950	19.465	86.839
9	1	4	22.995	1.643	21.352	92.853
10	3	4	27.039	5.665	21.375	79.050
11	2	4	22.652	4.515	18.136	80.066
12	1	3	25.420	3.549	21.871	86.040
13	1	5	26.390	4.128	22.262	84.359
14	3	5	19.262	3.958	15.304	79.453
15	2	5	20.438	2.435	18.003	88.088
16	3	8	25.340	4.700	20.640	81.451
17	3	6	26.456	5.552	20.904	79.015
18	2	6	23.575	4.177	19.398	82.283
19	1	6	----	----	----	----
20	2	7	23.726	2.604	21.122	89.026
21	3	7	24.646	2.695	21.951	89.067
22	1	7	27.501	4.298	23.203	84.372
23	2	8	20.582	3.108	17.473	84.897
24	1	8	21.637	3.350	18.287	84.516

Trt 1: Corn A
Trt 2: Corn B
Trt 3: Corn C

Dashes indicate data for this pig were removed from statistical analysis due to inadequate feed intake.

Appendix Table 22

Analysis of variance for nitrogen intake, fecal nitrogen excretion, nitrogen absorbed, and percentage of nitrogen absorbed (DM basis) – Experiment 2.

		Mean Squares			
Source	df	N intake (g/d)	Fecal N (g/d)	N absorbed (g/d)	N absorption (% of intake)
Total	22				
Error	13	5.63432781	0.97420316	3.91119699	13.07686123
Repetition	7	9.10934561	0.64538923	7.94449029	9.85458860
Treatment	2	10.49066444	3.07264137	5.49778855	39.59554900
A vs B	1	15.47963364	0.38378194	10.99260111	0.02000928
A vs C	1	0.03847895	2.78046934	3.47375337	54.21375606
B vs C	1	15.47183223	5.79064064	2.33325625	62.35076406
C.V., %		10.40	27.44	10.28	4.29

Appendix Table 23

Pig means for urinary nitrogen excretion, nitrogen retained, percentage of nitrogen retained, and retention of nitrogen as a percentage of absorbed nitrogen (DM basis) – Experiment 2.

Pen	Trt	Rep	Urinary N (g/d)	N retained (g/d)	N retention (% of intake)	Ret:Abs N (%)
1	3	1	4.2561	12.714	59.023	74.920
2	2	1	3.3080	12.911	68.263	79.605
3	1	1	3.5513	13.952	67.371	79.711
4	3	2	4.0076	13.426	61.033	77.012
5	1	2	4.3982	11.496	61.256	72.329
6	2	2	3.8012	16.517	71.462	81.292
7	2	3	3.6421	13.621	68.230	78.902
8	3	3	3.8014	15.664	69.880	80.471
9	1	4	4.6406	16.711	72.672	78.266
10	3	4	5.4502	15.924	58.894	74.501
11	2	4	5.3029	12.833	56.656	70.761
12	1	3	5.1603	16.711	65.740	76.406
13	1	5	4.1021	18.160	68.815	81.574
14	3	5	2.7840	12.520	64.999	81.809
15	2	5	3.8501	14.153	69.250	78.615
16	3	8	4.5680	16.072	63.424	77.868
17	3	6	4.3057	16.599	62.740	79.403
18	2	6	4.3983	15.000	63.627	77.327
19	1	6	----	----	----	----
20	2	7	4.6920	16.430	69.250	77.786
21	3	7	4.8405	17.111	69.426	77.949
22	1	7	5.3637	17.840	64.869	76.884
23	2	8	4.6769	12.796	62.174	73.234
24	1	8	4.3871	13.900	64.240	76.010

Trt 1: Corn A
Trt 2: Corn B
Trt 3: Corn C

Dashes indicate data for this pig were removed from statistical analysis due to inadequate feed intake.

Appendix Table 24

Analysis of variance for urinary nitrogen excretion, nitrogen retained, percentage of nitrogen retained, and retention of nitrogen as a percentage of absorbed nitrogen (DM basis) – Experiment 2.

		Mean Squares			
Source	df	Urinary N (g/d)	N retained (g/d)	N retention (% of intake)	Ret:Abs N (%)
Total	22				
Error	13	0.25198466	3.41536722	21.34611442	8.38923329
Repetition	7	0.91734918	4.59001222	13.83005975	10.51124740
Treatment	2	0.21622573	3.66292575	15.71224128	1.35118344
A vs B	1	0.37741410	7.29352183	0.01503975	0.19371247
A vs C	1	0.28416896	1.77061825	22.59861689	1.17313457
B vs C	1	0.00731164	2.07801557	23.74564139	2.56886331
C.V., %		11.63	12.39	7.07	3.74

Appendix Table 25

Pig means for average daily feed intake, gross energy intake, fecal excretion, and urine excretion (DM basis) – Experiment 3.

Pen	Trt	Rep	ADFI (g)	GE intake (kcal/d)	Fecal excr. (g/d)	Urine excr. (g/d)
1	2	1	770.0	3632.67	88.4	5.18
2	1	1	1025.1	4538.88	92.1	16.82
3	3	1	878.3	3989.39	78.1	14.61
4	4	1	725.4	3268.98	86.1	15.27
5	2	2	1147.9	5415.64	108.3	26.98
6	1	2	1320.0	5844.66	127.4	29.54
7	3	2	1171.6	5321.59	114.0	27.50
8	4	2	1139.3	5134.44	114.0	20.34
9	2	3	1064.8	5023.74	99.8	28.91
10	4	3	----	----	----	----
11	3	3	1112.0	5050.66	114.5	18.09
12	1	3	935.8	4143.58	88.3	15.61
13	1	4	1476.7	6538.44	159.2	40.65
14	4	4	1081.2	4872.43	109.2	26.42
15	3	4	1384.1	6286.67	137.5	31.73
16	2	4	1241.8	5859.06	136.9	32.65
17	1	5	1477.3	6540.82	170.4	35.69
18	4	5	1614.4	7275.60	181.8	37.00
19	3	5	1445.9	6567.22	171.3	34.77
20	2	5	1429.8	6745.90	162.4	35.12
21	3	6	1124.7	5108.37	106.4	28.34
22	1	6	1153.3	5106.44	131.1	29.79
23	4	6	1089.4	4909.52	105.9	30.64
24	2	6	1074.3	5068.50	102.6	29.78

Trt 1: Corn A (diet DM % = 89.64)
Trt 2: Corn B (diet DM % = 89.51)
Trt 3: Corn C (diet DM % = 88.24)
Trt 4: Corn D (diet DM % = 89.44)

Dashes indicate data for this pig were removed from statistical analysis due to inadequate feed intake.

Appendix Table 26

Analysis of variance for average daily feed intake, gross energy intake, fecal excretion, and urine excretion (DM basis) – Experiment 3.

		Mean Squares			
Source	df	ADFI (g)	GE intake (kcal/d)	Fecal excr. (g/d)	Urine excr. (g/d)
Total	22				
Error	14	10457.626	211207.24	145.86961	22.139429
Repetition	5	194198.0200	4015955.16	3543.60676	275.166354
Treatment	3	19886.3833	238595.77	191.77154	10.109516
A vs B	1	36190.08333	77974.0530	409.5008333	7.50532467
A vs C	1	6120.08333	12604.8972	181.7408333	14.20231692
A vs D	1	44827.10588	628923.4743	435.6539739	28.17562169
B vs C	1	12545.33333	27877.9160	45.6300000	1.05886443
B vs D	1	1090.82647	281693.6565	3.4737288	7.47847243
C vs D	1	19110.00294	472774.8015	67.3878464	3.12614825
C.V., %		8.75	8.65	9.97	17.70

Appendix Table 27

Pig means for fecal energy excretion (kcal/kg, kcal/d) and urine energy excretion (kcal/kg, kcal/d) (DM basis) – Experiment 3.

Pen	Trt	Rep	Fecal energy (kcal/kg)	Fecal energy (kcal/d)	Urine energy (kcal/kg)	Urine energy (kcal/d)
1	2	1	4920.27	454.05	3272.11	16.947
2	1	1	4699.60	453.24	2490.03	41.891
3	3	1	4517.19	369.24	2475.13	36.168
4	4	1	4736.64	432.39	2547.98	38.909
5	2	2	4903.58	553.93	2450.86	66.128
6	1	2	4736.63	630.81	2431.94	71.845
7	3	2	4582.29	546.92	2500.14	68.765
8	4	2	4716.32	561.18	1889.29	38.428
9	2	3	4972.14	521.08	2782.10	80.427
10	4	3	----	----	----	----
11	3	3	4568.67	547.34	2682.54	48.527
12	1	3	4634.82	429.58	2696.99	42.108
13	1	4	4651.23	774.36	2375.78	96.566
14	4	4	4744.75	543.87	2452.74	64.808
15	3	4	4595.52	665.22	2393.50	75.956
16	2	4	4870.10	699.09	2348.14	76.661
17	1	5	4609.87	823.68	2519.32	89.909
18	4	5	4599.15	874.60	2407.60	89.075
19	3	5	4545.74	813.07	2778.02	96.601
20	2	5	4938.94	840.38	2581.77	90.662
21	3	6	4667.97	519.72	2604.02	73.786
22	1	6	4716.23	648.56	2652.92	79.038
23	4	6	4656.83	516.75	2602.72	79.744
24	2	6	4821.76	516.74	2517.51	74.976

Trt 1: Corn A
Trt 2: Corn B
Trt 3: Corn C
Trt 4: Corn D

Dashes indicate data for this pig were removed from statistical analysis due to inadequate feed intake.

Appendix Table 28

Analysis of variance for fecal energy excretion (kcal/kg, kcal/d) and urine energy excretion (kcal/kg, kcal/d) (DM basis) – Experiment 3.

		Mean Squares			
Source	Df	Fecal energy (kcal/kg)	Fecal energy (kcal/d)	Urine energy (kcal/kg)	Urine energy (kcal/d)
Total	22				
Error	14	3330.1709	3398.0880	43736.659	159.14160
Repetition	5	1677.9384	82486.8351	89906.1565	1673.774598
Treatment	3	112558.0341	4020.4990	57937.7424	97.810309
A vs B	1	158334.5107	2550.916800	51418.8300	20.1657613
A vs C	1	27170.0833	7436.136533	5912.7481	38.7145763
A vs D	1	776.9967	9900.868620	38697.2455	278.7654191
B vs C	1	316683.2790	1276.378133	22458.8616	2.9980003
B vs D	1	119646.2777	2710.287067	167868.3967	155.7019031
C vs D	1	33382.4962	342.297201	72331.8768	117.7576730
C.V., %		1.22	9.76	8.23	18.87

Appendix Table 29

Pig means for digestible energy and metabolizable energy of diets (kcal/kg) and DE and ME intake of pigs (kcal/d) (DM basis) – Experiment 3.

Pen	Trt	Rep	DE (kcal/kg)	DE (kcal/d)	ME (kcal/kg)	ME (kcal/d)
1	2	1	4128.33	3178.62	4106.32	3161.67
2	1	1	3985.48	4085.64	3944.61	4043.75
3	3	1	4121.62	3620.15	4080.45	3583.98
4	4	1	3910.47	2836.59	3856.83	2797.68
5	2	2	4235.46	4861.71	4177.85	4795.58
6	1	2	3949.74	5213.86	3895.32	5142.01
7	3	2	4075.22	4774.67	4016.53	4705.91
8	4	2	4014.00	4573.25	3980.28	4534.83
9	2	3	4228.67	4502.66	4153.14	4422.23
10	4	3	----	----	----	----
11	3	3	4049.80	4503.32	4006.16	4454.80
12	1	3	3968.58	3714.00	3923.59	3671.89
13	1	4	3903.24	5764.08	3837.85	5667.51
14	4	4	4003.53	4328.56	3943.58	4263.75
15	3	4	4061.41	5621.45	4006.53	5545.50
16	2	4	4155.09	5159.97	4093.36	5083.31
17	1	5	3870.05	5717.14	3809.18	5627.23
18	4	5	3964.82	6400.99	3909.65	6311.92
19	3	5	3979.68	5754.15	3912.87	5657.55
20	2	5	4130.28	5905.52	4066.87	5814.86
21	3	6	4079.92	4588.65	4014.31	4514.87
22	1	6	3865.27	4457.88	3796.74	4378.85
23	4	6	4032.22	4392.76	3959.02	4313.02
24	2	6	4237.03	4551.76	4167.24	4476.79

Trt 1: Corn A
Trt 2: Corn B
Trt 3: Corn C
Trt 4: Corn D

Dashes indicate data for this pig were removed from statistical analysis due to inadequate feed intake.

Appendix Table 30

Analysis of variance for digestible energy and metabolizable energy of diets (kcal/kg) and DE and ME intake of pigs (kcal/d) (DM basis) – Experiment 3.

		Mean Squares			
Source	Df	DE (kcal/kg)	DE (kcal/d)	ME (kcal/kg)	ME (kcal/d)
Total	22				
Error	14	2142.6766	177975.30	2201.3788	173151.45
Repetition	5	3565.7050	2971200.35	4422.7451	2843306.89
Treatment	3	74329.7186	198807.26	72791.5341	190797.37
A vs B	1	206063.0208	52319.5308	202147.9250	50284.8533
A vs C	1	56758.6320	678.1537	57347.4828	392.5064
A vs D	1	11658.0858	481020.6209	12031.0990	458132.7257
B vs C	1	46526.8987	41084.5519	44156.8404	41792.0624
B vs D	1	101398.5025	229151.5164	97748.4010	217356.9401
C vs D	1	13413.2430	447687.9596	13284.7919	433286.6169
C.V., %		1.15	8.94	1.18	8.95

Appendix Table 31

Pig means for DE as a percentage of GE, ME as a percentage of DE, and ME as a percentage of GE (DM basis) – Experiment 3.

Pen	Trt	Rep	DE:GE %	ME:DE %	ME:GE %
1	2	1	87.50	99.47	87.03
2	1	1	90.01	98.97	89.09
3	3	1	90.74	99.00	89.84
4	4	1	86.77	98.63	85.58
5	2	2	89.77	98.64	88.55
6	1	2	89.21	98.62	87.98
7	3	2	89.72	98.56	88.43
8	4	2	89.07	99.16	88.32
9	2	3	89.63	98.21	88.03
10	4	3	----	----	----
11	3	3	89.16	98.92	88.20
12	1	3	89.63	98.87	88.62
13	1	4	88.16	98.32	86.68
14	4	4	88.84	98.50	87.51
15	3	4	89.42	98.65	88.21
16	2	4	88.07	98.51	86.76
17	1	5	87.41	98.43	86.03
18	4	5	87.98	98.61	86.75
19	3	5	87.62	98.32	86.15
20	2	5	87.54	98.46	86.20
21	3	6	89.83	98.39	88.38
22	1	6	87.30	98.23	85.75
23	4	6	89.47	98.18	87.85
24	2	6	89.80	98.35	88.33

Trt 1: Corn A
Trt 2: Corn B
Trt 3: Corn C
Trt 4: Corn D

Dashes indicate data for this pig were removed from statistical analysis due to inadequate feed intake.

Appendix Table 32

Analysis of variance for DE as a percentage of GE, ME as a percentage of DE, and ME as a percentage of GE (DM basis) – Experiment 3.

		Mean Squares		
Source	Df	DE:GE %	ME:DE %	ME:GE %
Total	22			
Error	14	1.03846516	0.07261976	1.08527373
Repetition	5	1.70108822	0.26262200	2.14018956
Treatment	3	0.93249315	0.00501333	0.98936148
A vs B	1	0.02900833	0.00333333	0.04687500
A vs C	1	1.89607500	0.01333333	2.13363333
A vs D	1	0.01818680	0.00791059	0.00340944
B vs C	1	1.45603333	0.00333333	1.54800833
B vs D	1	0.08693337	0.00120471	0.06851974
C vs D	1	2.04005886	0.00038118	2.04626042
C.V., %		1.15	0.273	1.19

Appendix Table 33

Pig means for nitrogen intake, fecal nitrogen excretion, nitrogen absorbed, and percentage of nitrogen absorbed (DM basis) – Experiment 3.

Pen	Trt	Rep	N intake (g/d)	Fecal N (g/d)	N absorbed (g/d)	N absorption (% of intake)
1	2	1	17.4597	3.2213	14.2384	81.550
2	1	1	22.7711	2.9232	19.8478	87.163
3	3	1	20.9800	2.5876	18.3924	87.666
4	4	1	16.8755	3.4646	13.4109	79.469
5	2	2	26.0292	3.3140	22.7152	87.268
6	1	2	29.3220	4.3467	24.9753	85.176
7	3	2	27.9860	4.1002	23.8858	85.349
8	4	2	26.5055	4.4425	22.0630	83.239
9	2	3	24.1456	3.2587	20.8870	86.504
10	4	3	----	----	----	----
11	3	3	26.5612	4.4240	22.1372	83.344
12	1	3	20.7879	3.3107	17.4772	84.074
13	1	4	32.8026	5.0586	27.7440	84.579
14	4	4	25.1530	4.2796	20.8734	82.986
15	3	4	33.0614	5.1643	27.8971	84.380
16	2	4	28.1604	4.9182	23.2422	82.535
17	1	5	32.8146	5.7079	27.1066	82.605
18	4	5	37.5589	6.8470	30.7119	81.770
19	3	5	34.5368	6.9283	27.6085	79.939
20	2	5	32.4228	5.4284	26.9944	83.257
21	3	6	26.8647	3.7077	23.1570	86.199
22	1	6	25.6185	4.6339	20.9846	81.912
23	4	6	25.3444	3.5589	21.7855	85.958
24	2	6	24.3608	3.6254	20.7354	85.118

Trt 1: Corn A
Trt 2: Corn B
Trt 3: Corn C
Trt 4: Corn D

Dashes indicate data for this pig were removed from statistical analysis due to inadequate feed intake.

Appendix Table 34

Analysis of variance for nitrogen intake, fecal nitrogen excretion, nitrogen absorbed, and percentage of nitrogen absorbed (DM basis) – Experiment 3.

		Mean Squares			
Source	Df	N intake (g/d)	Fecal N (g/d)	N absorbed (g/d)	N absorption (% of intake)
Total	22				
Error	14	5.5401085	0.29719727	4.9012946	5.3207484
Repetition	5	102.8317531	4.86481703	64.3927180	5.46121854
Treatment	3	11.1401247	0.31498902	8.7669762	3.36773422
A vs B	1	11.09417160	0.40885208	7.24303870	0.04356075
A vs C	1	2.87473563	0.07224560	2.03569219	0.15595200
A vs D	1	7.70973616	0.01277819	8.34987446	6.05556066
B vs C	1	25.26365121	0.82482877	16.95846976	0.03466875
B vs D	1	0.12396920	0.50932039	0.13074641	7.05888265
C vs D	1	19.09069820	0.01944331	17.89153303	8.01884184
C.V., %		8.76	12.63	9.81	2.75

Appendix Table 35

Pig means for urinary nitrogen excretion, nitrogen retained, percentage of nitrogen retained, and retention of nitrogen as a percentage of absorbed nitrogen (DM basis) – Experiment 3.

Pen	Trt	Rep	Urinary N (g/d)	N retained (g/d)	N retention (% of intake)	Ret:Abs N (%)
1	2	1	1.4726	12.7659	73.116	89.658
2	1	1	2.5285	17.3193	76.058	87.261
3	3	1	2.2576	16.1348	76.906	87.725
4	4	1	2.3686	11.0423	65.434	82.338
5	2	2	3.7686	18.9466	72.790	83.410
6	1	2	4.3524	20.6229	70.332	82.573
7	3	2	3.9279	19.9579	71.314	83.555
8	4	2	3.4230	18.6401	70.325	84.486
9	2	3	4.6305	16.2564	67.327	77.830
10	4	3	----	----	----	----
11	3	3	3.4067	18.7305	70.518	84.611
12	1	3	3.0343	14.4428	69.477	82.638
13	1	4	6.1047	21.6393	65.968	77.996
14	4	4	4.3112	16.5622	65.846	79.346
15	3	4	4.9332	22.9639	69.458	82.316
16	2	4	4.9083	18.3339	65.105	78.882
17	1	5	5.1296	21.9771	66.974	81.076
18	4	5	5.3037	25.4082	67.649	82.731
19	3	5	5.0848	22.5237	65.216	81.582
20	2	5	5.5394	21.4550	66.173	79.479
21	3	6	4.2723	18.8847	70.296	81.551
22	1	6	4.1044	16.8802	65.891	80.441
23	4	6	4.0593	17.7262	69.941	81.367
24	2	6	4.5575	16.1779	66.410	78.021

Trt 1: Corn A
Trt 2: Corn B
Trt 3: Corn C
Trt 4: Corn D

Dashes indicate data for this pig were removed from statistical analysis due to inadequate feed intake.

Appendix Table 36

Analysis of variance for urinary nitrogen excretion, nitrogen retained, percentage of nitrogen retained, and retention of nitrogen as a percentage of absorbed nitrogen (DM basis) – Experiment 3.

		Mean Squares			
Source	df	Urinary N (g/d)	N retained (g/d)	N retention (% of intake)	Ret:Abs N (%)
Total	22				
Error	14	0.28299993	3.6706321	6.9608138	213.3894546
Repetition	5	5.03618032	35.5016348	26.1396317	26.8788944
Treatment	3	0.17050314	8.4228433	8.1085648	5.8152932
A vs B	1	0.01184408	6.66909390	1.19007008	1.84475208
A vs C	1	0.15672816	3.32211110	6.76200533	7.29300208
A vs D	1	0.42372708	5.01160245	4.73628424	0.00844011
B vs C	1	0.08240261	19.40512467	13.62561408	16.47363333
B vs D	1	0.30108787	0.03502021	1.32612575	1.40174283
C vs D	1	0.07788017	15.60848390	21.33458400	6.90954106
C.V., %		13.09	10.36	3.82	2.55

Appendix Table 37

Pig means for average daily feed intake, gross energy intake, fecal excretion, and urine excretion (DM basis) – Experiment 4.

Pen	Trt	Rep	ADFI (g)	GE intake (kcal/d)	Fecal excr. (g/d)	Urine excr. (g/d)
1	3	1	1331.76	5759.65	144.63	8.85
2	1	1	860.77	3834.15	73.99	31.18
3	2	1	1225.41	5307.42	110.95	15.24
4	2	2	1254.96	5435.40	175.83	13.40
5	1	2	1078.68	4804.81	87.45	17.47
6	3	2	1096.39	4741.72	121.16	8.26
7	2	3	1204.86	5218.41	188.78	13.72
8	3	3	967.36	4183.68	106.11	66.52
9	2	4	1237.52	5359.88	167.70	20.23
10	1	4	----	----	----	----
11	3	4	787.33	3405.09	92.15	9.43
12	1	3	716.17	3190.06	63.07	20.18
13	1	5	1100.94	4903.96	94.28	19.99
14	3	5	1101.75	4764.91	131.65	7.79
15	2	5	846.22	3665.12	163.40	11.70
16	2	6	1470.13	6367.34	185.81	27.52
17	1	8	1090.63	4858.03	85.82	28.52
18	2	8	776.75	3364.21	96.33	14.82
19	3	8	1111.64	4807.67	131.40	18.07
20	3	7	1355.36	5861.71	172.43	20.87
21	1	7	1310.53	5837.54	129.95	32.44
22	2	7	951.02	4119.02	146.16	19.09
23	1	6	1594.30	7101.52	142.36	37.18
24	3	6	1263.38	5463.95	142.30	20.82
25	2	9	1385.4	5954.33	194.62	22.66
26	1	9	1369.8	5968.14	137.13	30.57
27	3	9	1504.1	6383.29	211.13	20.38
28	1	10	1264.3	5550.72	119.19	29.93
29	3	10	1589.2	6744.51	235.02	18.34
30	2	10	1381.2	5891.17	164.08	16.73
31	2	11	1646.2	7021.68	245.75	25.39
32	1	11	1282.2	5629.45	75.76	38.88
33	1	12	1262.6	5490.04	119.79	22.31
34	3	12	1023.6	4386.15	98.73	13.48
35	2	12	1492.6	6366.46	197.56	27.64
36	3	11	1303.5	5531.80	138.66	20.46

Trt 1: Mill-run corn (Diet DM % = 88.33)
Trt 2: Mill-run red sorghum (Diet DM % = 90.23)
Trt 3: Identity-preserved white endosperm sorghum (Diet DM % = 90.50)

Dashes indicate data for this pig were removed from statistical analysis due to inadequate feed intake.

Appendix Table 38

Analysis of variance for gross energy intake, fecal excretion, and urine excretion (DM basis) – Experiment 4.

		Mean Squares		
Source	df	GE intake (kcal/d)	Fecal excr. (g/d)	Urine excr. (g/d)
Total	34			
Error	20	753.11	464.53976	116.389526
Repetition	11	4861.31	436.94105	101.410297
ADFI[a]	1	15902174.18	16420.02841	39.322470
Treatment	2	73010.89	9207.13775	279.373015
Corn vs Sorg	1	144690.4778	16042.49198	557.2600774
Red vs White	1	879.1430	2597.69789	2.6985190
C.V., %		0.524	15.42	49.03

[a] Average daily feed intake (DM basis) was used as a covariate in analysis.

Appendix Table 39

Pig means for fecal energy excretion (kcal/kg, kcal/d) and urine energy excretion (kcal/kg, kcal/d) (DM basis) – Experiment 4.

Pen	Trt	Rep	Fecal energy (kcal/kg)	Fecal energy (kcal/d)	Urine energy (kcal/kg)	Urine energy (kcal/d)
1	3	1	5119.02	740.38	2426.87	21.475
2	1	1	4820.12	356.63	2650.29	82.628
3	2	1	5030.56	558.17	2691.09	41.023
4	2	2	4885.01	858.93	2470.21	33.110
5	1	2	4830.38	422.42	2338.00	40.844
6	3	2	5179.93	627.60	2802.14	23.141
7	2	3	4801.15	906.37	2444.11	33.536
8	3	3	5303.50	562.77	2868.31	190.788
9	2	4	4835.45	810.88	2527.69	51.147
10	1	4	----	----	----	----
11	3	4	5210.80	480.19	2760.72	26.027
12	1	3	5039.04	317.84	2453.35	49.504
13	1	5	4761.78	448.96	2157.62	43.121
14	3	5	5140.72	676.76	2103.55	16.381
15	2	5	4610.60	753.36	2178.61	25.495
16	2	6	4631.01	860.48	2654.79	73.066
17	1	8	4776.35	409.93	2260.62	64.475
18	2	8	4772.89	459.78	2763.12	40.955
19	3	8	5046.73	663.12	2937.52	53.072
20	3	7	4956.03	854.58	2870.85	59.910
21	1	7	4654.75	604.90	2569.43	83.364
22	2	7	4620.18	675.30	3260.91	62.238
23	1	6	4808.92	684.61	2283.72	84.917
24	3	6	5142.84	731.80	2905.78	60.508
25	2	9	4780.73	930.43	2799.90	63.436
26	1	9	4789.22	656.76	2596.97	79.393
27	3	9	4964.03	1048.04	2798.56	57.046
28	1	10	4659.21	555.33	2305.01	68.984
29	3	10	4874.09	1145.52	2807.22	51.494
30	2	10	4722.21	774.83	2687.59	44.958
31	2	11	4744.05	1165.85	2686.53	68.214
32	1	11	4842.79	366.90	2441.20	94.915
33	1	12	4761.21	570.35	1868.84	41.688
34	3	12	4998.66	493.50	3116.67	42.010
35	2	12	4711.06	930.71	2663.41	73.620
36	3	11	4888.61	677.84	2820.09	57.707

Trt 1: Mill-run corn
Trt 2: Mill-run red sorghum
Trt 3: Identity-preserved white endosperm sorghum

Dashes indicate data for this pig were removed from statistical analysis due to inadequate feed intake.

Appendix Table 40

Analysis of variance for fecal energy excretion (kcal/kg, kcal/d) and urine energy excretion (kcal/kg, kcal/d) (DM basis) – Experiment 4.

Source	df	Mean Squares Fecal energy (kcal/kg)	Fecal energy (kcal/d)	Urine energy (kcal/kg)	Urine energy (kcal/d)
Total	34				
Error	20	8269.680	9628.740	33953.158	969.45614
Repetition	11	21308.2823	9616.4317	117561.199	919.26539
ADFI[a]	1	766.3372	390829.6823	315345.800	36.36482
Treatment	2	326579.9865	216934.7317	593493.277	637.61612
Corn vs Sorg	1	89857.7106	417504.8343	1125737.317	1177.753321
Red vs White	1	555070.5384	19462.2054	52163.189	109.994586
C.V., %		1.86	14.44	7.09	54.37

[a] Average daily feed intake (DM basis) was used as a covariate in analysis.

Appendix Table 41

Pig means for digestible energy and metabolizable energy of diets (kcal/kg) and DE and ME intake of pigs (kcal/d) (DM basis) – Experiment 4.

Pen	Trt	Rep	DE (kcal/kg)	DE (kcal/d)	ME (kcal/kg)	ME (kcal/d)
1	3	1	3768.91	5019.27	3752.78	4997.80
2	1	1	4040.01	3477.52	3944.02	3394.89
3	2	1	3875.66	4749.25	3842.18	4708.23
4	2	2	3646.72	4576.47	3620.33	4543.36
5	1	2	4062.72	4382.39	4024.86	4341.55
6	3	2	3752.43	4114.12	3731.32	4090.98
7	2	3	3578.89	4312.04	3551.05	4278.51
8	3	3	3743.09	3620.91	3545.86	3430.12
9	2	4	3675.90	4549.00	3634.57	4497.85
10	1	4	----	----	----	----
11	3	4	3714.96	2924.90	3681.90	2898.87
12	1	3	4010.53	2872.22	3941.41	2822.72
13	1	5	4046.53	4455.00	4007.36	4411.88
14	3	5	3710.59	4088.15	3695.72	4071.77
15	2	5	3440.89	2911.76	3410.76	2886.27
16	2	6	3745.84	5506.86	3696.14	5433.79
17	1	8	4078.47	4448.10	4019.35	4383.63
18	2	8	3739.22	2904.43	3686.50	2863.48
19	3	8	3728.33	4144.55	3680.58	4091.47
20	3	7	3694.33	5007.13	3650.13	4947.22
21	1	7	3992.76	5232.64	3929.15	5149.28
22	2	7	3621.07	3443.72	3555.63	3381.49
23	1	6	4024.92	6416.91	3971.65	6332.00
24	3	6	3745.61	4732.15	3697.72	4671.64
25	2	9	3626.43	5023.90	3580.64	4960.46
26	1	9	3877.48	5311.38	3819.52	5231.99
27	3	9	3547.10	5335.25	3509.18	5278.21
28	1	10	3951.08	4995.40	3896.51	4926.41
29	3	10	3523.09	5598.99	3490.68	5547.50
30	2	10	3704.37	5116.34	3671.82	5071.38
31	2	11	3557.17	5855.83	3515.73	5787.62
32	1	11	4104.17	5262.54	4030.15	5167.63
33	1	12	3896.37	4919.69	3863.35	4878.00
34	3	12	3802.97	3892.65	3761.93	3850.64
35	2	12	3641.82	5435.76	3592.50	5362.14
36	3	11	3723.86	4853.96	3679.59	4796.26

Trt 1: Mill-run corn
Trt 2: Mill-run red sorghum
Trt 3: Identity-preserved white endosperm sorghum

Dashes indicate data for this pig were removed from statistical analysis due to inadequate feed intake.

Appendix Table 42

Analysis of variance for digestible energy and metabolizable energy of diets (kcal/kg) and DE and ME intake of pigs (kcal/d) (DM basis) – Experiment 4.

		Mean Squares			
Source	df	DE (kcal/kg)	DE (kcal/d)	ME (kcal/kg)	ME (kcal/d)
Total	34				
Error	20	7272.043	13244.28	7515.916	12754.18
Repetition	11	9351.1621	15341.53	10254.4881	17041.37
ADFI[a]	1	4279.6905	11307019.53	976.2680	11266509.65
Treatment	2	378950.1649	531059.37	354775.5379	495567.10
Corn vs Sorg	1	747829.5603	1053758.296	701891.7526	984482.0828
Red vs White	1	13425.0190	12068.080	10516.1460	9873.4589
C.V., %		2.25	2.53	2.32	2.51

[a] Average daily feed intake (DM basis) was used as a covariate in analysis.

Appendix Table 43

Pig means for DE as a percentage of GE, ME as a percentage of DE, and ME as a percentage of GE (DM basis) – Experiment 4.

Pen	Trt	Rep	DE:GE %	ME:DE %	ME:GE %
1	3	1	87.15	99.57	86.77
2	1	1	90.70	97.62	88.54
3	2	1	89.48	99.14	88.71
4	2	2	84.20	99.28	83.59
5	1	2	91.21	99.07	90.36
6	3	2	86.76	99.44	86.28
7	2	3	82.63	99.22	81.99
8	3	3	86.55	94.73	81.99
9	2	4	84.87	98.88	83.92
10	1	4	----	----	----
11	3	4	85.90	99.11	85.13
12	1	3	90.04	98.28	88.48
13	1	5	90.84	99.03	89.97
14	3	5	85.80	99.60	85.45
15	2	5	79.45	99.12	78.75
16	2	6	86.49	98.67	85.34
17	1	8	91.56	98.55	90.23
18	2	8	86.33	98.59	85.12
19	3	8	86.21	98.72	85.10
20	3	7	85.42	98.80	84.40
21	1	7	89.64	98.41	88.21
22	2	7	83.61	98.19	82.09
23	1	6	90.36	98.68	89.16
24	3	6	86.61	98.72	85.50
25	2	9	84.37	98.74	83.31
26	1	9	89.00	98.51	87.67
27	3	9	83.58	98.93	82.69
28	1	10	90.00	98.62	88.75
29	3	10	83.02	99.08	82.25
30	2	10	86.85	99.12	86.08
31	2	11	83.40	98.84	82.42
32	1	11	93.48	98.20	91.80
33	1	12	89.61	99.15	88.85
34	3	12	88.75	98.92	87.79
35	2	12	85.38	98.65	84.22
36	3	11	87.75	98.81	86.70

Trt 1: Mill-run corn
Trt 2: Mill-run red sorghum
Trt 3: Identity-preserved white endosperm sorghum

Dashes indicate data for this pig were removed from statistical analysis due to inadequate feed intake.

Appendix Table 44

Analysis of variance for DE as a percentage of GE, ME as a percentage of DE, and ME as a percentage of GE (DM basis) – Experiment 4.

		Mean Squares		
		DE:GE	ME:DE	ME:GE
Source	df	%	%	%
Total	34			
Error	20	3.4175009	0.65892738	3.5922979
Repetition	11	3.9397285	0.65596409	4.3653181
ADFI[a]	1	1.6464315	0.76175886	0.2521571
Treatment	2	94.7051868	0.12967392	86.8511964
Corn vs Sorg	1	180.5550113	0.15872119	166.5822327
Red vs White	1	10.3466171	0.10518359	8.4083022
C.V., %		2.12	0.822	2.21

[a] Average daily feed intake (DM basis) was used as a covariate in analysis.

Appendix Table 45

Pig means for nitrogen intake, fecal nitrogen excretion, nitrogen absorbed, and percentage of nitrogen absorbed (DM basis) – Experiment 4.

Pen	Trt	Rep	N intake (g/d)	Fecal N (g/d)	N absorbed (g/d)	N absorption (% of intake)
1	3	1	34.7735	5.5697	29.2038	83.983
2	1	1	20.8747	2.4046	18.4701	88.481
3	2	1	31.9580	3.8203	28.1378	88.046
4	2	2	32.7287	5.5412	27.1875	83.069
5	1	2	26.1594	2.6262	23.5332	89.961
6	3	2	28.6278	4.7962	23.8316	83.246
7	2	3	31.4221	6.5748	24.8473	79.076
8	3	3	25.2586	4.2132	21.0454	83.320
9	2	4	32.2739	5.1217	27.1523	84.131
10	1	4	----	----	----	----
11	3	4	20.5579	3.6897	16.8682	82.052
12	1	3	17.3680	2.1965	15.1715	87.353
13	1	5	26.6992	3.1577	23.5415	88.173
14	3	5	28.7678	5.5636	23.2042	80.660
15	2	5	22.0691	5.0294	17.0398	77.211
16	2	6	38.3402	5.8318	32.5085	84.789
17	1	8	26.4491	2.7194	23.7298	89.718
18	2	8	20.2572	2.9293	17.3280	85.540
19	3	8	29.0259	5.5416	23.4843	80.908
20	3	7	35.3896	7.2453	28.1443	79.527
21	1	7	31.7820	3.9819	27.8001	87.471
22	2	7	24.8023	5.1247	19.6775	79.338
23	1	6	38.6637	4.4212	34.2425	88.565
24	3	6	32.9882	5.7703	27.2179	82.508
25	2	9	36.1295	7.8526	28.2769	78.265
26	1	9	33.2194	4.7661	28.4533	85.653
27	3	9	39.2739	9.9799	29.2940	74.589
28	1	10	30.6611	4.6414	26.0197	84.862
29	3	10	41.4963	10.4687	31.0276	74.772
30	2	10	36.0201	6.7358	29.2842	81.300
31	2	11	42.9323	9.6605	33.2718	77.498
32	1	11	31.0960	2.9310	28.1650	90.574
33	1	12	30.6204	3.5506	27.0698	88.404
34	3	12	26.7267	4.1178	22.6089	84.593
35	2	12	38.9262	7.3926	31.5336	81.009
36	3	11	34.0350	6.7768	27.2582	80.089

Trt 1: Mill-run corn
Trt 2: Mill-run red sorghum
Trt 3: Identity-preserved white endosperm sorghum

Dashes indicate data for this pig were removed from statistical analysis due to inadequate feed intake.

Appendix Table 46

Analysis of variance for nitrogen intake, fecal nitrogen excretion, nitrogen absorbed, and percentage of nitrogen absorbed (DM basis) – Experiment 4.

		Mean Squares			
Source	df	N intake (g/d)	Fecal N (g/d)	N absorbed (g/d)	N absorption (% of intake)
Total	34				
Error	20	0.055804	0.8139091	0.6332110	5.4966766
Repetition	11	0.0255341	1.54169613	1.4844352	13.1461188
ADFI[a]	1	556.0084693	23.48208791	350.9638891	4.4138631
Treatment	2	17.1476363	22.05334683	0.6223343	171.4225945
Corn vs Sorg	1	34.27161376	43.07628050	0.50276849	337.2464441
Red vs White	1	0.00236795	0.80473064	0.71989153	4.1453135
C.V., %		0.767	17.28	3.11	2.81

[a] Average daily feed intake (DM basis) was used as a covariate in analysis.

Appendix Table 47

Pig means for urinary nitrogen excretion, nitrogen retained, percentage of nitrogen retained, and retention of nitrogen as a percentage of absorbed nitrogen (DM basis) – Experiment 4.

Pen	Trt	Rep	Urinary N (g/d)	N retained (g/d)	N retention (% of intake)	Ret:Abs N (%)
1	3	1	3.6135	25.590	73.591	87.627
2	1	1	3.8411	14.629	70.080	79.204
3	2	1	3.6505	24.487	76.623	87.026
4	2	2	3.8795	23.308	71.216	85.731
5	1	2	4.4649	19.068	72.893	81.027
6	3	2	2.3745	21.457	74.952	90.036
7	2	3	3.2712	21.576	68.665	86.835
8	3	3	2.9733	18.072	71.548	85.872
9	2	4	3.4922	23.660	73.310	87.139
10	1	4	----	----	----	----
11	3	4	2.2139	14.654	71.283	86.875
12	1	3	3.6567	11.515	66.299	75.898
13	1	5	4.3668	19.175	71.817	81.450
14	3	5	4.0983	19.106	66.414	82.338
15	2	5	2.5432	14.497	65.687	85.075
16	2	6	6.3661	26.142	68.185	80.417
17	1	8	4.7232	19.007	71.861	80.096
18	2	8	3.2930	14.035	69.284	80.996
19	3	8	3.2144	20.270	69.834	86.313
20	3	7	5.1336	23.011	65.021	81.760
21	1	7	6.4273	21.373	67.248	76.880
22	2	7	3.9231	15.754	63.520	80.063
23	1	6	4.2333	30.009	77.616	87.637
24	3	6	4.5813	22.637	68.620	83.168
25	2	9	3.4649	24.812	68.675	87.747
26	1	9	3.1499	25.303	76.171	88.929
27	3	9	2.7560	26.538	67.571	90.592
28	1	10	3.6955	22.324	72.809	85.797
29	3	10	3.8805	27.147	65.420	87.493
30	2	10	2.1882	27.096	75.225	92.528
31	2	11	2.8529	30.419	70.853	91.426
32	1	11	5.9039	22.261	71.588	79.038
33	1	12	3.0346	24.035	78.494	88.790
34	3	12	4.4891	18.120	67.797	80.144
35	2	12	4.0113	27.522	70.704	87.279
36	3	11	3.2055	24.053	70.670	88.240

Trt 1: Mill-run corn
Trt 2: Mill-run red sorghum
Trt 3: Identity-preserved white endosperm sorghum

Dashes indicate data for this pig were removed from statistical analysis due to inadequate feed intake.

Appendix Table 48

Analysis of variance for urinary nitrogen excretion, nitrogen retained, percentage of nitrogen retained, and retention of nitrogen as a percentage of absorbed nitrogen (DM basis) – Experiment 4.

		Mean Squares			
Source	df	Urinary N (g/d)	N retained (g/d)	N retention (% of intake)	Ret:Abs N (%)
Total	34				
Error	20	0.84274598	0.9470657	9.9515551	10.6625420
Repetition	11	1.23832106	1.5671041	16.7371150	14.9362739
ADFI[a]	1	0.81401895	317.9700755	27.7881680	72.2454209
Treatment	2	2.02071061	1.1909524	38.8613903	32.1360305
Corn vs Sorg	1	4.04046511	1.69284380	75.40337175	63.91710501
Red vs White	1	0.00002684	0.72816838	1.86808406	0.20440963
C.V., %		24.16	4.47	4.47	3.85

[a] Average daily feed intake (DM basis) was used as a covariate in analysis.

Appendix Table 49

Analysis of twenty-two sorghum grains for percentage of dry matter, gross energy concentration (kcal/kg), percentage of nitrogen, and percentage of crude protein – Experiment 4.

		DM basis		
Sorghum Grain	DM (%)	GE (kcal/kg)	Nitrogen (%)	CP (%)
White sorghum*	89.778	4423.34	1.681	10.51
Mill-run red sorghum*	89.819	4377.46	1.675	10.47
GH H-388W Stevens Co.	90.169	4455.18	1.473	9.21
GH H296W Stevens Co.	90.910	4445.48	1.610	10.06
7W97 - NC+	91.127	4419.61	1.673	10.46
A504 Asgrow	91.506	4427.11	1.655	10.34
GH H-430Y Stevens Co.	84.574	4630.99	1.390	8.69
White on Tan 5530 Stevens Co.	86.487	4567.33	1.366	8.54
GH 5530 Dryland	91.784	4350.64	1.306	8.16
GH 588W Dryland	91.501	4411.22	1.460	9.13
White on Tan 5525 Stevens Co.	85.527	4546.63	1.287	8.05
DeKalb 41Y	88.810	4502.86	1.914	11.96
GH 5525 Dryland	91.206	4354.62	1.349	8.43
Asgrow 504	90.459	4416.78	1.643	10.27
H-495W Stevens Co.	84.192	4674.08	1.427	8.92
H-495W Ford Co.	83.809	4739.61	1.886	11.79
White on Tan 5525 Ford Co.	85.330	4600.69	1.558	9.74
H-505 BW Ford Co.	84.266	4699.41	1.726	10.79
White on Tan 5530 Ford Co.	84.532	4682.45	1.587	9.92
H-499Y Ford Co.	83.549	4718.17	1.624	10.15
5491 Stevens Co.	84.458	4644.37	1.332	8.32
H-499Y Stevens Co.	84.323	4642.87	1.252	7.82

*used in energy and nitrogen balance study in Experiment 4 (Chapter 6)

Appendix Table 50

Analysis of twenty-two sorghum grains for percentages of ether extract, acid detergent fiber (ADF), and ash (DM basis) – Experiment 4.

Sorghum Grain	Ether extract (%)	ADF (%)	Ash (%)
White sorghum*	2.185	5.718	2.467
Mill-run red sorghum*	2.337	6.256	2.821
GH H-388W Stevens Co.	4.213	5.885	1.533
GH H296W Stevens Co.	3.014	6.419	1.860
7W97 – NC+	3.090	6.862	1.510
A504 Asgrow	2.590	6.038	1.488
GH H-430Y Stevens Co.	2.303	6.156	1.869
White on Tan 5530 Stevens Co.	3.417	4.493	1.620
GH 5530 Dryland	3.673	4.700	1.668
GH 588W Dryland	3.556	5.693	1.751
White on Tan 5525 Stevens Co.	2.962	4.067	1.635
DeKalb 41Y	2.940	7.283	2.005
GH 5525 Dryland	3.130	4.600	1.590
Asgrow 504	2.967	6.635	1.784
H-495W Stevens Co.	2.602	5.482	1.516
H-495W Ford Co.	2.421	7.136	1.543
White on Tan 5525 Ford Co.	1.991	5.648	1.386
H-505 BW Ford Co.	2.396	6.444	1.493
White on Tan 5530 Ford Co.	2.502	6.123	1.443
H-499Y Ford Co.	2.297	5.842	1.432
5491 Stevens Co.	2.998	4.935	1.543
H-499Y Stevens Co.	2.362	4.369	1.575

*used in energy and nitrogen balance study in Experiment 4 (Chapter 6)

Appendix Table 51

Analysis of twenty-two sorghum grains for Minolta color scores (L*, a*, and b*) – Experiment 4.[a]

Sorghum Grain	L*	a*	b*
White sorghum[b]	78.74	2.81	12.28
Mill-run red sorghum[b]	75.51	4.06	14.46
GH H-388W Stevens Co.	79.73	3.62	9.90
GH H296W Stevens Co.	78.47	2.41	10.86
7W97 – NC+	82.00	1.21	12.90
A504 Asgrow	79.58	2.83	10.32
GH H-430Y Stevens Co.	80.56	3.88	13.62
White on Tan 5530 Stevens Co.	82.28	1.64	15.09
GH 5530 Dryland	84.09	1.07	13.74
GH 588W Dryland	80.31	3.68	10.68
White on Tan 5525 Stevens Co.	84.00	1.47	13.61
DeKalb 41Y	79.82	2.49	15.12
GH 5525 Dryland	83.67	1.31	13.49
Asgrow 504	79.17	2.79	11.17
H-495W Stevens Co.	81.25	3.77	13.61
H-495W Ford Co.	78.52	3.46	13.96
White on Tan 5525 Ford Co.	82.52	1.56	14.20
H-505 BW Ford Co.	78.90	3.71	13.83
White on Tan 5530 Ford Co.	81.41	1.67	16.60
H-499Y Ford Co.	80.66	2.61	14.00
5491 Stevens Co.	82.08	3.63	12.89
H-499Y Stevens Co.	83.06	3.27	12.99

[a] Means of three measurements per sample.

[b] Used in energy and nitrogen balance study in Experiment 4 (Chapter 6).

2

VITA

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Candidate for the Degree of

Master of Science

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