EFFECTS OF BODY WEIGHT AND RESEARCH CONDITIONS ON THE PRODUCTIVE ENERGY CONTENT OF CORN GERM MEAL FED TO GROWING-FINISHING PIGS

BY

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DISSERTATION

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ABSTRACT: Four experiments were conducted to investigate the effect of corn germ meal (CGM) inclusion level on growth performance and carcass traits of pigs, and to determine the productive energy (PE) of CGM by correcting ME estimates for caloric efficiency relative to a control (reference diet). All four experiments used a RCBD. The first two experiments were conducted from weaning (~6.5 kg BW) to finishing (~130 kg BW) at a commercial facility with CGM inclusions that ranged from 0 (Control) to 40%. The corn-soybean meal-based control diet (0% CGM) was used as the reference diet to compare with the CGM diets to estimate PE. Caloric efficiency (calories consumed per unit of weight gain) was calculated for each treatment using the feed:gain ratio. The ME value of CGM used to formulate diets in the first experiment was 3,037 kcal/kg. In this study, increasing CGM level linearly increased feed:gain ($P < 0.05$); based on these results the estimate of productive ME for CGM was 2,604 kcal/kg. In the second study, CGM diets were formulated using the ME value from the first experiment. In this study, increasing CGM inclusion level linearly increased ($P < 0.05$) feed:gain. This resulted in an estimate productive ME of CGM of 2,462 kcal/kg. Also, increasing CGM inclusion level linearly decreased ($P < 0.05$) carcass yield in both experiments. These results suggest that including CGM in diets for growing-finishing pigs has a negative impact on feed efficiency, and carcass yield. In addition, there was considerable variation in estimates of the PE content of CGM derived from these two growth studies. Two subsequent studies (Experiments 1 and 2) were conducted to determine the effect of research conditions (Commercial site vs University site), and different body weight ranges on estimates of PE of CGM. The same treatments were used in the 2 experiments; Exp. 1 was carried out at a commercial site and Exp. 2 was carried out at a university research facility. Three dietary treatments were compared: Control (corn-soybean meal-based diet), 20% CGM-No Fat (4.8% lower ME compared to the Control diet), and 20% CGM+Fat (yellow grease added to provide the same ME level as the Control diet); and 4 Growing periods were used: Early-Growing (29 to 64 kg BW), Late-Growing (64 to 96 kg BW), Finishing (96 to 127 kg BW), or Growing-Finishing (29 to 127 kg BW). At the commercial site the CGM+Fat diet was only fed during the Growing-Finishing period. A total of 3,672 and 576 were used in Experiment 1 and 2, respectively, housed in groups of 34 and 4, respectively (mixed-sex pens of barrows and gilts). The ME value of CGM used to formulate diets was that obtained in the previous growth study (adjusted for chemical composition of CGM batch used in these experiments). The variation in growth performance and caloric efficiency was considerably greater for Exp. 2 than Exp. 1 as evidenced by the SEM which were, on average, 1.7 times higher, resulting in greater variation in PE estimates from Exp. 2 compared to Exp. 1. Estimates of the productive ME of CGM based on the CGM–No Fat diets for the Early-Growing, Late-Growing, and Growing-Finishing periods were similar ($P > 0.05$) in both experiments but numerically very different in Exp. 2 (2,465, 2,568, and 2,439, respectively, for Exp.1, and 2,455, 1,829, and 1,924, respectively, for Exp. 2). For Exp. 1 (commercial conditions), adding fat to the CGM diet resulted in similar productive ME estimates for CGM compared to CGM–No Fat diet when measured during the whole of the Growing-Finishing period. Under university conditions (Exp. 2), fat addition to the CGM diet resulted in variable PE estimates between growing periods, and numerically greater values than those obtained with the CGM-No Fat diets. The results of these experiments suggest that the PE of CGM should be determined under commercial research conditions due to the variable results obtained under university conditions. Also, estimating PE over a limited part of the growing period resulted in similar PE estimates to those obtained during the whole of the growing-finishing period.

Keywords: pigs, productive energy, corn germ meal, growing period, research conditions.

I would like to dedicate the work of this dissertation to my wife and daughter, Sandra and Valeria, and to my parents, Jorge I. Estrada and Luz M. de Estrada. Their love and support have made possible this great achievement.

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CHAPTER 1:

INTRODUCTION

Formulating diets for swine is becoming a more precise process as research to measure the availability and metabolism of nutrients in specific feeds develops. One key factor in the formulation of diets to meet the nutrient requirements of the animal at the different stages of production is having accurate estimates of the amount and availability of nutrients contained within a feedstuff that can be used for maintenance and production. Many of those nutrients (i.e., carbohydrates, protein, lipids, and fiber) contain energy that the animal can use.

Traditionally in the US, corn has been used as the main source of energy in swine diets; however, during recent years the availability of corn co-products coming from the dry and wet milling industries (where the main products are ethanol, corn starch, sweeteners, corn oil, etc.) has increased. This has resulted in these feedstuffs becoming available as economically viable energy and protein sources (RFA, 2014). The challenge that swine nutritionists are facing is that there is a high variation in nutrient composition among co-products sources (Stein and Shurson, 2009; Anderson et al., 2012; Mendoza, 2013). In addition, limited information is available on the use of these feedstuffs in swine diets. Therefore, obtaining accurate estimates of the nutrients provided by these ingredients is crucial to successfully formulate a diet that meets the nutrient requirements of the animal, maximizes nutrients utilization, and, ultimately, animal performance.

Corn germ meal (CGM) is a co-product from the corn wet-milling industry that has a similar amino acid composition of that of corn and approximately 83% ME content compared to corn ME (NRC, 2012). However, there is limited published research of the use of CGM in swine diets, with only 2 studies evaluating the effect of dietary inclusion of CGM on the growth performance of pigs and 3 publications regarding the energy content of CGM. Therefore, the research presented in this document was conducted with two main objectives: 1) determine the effects of CGM on growth performance and carcass characteristics of pigs; 2) determine the productive ME of CGM using growth performance assays. Chapter 3 presents data from two experiments evaluating the effects of increasing levels of CGM on the growth performance and carcass characteristics of wean-to-finish pigs, and the productive ME of CGM was determined using the growth performance results. Chapter 4 presents data from two experiments to determine the productive ME of CGM at two research sites (typical commercial wean-to-finish barn vs typical university research facility) and obtained using pigs during four different body weight ranges.

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CHAPTER 2:

LITERATURE REVIEW

ENERGY DIGESTIBILITY

Energy is described as the capacity to do work, and can be available in different forms including atomic, chemical, electrical, or mechanical energy. The total energy contained in a feedstuff is known as gross energy (GE), which is defined as "the amount of energy produced when a compound is completely oxidized" (NRC, 2012), and is usually measured by burning the substrate to determine the amount energy released in form of heat. The amount of GE in a feedstuff is directly related to the chemical composition of the substrate. However, the conversion of energy into animal products (e.g., muscle, fat, milk) cannot be predicted using GE, given that the energy losses that occur during ingestion, digestion, and metabolism of feed are not taken into account (Ewan, 2001).

In order to better understand how much of the GE of a given ingredient is used by the pig, the energy intake can be divided into three general categories: heat, product (tissue), and waste products (NRC, 2012). The partitioning of dietary gross energy by the pig is generally considered at three levels: digestible energy (DE), metabolizable energy (ME), and net energy (NE). Each of these levels has at some time been used as a system of energy evaluation of feedstuffs for use in diet formulation. Additionally, two systems have been introduced in recent years; these are "effective metabolizable energy" and "productive energy" systems. All of these systems will be reviewed below.

Digestible Energy:

The digestible energy is defined as the energy that is available for utilization by the pig (Ewan, 2001), and is calculated by subtracting the GE in feces from the GE of the diet. Digestible energy is determined using metabolism studies and it gives a useful measurement of the energy that may be used by the animal. From the results obtained in several metabolism studies, equations have been developed to predict the DE content from the GE content and/or chemical composition of a feedstuff or complete diet, and these equations are reported in NRC (2012). These equations are presented below (chemical components are expressed as g/kg DM):

$$DE\ (kcal/kg) = 1{,}161 + (0.749\ \times GE) - (4.3\ \times Ash) - (4.1 \times NDF) \quad \mathbf{Eq. 2.1}$$

$$DE\ (kcal/kg) = 4{,}168 - (9.1\ \times Ash) + (1.9 \times CP) + (3.9 \times EE) - (3.6 \times NDF) \quad \mathbf{Eq. 2.2}$$

In general, most of the published DE values are expressed as apparent DE, given that the GE in feces is not partitioned between energy of endogenous or feed origin (NRC, 2012). Kil et al. (2013) in a review, reported that DE content for most diets fed to pigs are between 70 and 90% of the GE, and a typical corn-soybean diet has a DE content of approximately 82% relative to GE.

Digestible energy is relatively easy to measure and historically has been used for diet formulation in many countries. However, the main disadvantage of this system is that it does not take into account losses of energy in urine or combustible gases produced during feed metabolism, which varies among feedstuffs. As a result, this system is not accurate in predicting the energy available to the animal for maintenance and production.

Metabolizable Energy:

The metabolizable energy (ME) is obtained by subtracting the energy in the gases produced by fermentation in the intestinal tract, and the energy in urine. Generally speaking, the ME represents approximately 92 to 98% of the DE for a complete feed (NRC, 2012).

Energy loss due to fermented combustible gases is normally less than 1% of the DE intake and is usually ignored when estimating ME. Noblet et al. (1994) determined that the losses as methane on growing pigs averaged 0.4% of the DE intake (61 experimental diets were tested); however, the proportion of DE intake lost due to gas production in sows can be up to 3% (Noblet, 2005). Gaseous energy loss comes mainly from methane, as hydrogen production in pigs is very low and can be ignored. In general, methane production increases with body weight, as bigger animals have greater fermentative capacity due to a bigger and more developed digestive tract, and also increases with increasing dietary fiber level (Noblet and Shi, 1993; Noblet, 2005).

Urine is the main factor determining the proportion of DE converted into ME. Urinary energy loss is mainly related to the nitrogen excretion, which is linked to the crude protein content of the diet and its digestibility (amino acid balance), and, also, to the protein retention by the pig (NRC, 2012; Noblet, 2005). As a result, the ME:DE ratio is linearly related to the protein content of the diet when determined in diets with typical contents of crude protein. The generally accepted approach to estimate the energy content in urine (for complete diets or feed ingredients) is through determination of its nitrogen content (Noblet, 2005).

Noblet and Perez (1993) developed and evaluated several equations to estimate the ME content of diets based on the chemical composition of the diet. The most widely used equation is presented below, where chemical components are expressed as g/kg of DM:

$$ME\ (kcal/kg) = 4{,}194 - (9.2 \times Ash) + (1.0 \times CP) + (4.1 \times EE) - (3.5 \times NDF) \quad \mathbf{Eq. 2.3}$$

The ME is the system of energy evaluation that is widely used in the US and worldwide to formulate swine diets (NRC, 2012). The ME value of most feed ingredients used in swine diets has been widely established and the ME requirements of the pigs are also clearly understood. However, the ME can be further partitioned into net energy and heat increment and, therefore, there is an increasing interest to move towards the NE system for feedstuffs evaluation, which can predict the amount of energy ultimately available to the animal for maintenance and production (NRC, 2012; Noblet, 2015).

Net Energy:

The net energy content (NE) of feedstuffs is calculated by subtracting the heat increment (HI) energy from the ME. The heat increment is produced during the metabolism and fermentation of nutrients in the digestive tract, and, also, during tissue formation (Ewan, 2001; Noblet, 2007; NRC, 2012). The NE can be further divided into NE for maintenance (NE_m), which is used to sustain life and maintain body temperature, and NE for production (NE_p), which is used for growth, pregnancy, and/or lactation.

In order to determine the NE value of feeds and feedstuffs, measurements of the energy retained by the animal and/or the heat produced by the pig are required. The comparative slaughter technique can be used to estimate the energy retained by the pig. This involves feeding of test diets and/or ingredient, and measuring the energy content of pigs slaughtered at the start of the trial, compared to the energy content of pigs slaughtered at the end of the trial. Subsequently, the energy retention is calculated by difference. Also heat production can be directly measured using direct calorimetry (using respiratory, gradient layer, or convection calorimeters), or estimated using indirect calorimetry, which consists of measuring the oxygen uptake, and carbon dioxide and methane production by the animal (Nienaber et al., 2009).

All three approaches to determining NE have advantages and disadvantages. The comparative slaughter technique provides an accurate estimate of the body composition of the animal and is usually carried out under conditions similar to practical feeding settings. However, different pigs are used to estimate the energy content of the animals at the start and end of the study, which is a source of variation in the estimate of energy gain. On the other hand, direct or indirect calorimetry trials are carried out in chambers that limit the physical activity of the animals and may have an impact on temperature regulation of the animals compared to those housed under practical conditions (Kil et al., 2013). In general, these techniques are relatively expensive and complex, and it is prudent to validate NE estimates under practical conditions through growth performance assessments.

The relationship between ME and NE values (NE:ME ratio) is dictated by the efficiency of conversion of ME to NE. This efficiency varies according to the purpose for which the animal utilizes the energy (maintenance, protein or fat deposition, fetal development, milk production, etc.), environmental conditions, physical activity level, and the chemical characteristics of feed (Noblet, 2007). Noblet et al. (1994) concluded that dietary protein and fiber had the lowest efficiency of conversion of ME to NE (~60%) while starch and fat had the highest (~82 and ~90%, respectively). The heat increment per unit of energy intake is influenced by the composition of the feed; dietary protein and fiber have a greater heat increment compared to fat or starch (Noblet, 2007).

The fact that the NE system takes into account the variation in heat increment to estimate the energy available to the animals for maintenance and production is, in theory at least, a significant advantage for the NE compared to DE and ME systems. As a result, the NE system expresses energy requirements and dietary energy values on the same basis.

In general, the measurement of NE is complex and expensive; it needs to be measured under very specific and controlled conditions in order to minimize variations between studies in the behavior of the pigs (related to physical activity), and with balanced diets to ensure that animals can express their growth potential (Noblet, 2015). The fact that this system is not appropriate for individual ingredient assessments represents a major limitation. However, prediction equations have been developed (presented below) based on DE or ME values in an attempt to overcome this issue (Noblet et al., 1994a). The following equations were adapted by NRC (2012) from Noblet et al. (1993) (all nutrient and digestible nutrient contents are expressed as g/kg of DM):

$$NE(kcal/kg\ DM) = (0.726 \times ME) + (1.33 \times EE) + (0.39 \times Starch) - (0.62 \times CP) - (0.83 \times ADF) \quad \textbf{Eq. 2.4}$$

$$NE\ (Kcal/kg\ DM) = (0.700 \times DE) + (1.61 \times EE) + (0.48 \times Starch) - (0.91 \times CP) - (0.87 \times ADF) \quad \textbf{Eq. 2.5}$$

Caution is needed when applying these equations to individual ingredients, since these equations were developed using complete diets and further research is needed to evaluate the use of these equations with single ingredients (NRC, 2012).

Effective Metabolizable Energy:

The most recent publication of the NRC Nutrients Requirements of Swine (2012), described the effective metabolizable energy concept, which combines the ME and NE systems. Effective ME accounts for marginal energy efficiency (for production) according to the dietary energy source (e.g., lipids, fiber, protein) and the growth stage of the animal, given that the efficiency of using ME for lipid gain is higher compared to that for either protein gain or maintenance (NRC, 2012).

To this end, the effective ME value is calculated from the dietary NE content using fixed conversion factors (effective ME = NE ÷ Conversion Factor) according to the production stage of the animal. The conversion factors are as follows: starting pigs (5 to 25 kg BW) conversion factor

= 0.72; growing-finishing pigs (25 to 135 kg BW), conversion factor = 0.75; and sows, conversion factor = 0.763. Also, when the effective ME approach is used, the actual calculated value is greater than published ME values for diets with large contents of low heat increment components (e.g., high in lipids), and lower than the published ME values for diets with high heat increment components (e.g., high in dietary fiber).

Currently, the utility of the effective ME system is limited given that it was developed using only corn-soybean meal diets to determine effective ME values. NRC (2012) stated that the amount of data published were insufficient to differentiate the energy content of feedstuffs by stage of production. On the same note, Kil et al. (2013) pointed out that the applicability of this system has not been tested, and that the dietary energy available for maintenance and production for growing-finishing pigs vary within the BW range of 25 to 135 kg, limiting the use of those effective ME values published by NRC (2012).

Productive Energy:

The concept of productive energy originates from concerns that published energy values (DE, ME, or NE) are not accurate and need to be validated and/or adjusted based on growth assays. This is particularly the case for high fiber ingredients and for ingredients that have not been widely evaluated such as corn germ meal (CGM). However, even though this is not a new concept, there is limited information documenting the procedures, results, and calculations to determine productive energy.

The determination of productive energy involves a growth performance trial carried out using a standard diet (e.g., corn-soybean meal diet) as a reference to be compared with a test diet including the test ingredient. The objective is to determine if there is any difference in caloric efficiency (calories consumed per unit of weight gain) between dietary treatments (Boyd et al., 2010; Boyd et al., 2011; Boyd et al., 2015). When there is a difference in caloric efficiency between the reference and the test diet, that difference in energy required per unit of weight gain is attributed entirely to the test ingredient. On this basis, the energy content of the ingredient can be adjusted accordingly. Commonly, the results are expressed as percentage of energy relative to corn (e.g., productive ME = X% relative to corn). Detailed calculations and equations used to determine productive energy will be presented later in this document (in the "Use of Corn Germ Meal in Swine Diets" section) using CGM as the test ingredient.

In an experiment carried out by Boyd et al. (2010) to determine productive energy of wheat middlings, a growth assay was carried out over a period of 26 days (from 79.5 to 109.2 kg BW) using 451 pigs. It was determined that the productive NE for wheat middlings was of 2,046 kcal/kg, which is a slightly lower value compared to that reported by NRC (2012) of 2,113 kcal/kg. In a similar study, Boyd et al., (2015) tested choice white grease using six fat inclusion levels [0 (Control), 1.90, 2.21, 2.58, 3.10, and 5.50%] over two different growth periods: early growth (33 to 66 kg BW) and late finishing (79 to 107 kg BW). Based on caloric efficiency differences between treatments, the authors concluded that the productive NE of choice white grease for early and late finishing pigs was of 7,779 and 8,058 kcal/kg, respectively. These values are higher compared to that reported by NRC (2012) of 7,148 kcal/kg.

As previously reviewed, the ME of ingredients high in fiber or fat is not accurate in predicting the amount of energy available to the pig for maintenance and production. In theory, the NE of high fiber ingredients should be a better predictor of energy available to the animal; however, NE is complex and costly to measure. Therefore, determining the productive energy of ingredients potentially offers a practical alternative to validate and/or adjust the values for ME or NE content of a feedstuff. Published information on the optimum approach to determine productive energy is limited, and further research is needed to determine the optimum conditions and procedures to use to estimate the productive energy content of feed ingredients.

Factors Affecting Energy Digestibility:

There are several factors that can have an effect on the energy digestibility of a feedstuff, such as: chemical composition (DM, fiber, starch, fat, and amino acid content), physiological state of the animal (age, body weight, pregnancy), genotype of the animal, feed processing (e.g., grinding and pelleting), and use of exogenous feed enzymes. This section of the review will focus on the effect of dietary fiber and body weight/age on the energy digestibility.

Effects of Dietary Fiber on Energy Digestibility:

The dietary fiber fraction of a feedstuff consists of the cell wall constituents (β-Glucans, pectins and gums, lignin, cellulose, and hemicellulose) and some non-structural carbohydrates (resistant starch). Furthermore, the total dietary fiber can be classified as either soluble fiber (resistant starch, β-Glucans, pectins, and gums) or insoluble fiber (cellulose, and hemicellulose) (NRC, 2012). Crude fiber is the standard analytical measurement of fiber that has been used in the swine industry for many years, and this is still reported in the proximate analysis of most feedstuffs. However, crude fiber includes just a portion of the total dietary fiber and, consequently, has become an obsolete parameter for swine diet formulation. Currently, the most common fiber measurement used in swine nutrition is obtained through detergent analysis methods, resulting in two fiber components: neutral detergent fiber (NDF), which includes cellulose, hemicellulose, and lignin; and acid detergent fiber (ADF), which includes cellulose and lignin (Grieshop et al., 2001).

Even though detergent fiber is a more inclusive measurement, it is still limited in value because it doesn't include the soluble fraction of the fiber which can be relatively high in certain feedstuffs (e.g., wheat middlings, canola meal, oat bran). Nowadays it is possible to analyze the total dietary fiber (TDF) of a feedstuff, which can quantify all the fiber fractions; however, the TDF procedure is more expensive and the results are more variable compared to detergent fiber analysis, which has limited its implementation in many nutrition laboratories (NRC, 2012).

The fiber fraction is indigestible by the digestive enzymes secreted by the pig in the upper digestive tract, but once it passes to the large intestine and cecum it can be degraded via fermentation by the microbial population present in these areas of the gut. Bacterial fermentation produces volatile fatty acids that can be a valuable source of energy for pigs (Ewan, 2001; Urriola et al., 2010; NRC, 2012). In an experiment carried out by Rérat et al. (1987) with pigs fed restricted amounts of feed, volatile fatty acids provided up to 30% of the maintenance requirement of growing pigs. However inclusion of feedstuffs with high fiber levels can result in a reduction of the dietary energy density, which can be a limiting factor for growth performance, particularly in young pigs which have limited feed intake capacity.

Although a fraction of the dietary fiber can be used by the animal as an energy source (as volatile fatty acids), the contribution of this to energy supply is very limited for young growing pigs (Noblet and van Milgen, 2004). The digestibility of fiber (through bacterial fermentation in the hindgut) is directly related to its physico-chemical characteristics; the soluble fiber fraction is highly digestible whereas the lignin fraction is almost indigestible for the pig. For example, Noblet and Le Goff (2001) showed that the NDF digestibility coefficient of sugar beet pulp, an ingredient with high content of pectins and low in lignin, was 0.60, while it was 0.15 for wheat bran, an ingredient with high content of lignin.

In addition to the production of volatile fatty acids, fiber fermentation in the hindgut produces gases (carbon dioxide, hydrogen, and methane), urea, and heat, plus a considerable bacterial mass. This increase in endogenous energy production and losses can have a significant effect on the amount energy available to the pig. With respect to hydrogen and methane, both are combustible gases, and, therefore, represent a loss of energy, particularly in the case of methane, which can represent up to 1% of the total dietary digestible energy (Noblet and Shi, 1994). All this fermentative activity results in an increase in heat production and this translates into a lower efficiency of converting DE to ME for dietary fiber compared to, for example, that for starch (0.55 vs. 0.80, respectively) (Noblet and Le Goff, 2001).

In conclusion, the dietary fiber content of feedstuffs is a major factor influencing energy digestibility, which is directly related with the fact that dietary fiber has a considerably lower digestibility (<50%) compared to starch, sugars, fat, or protein, which have digestibility coefficients ranging between 80 to 100%.

Effects of Body Weight/Age on Energy Digestibility:

The energy digestibility of certain nutrients in feedstuffs used in swine diets generally increases with the body weight of the pig. For example, Noblet and Shi (1994) carried out a digestibility experiment with pigs at three different weights (45, 100, and 150 kg BW) that were fed diets with different composition, and reported that the digestibility coefficient for starch and sucrose was close to 100% for all stages, for fat it was of 57.9, 66.1 and 65.5% for pigs of 45, 100, and 150 kg BW, respectively, and for NDF it was 52.6, 57.5, and 60.5%, respectively. This shows the increased capacity of heavier pigs to better digest certain nutrients, particularly dietary fiber. Comparatively, the information regarding the effect of BW on energy digestibility for younger pigs (i.e., newly-weaned and nursery pigs) is limited. Most authors recommend the use of energy values developed for growing pigs with younger animals, particularly considering that diets for that stage of production are generally low in fiber and are formulated with highly digestible ingredients (Noblet and van Milgen, 2004; Noblet, 2005; NRC, 2012).

The increase in energy digestibility with increasing body weight is greater for fibrous ingredients compared to those with, for example, a high content of starch or fat. The greater digestibility of high fiber ingredients by heavier animals is related to their increased hindgut fermentation capacity as well as to a slower rate of passage through the digestive tract (Noblet and van Milgen, 2004; Noblet, 2005). In general, growing pigs (between 40 to 100 kg BW) have a limited capability to digest dietary fiber, therefore, the digestibility of fiber sources shows limited variation across this weight range. On the other hand, adult sows have greater capacity to digest fiber and this capacity is more influenced by the characteristics of the fiber source (e.g., lignin content) (Le Goff and Noblet, 2001). For example, a study carried out by Noblet (2005) that compared the digestibility of different fiber sources in growing pigs and sows showed that corn bran (an ingredient with high lignin content) had dietary fiber digestibility coefficients of 0.32 and 0.74 for growing pigs and sows, respectively, while sugar beet pulp (an ingredient high in soluble fiber and with low lignin content) had coefficients of 0.70 and 0.76, respectively. This indicates that not only the body weight of the pig but also the composition of the fiber fraction play important roles in determining digestibility (Noblet, 2005). Moreover, Le Goff and Noblet (2001) determined that dietary NDF content was the main factor contributing to differences in energy digestibility when comparing growing pigs and sows; these authors showed that 1 g of dietary NDF contributed 3.4 and 6.8 kJ of DE for growing pigs and sows, respectively.

Conversely to the increasing energy digestibility with body weight, the ME:DE ratio actually decreases with weight due to greater energy losses in urine and as methane in heavier pigs.

As previously discussed, feedstuffs with high content of dietary fiber have increased fermentation and associated heat production, resulting in an increase in the difference between the ingredient DE and ME for high fiber ingredients (Noblet et al., 1994b; Noblet and van Milgen, 2004; Kil et al., 2013). Correspondingly, Noblet and Shi (1994) found that the ME content of the diet changed significantly with increasing body weight for diets with high fiber content, but no major changes in ME with increasing weight were found for pigs fed highly digestible diets (e.g., high in starch).

For practical diet formulation, taking into account the stage of production of the animal, it is recommended to use at least two energy values for each feedstuff, one for growing-finishing pigs and one for sows; this is particularly important for ingredients with high content of fiber. However, NRC (2012) reported that there was not enough information available to differentiate the energy content of each ingredient by stage of production; therefore, only one set of energy values (i.e.; GE, DE, ME, and NE) was presented for each ingredient in the last publication of Nutrient Requirements of Swine.

In summary, dietary composition (fiber, fat, starch, etc.) and body weight are factors that interact to impact energy digestibility and metabolism (particularly associated with heat and methane production). These factors determine the energy available to the animal for production. Further research is needed in this area to accurately determine the energy provided by alternative feed ingredients at the different stages of production.

USE OF CORN GERM MEAL IN SWINE DIETS

The corn wet milling industry produces starch and corn oil as primary products to principally be used in the human food industry; corn germ meal (CGM) is a co-product from this process (RFA, 2014). In this process, the germ is removed from the corn kernel and, subsequently, the oil is extracted from the germ; the remaining material after the oil extraction (defatted corn germ) is known as CGM. In 2016, CGM production in the U.S. was 758,594 tons, and most if not all of this was intended for use as livestock feed (USDA, 2017).

A summary of values for the composition of CGM is presented in Table 2.1. These values were obtained from 7 published sources and 2 unpublished studies. Corn germ meal is considered a fibrous ingredient with a crude fiber content ranging between 7.5 and 10%, and NDF ranging between 35 to 50% (NRC, 2012; Estrada, 2015 unpublished data). It contains less than 3% fat and between 20 and 25% crude protein. Corn germ meal has a comparable amino acid balance to that of corn with a slightly lower amino acid digestibility than corn (Almeida et al., 2011; NRC, 2012; Gutierrez et al. 2014), making it a potential ingredient for use in swine diets.

Effect of Corn Germ Meal on Growth Performance:

A summary of the studies investigating the effects of dietary CGM inclusion on the growth performance of pigs is presented in Table 2.2. To date the results of only 2 experiments have been published in the scientific literature; in addition, the results for 2 unpublished experiments (Estrada, 2014; 2015, unpublished data) have been included in the summary. The initial and final body weight in these studies ranged from 6 to 58 kg, and from 55 to 133 kg, respectively, and CGM inclusion levels ranged from 10 to 50% (Table 2.2).

None of the studies found any effect of CGM on feed intake (Table 2.2). Two of the studies reported effects on growth rate and three of them showed responses in feed efficiency to CGM inclusion. Jones (1987) reported that up to 25% of CGM could be included in the diet with no effect on growth rate or feed efficiency. However, when pigs were fed 50% CGM the reduction in daily gain and feed efficiency was 19 and 17%, respectively, compared to pigs fed a corn-soybean meal diet. Estrada (2015, unpublished data) evaluated the growth performance from weaning to finishing of pigs fed up to 40% CGM and concluded that increasing the CGM inclusion level resulted in linear reductions of daily gain and feed efficiency. Conversely, Weber et al. (2014) reported that feeding up to 38% CGM (between 31 to 55 kg body weight) had no effect on growth rate but reduced gain:feed ratio (quadratic response).

In conclusion, previous research has suggested CGM can be included in diets for pigs from weaning to finishing at up to 50% without affecting feed intake (Table 2.2). Increasing levels of CGM reduced growth rates in two of the studies reviewed but had no effect on average daily gain in two other studies (Table 2.2). However, CGM had a negative effect on feed efficiency in all of the studies reviewed (Table 2.2). This reduced feed efficiency in pigs fed diets including CGM could result from an overestimation of the energy in CGM that is available to the animal. There is a need for further research to establish the energy value of CGM for swine.

Effect of Corn Germ Meal on Carcass Characteristics:

A summary of the studies investigating the effects of dietary CGM inclusion on the carcass characteristics of pigs is presented in Table 2.3. Three out of the four studies previously reviewed (in the "Effect of Corn Germ Meal on Growth Performance" section) presented data relating to the effect of CGM on the carcass characteristics. The average harvest weight was of 104, 127, and 133 kg for the studies of Jones (1987) and Estrada (2014; 2015, unpublished data), respectively.

All three studies showed responses to increasing level of dietary CGM for hot carcass weight and carcass yield. Estrada (2014; 2015, unpublished data) in studies carried out under commercial conditions involving more than 3,000 pigs showed that increasing the level of CGM in the diet resulted in a linear decrease in hot carcass weight and carcass yield. Similarly, Jones (1987) found that pigs fed 50% CGM had 6.43 kg and 2.8 percentage units lower hot carcass weight and carcass yield, respectively, compared to pigs fed corn-soybean meal diet. However, in the study of Jones (1987) there was no effect of feeding diets with 25% CGM on hot carcass weight or carcass yield (Table 2.3).

Jones (1987) reported that pigs fed diets with 50% CGM had lower backfat depth compared to pigs fed diets with either 0 or 25% CGM (Table 2.3); however this effect could, in part at least, be associated with a numerically lower harvest weight of pigs fed 50% CGM (106.4, 104.7, and 101.8 kg for the 0, 25, and 50% CGM treatments, respectively). In contrast, Estrada (2014; 2015, unpublished data, Chapter 3 of this document) did not find any effect of CGM inclusion level on backfat depth.

These results suggest that inclusion of CGM in diets for growing pigs reduces carcass yield, with no consistent effect on other carcass traits (Table 2.3). This reduction of carcass yield could be associated with an increase in intestine size and gut fill resulting from feeding diets with high dietary fiber content (Jones, 1987; Pond et al., 1988; De Lange et al., 2003).

Energy Content of Corn Germ Meal:

A summary of the published values for the energy content of CGM is presented in Table 2.4. Three studies have been published measuring the energy of CGM and these show high variation in estimates. The energy content (as-fed basis, kcal/kg) ranged from 4,178 to 4,330 for GE, from 2,740 to 3,103 for DE, and from 2,630 to 3,011 for ME (Anderson et al. 2012; NRC, 2012; Gutierrez et al., 2014; Rojas et al., 2014). Factors contributing to this variation could be the measuring methodology used and/or the source of the CGM sample tested (Stein and Shurson, 2009; Urriola et al., 2010; Mendoza, 2013).

As a result of the limited amount of published information and the high variation in the estimates of the energy content of CGM, Estrada (2014, unpublished data) carried out a growth study over the wean-to-finish period to determine the productive energy of CGM (Experiment 1). A corn-soybean meal diet was used as the reference diet, and test diets with two CGM inclusion levels were evaluated (12.5 and 25.0%). The start and end body weight was 7 and 127 kg, respectively. The ME values used to formulate the diets for corn and CGM were 3,380 and 3,037 kcal/kg, respectively, with the ME value of CGM being 89.9% of that of corn. The ME values used for corn and CGM were those reported by the NRC (2012) and Anderson et al. (2012), respectively. For both ingredients the ME value was adjusted according to the analyzed chemical composition of the batches used in the study. Diets were formulated to the same ME and lysine levels; yellow grease was added to the CGM diets as required to achieve this.

The results of this study, which are summarized in Table 2.5, showed that increasing CGM inclusion level resulted in a linear increase in feed:gain ratio (2.34, 2.38, and 2.42 kg/kg for 0, 12.5, and 25.0% CGM diets, respectively). These feed:gain ratios were used to estimate the caloric energy efficiency and, subsequently, the productive ME of the CGM (Table 2.5).

The estimated productive ME for CGM was 2,604 kcal/kg (Table 2.5), which is significantly lower than the ME value originally used to formulate the test diets (3,037 kcal/kg). Thus, based on these results the productive ME of CGM is 77.6% of the ME of corn (Estrada, 2014 unpublished data, reported in Chapter 3 of this document).

To obtain the productive energy of CGM, the following calculations were used (all concentrations are expressed on an as-fed basis):

1) The ***Caloric Efficiency*** (CE) of each dietary treatment was obtained by multiplying the Feed:Gain ratio by the Formulated Energy content of the diet:

$CE\ (kcal/kg\ of\ gain)$

$$= Feed{:}Gain \times (Formulated\ Energy_{Diet}\ kcal/kg) \quad \textbf{Eq. 2.6}$$

2) To obtain the ***Corrected Energy*** content of the test diets (i.e., the diets including CGM), the Formulated Energy content of the test diet was multiplied by the Caloric Efficiency of the control diet divided by the Caloric Efficiency of the test diet:

$Corrected\ Energy_{Test\ diet}\ (kcal/kg)$

$$= Formulated\ Energy_{Test\ diet} \times \left(\frac{CE_{Control\ diet}}{CE_{Test\ diet}}\right) \quad \textbf{Eq. 2.7}$$

3) The ***Energy Difference*** (between formulated and corrected energy content) of the test diet was obtained by subtraction:

$Energy\ Difference_{Test\ diet}$

$$= Formulated\ Energy_{Test\ diet} - Corrected\ Energy_{Test\ diet} \quad \textbf{Eq. 2.8}$$

4) It was assumed that the Energy Difference of the test diet is due entirely to the test ingredient. Therefore, the ***Energy Difference of the test ingredient*** was calculated by dividing the Energy Difference of the test diet by the proportion of the test ingredient included (e.g., 25% CGM = 0.25 CGM inclusion):

$Energy\ Difference_{Test\ ingredient}\ (kcal/kg)$

$$= Energy\ difference_{Test\ diet,}\ kcal/kg$$

$$\div\ Test\ Ingredient\ inclusion \quad \textbf{Eq. 2.9}$$

5) The ***Productive Energy*** was obtained by subtracting the Energy Difference of the test ingredient from the Formulated Energy of the test ingredient:

$Productive\ Energy\ (kcal/kg)$

$$= Formulated\ Energy_{\ Test\ ingredient}$$

$$- Energy\ Difference_{Test\ ingredient} \quad \textbf{Eq. 2.10}$$

A second study (Experiment 2) was carried out by Estrada (2015, unpublished data) to validate and/or further adjust the productive ME of CGM obtained from the previous study (Estrada, 2014; unpublished data). The study also served to determine the effect of including greater CGM levels in swine diets. Pigs had a start and end body weight of 6 and 133 kg, respectively (wean-to-finish). A corn-soybean meal diet was used as the control and CGM inclusion levels of 10, 20, 30, and 40% were evaluated. The CGM source (plant of production) was the same as in the first experiment. The ME value used in diet formulation for corn was 3,367 kcal/kg. The ME value used for CGM was of 2,681 kcal/kg, which was obtained adjusting the previous estimate determined by Estrada (2014, unpublished data) in Experiment 1, for the chemical composition of the batch of CGM used in Experiment 2.

The results of this experiment, which are summarized in Table 2.6, showed that increasing CGM inclusion level resulted in a linear increase of feed:gain ratio (2.46, 2.48, 2.49, 2.50, and 2.55 kg/kg for 0, 10, 20, 30, and 40% CGM diets, respectively). As a result, the estimate of productive ME for this second experiment was 2,462 kcal/kg (obtained by averaging the productive energy for all 4 CGM treatments) (Table 2.6). However, in practical diets only up to 30% CGM is included, therefore, the productive energy was determined as the average of the three lowest CGM levels (i.e., 10, 20, and 30%). This resulted in an estimate of productive ME for CGM of 2,483 kcal/kg, which is 211 kcal lower than the estimate from the previous experiment.

There is no clear explanation for the difference in productive ME estimates between these two experiments. It could possibly be related with errors and/or variation in chemical composition analyses, as well as with variation between the studies in factors such as season of the year in which the study was carried out, the health status of the animals, etc. However, the slope for the change in caloric efficiency with increasing CGM level was numerically lower for Experiment 2

(Estrada, 2105; unpublished data) compared Experiment 1 (Estrada, 2014; unpublished data) (10.44 and 6.61 kcal/% of CGM for Study 1 and 2 respectively). This suggests that the adjusted ME value of CGM (2,681 kcal/kg) used to formulate diets in the Experiment 2 was more accurate compared to the value used for Experiment 1.

In conclusion, there is considerable variation between estimates in the literature of the energy content of CGM as well as between estimates of productive energy content from growth experiments carried out by the author. This variation could be due variation in composition between CGM sources and batches, as well as differences between energy determination methods. Further research is needed to further validate and/or adjust current energy values for CGM.

TABLES

Table 2.1. Estimates of the nutrient composition of corn germ meal.

	Reference								
	NRC, 2012[1]	Jones, 1987[1]	Weber et al., 2010[1]	Almeida et al., 2011	Anderson et al., 2012[2]	Rojas et al., 2014[1]	Gutierrez et al., 2014[1]	Estrada, 2014[1,7]	Estrada, 2015[1,7]
Number of samples	1 or 2	NR	1	1	NR	1	1	13	7
Laboratory	NR	Ajinomoto[3]	AESCL[4]	NR	AESCL[4]	NR	AESCL[4]	Midwest Labs[5] and Ajinomoto[3]	Midwest Labs[5] and Ajinomoto[3]
Component, %									
Dry matter	90.10	-	-	89.41	89.13	89.41	91.90	88.27	88.56
Crude protein	23.33	20.00	21.07	24.76	23.64	24.76	20.60	23.84	23.69
Amino acids									
Lysine	1.70	0.90	1.70	0.94	1.17	0.94	1.10	0.96	1.02
Tryptophan	0.78	0.10	0.78	0.18	0.20	0.18	0.20	0.26	0.25
Threonine	0.89	-	0.89	0.83	0.88	0.83	0.80	0.88	0.90
Methionine	1.04	-	1.04	0.40	0.42	0.40	0.40	0.43	0.43
Crude fiber	9.53	-	9.53	-	10.69	-	-	7.56	7.52
Total dietary fiber	41.56	-	42.57	-	47.76	-	44.10	-	-
NDF	44.46	-	54.41	49.29	61.05	49.29	46.20	37.27	36.99
ADF	10.75	-	11.13	11.30	12.49	11.30	11.50	12.05	11.21
Lignin	1.09	-	1.09	-	1.22	-	-	-	-
Ether extract	2.12	-	2.12	-	2.38	2.06[6]	3.10	2.03	2.71
Ash	2.96	-	2.41	-	2.70	5.47	-	2.59	2.77
Calcium	0.03	0.04	0.03	-	0.04	0.18	-	0.02	0.03
Phosphorus	0.90	0.50	5.79	-	0.65	0.87	-	0.78	0.82

NR = data not reported

[1]As-fed basis

[2]Dry matter basis

[3]Ajinomoto Heartland Inc., Chicago, IL.

[4] AESCL = University of Missouri Agriculture Experiment Station Chemical Laboratories, Columbia, MO.

[5]Midwest Labs = Midwest Laboratories, Omaha, NE

[6]Acid ether extract

[7]Unpublished data. Amino acids content analyzed by Ajinomoto; proximate composition analyzed by Midwest Labs.

Table 2.2. Summary of studies investigating the effect of feeding corn germ meal on the growth performance of pigs.

				Corn germ meal inclusion level, %							
Reference	N[1]	Body weight range, kg	Control[2]	10	12.5	20	25	30	40[3]	50	*P*-value
Average daily gain, kg											
Jones, 1987	120	58-106	0.843[a]	-	-	-	0.801[a]	-	-	0.682[b]	*
Weber et al., 2010	48	31-55	0.84	-	0.88	-	0.84	-	0.82	-	NS
Estrada, 2014[4]	1020	7-127	0.798	-	0.798	-	0.789	-	-	-	NS
Estrada, 2015[4]	2380	6-133	0.758[a]	0.758[a]	-	0.748[a]	-	0.748[a]	0.730[b]	-	**Linear
Average daily feed intake, kg											
Jones, 1987	120	58-106	3.063	-	-	-	2.988	-	-	3.001	NS
Weber et al., 2010	48	31-55	1.92	-	1.89	-	1.88	-	1.91	-	NS
Estrada, 2014[4]	1020	7-127	1.873	-	1.896		1.905	-	-	-	NS
Estrada, 2015[4]	2380	6-133	1.873	1.878	-	1.864	-	1.869	1.869	-	NS
Gain:Feed ratio, kg:kg											
Jones, 1987	120	58-106	0.276[a]	-	-	-	0.269[a]	-	-	0.228[b]	*
Weber et al., 2010	48	31-55	0.441	-	0.464	-	0.446	-	0.430	-	*Quadratic
Estrada, 2014[4]	1020	7-127	0.428[a]	-	0.421[ab]	-	0.414[b]	-	-	-	*Linear
Estrada, 2015[4]	2380	6-133	0.406[a]	0.403[ab]	-	0.402[ab]	-	0.399[b]	0.392[c]		**Linear

*$P < 0.05$; ** $P < 0.01$; NS = $P > 0.05$; NR = Data not reported

[a,b,c]Within a study and variable, means with different superscripts are different ($P > 0.05$)

[1]N = Total number of pigs used

[2]Corn-Soybean meal based diet

[3]Weber et al., 2010. Greatest CGM inclusion level was at 38%.

[4]Unpublished data

Table 2.3. Summary of studies investigating the effect of feeding corn germ meal on the carcass characteristics of pigs.

					Corn germ meal inclusion level, %							
Reference	N[1]	Harvest BW, kg	Time on feed, d	Control[2]	10	12.5	20	25	30	40	50	*P*-value
Hot carcass weight, kg												
Jones, 1987	48	104	NR	82.94[a]	-	-	-	80.84[ab]	-	-	76.51[b]	*
Estrada, 2014[3]	1020	127	150	94.39[a]	-	93.80[a]	-	92.44[b]	-	-	-	*Linear
Estrada, 2015[3]	2380	133	168	99.97[a]	99.34[a]	-	99.47[a]	-	98.29[b]	98.34[b]	-	**Linear
Carcass yield, %												
Jones, 1987	42	104	NR	77.96[a]	-	-	-	77.18[a]	-	-	75.16[b]	*
Estrada, 2014[3]	1020	127	150	74.43[a]	-	73.53[b]	-	72.87[c]	-	-	-	*Linear
Estrada, 2015[3]	2380	133	168	75.04[a]	74.60[b]	-	74.33[bc]	-	73.94[cd]	73.70[d]	-	**Linear
10[th] rib back fat depth, cm												
Jones, 1987	42	104	NR	4.18[a]	-	-	-	3.66[a]	-	-	2.90[b]	*
Estrada, 2014[3]	1020	127	150	1.68	-	1.65	-	1.65	-	-	-	NS
Estrada, 2015[3]	2380	133	168	1.75	1.73	-	1.75	-	1.73	1.70	-	NS
Loin 10[th] rib depth, cm												
Jones, 1987	48	104	NR	-	-	-	-	-	-	-	-	-
Estrada, 2014[3]	1020	127	150	6.12	-	6.05	-	5.89	-	-	-	NS
Estrada, 2015[3]	2380	133	168	6.58[a]	6.45[ab]	-	6.32[bc]	-	6.22[cd]	6.07[d]	-	**Linear

*$P < 0.05$; ** $P < 0.01$; NS = $P > 0.05$; NR = Data not reported

[a,b,c,d]Within a study and variable, means with different superscripts are different ($P > 0.05$)

[1]N = Total number of pigs used

[2]Corn-Soybean meal based diet

[3]Unpublished data

Table 2.4. Summary of published estimates for GE, DE, and ME (kcal/kg as-fed basis) and apparent total tract digestibility (ATTD) of DM and energy of corn germ meal and corn.

		Corn germ meal (CGM)						Corn						CGM relative to NRC (2012) corn (%)	
					ATTD, %						ATTD, %				
Reference	N	GE	DE	ME	DM	NDF	Energy	GE	DE	ME	DM	NDF	Energy	DE	ME
NRC, 2012	-	4,178	2,988	2,830	-	-	-	3,933	3,451	3,395	-	-	-	-	-
Anderson et al., 2012[1]	1	4,201	3,103	3,011	-	-	-	3,799	3,456	3,387	-	-	-	89.9	88.7
Gutierrez et al, 2014[2]	1	4,330	2,740	2,630	67	73	63.2	-	-	-	-	-	-	79.4	77.5
Rojas et al., 2014[1]	1	4,184	3,073	2,817	-	-	73.9	3,924	3,498	3,375	-	-	89.4	89.0	83.0

[1]Energy concentration measured using standard experiments in which the apparent DE and ME are measured by difference in GE content.

[2]DE value was determined by multiplying the GE by the observed ATTD of GE of the ingredient, and the ME was estimated from the calculated DE and CP of the ingredient (Noblet and Perez, 1993)

Table 2.5. Summary of the growth performance of wean-to-finish pigs and calculation of the productive ME of corn germ meal (CGM) from Experiment 1 (Estrada, 2014; unpublished data).

	Corn germ meal inclusion level, %			
Item	0 (Control)	12.5	25	*P*-value
Growth performance:				
Average daily gain, kg	0.798	0.798	0.789	0.21
Average daily feed intake, kg	1.873	1.896	1.905	0.36
Feed:Gain ratio, kg/kg	2.336[a]	2.375[ab]	2.415[b]	0.01
Formulated energy content, (kcal/kg)[1]:				
Dietary ME	3,289	3,289	3,289	-
Corn germ meal ME	-	3,037	3,037	-
Calculations:				
1) Caloric Efficiency[2], kcal/kg	7,683	7,812	7,944	-
2) Corrected Energy of test diet[3], kcal/kg	-	3,235	3,181	-
3) Energy Difference of test diet[4], kcal	-	54	108	-
4) Energy Difference of test ingredient[5], kcal/kg	-	432	432	-
5) Productive ME of CGM[6], kcal/kg	-	2,604	2,604	-

[a,b]Means with different superscripts are different ($P > 0.05$)

[1]As-fed basis

[2]Caloric Efficiency (CE), kcal/kg of gain = Feed:Gain × (Formulated Energy of the Diet, kcal/kg)

[3]Corrected Energy of Test Diet, kcal/kg = Formulated Energy of Test Diet × (CE of Control diet ÷ CE of Test Diet)

[4]Energy Difference of Test Diet = Formulated Energy of Test Diet - Corrected Energy of Test Diet

[5]Energy Difference of Test Ingredient (i.e., CGM) = Energy Difference of Test Diet ÷ Test Ingredient Inclusion

[6]Productive Energy, kcal/kg = Formulated Energy of Test Ingredient - Energy Difference of Test Ingredient

Table 2.6. Summary of the growth performance of wean-to-finish pigs and calculation of the productive ME of corn germ meal (CGM) from Experiment 2 (Estrada, 2015; unpublished data).

	Corn germ meal inclusion level, %					
Item	0 (Control)	10	20	30	40	*P*-value
Growth performance:						
Average daily gain, kg	0.758[a]	0.758[a]	0.748[a]	0.748[a]	0.730[b]	0.001
Average daily feed intake, kg	1.873	1.878	1.864	1.869	1.869	0.95
Feed:Gain ratio, kg/kg	2.463[a]	2.481[ab]	2.488[ab]	2.506[b]	2.551[c]	0.002
Formulated energy content, (kcal/kg)[1]:						
Dietary ME	3,300	3,300	3,300	3,300	3,300	-
Corn germ meal ME	-	2,681	2,681	2,681	2,681	-
Calculations:						
1) Caloric Efficiency[2], kcal/kg	8,129	8,189	8,210	8,271	8,419	-
2) Corrected Energy of test diet[3], kcal/kg	-	3,276	3,268	3,243	3,187	-
3) Energy Difference of test diet[4], kcal	-	24	32	57	114	-
4) Energy Difference of test ingredient[5], kcal/kg	-	243.3	162	189.1	283.9	-
5) Productive ME of CGM[6], kcal/kg	-	2,438	2,519	2,492	2,397	-

[a,b,c]Means with different superscripts are different (*P* > 0.05)

[1]As-fed basis

[2]Caloric Efficiency (CE), kcal/kg of gain = Feed:Gain × (Formulated Energy of the Diet, kcal/kg)

[3]Corrected Energy of Test Diet, kcal/kg = Formulated Energy of Test Diet × (CE of Control diet ÷ CE of Test Diet)

[4]Energy Difference of Test Diet = Formulated Energy of Test Diet - Corrected Energy of Test Diet

[5]Energy Difference of Test Ingredient (e.g., CGM) = Energy Difference of Test Diet ÷ Test Ingredient Inclusion

[6]Productive Energy, kcal/kg = Formulated Energy of Test Ingredient - Energy Difference of Test Ingredient

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CHAPTER 3:

EFFECTS OF CORN GERM MEAL (CGM) ON GROWTH PERFORMANCE AND CARCASS CHARACTERISTICS OF WEAN-TO-FINISH PIGS, AND DETERMINATION OF THE PRODUCTIVE ENERGY CONTENT OF CGM

ABSTRACT

Two wean-to-finish growth experiments were carried out to evaluate the effect of CGM inclusion level on growth performance and carcass traits and to determine the productive energy (PE) of CGM by correcting ME estimates for caloric efficiency relative to a control (reference diet). Both experiments used a RCBD with CGM inclusion levels of 0, 12.5, and 25% in Experiment 1, and 0, 10, 20, 30, and 40% in Experiment 2. The CGM was from a single source; the chemical composition averaged across both studies was: DM, 88.4%; CP, 23.8%; Crude Fat, 2.4%; NDF, 37.1%; ADF, 11.6%; Ash, 2.7. A total of 1,020 (10 replicates) and 2,380 (14 replicates) barrows and gilts were used in Experiment 1 and 2, respectively, housed in groups of 34 (Experiment 1 single-sex; Experiment 2 mixed-sex). Start and end BW were 6.6 ± 0.54 and 6.4 ± 0.56 to 127.1 ± 1.71 and 133.3 ± 1.62 kg, for Experiment 1 and 2, respectively. An 8-phase dietary program was used with diets formulated to be isocaloric (by using supplemental fat), to a constant standard ileal digestible lysine to energy ratio within phase, and to meet or exceed nutrient requirements proposed by NRC (2012). The corn-soybean meal-based control diet (0% CGM) was used as the reference diet to compare with the CGM diets to estimate PE. Caloric efficiency (calories consumed per unit of weight gain) was calculated for each treatment using the feed:gain ratio. For Experiment 1, the ME value of CGM used to formulate diets, based on published values and previous unpublished research, was 3,037 kcal/kg. The pen of pigs was the experimental unit; data were analyzed using PROC MIXED of SAS; the model accounted for the effects of CGM level and block. In Experiment 1, increasing CGM level linearly increased feed:gain ($P < 0.05$;

2.34, 2.38, and 2.42 kg/kg for 0, 12.5, and 25.0% CGM diets, respectively; SEM 0.023) which gave an estimate of productive ME for CGM of 2,604 kcal/kg (averaged across CGM diets). For Experiment 2, the ME of CGM used in diet formulation was of 2,681 kcal/kg (based on the ME value from Experiment 1 adjusted for the chemical composition of the batch of CGM used). Increasing CGM inclusion level linearly decreased ($P < 0.05$) ADG (0.758, 0.758, 0.748, 0.748, and 0.730 kg/d for 0, 10, 20, 30, and 40% CGM diets, respectively; SEM 0.0059), and linearly increased ($P < 0.05$) feed:gain (2.46, 2.49, 2.49, 2.51, and 2.55 kg/kg for 0, 10, 20, 30, and 40% CGM diets, respectively; SEM 0.018) and this resulted in an estimate productive ME of CGM of 2,462 kcal/kg (averaged across CGM diets). There was no effect on ADFI in either experiment. Increasing CGM inclusion level linearly decreased ($P < 0.05$) carcass yield in both experiments. These results suggest that including CGM in diets for growing-finishing pigs has a negative impact on feed efficiency, and carcass yield, with no consistent effect on growth rate. In addition, there was considerable variation in estimates of the PE content of CGM derived from growth studies, and further research is needed to define appropriate methodology to determine PE and validate the energy content of CGM.

Keywords: pigs, productive energy, corn germ meal

INTRODUCTION

Corn germ meal (CGM) is a co-product from the corn wet milling industry. This co-product is an alternative source of energy and protein that can be used in swine diets. Corn germ meal has a comparable amino acid balance to that of corn with a slightly lower amino acid digestibility than corn (Almeida et al., 2011; NRC, 2012; Gutierrez et al. 2014), and it has been utilized in diets for both growing-finishing pigs and sows.

However, there is limited published information on the effects of this ingredient in swine feeding programs, with only 2 studies reported in the literature (Jones, 1987; Weber et al., 2010). Jones (1987) found that increasing CGM reduced growth rate and feed efficiency in pigs fed 50% CGM compared to pigs fed 0 or 25% CGM over the live weight range 58 to 106 kg, with no effect on feed intake (Table 2.2). Weber et al. (2010) fed up to 39% CGM to growing pigs (from 31 to 55 kg live weight) and reported no difference in growth rate or feed intake, however, increasing CGM level had a quadratic response on feed efficiency (Table 2.2). The only study to report on the effects of feeding CGM on carcass traits was that of Jones (1987) and this study found that pigs fed 50% CGM had lower hot carcass weight, carcass yield, and backfat, compared to pigs fed 0 or 25% CGM (Table 2.3).

With respect to the energy content of CGM, published estimates of the ME content, measured using metabolism studies, show wide variation, with values from 2,630 to 3,011 kcal/kg ME being reported (Anderson et al. 2012; NRC, 2012; Gutierrez et al., 2014; Rojas et al., 2014). Factors contributing to this variation could be the measuring methodology used and/or the source of the CGM sample tested (Stein and Shurson, 2009; Urriola et al., 2010; Mendoza, 2013).

Because of concerns that energy values (DE, ME, or NE) of CGM are not accurate and/or need to be validated, the determination of productive energy (PE) has been suggested as an alternative approach to determine the energy content of an ingredient (Boyd et al., 2010; Boyd et al., 2011; Boyd et al., 2015). The PE can be measured by carrying out a growth study involving the feeding of a control diet (corn-soybean meal based) and a diet containing the test ingredient (e.g., CGM). The caloric efficiency (ratio between the calories consumed and the live weight produced) are estimated for each diet and the energy content of CGM is calculated by comparing the caloric efficiency of the diet containing CGM with that of the control.

In order to use CGM in commercial swine diets, there is a need to have an accurate estimation of the energy available to the animal for production and to better understand the maximum CGM level that can be included in the diets without negatively affecting growth performance and carcass measures. Therefore, two studies were carried out to: 1) determine the PE of CGM on a ME content; and 2) determine the effect of corn germ meal inclusion level on the growth performance and carcass characteristics of wean-to-finish pigs.

MATERIALS AND METHODS

Two related experiments were conducted at The Maschhoffs' Georgia Technology Center, a standard wean-to-finish facility located near New Minden, IL. The experimental protocol was approved by the University of Illinois Institutional Animal Care and Use Committee (IACUC# 15014).

Experimental Design and Treatments:

Both experiments were carried out with a randomized complete block design with 3 and 5 CGM inclusion levels for Experiments 1 and 2, respectively. The CGM inclusion levels were as follows: Experiment 1: 0, 12.5, and 25%; Experiment 2: 0, 10, 20, 30, and 40%. Start date was used as the blocking factor.

Animals and Allotment:

Both experiments used standard commercial crossbred pigs (progeny of PIC 359 sires mated to commercial dams) that were housed in a wean-to-finish barn from weaning (6.6 ± 0.54 and 6.4 ± 0.56 for Experiment 1 and 2, respectively) to approximately 23 weeks post weaning (127.1 ± 1.71 and 133.3 ± 1.62 kg live weight for Experiment 1 and 2, respectively).

Experiment 1: A total of 1,020 pigs were used and allotted to 30 single-sex pens of 34 pigs to achieve 10 replications per treatment. At weaning pigs were individually weighed and sorted into outcome groups of 3 pigs with similar body weight. This process was repeated until there were 34 pigs (barrows or gilts) in each pen. Pens within gender were randomly allotted to dietary treatment and immediately started on test.

Experiment 2: A total of 2,380 pigs were used and allotted to 70 mixed-gender pens of 34 pigs to achieve 14 replications per treatment. At weaning pigs were individually weighed and sorted by gender, and formed into outcome groups of 5 barrows and 5 gilts with similar body weight. This process was repeated until there were 34 pigs (17 barrows and 17 gilts) in each pen. Pens were randomly allotted to dietary treatment and immediately started on test.

Housing:

The same facility was used for both experiments. Experiment 1 was carried out between June and November of 2014, and Experiment 2 was carried out from December of 2014 to June of 2015. Pigs were housed in a wean-to-finish building that had fully slatted concrete flooring and was tunnel ventilated. Pen divisions were of horizontal bars. Each pen was equipped with a standard 4-space wet-dry feeder and two cup-type water drinkers. Feed and water were available *ad libitum* throughout the study period. The temperature was set at 27.2°C for the first 6 days, and reduced by 0.3°C per day until it reached 22.8°C, where it was held at 22.8°C for 6 days, and reduced by 0.3°C per day until it reached 18.3°C, where it was held constant throughout the remainder of the experiments. Air temperature in the building was maintained throughout the study period using thermostatically controlled heaters and fan ventilation. During the first 14 days post-weaning, supplemental heat was provided by one heat reflective heat lamp (125 W) per pen suspended 75 cm above the floor. Under hot conditions when the ambient room temperature reached 29.4° C, water sprinklers were used in an attempt to cool the pigs.

The floor space was 0.63 m^2/pig for all treatments. In the event of a mortality or removal of a morbid animal during the study, pen size was adjusted using a moveable partition to maintain a constant floor space.

Feed and Growth Measurements:

Individual body weights were taken at the start and group weights were taken every 2 weeks during the study and used to calculate average daily gain. A computerized feed system (Howema Feeding System, Big Dutchman Inc., Holland, MI) was used to deliver the feed and record the amount of feed delivered. All feed additions and the feed remaining in the feeder were recorded at the time of pig weighing, and were used to calculate average daily feed intake, and gain:feed ratio. Pigs experiencing health problems or injuries that did not respond to treatment were removed from the study and the date of removal, pig weight, and reason for removal were recorded; the weight of pigs removed was included in the calculation of growth rate and feed intake.

Dietary Treatments:

All diets were formulated to meet or exceed the requirements of pigs across the weight range used in these studies recommended by the NRC (2012). For both experiments diets were manufactured at the Carlyle Mill of The Maschhoffs in pellet form in 8 phases according to the feed budget shown in Table 3.1. All pigs received the same diets during the first 3 weeks of study (Nursery phases 1 and 2, from weaning to 12.2 kg of live weight).

All diets were formulated to the same standardized ileal digestible (SID) lysine and ME levels (within experiment), with yellow grease being added to diets including CGM as required to achieve this. The CGM used for both experiment was obtained from a single source (Archer Daniels Midland, Decatur, IL). The analyzed composition of corn, soybean meal, and CGM used in each experiment is shown in Table 3.2.

For Experiment 1, the ME values used to formulate the diets for corn and CGM were 3,380 and 3,037 kcal/kg, respectively, with the ME value of CGM being 89.9% of that of corn. The ME values used for corn and CGM were those reported by the NRC (2012) and Anderson et al. (2012), respectively. For both ingredients the ME value was adjusted according to the analyzed chemical composition of the batches used in the study. In addition, the soybean meal energy value used in diet formulation was 3,285 kcal/kg. Diets formulation and composition for both experiments are presented in Tables 3.3 to 3.8 (growing-finishing period: phases 3, 4, 5, 6, 7, and 8).

For Experiment 2, the ME value used in diet formulation for corn was 3,367 kcal/kg. The ME value used for CGM was of 2,681 kcal/kg, which was obtained by adjusting the previous estimate determined in Experiment 1, for the chemical composition of the batch of CGM used in Experiment 2. Calculations to determine the productive ME of CGM are detailed later in this chapter.

Harvest and Carcass Measurements:

Intact pens were taken off test and sent for harvest when the pen mean was 127.1 ± 1.71 kg, and 133.3 ± 1.63 kg live weight for Experiments 1 and 2, respectively. Within 12 h after end of test, final farm live weights (harvest) were collected, and the pigs were loaded on a standard transport trailer (with 165 pigs/load) and transported to Cargill Meat Solutions plant in Beardstown, IL. Pigs were allowed a period in lairage of at least 3 hours prior to slaughter, which was carried out using standard procedures. Carcass grading measurements were taken on the slaughter line including hot carcass weight, and Fat-O-Meater® backfat thickness and *Longissimus* (loin) muscle depth, and these measurements were used to calculate a predicted carcass lean content.

Productive Metabolizable Energy Calculations:

The following calculations were used to estimate the Productive ME of CGM (all concentrations are expressed on an as-fed basis):

1) The ***Caloric Efficiency*** (CE) of each dietary treatment was obtained by multiplying the feed:gain ratio by the formulated ME content of the diet:

$$CE\ (kcal/kg\ of\ gain) = Feed{:}Gain\ \times (Formulated\ ME_{Diet}\ kcal/kg) \quad \textbf{Eq. 3.1}$$

2) To obtain the ***Corrected ME*** content of the test diets (i.e., the diets including CGM), the Formulated ME content of the test diet was multiplied by the Caloric Efficiency of the control diet divided by the Caloric Efficiency of the test diet:

$$Corrected\ ME_{Test\ diet}\ (kcal/kg) = Formulated\ ME_{Test\ diet}\ \times \left(\frac{CE_{Control\ diet}}{CE_{Test\ diet}}\right) \quad \textbf{Eq. 3.2}$$

3) The ***ME Difference*** (between formulated and corrected ME content) of the test diet was obtained by subtraction:

$$ME\ Difference_{Test\ diet} = Formulated\ ME_{Test\ diet} - Corrected\ ME_{Test\ diet} \quad \textbf{Eq. 3.3}$$

4) It was assumed that the ME Difference of the test diet is due entirely to the test ingredient. Therefore, the ***ME Difference of the test ingredient*** was calculated by dividing the ME Difference of the test diet by the proportion of the test ingredient included (e.g., 25% CGM = 0.25 CGM inclusion):

$$ME\ Difference_{Test\ ingredient}\ (kcal/kg)$$
$$= ME\ difference_{Test\ diet,}\ kcal/kg$$
$$\div\ Test\ Ingredient\ inclusion\ \ \textbf{Eq. 3.4}$$

5) The ***Productive ME*** was obtained by subtracting the Energy Difference of the test ingredient from the Formulated Energy of the test ingredient:

$$Productive\ Energy\ (kcal/kg)$$
$$= Formulated\ ME\ _{Test\ ingredient}$$
$$- ME\ Difference_{Test\ ingredient}\ \ \textbf{Eq. 3.5}$$

Statistical Analysis:

All data were tested for normality using the PROC UNIVARIATE procedure of SAS (SAS Institute Inc., Cary, NC). Data meeting the criteria for analysis of variance were analyzed using the PROC MIXED procedure of SAS as a randomized complete block design with pen as the experimental unit. The model included the fixed effect of CGM inclusion level and the random effect of replicate (which accounted for room and start date). Least-squares means were compared using the PDIFF option of SAS. Orthogonal polynomial contrasts were used to analyze the linear, quadratic (Experiment 1) and cubic effects (Experiment 2) of the CGM inclusion level. Morbidity and mortality data were not normally distributed and were analyzed using a Chi-square rank-based test (Steel and Torrie, 1980), using the PROC RANK procedure of SAS.

RESULTS AND DISCUSSION

The effects of CGM inclusion level on growth performance and carcass characteristics for Experiment 1 and 2 are summarized in Tables 3.9 and 3.10, respectively.

Effects of CGM inclusion level on growth performance:

There was no effect of including CGM in the diet on feed intake in either experiment. In Experiment 1, there was no effect ($P = 0.21$) of increasing the CGM inclusion level (up to 25%) on growth rate. Similarly in Experiment 2, pigs fed diets with up to 30% CGM had similar growth rates to those fed the Control diet (0% CGM), whereas pigs fed 40% CGM had lower daily gain ($P < 0.001$) compared to the other treatments (0.758, 0.758, 0.748, 0.748, and 0.730 kg/d, for 0, 10, 20, 30, and 40% CGM, respectively). Increasing the CGM dietary level resulted in linear ($P < 0.05$) reduction of the gain:feed in both experiments. The slopes of the regression lines were -0.0006 and -0.0003 kg/% of CGM, for Experiments 1 and 2, respectively, indicating that the decrease in feed efficiency with increasing CGM inclusion level was less in Experiment 2 compared to Experiment 1. This difference in gain:feed response between experiments can be attributed to the adjustment that was carried to the ME content of CGM for Experiment 2 using the results from Experiment 1.

The results from the present experiments are in agreement to those reported by Jones (1987) from a study where pigs (between 58 and 106 kg of live weight) that were fed diets containing 25% CGM had similar growth rate to those on the control diet (0% CGM), however, pigs fed 50% CGM had lower daily gain. The study of Jones (1987) also showed no effect of CGM on feed intake (Table 2.2). In contrast, Weber et al. (2010) did not find any effect on growth rate or feed intake when up to 39% CGM was included in the diet of growing pigs (31 – 55 kg of live weight; Table 2.2).

Weber et al. (2010), reported that the gain:feed was increased at lower inclusion levels of CGM (12.5 and 25%) compared to the control (0% CGM) and decreased when 39% CGM was included in the diet (i.e., gain:feed showed a quadratic response with values of: 0.441, 0.464, 0.446, and 0.430 kg:kg for 0, 12.5, 25, and 39% CGM inclusion rates, respectively). That quadratic response in feed efficiency differs from the linear response obtained from the present two experiments. Weber et al. (2010) formulated the diets to meet or exceed nutritional requirements (NRC, 1998), however, the ME of the diets actually decreased as the inclusion of CGM in the diet increased (3.31, 3.26, 3.21, and 3.16 Mcal/kg for 0, 12.5, 25, and 39% CGM, respectively). Other studies have generally shown that decreases in dietary energy concentration are associated with lower gain:feed ratios (Smith et al., 1999; Apple et al. 2004; Patience et al., 2015) and, therefore, the gain:feed results for 12.5 and 25% CGM diets reported by Weber et al. (2010) are surprising and difficult to explain.

In conclusion, the results of the present experiments and those of the limited number of published studies suggest that, generally speaking, inclusion of 25% or less CGM in the diet has little effect on growth rate and up to 1.6% decrease on feed efficiency, however greater CGM inclusion levels have a negative effect on these traits. The reduction of feed efficiency is probably related to a decline of energy digestibility of diets containing CGM. This is mainly due to increased dietary fiber, which has a lower digestibility compared to other dietary components such as starch or fat (Noblet and Shi, 1994; Noblet and Le Goff, 2001). Further research is needed to establish the maximum level of CGM that can be included in swine diets without affecting growth performance.

Effects of CGM inclusion level on carcass characteristics:

In both of the current experiments, increasing the CGM dietary level resulted in a linear reduction of hot carcass weight and carcass yield, but there was no effect on backfat thickness (Tables 3.9 and 3.10). Furthermore, in Experiment 2, increasing dietary CGM also linearly reduced loin depth and predicted carcass lean content (Table 3.10).

Jones (1987) reported that including 25% CGM in the diet of growing-finishing pigs had no effect on carcass yield, however, feeding diets with 50% CGM reduced carcass yield by 2.8% units compared to pigs fed the control diet (0% CGM). Backfat thickness was reduced at both CGM levels compared to the control, with no differences in loin eye area (Jones, 1987).

Generally speaking, the results of the current experiments and that of Jones (1987) suggest that inclusion of CGM in diets for growing-finishing pigs has a negative effect on carcass yield, which is in agreement with previous reports where diets including corn co-products or diets with high fiber content have been fed to pigs (Pond, 1988; Stein and Shurson, 2009; Xu et al., 2010; Lee, 2011; Lee et al., 2012).

In conclusion the results from the two experiments reported in this chapter are in general agreement with previous research, showing that the inclusion of CGM (a corn co-product with high fiber content) in diets for growing-finishing pigs has a negative effect on hot carcass weight and carcass yield. However, there was variation between experiments in relation to the effect of CGM on other carcass measurements.

Estimation of the Productive Metabolizable Energy of Corn Germ Meal:

A summary of the effect of CGM inclusion level on the feed:gain ratio of wean-to-finish pigs, and the calculation of the productive ME of CGM for Experiment 1 and 2 are presented in Table 3.11. The regression equations representing the linear effect of CGM inclusion level on the caloric efficiency for the two experiments are presented in Figure 3.1.

Experiment 1:

The results of this experiment showed that increasing CGM inclusion level resulted in a linear increase in feed:gain ratio (2.34, 2.38, and 2.42 kg/kg for 0, 12.5, and 25.0% CGM diets, respectively). These feed:gain ratios were used to estimate the caloric energy efficiency (equation 3.1) and, subsequently, the productive ME of the CGM (equations 3.2 to 3.5).

The estimated productive ME for CGM was determined by averaging the productive ME of CGM of both inclusion levels (12.5 and 25%), and resulted in a productive ME of 2,604 kcal/kg. This value is significantly lower than the ME value that was originally used to formulate the test diets for this experiment (3,037 kcal/kg), which was obtained from the literature (Anderson et al, 2012; NRC, 2012). Thus, based on these results the productive ME of CGM was 77.0% of that of corn (3,380 kcal/kg).

These results are in agreement with the concept that diets with higher content of fiber have a lower ME:NE ratio; NE is the energy available to the animal to use for maintenance and production (Noblet, 2007; NRC, 2012; Kil et al., 2013). Therefore, from the results of this study there is evidence that the ME value for CGM used to formulate the treatment diets in this experiment, which were obtained from metabolism studies (Anderson et al., 2012; NRC, 2012), was an overestimate. Therefore, a second study (Experiment 2) was carried out to validate and/or further adjust the productive ME of CGM obtained in Experiment 1.

Experiment 2:

Similar to the results of Experiment 1, the results of this study (Table 3.11) showed that increasing CGM inclusion level resulted in a linear increase of feed:gain ratio (2.46, 2.48, 2.49, 2.50, and 2.55 kg/kg for 0, 10, 20, 30, and 40% CGM diets, respectively). As a result, the estimate of productive ME for this second experiment was 2,462 kcal/kg (obtained by averaging the productive energy for all 4 CGM treatments) [Table 3.11].

The slope for the change in caloric efficiency with increasing CGM level was numerically lower for the second Experiment 2 compared to Experiment 1 (Figure 3.1), resulting in 10.44 and 6.62 kcal/% of CGM for Experiment 1 and 2, respectively (R^2 = 0.99 and 0.90 for Experiment 1 and 2, respectively). This suggests that the adjusted ME value of CGM (2,681 kcal/kg) used to formulate diets in the Experiment 2 was more accurate compared to the value originally used for Experiment 1 which was obtained from the literature (3,037 kcal/kg).

There is no clear explanation for the difference in productive ME estimates between these two studies. It could possibly be related with errors and/or variation in chemical composition analyses, as well as with variation between the studies in factors such as season of the year in which the study was carried out, the health status of the animals, etc.

In conclusion, there is considerable variation between estimates in the literature of the energy content of CGM as well as between estimates of productive energy content from the growth experiments reported in this chapter. This variation could be due to variation in composition between CGM sources and batches, as well as differences between energy determination methods. Further research is needed to further validate and/or adjust current energy values for CGM.

CONCLUSIONS

The results of this research, which involved two growth experiments to determine the effect of increasing the dietary levels of CGM on the growth performance and carcass characteristics of wean-to-finish pigs, and the determination of productive ME of CGM, suggest that, generally speaking, inclusion of CGM in diets for growing-finishing pigs has a negative impact on feed efficiency, and carcass yield, with no consistent effect on growth rate. Also, the results of these growth studies suggest that the ME values of CGM reported in the literature (and used to formulate the experimental diets) overestimate the ME content of CGM. The estimated productive ME of CGM based on the growth experiments were 2,604 and 2,483 kcal/kg for Experiment 1 and 2, respectively [8.0 and 12.3% lower, respectively, compared to the ME reported by the NRC (2012)].

TABLES AND FIGURES

Table 3.1. Dietary phases and feed budget for experiments 1 and 2.

	Experiment 1				Experiment 2	
	Barrows		Gilts		Mixed-sex	
Dietary Phase[1]	kg of feed/pig	Live Weight Range (kg)	kg of feed/pig	Live Weight Range (kg)	kg of feed/pig	Live Weight Range (kg)
1	2.7	5.9-8.6	2.7	5.9-8.6	2.7	6.4-8.2
2	5.4	8.7-12.2	5.4	8.7-12.2	5.4	8.6-12.2
3	15.9	12.7-25.9	15.9	12.3-25.9	16.3	12.7-22.7
4	36.3	26.0-42.6	36.3	26.0-43.5	43.1	22.7-45.4
5	54.4	42.7-55.8	52.2	43.6-61.2	52.2	45.8-68.0
6	63.5	55.9-68.5	59.9	61.3-74.4	61.7	68.5-90.7
7	59.0	68.6-90.3	54.4	74.5-101.2	55.8	91.2-108.9
8	99.8	90.4-129.3	90.7	101.3-129.3	61.7	109.3-133.0

[1]Phase 1 diet was fed in crumble form. The rest of the diets were in pellet form.

Table 3.2. Analyzed composition of corn, soybean meal (SBM), and corn germ meal (CGM) used to manufacture experimental diets.

	Corn		SBM[1]		CGM[1]	
Item	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2
Proximate analysis, % as-fed basis[2]						
Dry matter	86.35	87.42	87.7	87.34	88.25	88.56
Crude protein	7.52	7.87	47.59	47.37	23.8	23.69
Crude fat	3.36	3.32	0.98	1.18	1.78	2.71
Crude fiber	1.78	1.79	3.20	3.22	7.57	7.52
Acid detergent fiber	2.60	2.63	5.61	5.65	12.02	11.21
Neutral detergent fiber	6.90	7.30	7.47	7.11	37.2	36.99
Phosphorus	0.27	0.28	0.71	0.71	0.79	0.82
Calcium	0	0	0.32	0.32	0.02	0.03
Sodium	-	-	-	-	0.02	0.02
Ash	1.17	1.12	6.09	6.26	2.58	2.77
Chloride	-	-	-	-	0.06	0.05
Amino acid analysis, % as-fed basis[3, 4]						
Alanine	0.51	-	2.06	2.1	1.43	1.47
Arginine	0.35	-	3.4	3.47	1.61	1.66
Aspartic acid	0.48	-	5.43	5.54	1.7	1.74
Cystine	0.18	-	0.68	0.68	0.33	0.32
Glutamic acid	1.23	-	8.48	8.57	3.08	3.16
Glycine	0.29	-	1.99	2.04	1.27	1.32
Histidine	0.19	-	1.22	1.24	0.65	0.68
Isoleucine	0.24	-	2.18	2.16	0.82	0.85
Leucine	0.8	-	3.56	3.56	1.73	1.8
Lysine	0.22	-	2.92	2.98	0.96	1.02
Methionine	0.16	-	0.66	0.67	0.43	0.43
Methionine + Cystine	0.33	-	1.35	1.35	0.75	0.75
Phenylalanine	0.32	-	2.44	2.48	1.03	1.08
Proline	0.61	-	2.40	2.44	1.09	1.13
Serine	0.34	-	2.40	2.43	1.09	1.12
Threonine	0.25	-	1.85	1.89	0.88	0.9
Tryptophan	0.06	-	0.64	0.63	0.26	0.25
Tyrosine	0.1	-	1.24	1.26	0.51	0.52
Valine	0.33	-	2.20	2.18	1.25	1.29

[1]SBM and CGM origin: Archer Daniels Midland, Decatur, IL.

[2]Proximate analysis was performed at Midwest Laboratories, Omaha, NE.

[3]Amino acid analysis was performed using High-Performance Liquid Chromatography (HPLC), Ajinomoto Heartland, LLC, Chicago, IL.

[4]Amino acid analysis for corn used in Experiment 2 was not recorded.

Table 3.3. Diet formulation and nutritional composition for phase 3 (as-fed-basis[1]).

	Corn germ meal level, %							
	Experiment 1			Experiment 2				
	0 (Control)	10.75	21.50	0 (Control)	10	20	30	40
Ingredient, %								
Corn	61.96	55.42	48.89	59.37	51.24	43.12	35.00	26.88
Corn germ meal	0.00	10.75	21.50	0.00	10.00	20.00	30.00	40.00
Soybean meal	33.54	29.13	24.71	36.32	33.20	30.07	26.94	23.82
Fat (Yellow grease-mixer)	0.35	0.79	1.24	0.70	0.70	0.70	0.70	0.70
Fat (Yellow grease-postpellet)	-	-	-	0.00	1.29	2.59	3.88	5.17
Limestone	1.29	1.15	1.01	1.21	1.22	1.22	1.22	1.22
Mono-cal 21% P	1.53	1.35	1.16	1.10	1.01	0.92	0.83	0.74
Salt	0.55	0.53	0.51	0.50	0.49	0.48	0.48	0.47
L-Lysine HCl- Dry (98.5%)	0.35	0.42	0.49	0.35	0.38	0.42	0.46	0.50
Methionine (HMB[2])	0.19	0.20	0.21	0.20	0.21	0.21	0.22	0.22
Threonine (98%)	0.08	0.10	0.12	0.09	0.09	0.10	0.10	0.11
Trace minerals premix	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Copper chloride (58%)	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02
Vitamins premix	0.03	0.03	0.03	0.05	0.05	0.05	0.05	0.05
Diet composition								
ME, kcal/kg	3,244	3,246	3,248	3,277	3,277	3,277	3,277	3,277
Crude protein, %	20.74	20.76	20.79	21.85	22.16	22.46	22.76	23.07
Crude fat, %	2.43	2.77	3.10	2.71	3.79	4.88	5.96	7.05
Crude fiber, %	1.82	2.35	2.88	1.86	2.36	2.86	3.35	3.85
NDF, %	6.53	9.68	12.83	6.55	9.41	12.28	15.14	18.00
ADF, %	3.28	4.18	5.08	3.36	4.21	5.05	5.89	6.74
Calcium, %	0.90	0.80	0.70	0.80	0.77	0.75	0.72	0.70
Phosphorus, %	0.69	0.69	0.69	0.61	0.63	0.64	0.66	0.68
Calcium:Phosphorus	1.29	1.16	1.02	1.30	1.23	1.16	1.10	1.03
Sodium, %	0.24	0.23	0.22	0.22	0.21	0.21	0.20	0.20
Lysine, %	1.38	1.39	1.41	1.45	1.47	1.48	1.50	1.51
SID[3] lysine, %	1.24	1.24	1.24	1.31	1.31	1.31	1.31	1.31
SID[3] lysine:ME	5.65	5.64	5.63	4.00	4.00	4.00	4.00	4.00
SID[3] AA:Lysine ratio								
Met + Cys	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57
Tryptophan	0.18	0.17	0.17	0.18	0.18	0.18	0.18	0.18
Threonine	0.18	0.17	0.17	0.60	0.60	0.60	0.60	0.60
Isoleucine	0.62	0.60	0.57	0.63	0.62	0.60	0.59	0.58
Valine	0.65	0.65	0.65	0.65	0.66	0.67	0.67	0.68

[1]Diets delivered in pellet form.

[2]HMB = 2-hydroxy-4-(methylthio) butanoic acid

[3]SID = standardized ileal digestible

Table 3.4. Diet formulation and nutritional composition for phase 4 (as-fed-basis[1]).

	Corn germ meal level, %							
	Experiment 1			Experiment 2				
	0 (Control)	12.5	25.0	0 (Control)	10	20	30	40
Ingredient, %								
Corn	71.05	61.26	51.47	70.39	61.97	53.54	45.12	36.69
Corn germ meal	0.00	12.50	25.00	0.00	10.00	20.00	30.00	40.00
Soybean meal	25.42	22.00	18.59	25.43	22.56	19.68	16.81	13.94
Fat (Yellow grease-mixer)	0.35	1.10	1.84	0.70	0.70	0.70	0.70	0.70
Fat (Yellow grease-postpellet)	-	-	-	0.00	1.36	2.71	4.07	5.42
Limestone	0.98	1.05	1.11	1.21	1.20	1.20	1.19	1.19
Monocal 21% P	1.01	0.90	0.78	1.04	0.95	0.87	0.78	0.69
Salt	0.50	0.48	0.46	0.50	0.49	0.48	0.47	0.46
L-Lysine HCl- Dry (98.5%)	0.34	0.37	0.40	0.35	0.38	0.42	0.46	0.49
Methionine (HMB[2])	0.14	0.13	0.13	0.14	0.14	0.15	0.15	0.16
Threonine (98%)	0.08	0.08	0.07	0.09	0.09	0.10	0.10	0.11
Trace minerals	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10
Cooper chloride (58%)	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03
Vitamins premix	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Calculated composition								
ME, kcal/kg	3,280	3,280	3,280	3,313	3,312	3,312	3,312	3,311
Crude protein, %	17.57	18.18	18.80	18.03	18.37	18.71	19.05	19.39
Crude fat, %	2.62	3.18	3.74	3.02	4.16	5.30	6.43	7.57
Crude fiber, %	1.70	2.34	2.98	1.73	2.24	2.76	3.27	3.79
NDF, %	6.57	10.20	13.84	7.68	10.36	13.05	15.73	18.42
ADF, %	3.06	4.15	5.24	3.04	3.79	4.53	5.28	6.03
Calcium, %	0.66	0.66	0.65	0.75	0.73	0.70	0.68	0.65
Phosphorus, %	0.55	0.57	0.60	0.58	0.59	0.61	0.62	0.64
Calcium:Phosphorus	1.20	1.14	1.09	1.30	1.22	1.15	1.08	1.02
Sodium, %	0.22	0.21	0.20	0.22	0.21	0.21	0.20	0.20
Lysine, %	1.16	1.18	1.20	1.23	1.25	1.26	1.28	1.29
SID[3] lysine, %	1.04	1.04	1.04	1.11	1.11	1.11	1.11	1.11
SID[3] lysine:ME	3.17	3.17	3.17	3.34	3.34	3.34	3.34	3.34
SID[3] AA:Lysine ratio								
Met + Cys	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57
Tryptophan	0.17	0.17	0.18	0.17	0.17	0.17	0.17	0.17
Threonine	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
Isoleucine	0.61	0.60	0.59	0.59	0.58	0.57	0.56	0.55
Valine	0.65	0.67	0.70	0.65	0.66	0.67	0.68	0.69

[1]Diets delivered in pellet form.

[2]HMB = 2-hydroxy-4-(methylthio) butanoic acid

[3]SID = standardized ileal digestible

Table 3.5. Diet formulation and nutritional composition for phase 5 (as-fed-basis[1]).

	Corn germ meal level, %							
	Experiment 1			Experiment 2				
	0 (Control)	12.5	25.0	0 (Control)	10	20	30	40
Ingredient, %								
Corn	76.81	67.04	57.27	76.78	68.46	60.15	51.83	43.52
Corn germ meal	0.00	12.50	25.00	0.00	10.00	20.00	30.00	40.00
Soybean meal	19.72	16.24	12.77	19.32	16.42	13.52	10.62	7.72
Fat (Yellow grease-mixer)	0.50	1.28	2.05	0.70	0.70	0.70	0.70	0.70
Fat (Yellow grease-postpellet)	-	-	-	0.00	1.28	2.56	3.85	5.13
Limestone	0.94	1.00	1.06	1.11	1.11	1.12	1.12	1.12
Mono-cal 21% P	0.95	0.83	0.72	0.89	0.80	0.71	0.62	0.54
Salt	0.45	0.44	0.44	0.50	0.49	0.48	0.47	0.46
L-Lysine HCl- Dry (98.5%)	0.33	0.37	0.40	0.35	0.38	0.41	0.44	0.46
Methionine (HMB[2])	0.10	0.10	0.10	0.11	0.11	0.11	0.11	0.12
Threonine (98%)	0.07	0.07	0.07	0.10	0.10	0.10	0.10	0.10
Trace minerals premix	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09
Cooper chloride (58%)	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03
Vitamins premix	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Calculated composition								
ME, kcal/kg	3,297	3,299	3,300	3,291	3,291	3,291	3,291	3,291
Crude protein, %	15.31	15.90	16.49	15.05	15.44	15.83	16.22	16.61
Crude fat, %	2.88	3.46	4.05	3.23	4.29	5.36	6.42	7.49
Crude fiber, %	1.61	2.25	2.89	1.83	2.33	2.82	3.32	3.81
NDF, %	6.55	10.19	13.82	6.79	9.58	12.37	15.16	17.95
ADF, %	2.90	3.99	5.07	2.86	3.61	4.36	5.11	5.87
Calcium, %	0.62	0.61	0.60	0.68	0.65	0.63	0.60	0.58
Phosphorus, %	0.51	0.54	0.56	0.52	0.54	0.55	0.57	0.58
Calcium:Phosphorus	2.46	2.43	2.40	1.30	1.22	1.14	1.07	1.00
Sodium, %	0.20	0.19	0.19	0.22	0.21	0.21	0.20	0.20
Salt, %	0.52	0.52	0.51	0.57	0.56	0.55	0.54	0.53
Lysine, %	1.00	1.02	1.04	1.00	1.01	1.03	1.05	1.07
SID[3] lysine, %	0.90	0.90	0.90	0.89	0.89	0.89	0.89	0.89
SID[3] lysine:ME	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72
SID[3] AA:Lysine ratio								
Met + Cys	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57
Tryptophan	0.17	0.17	0.17	0.16	0.17	0.17	0.17	0.17
Threonine	0.60	0.60	0.60	0.62	0.62	0.62	0.62	0.62
Isoleucine	0.60	0.59	0.57	0.60	0.59	0.58	0.56	0.55
Valine	0.65	0.67	0.70	0.65	0.67	0.69	0.70	0.72

[1]Diets delivered in pellet form.

[2]HMB = 2-hydroxy-4-(methylthio) butanoic acid

[3]SID = standardized ileal digestible

Table 3.6. Diet formulation and nutritional composition for phase 6 (as-fed-basis[1]).

	Corn germ meal level, %							
	Experiment 1			Experiment 2				
	0 (Control)	12.5	25.0	0 (Control)	10	20	30	40
Ingredient, %								
Corn	81.29	71.57	61.85	79.69	71.46	63.23	55.00	46.78
Corn germ meal	0.00	12.50	25.00	0.00	10.00	20.00	30.00	40.00
Soybean meal	15.63	12.09	8.55	16.89	13.89	10.89	7.88	4.88
Fat (Yellow grease-mixer)	0.35	1.11	1.87	0.70	0.70	0.70	0.70	0.70
Fat (Yellow grease-postpellet)	-	-	-	0.00	1.28	2.56	3.85	5.13
Limestone	0.87	0.94	1.01	1.06	1.07	1.08	1.09	1.10
Mono-cal 21% P	0.83	0.71	0.60	0.71	0.62	0.54	0.45	0.36
Salt	0.43	0.43	0.44	0.50	0.49	0.48	0.47	0.46
L-Lysine HCl- Dry (98.5%)	0.33	0.37	0.40	0.24	0.27	0.30	0.33	0.36
Methionine (HMB[2])	0.08	0.08	0.08	0.04	0.04	0.04	0.04	0.05
Threonine (98%)	0.09	0.09	0.08	0.05	0.05	0.06	0.06	0.06
Trace minerals premix	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Cooper chloride (58%)	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03
Vitamins premix	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Diet composition								
ME, kcal/kg	3,300	3,300	3,300	3,301	3,301	3,301	3,300	3,300
Crude protein, %	13.72	14.28	14.85	13.97	14.33	14.68	15.03	15.38
Crude fat, %	2.83	3.40	3.97	3.29	4.36	5.42	6.49	7.56
Crude fiber, %	1.55	2.19	2.83	1.80	2.30	2.79	3.29	3.78
NDF, %	6.57	10.20	13.83	6.81	9.60	12.39	15.17	17.96
ADF, %	2.79	3.87	4.96	2.81	3.56	4.31	5.06	5.80
Calcium, %	0.55	0.55	0.55	0.62	0.60	0.57	0.55	0.53
Phosphorus, %	0.47	0.50	0.52	0.48	0.49	0.50	0.52	0.53
Calcium:Phosphorus	2.52	2.51	2.50	1.30	1.22	1.14	1.07	1.00
Sodium, %	0.19	0.19	0.19	0.22	0.21	0.21	0.20	0.20
Lysine, %	0.89	0.91	0.93	0.85	0.86	0.88	0.90	0.91
SID[3] lysine, %	0.80	0.80	0.80	0.75	0.75	0.75	0.75	0.75
SID[3] lysine:ME	2.41	2.41	2.41	2.27	2.27	2.27	2.27	2.27
SID[3] AA:Lysine ratio								
Met + Cys	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57
Tryptophan	0.16	0.16	0.16	0.18	0.18	0.18	0.18	0.18
Threonine	0.62	0.62	0.62	0.63	0.63	0.63	0.63	0.63
Isoleucine	0.59	0.57	0.55	0.66	0.64	0.63	0.61	0.59
Valine	0.65	0.68	0.70	0.72	0.74	0.76	0.78	0.80

[1]Diets delivered in pellet form.

[2]HMB = 2-hydroxy-4-(methylthio) butanoic acid

[3]SID = standardized ileal digestible.

Table 3.7. Diet formulation and nutritional composition for phase 7 (as-fed-basis[1]).

	Corn germ meal level, %							
	Experiment 1			Experiment 2				
	0 (Control)	12.5	25.0	0 (Control)	10	20	30	40
Ingredient, %								
Corn	82.47	72.23	61.99	82.88	74.65	66.41	58.17	49.94
Corn germ meal	0.00	12.50	25.00	0.00	10.00	20.00	30.00	40.00
Soybean meal	14.84	11.95	9.07	13.90	10.90	7.91	4.91	1.91
Fat (Yellow grease-mixer)	0.35	1.07	1.78	0.70	0.70	0.70	0.70	0.70
Fat (Yellow grease-postpellet)	-	-	-	0.00	1.29	2.57	3.86	5.14
Limestone	0.86	0.89	0.92	1.02	1.04	1.05	1.07	1.09
Mono-cal 21% P	0.64	0.52	0.41	0.63	0.54	0.46	0.37	0.28
Salt	0.45	0.44	0.44	0.46	0.44	0.43	0.42	0.41
L-Lysine HCl- Dry (98.5%)	0.22	0.24	0.25	0.22	0.25	0.28	0.31	0.34
Methionine (HMB[2])	0.02	0.01	0.00	0.01	0.01	0.02	0.02	0.02
Threonine (98%)	0.04	0.03	0.02	0.05	0.05	0.05	0.05	0.05
Trace minerals premix	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Cooper chloride (58%)	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03
Vitamins premix	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Diet composition								
ME, kcal/kg	3,305	3,304	3,303	3,309	3,309	3,309	3,309	3,309
Crude protein, %	13.29	14.10	14.92	12.78	13.13	13.48	13.83	14.18
Crude fat, %	2.86	3.38	3.90	3.36	4.43	5.50	6.57	7.64
Crude fiber, %	1.55	2.20	2.85	1.76	2.26	2.75	3.25	3.74
NDF, %	6.59	10.23	13.87	6.81	9.59	12.38	15.17	17.95
ADF, %	2.78	3.88	4.99	2.74	3.49	4.24	4.99	5.73
Calcium, %	0.52	0.50	0.48	0.58	0.56	0.54	0.52	0.50
Phosphorus, %	0.43	0.46	0.48	0.45	0.46	0.47	0.49	0.50
Calcium:Phosphorus	2.87	2.77	2.67	1.30	1.22	1.14	1.07	1.00
Sodium, %	0.20	0.19	0.19	0.20	0.20	0.19	0.19	0.18
Total lysine, %	0.78	0.81	0.83	0.75	0.77	0.79	0.80	0.82
SID[3] lysine, %	0.69	0.69	0.69	0.66	0.66	0.66	0.66	0.66
SID[3] lysine:ME	2.09	2.09	2.09	2.00	2.00	2.00	2.00	2.00
SID[3] AA:Lysine ratio								
Met + Cys	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57
Tryptophan	0.18	0.19	0.19	0.18	0.18	0.18	0.18	0.18
Threonine	0.63	0.63	0.63	0.64	0.64	0.64	0.64	0.64
Isoleucine	0.66	0.66	0.66	0.67	0.65	0.63	0.61	0.59
Valine	0.73	0.78	0.83	0.75	0.77	0.79	0.81	0.83

[1]Diets delivered in pellet form.

[2]HMB = 2-hydroxy-4-(methylthio) butanoic acid

[3]SID = standardized ileal digestible

Table 3.8. Diet formulation and nutritional composition for phase 8 (as-fed-basis[1]).

	Corn germ meal level, %							
	Experiment 1			Experiment 2				
	0 (Control)	12.5	25.0	0 (Control)	10	20	30	40
Ingredient, %								
Corn	84.93	74.60	64.28	84.02	75.73	67.44	59.14	50.85
Corn germ meal	0.00	12.50	25.00	0.00	10.00	20.00	30.00	40.00
Soybean meal	12.37	9.62	6.87	12.79	9.84	6.89	3.95	1.00
Fat (Yellow grease-mixer)	0.35	1.05	1.74	0.70	0.70	0.70	0.70	0.70
Fat (Yellow grease-postpellet)	-	-	-	0.00	1.29	2.59	3.88	5.17
Limestone	0.85	0.88	0.92	1.02	1.03	1.05	1.07	1.08
Mono-cal 21% P	0.65	0.54	0.42	0.64	0.55	0.46	0.38	0.29
Salt	0.50	0.47	0.44	0.46	0.44	0.43	0.42	0.41
L-Lysine HCl- Dry (98.5%)	0.20	0.22	0.23	0.21	0.24	0.27	0.30	0.33
Methionine (HMB[2])	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Threonine (98%)	0.03	0.02	0.01	0.04	0.04	0.04	0.04	0.04
Trace minerals premix	0.06	0.06	0.06	0.08	0.08	0.08	0.08	0.08
Cooper chloride (58%)	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03
Vitamins premix	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03
Diet composition								
ME, kcal/kg	3,305	3,304	3,303	3,311	3,311	3,311	3,311	3,311
Crude protein, %	12.30	13.16	14.02	12.32	12.69	13.06	13.43	13.81
Crude fat, %	2.91	3.41	3.91	3.38	4.46	5.53	6.61	7.68
Crude fiber, %	1.51	2.16	2.81	1.75	2.24	2.74	3.23	3.73
NDF, %	6.58	10.23	13.87	6.80	9.59	12.37	15.16	17.95
ADF, %	2.71	3.82	4.93	2.72	3.46	4.21	4.96	5.71
Calcium, %	0.51	0.49	0.48	0.58	0.56	0.54	0.52	0.50
Phosphorus, %	0.42	0.45	0.48	0.44	0.46	0.47	0.49	0.50
Calcium:Phosphorus	2.82	2.73	2.64	1.30	1.22	1.14	1.07	1.00
Sodium, %	0.22	0.2	0.19	0.20	0.20	0.19	0.19	0.18
Lysine, %	0.71	0.73	0.75	0.72	0.73	0.75	0.77	0.78
SID[3] lysine, %	0.62	0.62	0.62	0.63	0.63	0.63	0.63	0.63
SID[3] lysine:ME	1.87	1.87	1.87	1.90	1.90	1.90	1.90	1.90
SID[3] AA:Lysine ratio								
Met + Cys	0.58	0.59	0.60	0.57	0.57	0.57	0.57	0.57
Tryptophan	0.18	0.19	0.20	0.18	0.18	0.18	0.18	0.18
Threonine	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64
Isoleucine	0.66	0.67	0.67	0.67	0.65	0.63	0.61	0.59
Valine	0.75	0.81	0.87	0.75	0.78	0.80	0.82	0.85

[1]Diets delivered in pellet form.

[2]HMB = 2-hydroxy-4-(methylthio) butanoic acid

[3]SID = standardized ileal digestible

Table 3.9. Experiment 1: Effect of Corn Germ Meal (CGM) inclusion level on the growth performance of wean-to-finish pigs.

	Corn germ meal level, %				*P*-value		
Item	0	12.5	25.0	SEM	CGM	Linear	Quadratic
Number of pens	10	10	10	-	-	-	-
Number of pigs	340	340	340	-	-	-	-
Growth performance[1]							
Live weight, kg							
Start of test (at weaning)	6.6	6.6	6.6	0.17	0.37	0.79	0.17
End of test	126.9	127.6	127.0	0.55	0.51	0.82	0.26
Days on test	149.3	150.1	150.9	-	-	-	-
Average daily gain, kg	0.798	0.798	0.789	0.0091	0.21	0.10	0.57
Average daily feed intake, kg	1.873	1.896	1.905	0.0308	0.36	0.17	0.76
Gain:Feed, kg	0.428[a]	0.421[ab]	0.414[b]	0.0040	0.01	0.004	0.92
Carcass characteristics							
Harvest live weight, kg[2]	126.9	127.6	126.9	0.56	0.45	0.96	0.22
Hot carcass weight, kg	94.4[a]	93.8[a]	92.4[b]	0.49	0.01	0.002	0.43
Carcass yield, %	74.43[a]	73.53[b]	72.87[c]	0.203	<0.001	<0.001	0.57
Fat-O-Meater back fat depth, cm	1.68	1.65	1.65	0.066	0.85	0.71	0.69
Fat-O-Meater *Longissimus* muscle depth, cm	6.12	6.05	5.89	0.127	0.30	0.13	0.90
Predicted carcass lean content, %	53.86	53.83	53.61	0.247	0.12	0.06	0.35

[a,b,c]Means within a row with different superscripts are different ($P \leq 0.05$).

[1]Pigs on all treatments were fed a common diet during nursery (phases 1 and 2), and dietary treatments were applied starting with dietary phase 3 (approximately at week 3 post weaning).

[2]Harvest live weight = final farm live weight; average of all pigs sent for harvest (within pen).

Table 3.10. Experiment 2: Effect of Corn Germ Meal (CGM) inclusion level on the growth performance of wean-to-finish pigs.

							P-value			
	Corn germ meal level, %							Orthogonal contrasts		
Item	0	10	20	30	40	SEM	CGM	Linear	Quadratic	Cubic
Number of pens	14	14	14	14	14	-	-	-	-	-
Number of pigs	476	476	476	476	476	-	-	-	-	-
Growth performance[1]										
Live weight, kg										
Start of test (weaning)	6.4	6.4	6.4	6.4	6.4	0.15	0.99	0.93	0.94	0.79
End of test	133.1	133.1	133.8	132.9	133.4	0.44	0.56	0.85	0.85	0.61
Days on test	165.4	166.1	167.4	167.9	171.4	-	-	-	-	-
Average daily gain, kg	0.758^{a}	0.758^{a}	0.748^{a}	0.748^{a}	0.730^{b}	0.0059	0.001	<0.001	0.16	0.70
Average daily feed intake, kg	1.873	1.878	1.864	1.869	1.869	0.0168	0.95	0.64	0.98	0.67
Gain:Feed, kg	0.406^{a}	0.403^{ab}	0.402^{ab}	0.399^{b}	0.392^{c}	0.0029	0.002	<0.001	0.19	0.40
Carcass characteristics										
Harvest live weight, kg[2]	133.3	133.1	133.8	132.9	133.4	0.44	0.56	0.85	0.84	0.62
Hot carcass weight, kg	100.0^{a}	99.3^{a}	99.5^{a}	98.3^{b}	98.3^{b}	0.37	0.001	<0.001	0.94	0.70
Carcass yield, %	75.04^{a}	74.60^{b}	74.33^{bc}	73.94^{cd}	73.70^{d}	0.154	<0.001	<0.001	0.62	0.97
Fat-O-Meater back fat depth, cm	1.75	1.73	1.75	1.73	1.70	0.025	0.82	0.47	0.66	0.46
Fat-O-Meater *Longissimus* muscle depth, cm	6.58^{a}	6.45^{ab}	6.32^{bc}	6.22^{cd}	6.07^{d}	0.062	<0.001	<0.001	0.93	0.69
Predicted carcass lean content, %	53.87^{a}	53.60^{ab}	53.28^{b}	53.31^{b}	53.27^{b}	0.122	0.002	<0.001	0.08	0.93

^{a,b,c,d}Means within a row with different superscripts are different ($P \leq 0.05$).

[1]Pigs on all treatments were fed a common diet during nursery (phases 1 and 2), and dietary treatments were applied starting with dietary phase 3 (approximately at week 3 post weaning).

[2]Harvest live weight = final farm live weight; average of all pigs sent for harvest (within pen).

Table 3.11. Experiments 1 and 2: Summary of the effect of Corn Germ Meal (CGM) inclusion level on the feed:gain ratio of wean-to-finish pigs, and calculation of the productive ME of CGM.

	Experiment 1				**Experiment 2**					
	Corn germ meal level, %				Corn germ meal level, %					
Item	0	12.5	25	*P*-value	0	10	20	30	40	*P*-value
Feed:Gain ratio, kg:kg	2.336[b]	2.375[ab]	2.415[s]	0.01	2.463[c]	2.481[bc]	2.488[bc]	2.506[b]	2.551[a]	0.002
Formulated energy content, (kcal/kg)[1]:										
Dietary ME	3,289	3,289	3,289	-	3,300	3,300	3,300	3,300	3,300	-
Corn germ meal ME	-	3,037	3,037	-	-	2,681	2,681	2,681	2,681	-
Calculations:										
1) Caloric Efficiency[2], kcal/kg	7,683	7,812	7,944	-	8,129	8,189	8,210	8,271	8,419	-
2) Corrected Energy of test diet[3], kcal/kg	-	3,235	3,181	-	-	3,276	3,268	3,243	3,187	-
3) Energy Difference of test diet[4], kcal	-	54	108	-	-	24	32	57	114	-
4) Energy Difference of test ingredient[5], kcal/kg	-	432	432	-	-	243.3	162	189.1	283.9	-
5) Productive ME of CGM[6], kcal/kg	-	2,604	2,604	-	-	2,438	2,519	2,492	2,397	-

[a,b,c]Means with different superscripts within experiment are different ($P \leq 0.05$).

[1]As-fed basis.

[2]Caloric Efficiency (CE), kcal/kg of gain = Feed:Gain × (Formulated Energy of the Diet, kcal/kg)

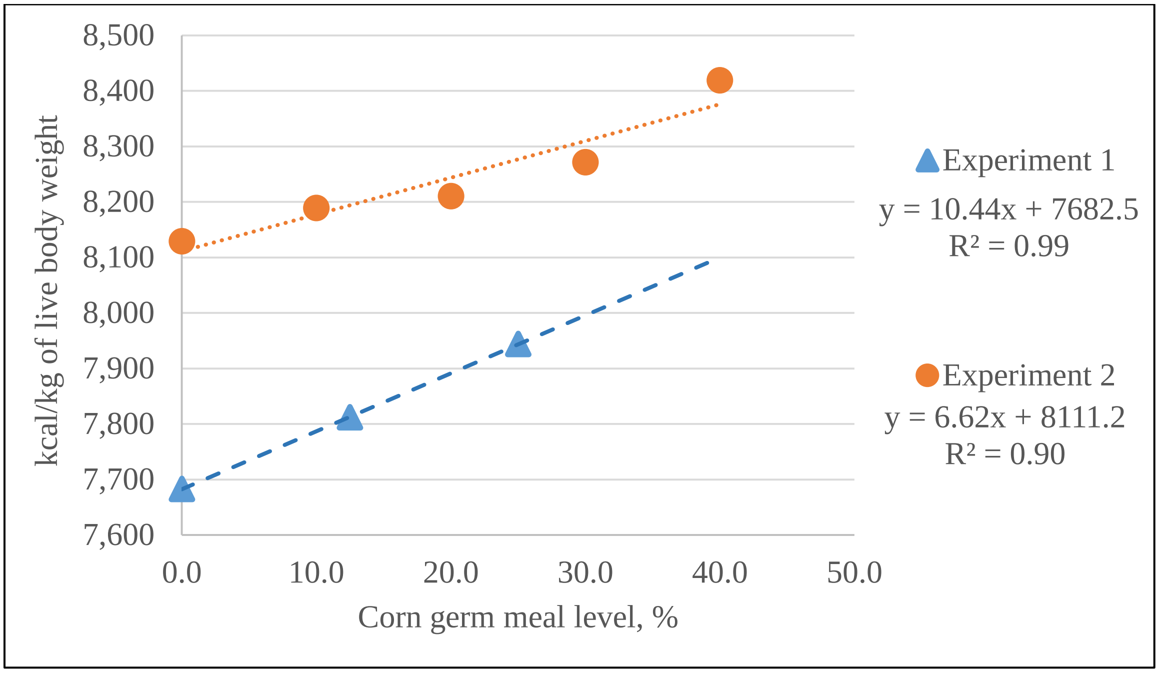
[3]Corrected Energy of Test Diet, kcal/kg = Formulated Energy of Test Diet × (CE of Control diet ÷ CE of Test Diet)

[4]Energy Difference of Test Diet = Formulated Energy of Test Diet - Corrected Energy of Test Diet

[5]Energy Difference of Test Ingredient (i.e., CGM) = Energy Difference of Test Diet ÷ Test Ingredient Inclusion

[6]Productive Energy, kcal/kg = Formulated Energy of Test Ingredient - Energy Difference of Test Ingredient

Figure 3.1. Linear regression and equations for the effect of Corn germ meal level on the caloric efficiency of live body weight gain.



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CHAPTER 4:

EFFECT OF RESEARCH SITE AND LIVE WEIGHT RANGE ON ESTIMATES OF THE PRODUCTIVE ENERGY OF CORN GERM MEAL

ABSTRACT

Two experiments were carried out to determine the effect of research conditions (Commercial site vs University site), and different body weight ranges on estimates of productive energy (PE) of corn germ meal (CGM). The same experimental design and treatments were used in the 2 experiments; Experiment 1 was carried out at a commercial site and Experiment 2 was carried out at a university research facility. Both experiments used a RCBD with 3 dietary treatments: Control (corn-soybean meal-based diet), 20% CGM-No Fat (4.8% lower ME compared to the Control diet), and 20% CGM+Fat (yellow grease added to provide the same ME level as the Control diet); and 4 Growing periods: Early-Growing (29 to 64 kg BW), Late-Growing (64 to 96 kg BW), Finishing (96 to 127 kg BW), and Growing-Finishing (29 to 127 kg BW). At the commercial site the CGM+Fat diet was only fed during the Growing-Finishing period. The CGM used in both experiments was from a single source; the chemical composition was: DM, 87.5%; CP, 23.5%; Crude Fat, 2.5%; NDF, 37.9%; ADF, 12.5%; Ash, 2.7. Diets for both experiments were manufactured in pellet form at the same feed mill using the same batches of ingredients. A total of 3,672 and 576 barrows and gilts were used in Experiment 1 and 2, respectively, housed in groups of 34 and 4, respectively (mixed-sex pens). A 3-phase dietary program was used with one phase being used for each of the Early-Growing, Late-Growing, or Finishing periods. Diets were formulated to a constant standardized ileal digestible lysine to energy ratio within phase, and to meet or exceed nutrient requirements proposed by NRC (2012). The ME value of CGM used to formulate diets, based on previous unpublished research, was of 2,548 kcal/kg. The Control diet was used as the reference diet to compare with the CGM diets to estimate PE. Caloric efficiency

(calories consumed per unit of weight gain) was calculated for each treatment using the feed:gain ratio and the formulated dietary ME content. The pen of pigs was the experimental unit; data were analyzed using PROC MIXED or PROC TTEST of SAS; the model accounted for the effects of CGM level and block. Pigs on the CGM+Fat dietary treatments had similar ($P > 0.05$) caloric efficiency to those on the Control treatment for all growing periods. In Experiment 2, pigs fed CGM-No Fat diets had greater caloric efficiency ($P < 0.05$) compared to the Control during Late-Growing and Growing-Finishing periods but not in the other growing periods. During the Finishing period (from 96 to 126 kg of BW), pigs fed diets including CGM had lower caloric efficiency [statistically significant ($P < 0.05$) in Experiment 1; numerically lower in Experiment 2) than pigs fed the Control diet. The SEM for caloric efficiency in Experiment 2 was, on average, 1.7 times higher compared to that in Experiment 1, resulting in greater variation in PE estimates from Experiment 2 compared to Experiment 1. Estimates of the productive ME of CGM based on the CGM–No Fat diets for the Early-Growing, Late-Growing, and Growing-Finishing periods were similar ($P > 0.05$) in both experiments but numerically very different in Experiment 2 (2,465, 2,568, and 2,439, respectively, for Experiment 1, and 2,455, 1,829, and 1,924, respectively, for Experiment 2). For Experiment 1 (commercial conditions), adding fat to the CGM diet resulted in similar productive ME estimates for CGM compared to CGM–No Fat diet when measured during the whole of the Growing-Finishing period. Under university conditions (Experiment 2), fat addition to the CGM diet resulted in variable PE estimates between growing periods, which were numerically greater than those obtained with the CGM-No Fat diets. The results of these experiments suggest that the PE of CGM should be determined under commercial conditions due to the variable results obtained under university conditions. They also suggest that growth trials carried over a shorter period of time, involving pigs between 29 and 96 kg of BW, resulted in similar PE estimates as those obtained during the whole Growing-Finishing period.

Keywords: pigs, productive energy, corn germ meal, growing period, research conditions.

INTRODUCTION

Corn germ meal (CGM) is a co-product from the corn wet milling industry that can be used in swine diets. On average, CGM contains approximately 23% crude protein with an amino acid balance that is comparable to that of corn, with a slightly lower amino acid digestibility than corn (Almeida et al., 2011; NRC, 2012; Gutierrez et al. 2014). However, the fiber content of CGM is relatively high (44.5% NDF; NRC, 2012), which limits the energy digestibility of the ingredient. Moreover, the three studies that have been published measuring the energy of CGM show high variation in estimates (Table 2.4).

There have been concerns that the estimates of the energy content of some feedstuffs are not accurate or need validation. This is specifically the case for ingredients with relatively high content of fiber such as CGM. One approach that has been suggested to determine or validate the energy value of feed ingredients is using growth studies to determine the productive energy (PE) content (Boyd et al., 2010; Boyd et al., 2011; Boyd et al., 2015). Productive energy is determined by carrying out a growth study involving the feeding of a control diet (e.g., corn-soybean meal based) and a diet containing the test ingredient (e.g., CGM). Caloric efficiency (ratio between the calories consumed and the live weight produced) is estimated for each diet and the PE content of CGM is calculated by comparing the caloric efficiency of the diet containing CGM with that of the control.

Estimation of PE presents a practical approach that can be adopted by the producer to evaluate the available energy for novel ingredients. However, studies that have used this approach have found considerable variation in the PE value of the same ingredient. For example, Estrada (2014; 2015; unpublished data, Chapter 3 of this document) conducted two experiments of similar design and under the same production conditions to determine the productive ME of CGM. Productive ME values determined in the two studies were 2,604 and 2,462 kcal/kg, which represents a difference of 142 kcal between the estimates. There was no clear explanation for the variation between the energy estimates found in these two studies.

Published information regarding the optimum approach to determine productive energy is limited, and more research is needed to determine the optimum conditions and procedures to use to estimate the productive energy content of feed ingredients. Therefore, the objectives of the present investigation were: 1) Compare the productive energy of CGM estimated using growth performance measured over the entire grow-finish period compared to estimates based on growth performance measured over a range of interim live weights (and shorter periods of time), and 2) Determine the relationship between estimates of productive energy of CGM from growth studies carried out under either university research or commercial conditions.

MATERIALS AND METHODS

Two experiments with the same design and treatments were carried out in the same time period to determine the productive energy of CGM. Experiment 1 was carried out at the Georgia Technology Center of The Maschhoffs, Carlyle, IL, which is a standard commercial wean-to-finish facility that is equipped to collect data on growth performance and feed intake under typical commercial conditions. Experiment 2 was carried out at the Swine Research Center (SRC) of the

University of Illinois, Urbana-Champaign, under typical, more controlled, university research facility conditions. The experimental protocol was approved by the University of Illinois Institutional Animal Care and Use Committee (IACUC# 16097).

Experimental Design and Treatments:

Both experiments were conducted with a randomized complete block design. Start date was used as the blocking factor and there were 4 blocks and 12 replicates per treatment.

The treatments used in these experiments involved combinations of diets with differing CGM inclusion levels and different growth periods (according to the following body live weight ranges: Growing-Finishing from 29 to 127 kg; Early-Growing from 29 to 64 kg; Late-Growing from 64 to 96 kg; and Finishing from 96 to 127 kg). The specific treatments were as follows:

Treatment 1: Control – 0% CGM (corn-soybean meal based diet); fed during Growing-Finishing period.

Treatment 2: 20% CGM – No Added Fat; fed during Growing-Finishing period.

Treatment 3: 20% CGM + Added Fat; fed during Growing-Finishing period.

Treatment 4: Control – 0% CGM (corn-soybean meal based diet); fed during Early-Growing period.

Treatment 5: 20% CGM – No Added Fat; fed during Early-Growing period.

Treatment 6: 20% CGM + Added Fat; fed during Early-Growing period.

Treatment 7: Control – 0% CGM (corn-soybean meal based diet); fed during Late-Growing period.

Treatment 8: 20% CGM – No Added Fat; fed during Late-Growing period.

Treatment 9: 20% CGM + Added Fat; fed during Late-Growing period.

Treatment 10: Control – 0% CGM (corn-soybean meal based diet); fed during Finishing period.

Treatment 11: 20% CGM – No Added Fat; fed during Finishing period.

Treatment 12: 20% CGM + Added Fat; fed during Finishing period.

Note: Treatments 6, 9, and 12 were only carried out in Experiment 2 at SRC.

Dietary Treatments:

All diets were formulated to meet or exceed the requirements of pigs across the weight range used in these studies recommended by the NRC (2012). For both experiments diets were manufactured at the Carlyle Mill of The Maschhoffs in pellet form in 3 phases (one per growing period). All diets were formulated to have the same lysine:calorie ratio within phase. Dietary Treatments 2, 5, 8, and 11 (i.e., diets of 20% CGM – No Added Fat) had lower ME level (approximately 160 kcal/kg) compared to Control treatments (i.e., Treatments 1, 4, 7, and 10). Dietary Treatments 3, 6, 9, and 12 (i.e., diets of 20% CGM + Added Fat), were formulated to the same ME level as the Control diet; yellow grease was added to these diets as required to achieve this. The CGM used for both experiments was obtained from a single source (Archer Daniels Midland, Decatur, IL). The analyzed composition of corn, soybean meal, and CGM used in each experiment is shown in Table 4.1.

The ME values used to formulate the diets for corn and CGM were 3,403 and 2,549 kcal/kg, respectively, with the ME value of CGM being 74.9% of that of corn. The ME of CGM was based on the productive ME determined by Estrada (2015) and presented in the results of Chapter 3 of this thesis, and adjusted for the chemical composition of the batches of CGM used for diet manufacture. In addition, the ME value of soybean meal used in diet formulation was 3,319 kcal/kg. The NRC (2012) values of ME of corn and soybean meal were used, and adjusted for the chemical composition of the batches used for diet manufacture. Diets formulation and composition are presented in Tables 4.2, 4.3, and 4.4 for Early Growing, Late Growing, and Finishing diets, respectively.

Animals, Housing, and Allotment to Treatment:

Experiment 1: Georgia Technology Center

Experiment 1 used a total of 3,672 commercial crossbred pigs (progeny of PIC 359 sires mated to commercial dams) that were housed in a commercial barn from week 8 post-weaning (28.7 ± 0.60 kg live weight) to approximately 23 weeks post weaning (126.5 ± 1.86 kg live weight).

Pigs were housed in 108 mixed-gender pens of 34 pigs giving 12 replications per treatment. Allotment was carried out at week 8 post-weaning. Pigs were individually weighed and sorted by gender, and formed into outcome groups of 9 barrows and 9 gilts with similar body weight. Pigs were randomly allotted from within outcome group to one of 9 pens (1 barrow and 1 gilt per pen). This process was repeated until there were 34 pigs (17 barrows and 17 gilts) in each pen. Pens were randomly allotted to treatment and immediately started on test.

Pen divisions were of horizontal bars. Each pen was equipped with a standard 4-space wet-dry feeder and two cup-type water drinkers. Feed and water were available *ad libitum* throughout the study period. The floor space was 0.63 m^2/pig for all treatments. In the event of a mortality or removal of a morbid animal during the study, pen size was adjusted using a moveable partition to maintain a constant floor space.

Experiment 2: Swine Research Center

Experiment 2 used a total of 576 commercial crossbred pigs (progeny of PIC 359 sires mated to Camborough or PIC F46G dams) that were housed in a growing-finishing facility from week 8 post-weaning (29.1 ± 2.36 kg live weight) to approximately 23 weeks post weaning (126.9 ± 2.22 kg live weight). Pen divisions were of vertical bars. Each pen was equipped with a standard single-space dry box feeder and a nipple drinker. The floor space was 0.58 m^2/pig for all treatments. Feed and water were available *ad libitum* throughout the study period.

Pigs were housed in 144 mixed-gender pens of 4 pigs giving 12 replications per treatment. Allotment was carried out at week 8 post-weaning. Pigs were individually weighed and sorted by gender, and formed into outcome groups of 12 barrows and 12 gilts with similar body weight. Pigs were randomly allotted from within outcome group to one of 12 pens (1 barrow and 1 gilt per pen). This process was repeated until there were 4 pigs (2 barrows and 2 gilts) in each pen. Pens were randomly allotted to treatment and immediately started on test

For both experiments two extra pigs (1 barrow and 1 gilt) were allotted to pens for the treatments that started on test at 64 and 96 kg of body weight (Late Growing and Finishing period, respectively) to allow for any losses of pigs during the period prior to these pens starting on test. When pigs in pens corresponding to these treatments reached the start weight (i.e., 64 and 96 kg BW for Late Growing and Finishing periods, respectively), pigs were weighed individually (at SRC) or as a group (at Georgia Technology Center) and the extra animals (if any) were removed to achieve same number of pigs per pen (equal number of barrows and gilts in pens within a replicate) and similar body weight between pens within a replicate.

Feed and Growth Measurements:

For both experiments, individual weights were collected at allotment (week 8 post-weaning) for all treatments. For Experiment 1 (Georgia Technology Center), group weights were collected as follows: for Early Growing on day 0 (start of Early Growing), 13, 27, and 40 (end of Early Growing); for Late Growing on day 40 (start of Late Growing), 56, and 70 (end of Late Growing); and for Finishing on day 70 (start of Finishing), 84, 98, and 102 (end of Finishing). At the Georgia Technology Center a computerized feed system (Howema Feeding System, Big Dutchman Inc., Holland, MI) was used to deliver the feed and record the amount of feed delivered. For Experiment 2 (SRC), pigs were weighed individually as follows: for Early Growing on day 0 (start of Early Growing), 13, 27, and 38 (end of Early Growing); for Late Growing on day 38 (start of Late Growing), 51, and 66 (end of Late Growing); and for Finishing on day 66 (start of Finishing), 80, 90, and 94 (end of Finishing). At both locations all feed additions and the feed remaining in the feeder were recorded at the time of pig weighing, and were used to calculate average daily feed intake, and feed efficiency.

Pigs experiencing health problems or injuries that did not respond to treatment were removed from the study and the date of removal, pig weight, and reason for removal were recorded; the weight of pigs removed was included in the calculation of growth rate and feed intake.

Productive Metabolizable Energy Calculations:

The following calculations were used to estimate the Productive ME of CGM (all concentrations are expressed on an as-fed basis):

1) The ***Caloric Efficiency*** (CE) of each dietary treatment was obtained by multiplying the feed:gain ratio by the formulated ME content of the diet:

$$CE\ (kcal/kg\ of\ gain) = Feed{:}Gain\ \times (Formulated\ ME_{Diet}\ kcal/kg) \quad \mathbf{Eq. 4.1}$$

2) To obtain the ***Corrected ME*** content of the test diets (i.e., the diets including CGM), the Formulated ME content of the test diet was multiplied by the Caloric Efficiency of the control diet divided by the Caloric Efficiency of the test diet:

$$Corrected\ ME_{Test\ diet}\ (kcal/kg) = Formulated\ ME_{Test\ diet}\ \times \left(\frac{CE_{Control\ diet}}{CE_{Test\ diet}}\right) \quad \mathbf{Eq. 4.2}$$

3) The ***ME Difference*** (between formulated and corrected ME content) of the test diet was obtained by subtraction:

$$ME\ Difference_{Test\ diet} = Formulated\ ME_{Test\ diet} - Corrected\ ME_{Test\ diet} \quad \mathbf{Eq. 4.3}$$

4) It was assumed that the ME Difference of the test diet is due entirely to the test ingredient. Therefore, the ***ME Difference of the test ingredient*** was calculated by dividing the ME Difference of the test diet by the proportion of the test ingredient included (e.g., 25% CGM = 0.25 CGM inclusion):

$$ME\ Difference_{Test\ ingredient}\ (kcal/kg) = ME\ difference_{Test\ diet,}\ kcal/kg \div Test\ Ingredient\ inclusion \quad \mathbf{Eq. 4.4}$$

5) The ***Productive ME*** was obtained by subtracting the Energy Difference of the test ingredient from the Formulated Energy of the test ingredient:

$$Productive\ Energy\ (kcal/kg) = Formulated\ ME\ _{Test\ ingredient} - ME\ Difference_{Test\ ingredient} \quad \mathbf{Eq. 4.5}$$

Statistical Analysis:

All data were tested for normality using the PROC UNIVARIATE procedure of SAS (SAS Institute Inc., Cary, NC). Data meeting the criteria for analysis of variance were analyzed using the PROC MIXED procedure of SAS as a randomized complete block design with pen as the experimental unit. The model included the fixed effect of treatment and the random effect of block. Least-squares means were compared using the PDIFF option of SAS. The productive energy data did not meet the homogeneity of variances test, and, therefore, the comparison of productive energy estimates between growing periods and dietary treatments was conducted using the two-sample Student's *t*-test, using the PROC TTEST procedure of SAS.

RESULTS AND DISCUSSION

Data for each growing period for both Experiments 1 (Commercial site) and 2 (University site) were analyzed separately and the results for the effect of diet on growth performance and caloric efficiency within each growing period are presented in Table 4.5. Based on numerous previous studies, differences in growth performance between growing periods (body weight ranges) were expected. However, it was not an objective of this study to compare the growth performance *per se* in different growing periods and, therefore, each growing period was analyzed separately within each research site. The main objective of having different growing periods was to determine if the weight range over which growth performance was measured impacts the estimate of the PE of CGM and also to identify the most appropriate body weight range to use to estimate PE.

Three diets were used; a control based on corn and soybean meal without CGM, and two test diets including CGM, either without or with added fat. The CGM diet with added fat was formulated to have the same ME level as the control diet, whereas the CGM diet without fat had a lower energy content (approximately 160 kcal/kg of ME) compared to the control. This approach was used to determine if dietary energy content would influence the estimate of PE. The CGM diet with added fat was fed in all 4 growing periods in Experiment 2 but, due to space limitations at the commercial site, only in the Growing-Finishing period in Experiment 1.

Based on the results presented in Table 4.5, the productive ME of CGM was estimated for the 2 experiments, both CGM diets (with and without fat), and for each growing period and these estimates are shown in Table 4.6.

Effects of CGM inclusion on growth performance:

In general, the effect of including CGM in the diet (either without or with added fat) on growth performance in all of the growth periods was relatively similar in the two experiments. However, the standard errors associated with the growth performance variables were considerably greater at the University site than at the Commercial site (on average approximately 1.9 times greater) (Table 4.5). This difference in variation between sites was expected due to the much greater number of animals involved in the experiment at the Commercial site compared to the University site (3,672 vs 576 pigs, respectively).

Effect of feeding the diet containing CGM without added fat (CGM–No Fat):

In general, differences between the Control and CGM–No Fat diets in both experiments were similar for all growth periods (Table 4.5). Growth rates were greater ($P < 0.05$) for pigs fed the Control diet compared to those fed the CGM–No Fat diet in all growing periods except Finishing in Experiment 1 and 2, and in the Early-Growing in Experiment 2. For feed intake, there was no difference ($P > 0.05$) between the Control and CGM–No Fat diets in any of the growing periods except in the Growing-Finishing period for Experiment 1. For the Growing-Finishing period in Experiment 1, pigs fed the control diet had a lower ($P < 0.05$) feed intake than those fed the CGM–No Fat diet. Feed:Gain ratio was greater ($P < 0.05$) for the CGM–No Fat diet than for the Control in the Early-Growing, Late-Growing, and Growing-Finishing periods in both experiments. However, there was no difference in feed:gain ratio between the two dietary treatments during the Finishing period (Table 4.5).

The growth rate and feed intake results for the Early, Late, and Growing finishing periods differ from those reported in previous research (Jones, 1987; Weber et al., 2010; and Estrada, 2014; 2015, Chapter 3 of this document), where pigs fed up to 25% CGM had similar growth rate and feed intake compared to pigs fed a corn-soybean meal based diet. In one of the experiments carried out by Estrada (2014, unpublished data) reported in Chapter 3, and in the study of Weber et al. (2010), feeding increasing levels of CGM up to 40% inclusion was associated with increases in feed:gain ratio, which is in agreement with the results of the present experiments. However, in the second experiment carried out by Estrada (2015) and reported in Chapter 3, including 20% CGM in the diet had no effect on feed efficiency compared to the Control treatment. However, for that trial the diet including 20% CGM was formulated to the same ME level as the Control diet, which was not the case for the CGM–No Fat diet used in the present experiments.

Effect of feeding the diet containing CGM with added fat (CGM+Fat):

For Experiment 2 (University site), pigs fed the Control and CGM+Fat diets had similar ($P > 0.05$) growth performance during all growing periods (Table 4.5). In contrast, for Experiment 1 (Commercial site), where the CGM+Fat diet was only fed during the Growing-Finishing period, pigs fed that diet had lower ($P < 0.05$) growth rate and feed intake compared to pigs fed the Control diet. However, the differences between the treatments were relatively small (2.6 and 2.2% for growth rate and feed intake, respectively) and there was no difference ($P > 0.05$) in feed:gain ratio between CGM+Fat and Control treatments, which is similar to the results of Experiment 2. These findings regarding the feed:gain ratio are in agreement with those reported by Estrada (2015, unpublished data, reported in Chapter 3), where pigs fed diets 20% CGM that were isocaloric with the Control diet had similar feed efficiency compared to the Control diet.

Overall, the results presented in this section in general suggest that feeding CGM diets without added fat (with a lower ME level compared to the Control) had a negative effect on growth performance during Early, Late, and Growing-Finishing periods, but not during Finishing. The inclusion of fat in the CGM diet resulted in similar feed efficiency ($P > 0.05$) during all growing periods compared to the Control diet. However, inclusion of CGM with added fat in the diet decreased ($P < 0.05$) growth rate and feed intake during the Growing-Finishing period in Experiment 1 but not in Experiment 2. This suggests that up to 20% CGM can be included in diets for growing-finishing pigs with limited impact on growth performance (for diets with adequate and similar ME levels compared to a standard corn-soybean meal based diet).

Effects of CGM inclusion on caloric efficiency:

Caloric efficiency is defined as the amount of energy consumed per unit of body live weight gain. Caloric efficiency is calculated by multiplying the feed:gain ratio by the energy content of the diet. This variable is especially useful when comparing dietary treatments that have different energy contents (Gaines et al., 2012; Patience et al., 2015), which was the case in the present experiments. However, the reliability of caloric efficiency is highly dependent on the accuracy of the estimated energy content of the diet as well as the energy system used for diet formulation (Patience, 2012).

Effect of feeding the diet containing CGM without added fat (CGM–No Fat):

The effects of including CGM in the diet (with no fat addition) on caloric efficiency were relatively variable between experiments (Table 4.5). In Experiment 1 (Commercial site), the caloric efficiency was similar ($P > 0.05$) between dietary treatments during Early-Growing, Late-Growing, and Growing-Finishing periods. However, during Finishing in Experiment 1, pigs fed the CGM–No Fat diet had lower ($P < 0.05$) caloric efficiency compared to pigs fed the Control diet. Conversely, for Experiment 2 (University site), pigs fed the CGM–No Fat diet had greater ($P < 0.05$) caloric efficiency during Late-Growing and Growing-Finishing periods compared to the Control; however, there was no difference ($P > 0.05$) between dietary treatments during the Early-Growing or Finishing periods.

Effect of feeding the diet containing CGM with added fat (CGM+Fat):

The addition of fat to the CGM diet (to achieve same ME level as the Control) resulted in similar ($P > 0.05$) caloric efficiency compared to the Control treatment during all of the growing periods in both experiments.

The basis of this research was that using the adjusted PE values reported by Estrada (2015, unpublished data) from the second experiment in Chapter 3, the caloric efficiency would be similar between the dietary treatments within each growing period. This was the case for the results obtained in Experiment 1 for all growing periods with the exception of Finishing. The lower caloric efficiency exhibited by pigs fed CGM–No Fat diet during Finishing (statistically significant in Experiment 1 and numerically different in Experiment 2) may possibly be related to the greater capacity of heavier pigs to digest the fibrous fraction of the diet (Noblet et al., 1994; Noblet and LeGoff, 2001; Noblet and van Milgen, 2004; Cozzanet et al., 2010). In the present experiments, the analyzed content of NDF for the Control and CGM–No Fat diet was 8.2% and 13.8%, respectively, illustrating the higher dietary fiber content of the CGM–No Fat diet compared to the Control. Given these points, the improvement in caloric efficiency of pigs fed diets containing greater dietary fiber compared to the Control during the finishing period can be related to the improved capacity of heavier pigs to better digest and utilize the fibrous fraction of the diet.

There is no clear explanation for the increased caloric efficiency of pigs fed CGM–No Fat diet during Late-Growing and Growing-Finishing periods in Experiment 2. It could possibly be related to a greater feed wastage for this treatment compared to the other two which would have a direct and negative impact on caloric efficiency; further research would be required to determine if feed wastage contributed to differences in caloric efficiency observed in Experiment 2.

In general, the variation in caloric efficiency for Experiment 2 was greater compared to Experiment 1 as evidenced by the differences in standard errors between experiments (about 1.7 times greater for Experiment 2; Table 4.5). This was especially the case during the Late-Growing and Growing-Finishing periods, where the standard errors for caloric efficiency for Experiment 1 compared to Experiment 2 were 72.5 vs 137.9, and 54.8 vs 95.1 kcal/kg of BW, respectively.

In conclusion, the results of these experiments suggest that finishing pigs (from 96 to 126 kg of BW) fed diets including CGM (which have higher content of fiber relative to a corn-soybean meal diet) had better caloric feed efficiency than pigs fed the Control diet. They also showed that pigs fed diets including CGM with added fat had similar caloric efficiency to those fed the Control diet (for all growing periods), suggesting that the energy estimates for the fat and CGM sources used in diet formulation were accurate (which are the only different ingredients included in the CGM+Fat diet compared to the Control).

Productive Energy of CGM:

The equations for productive energy calculation are described in the Materials and Methods section of this chapter (equations 4.1 to 4.5). As discussed in the previous section, the feed:gain ratio and dietary energy content of each treatment were used to calculate the caloric efficiency for each of the experimental units (pen of pigs), and then the least-square means for caloric efficiency for each treatment were derived using the PROC MIXED procedure of SAS (SAS Institute Inc., Cary, NC). The least-square means of caloric efficiency were ultimately used to calculate the productive ME of CGM (values presented in Table 4.6).

The productive ME of CGM was calculated on a pen basis in order to determine differences between estimates for the various growing periods or between PE from the different diets (e.g., CGM–No Fat vs CGM+Fat). Due to a lack of homogeneity of variances (homogeneity test *P*-value < 0.05), two-sample *t*-tests were carried out (using the PROC TTEST of SAS) instead of an analysis of variance of the least-square means. The treatment differences resulting from the multiple *t*-test comparisons are indicated using superscripts on the values of productive ME of CGM in Table 4.6.

Estimate of productive ME of CGM from the diet containing CGM without added fat (CGM–No Fat) at different body weight ranges:

In general, the estimates of the productive ME of CGM from the CGM–No Fat diet were similar ($P > 0.05$) for the Early-Growing, Late-Growing and Growing-Finishing periods, but were greater ($P < 0.05$) during the Finishing period compared to the other periods in both experiments. However, the productive ME estimates were relatively different between experiments, especially during the Late-Growing and Growing-Finishing periods (Table 4.6). For example, the productive ME values of CGM (using the CGM–No Fat diet) obtained during Early-Growing, Late-Growing, and Growing-Finishing periods for Experiment 1 and Experiment 2 were 2,465 and 2,455; 2,568 and 1,829; and 2,469 and 1,924 kcal/kg, respectively. Comparatively, the productive ME of CGM reported by Estrada in the second experiment (2015, unpublished data, reported in Chapter 3 of this document) was of 2,462 kcal/kg, which is very similar to the estimates obtained during Early-Growing (in both experiments), and during Late-Growing and Growing-Finishing in Experiment 1. This suggests that, at least under commercial conditions (Experiment 1), determining the productive ME of CGM during Early-Growing or Late-Growing gives a similar estimate to that from the whole Growing-Finishing period.

Even though there were no statistically significant differences between the estimates of productive ME of CGM from the Early-Growing, Late-Growing, and Growing-Finishing periods in Experiment 2 (University site), the numerical differences were relatively large. This lack of statistical significance for the estimates of PE between these specific growing periods in Experiment 2 is likely to be related with the high variation in the caloric efficiency obtained in this experiment, which was discussed in the previous section of this chapter (Table 4.6).

This greater variation in caloric efficiency (and in growth performance in general) in Experiment 2 compared to Experiment 1, resulted in greater variability in the PE estimates of CGM, and there are a number of factors that could be related with these differences between experiments (Commercial site vs University site). For example, differences in feeder design and feeder adjustment can result in differences in feed disappearance and feed efficiency of up to 30% (Hyun and Ellis, 2002; Patience et al., 2015). Additionally, aspects such as group size, floor space, and pen layout can influence the variation in growth performance (Ellis and Augspurger, 2001); all of these factors differed between these experiments. Furthermore, the CGM diets had, on average, 1.8 times more NDF compared to the Control diets, which could have a negative effect on feed palatability (Solà-Oriol et al., 2011). Any palatability effect could be exacerbated by the fact that pigs in Experiment 2 had greater access to the feeder compared to pigs in Experiment 1 (feeder space = 13.6 cm/pig vs 1.3 cm/pig, respectively), which could be related with an increase of feed wastage in Experiment 2. All these factors, plus the fact that Experiment 1 involved a much larger number of pigs compared Experiment 2, could explain the greater variation in PE estimates from Experiment 2.

The productive ME of CGM estimated from the CGM–No Fat treatment during the Finishing period was higher ($P < 0.05$) compared to the other periods (on average 28 and 49%

higher compared to the other growing periods, for Experiment 1 and 2, respectively). This is in agreement with the caloric efficiency results previously discussed, where pigs fed diets including CGM were more efficient (statistically significant in Experiment 1 and numerically different in Experiment 2) compared to pigs fed the Control diet. This suggests that the ME of CGM used for diet formulation (2,548 kcal/kg) underestimated the ME of CGM for finishing pigs.

In general, it has been recommended that at least two energy values for each feedstuff should be used in diet formulation: one for growing-finishing pigs and another one for sows (Noblet, 2005). However, the results from the present studies and other research suggest that finishing pigs have a greater capacity to digest feed ingredients with high content of fat or fiber compared to younger (lighter) animals (Noblet and van Milgen, 2004; Noblet, 2005; NRC, 2012; Kil et al., 2013). This suggests that specific energy values for fibrous ingredients for finishing pigs are needed. For example, Noblet and Shi (1994) carried out a digestibility experiment with pigs at three different weights (45, 100, and 150 kg BW) that were fed diets with different composition, and reported that the digestibility coefficient for starch and sucrose was close to 100% for all stages, the digestibility coefficient for fat was of 57.9, 66.1 and 65.5% for pigs of 45, 100, and 150 kg BW, respectively, and the digestibility coefficient for NDF was 52.6, 57.5, and 60.5%, respectively. Similarly, Boyd et al. (2015) estimated the productive NE of choice white grease based on caloric efficiency differences between treatments and concluded that the productive NE of choice white grease for early and late finishing pigs was of 7,779 and 8,058 kcal/kg, respectively. Therefore, the results from previous research, as well as from the present experiments, support the concept that specific energy values for ingredients should be used to formulate diets for finishing pigs, especially for ingredients with high fat or/and high fiber content (such as CGM).

In summary, the results from the present experiments suggest that estimating the productive ME of CGM (using the Control and CGM–No Fat diets) during Early-Growing (29 to 64 kg of BW) or Late-Growing (64 to 96 kg of BW) resulted in similar productive ME estimates compared to the whole Growing-Finishing period (29 to 127 kg of BW). However, the estimates of productive ME of CGM obtained under commercial conditions (Experiment 1) were more accurate (i.e., less variable) than those obtained under university conditions (Experiment 2), which were, in general, numerically lower compared to those obtained under commercial conditions. Additionally, the productive ME of CGM determined during Finishing (96 to 127 kg of BW) was higher compared to that obtained during the other periods, and compared to the value of the ME content of CGM used for dietary formulation. These results suggest that the ME of CGM used to formulate diets should be adjusted for the finishing phase.

Estimate of productive ME of CGM from the diet containing CGM with added fat (CGM+Fat) at different body weight ranges:

The estimates of the PE of CGM based on the CGM diets with added fat (to achieve the same ME level as the Control diet) were relatively variable between growing periods and experiments (Table 4.6). First of all, in Experiment 1 (Commercial site), where the CGM+Fat diet was only fed during the Growing-Finishing period, the productive ME estimates were similar ($P > 0.05$) for both CGM dietary treatments (2,439 and 2,508 kcal/kg for CGM–No Fat and CGM+Fat diet, respectively) (Table 4.6). This suggests that, at least under commercial conditions, the energy value used in diet formulation for the yellow grease (fat source used) was accurate, and, also, that the PE of CGM can be determined with diets of different ME levels than the Control or reference diet. Additionally, these estimates of the productive ME of CGM are similar to that reported in a previous research by Estrada (2015; unpublished data, reported in Chapter 3 of this document) of 2,462 kcal/kg, which used CGM diets with added fat to achieve the same ME as the Control diet.

In Experiment 2 (University site), during the Early-Growing, Late-Growing, and Finishing periods, fat addition to the CGM diet (CGM+Fat) resulted in similar ($P > 0.05$) productive ME of CGM compared to that of CGM–No Fat diet. Even though the PE estimates obtained from these two diets during Early-Growing and Late-Growing were not statistically different, the numerical differences were relatively large (2,455 vs 2,898, and 1,829 vs 2,215 kcal/kg, for CGM–No Fat and CGM+Fat diets, respectively). On the other hand, during the Growing-Finishing period, the PE estimate was greater ($P < 0.05$) for the CGM+Fat diet than the CGM–No Fat diet (2,904 vs. 1,924 kcal/kg, respectively). In general, the PE estimates were numerically greater for diets including fat (CGM+Fat) compared to CGM–No Fat diets in all growing periods (2,778 vs 2,324 kcal/kg, respectively, averaged across all growing periods in Experiment 2).

In relation to the effect of Growing Period on the productive ME estimate of CGM (Experiment 2), when CGM+Fat diets were fed, the estimate of productive ME was greater for Finishing compared to the Late-Growing period ($P < 0.05$). Productive energy estimates for the Early-Growing and Growing-Finishing periods were intermediate in value and not different ($P > 0.05$) to the other two growing periods. However, there was relatively high variation in productive ME estimates of CGM for the different growing periods, which is similar to the results obtained when using CGM–No Fat diets, where the lowest PE estimate was also obtained during the Late-Growing phase.

There is no clear explanation for the differences in results between experiments (during the Growing-Finishing phase), and for the higher PE values obtained from the CGM+Fat diets compared to the CGM–No Fat diets in all of the growing periods in Experiment 2. As previously discussed, these results may be related with the high variation associated with growth performance in Experiment 2 (University site).

Previous research has shown that the dietary fat sources, such as yellow grease that was used in this study, have greater digestibility than lipids present in intact ingredients (e.g., lipids in corn) (Kil et al., 2010; Kil et al., 2011). The overall greater productive ME of CGM obtained in Experiment 2 (University conditions) when pigs were fed CGM+Fat diets (2,778 kcal/kg, compared to 2,324 kcal/kg of the CGM–No Fat diets) could be an indication of better energy digestibility of the yellow grease from pigs housed under University conditions. However, and as previously discussed, differences in palatability and the greater variation in growth performance could have a significant influence on these results.

Additionally, a metabolism study was carried out by Estrada and Stein (2017; unpublished data) to determine the ME of the Control, CGM–NoFat, and CGM+Fat experimental diets used in the Early-Growing period, using pigs of approximately 53 kg of BW. Estimates of ME from this study were: 3,332, 3,250, and 3,422 kcal/kg for the Control, CGM–No Fat, and CGM+Fat diets, respectively; the formulated ME values were 3,296, 3,128, and 3,297, respectively. Therefore, the measured ME value of the Control diet was very close to the formulated value, indicating the accuracy of the ME values used for the Control diet formulation. However, the diets that included CGM had measured ME values that were, on average, 129 kcal/kg greater than the formulated ME values. As previously discussed, estimates of the ME value of CGM, obtained using metabolisim studies, have generally overestimated the energy value of CGM compared to PE estimates based on growth studies (Estrada, 2014; 2015; unpublished data, reported in Chapter 3 of this document). In addition, the diet including CGM+Fat had the greatest ME ($P < 0.05$) compared to the other 2 diets, even though this diet was formulated to have the same ME level as the Control diet. This, in part, is due to the overestimation of ME from CGM from metabolism studies, and is also in agreement with previous data reporting higher digestibility of diets including external sources of lipids (Kil et al., 2010; Kil et al., 2011).

In conclusion, the results from these experiments showed that, under commercial conditions (Experiment 1), adding fat to the CGM diet resulted in similar productive ME estimates for CGM compared to the CGM–No Fat diet when measured during the whole of the Growing-Finishing period. Additionally, they also showed that the productive ME estimates for CGM obtained in experiments carried out under university conditions (Experiment 2) had considerable variation regardless of whether or not fat is added to the CGM diet, and this decrease in the accuracy of the PE estimates make the results more difficult to interpret.

CONCLUSIONS

This research involved two growth experiments to determine the effect of research conditions (Commercial site vs University site), and different body weight ranges on estimates of PE of CGM. The results suggest that, generally speaking, the productive ME estimates of CGM determined under commercial research conditions were more accurate (i.e., less variable) compared to those obtained under university research conditions, and were similar to those reported in previous research. Additionally, determining the PE of CGM over shorter growth periods such as Early-Growing (29 to 64 kg of BW) or Late-Growing (64 to 96 kg of BW) resulted in similar productive ME estimates compared to those obtained from the whole Growing-Finishing period (29 to 127 kg of BW). The productive ME of CGM determined during the Finishing period (96 to 127 kg of BW) was higher compared to that obtained during the other periods, and compared to the value of the ME content of CGM used for diet formulation. This suggests that the ME of CGM used to formulate diets should be adjusted for finishing pigs.

In summary, the results from the present research validates the concept that the PE presents a practical alternative to determine and adjust the ME value of ingredients with high fiber content, such as CGM. However, care needs to be taken when estimating PE due to high variation in results related to the research conditions. These results also suggest that PE should be determined under commercial conditions in order to obtain more accurate estimates.

Tables

Table 4.1. Analyzed composition of corn, soybean meal (SBM), and corn germ meal (CGM) used to manufacture experimental diets.

Item	Corn	Soybean meal[1]	Corn germ meal[1]
Proximate analysis, % as-fed basis[2]			
Dry matter	86.56	86.94	87.49
Crude protein	7.42	47.19	23.52
Crude fat	3.17	0.90	2.53
Crude fiber	1.30	2.91	8.32
Acid detergent fiber	2.50	6.37	12.54
Neutral detergent fiber	7.23	7.47	37.88
Phosphorus	0.29	0.73	0.81
Calcium	-	0.35	0.02
Sodium	-	-	0.03
Ash	1.21	5.87	2.66
Chloride	-	-	0.03
Amino acid analysis, % as-fed basis[3]			
Alanine	-	2.08	1.39
Arginine	0.35	3.41	1.57
Aspartic acid	-	5.43	1.62
Cystine	0.17	0.68	0.31
Glutamic acid	-	8.53	2.98
Glycine	-	2.01	1.27
Histidine	0.21	1.20	0.63
Isoleucine	0.25	2.20	0.81
Leucine	0.88	3.67	1.70
Lysine	0.23	2.96	0.95
Methionine	0.15	0.66	0.41
Methionine + Cystine	0.32	1.33	0.71
Phenylalanine	0.36	2.47	1.02
Proline	-	2.38	1.03
Serine	-	2.40	1.06
Threonine	0.27	1.85	0.84
Tryptophan	0.06	0.64	0.25
Tyrosine	-	1.41	0.54
Valine	0.35	2.22	1.21

[1]SBM and CGM source: Archer Daniels Midland, Decatur, IL.
[2]Proximate analysis was performed at Midwest Laboratories, Omaha, NE.
[3]Amino acid analysis was performed using High-Performance Liquid Chromatography (HPLC), Ajinomoto Heartland, LLC, Chicago, IL.

Table 4.2. Diet formulation and calculated and analyzed composition for Early-Growing phase (BW = 29 to 64 kg).

	Diet					
	Control		CGM-No Fat		CGM+Fat	
Ingredient, %						
Corn	72.04		60.70		55.33	
Corn germ meal[1]	-		20.00		20.00	
Soybean meal[1]	24.57		15.81		17.99	
Fat (Yellow grease)	0.50		0.50		3.77	
Limestone	1.03		1.22		1.20	
Mono-cal 21% P	0.73		0.49		0.49	
Salt	0.50		0.49		0.46	
L-Lysine HCl- Dry (98.5%)	0.31		0.40		0.40	
Methionine (HMB[2])	0.12		0.11		0.13	
Threonine (98%)	0.06		0.08		0.08	
Trace minerals premix	0.08		0.08		0.08	
Copper chloride (58%)	0.03		0.03		0.03	
Vitamins premix	0.03		0.03		0.03	
Phytase (Ronozyme HiPhos 2500 GT)	0.01		0.02		0.02	
Red iron oxide	-		0.04		-	
Composition	Calculated	Analyzed[3]	Calculated	Analyzed[3]	Calculated	Analyzed[3]
ME, kcal/kg	3,296	-	3,138	-	3,297	-
Dry matter, %	86.52	86.62	86.73	87.01	87.17	87.54
Crude Protein, %	16.80	17.40	16.50	16.70	17.16	17.70
Crude Fat, %	2.71	2.92	2.65	3.53	5.57	6.81
Crude Fiber, %	1.51	2.50	2.64	3.88	2.64	3.66
NDF, %	6.17	8.00	12.21	14.40	12.02	12.70
ADF, %	2.84	3.30	4.49	4.40	4.52	5.00
Calcium, %	0.63	0.65	0.63	0.72	0.63	0.67
Phosphorus, %	0.52	0.53	0.52	0.57	0.52	0.56
Digestible phosphorus, %	0.33	-	0.31	-	0.31	-
Calcium:Phosphorus	1.20	-	1.20	-	1.19	-
Sodium, %	0.22	0.20	0.22	0.21	0.20	0.20
Lysine, %	1.11	1.14	1.09	1.14	1.14	0.19
SID[4] lysine, %	1.00	-	0.95	-	0.99	-
SID[4] lysine:ME, g:Mcal	3.02	-	3.01	-	3.01	-
SID[4] AA:SID[4] Lys ratio						
Met + Cys	0.57	-	0.57	-	0.57	-
Tryptophan	0.18	-	0.17	-	0.17	-
Threonine	0.59	-	0.60	-	0.60	-
Isoleucine	0.60	-	0.56	-	0.56	-
Valine	0.65	-	0.67	-	0.66	-

[1]Ingredient source: Archer Daniels Midland (Decatur, IL).

[2]HMB = 2-hydroxy-4-(methylthio) butanoic acid

[3]Diet analyses: proximate analyses were conducted by Midwest Labs using wet chemistry; and amino acids were conducted by Ajinomoto Heartland, Inc. laboratory using High-Performance Liquid Chromatography (HPLC).

[4]SID = standardized ileal digestible

Table 4.3. Diet formulation and calculated and analyzed composition for Late-Growing phase (BW = 64 to 96 kg).

	Diet					
	Control		CGM-No Fat		CGM+Fat	
Ingredient, %						
Corn	80.98		68.01		63.18	
Corn germ meal[1]	-		20.00		20.00	
Soybean meal[1]	16.35		9.34		10.98	
Fat (Yellow grease)	0.35		0.35		3.62	
Limestone	0.94		1.13		1.11	
Mono-cal 21% P	0.41		0.11		0.12	
Salt	0.50		0.50		0.46	
L-Lysine HCl- Dry (98.5%)	0.24		0.30		0.29	
Methionine (HMB[2])	0.04		0.02		0.04	
Threonine (98%)	0.05		0.04		0.05	
Trace minerals premix	0.08		0.08		0.08	
Copper chloride (58%)	0.03		0.03		0.03	
Vitamins premix	0.03		0.03		0.03	
Phytase (Ronozyme HiPhos 2500 GT)	0.02		0.03		0.03	
Red iron oxide	-		0.04		-	
Composition	Calculated	Analyzed[2]	Calculated	Analyzed[2]	Calculated	Analyzed[2]
ME, kcal/kg	3,311	-	3,152	-	3,311	-
Dry matter, %	86.31	86.51	86.54	86.96	86.98	87.57
Crude Protein, %	13.46	14.80	13.81	15.10	14.25	15.80
Crude Fat, %	2.78	3.25	2.68	3.24	5.61	5.57
Crude Fiber, %	1.39	1.04	2.55	2.95	2.54	3.40
NDF, %	6.15	8.20	12.21	14.50	12.02	14.80
ADF, %	2.53	4.30	4.25	6.10	4.25	7.10
Calcium, %	0.50	0.48	0.50	0.59	0.50	0.59
Phosphorus, %	0.42	0.45	0.42	0.51	0.42	0.52
Digestible phosphorus, %	0.26	-	0.25	-	0.25	-
Calcium:Phosphorus	1.19	-	1.20	-	1.20	-
Sodium, %	0.22	0.20	0.22	0.21	0.20	0.22
Lysine, %	0.84	0.87	0.83	0.90	0.87	0.95
SID[4] lysine, %	0.74	-	0.71	-	0.74	-
SID[4] lysine:ME, g:Mcal	2.24	-	2.24	-	2.24	-
SID[4] AA:SID[4] Lys ratio						
Met + Cys	0.57	-	0.57	-	0.57	-
Tryptophan	0.18	-	0.18	-	0.18	-
Threonine	0.62	-	0.62	-	0.62	-
Isoleucine	0.62	-	0.59	-	0.60	-
Valine	0.70	-	0.75	-	0.74	-

[1]Ingredient source: Archer Daniels Midland (Decatur, IL).

[2]Diet analyses: proximate analyses were conducted by Midwest Labs using wet chemistry; and amino acids were conducted by Ajinomoto Heartland, Inc. laboratory using High-Performance Liquid Chromatography (HPLC).

[3]HMB = 2-hydroxy-4-(methylthio) butanoic acid

[4]SID = standardized ileal digestible

Table 4.4. Diet formulation and calculated and analyzed composition for Finishing phase (BW = 96 to 127 kg).

	Diet					
	Control		CGM-No Fat		CGM+Fat	
Ingredient, %						
Corn	84.39		70.02		65.35	
Corn germ meal[1]	-		20.00		20.00	
Soybean meal[1]	13.20		7.60		9.08	
Fat (Yellow grease)	0.35		0.35		3.66	
Limestone	0.91		1.10		1.05	
Mono-cal 21% P	0.25		-		-	
Salt	0.46		0.46		0.41	
L-Lysine HCl- Dry (98.5%)	0.21		0.23		0.23	
Threonine (98%)	0.04		0.02		0.02	
Trace minerals premix	0.06		0.06		0.06	
Copper chloride (58%)	0.03		0.03		0.03	
Vitamins premix	0.03		0.03		0.03	
Phytase (Ronozyme HiPhos 2500 GT)	0.03		0.04		0.04	
Mycotoxin binder (Engage-M)	0.05		0.05		0.05	
Red iron oxide	-		0.04		-	
Composition	Calculated	Analyzed[2]	Calculated	Analyzed[2]	Calculated	Analyzed[2]
ME, kcal/kg	3,320	-	3,158	-	3,320	-
Dry matter, %	86.24	86.12	86.48	86.38	86.92	86.31
Crude Protein, %	12.17	13.10	13.03	13.80	13.41	14.20
Crude Fat, %	2.85	3.41	2.72	3.61	5.69	5.55
Crude Fiber, %	1.34	0.82	2.52	2.05	2.51	1.82
NDF, %	6.14	8.20	12.21	13.80	12.02	14.40
ADF, %	2.41	4.30	4.18	5.30	4.18	5.70
Calcium, %	0.45	0.50	0.46	0.54	0.45	0.47
Phosphorus, %	0.38	0.40	0.39	0.41	0.39	0.41
Digestible phosphorus, %	0.24	-	0.23	-	0.23	-
Calcium:Phosphorus	1.20	-	1.20	-	1.17	-
Sodium, %	0.20	0.17	0.20	0.18	0.18	0.17
Lysine, %	0.73	0.80	0.73	0.78	0.76	0.83
SID[3] lysine, %	0.64	-	0.61	-	0.64	-
SID[3] lysine:ME, g:Mcal	1.93	-	1.93	-	1.93	-
SID[3] AA:SID[4] Lys ratio						
Met + Cys	0.57	-	0.61	-	0.59	-
Tryptophan	0.18	-	0.19	-	0.19	-
Threonine	0.64	-	0.64	-	0.64	-
Isoleucine	0.64	-	0.64	-	0.64	-
Valine	0.74	-	0.83	-	0.81	-

[1]Ingredient source: Archer Daniels Midland (Decatur, IL).
[2]Diet analyses: proximate analyses were conducted by Midwest Labs using wet chemistry; and amino acids were conducted by Ajinomoto Heartland, Inc. laboratory using High-Performance Liquid Chromatography (HPLC).
[3]SID = standardized ileal digestible

Table 4.5. Effect of dietary Corn Germ Meal (CGM) inclusion fed during different growing periods in the growth performance and caloric efficiency of growing-finishing pigs.

	Experiment 1 (Commercial site)					Experiment 2 (University site)				
	Diet[1]					Diet[1]				
Item	Control[2]	CGM - No Fat	CGM + Fat	SEM	*P*-value	Control[2]	CGM - No Fat	CGM + Fat	SEM	*P*-value
Number of pens/growing period	12	12	12	-	-	12	12	12	-	-
Number of pens/growing period	408	408	408	-	-	48	48	48	-	-
Live Weight[3], kg										
Start Early Growing	28.6	28.8	-	0.18	0.07	29.2	29.3	29.2	0.68	0.43
End Early Growing	64.3^{a}	63.2^{b}	-	0.70	0.03	66.0	64.3	65.4	0.81	0.27
Start Late Growing	64.2	64.2	-	0.41	0.97	63.5	63.6	63.5	0.84	0.68
End Late Growing	95.7^{a}	94.3^{b}	-	0.63	0.02	96.9^{a}	94.4^{b}	96.3^{a}	0.76	0.02
Start Finishing	95.4	95.4	-	0.43	0.93	95.5	95.6	95.6	0.73	0.67
End Finishing	126.6	126.2	-	0.54	0.56	126.2	126.6	126.8	0.55	0.71
Start Growing-Finishing	28.7	28.8	28.7	0.18	0.13	29.3	29.2	29.1	0.69	0.32
End Growing-Finishing	126.3	127.3	126.0	0.57	0.25	128.3	126.5	127.5	0.71	0.21
Average Daily Gain, kg										
Early Growing	0.899^{a}	0.864^{b}	-	0.0091	0.04	0.981	0.926	0.957	0.0196	0.16
Late Growing	1.033^{a}	0.981^{b}	-	0.0174	<0.001	1.167^{a}	1.080^{b}	1.149^{a}	0.0248	0.02
Finishing	0.971	0.960	-	0.0108	0.41	1.149	1.088	1.146	0.0301	0.15
Growing-Finishing	0.980^{a}	0.945^{b}	0.954^{b}	0.0085	<0.001	1.067^{a}	1.012^{b}	1.064^{a}	0.0169	0.04
Average Daily Feed Intake, kg										
Early Growing	1.800	1.826	-	0.0231	0.23	1.947	1.941	1.858	0.0367	0.18
Late Growing	2.649	2.639	-	0.0330	0.64	2.843	2.882	2.859	0.0476	0.83
Finishing	3.015	3.013	-	0.0263	0.93	3.295	3.169	3.168	0.0704	0.06
Growing-Finishing	2.454^{b}	2.499^{a}	2.401^{c}	0.0251	<0.001	2.616	2.715	2.571	0.0474	0.08
Feed:Gain, kg:kg										
Early Growing	2.003^{b}	2.114^{a}	-	0.0170	<0.001	1.986^{b}	2.099^{a}	1.944^{b}	0.0219	<0.001
Late Growing	2.568^{b}	2.694^{a}	-	0.0225	<0.001	2.440^{b}	2.685^{a}	2.490^{b}	0.0429	<0.001
Finishing	3.108	3.139	-	0.0277	0.45	2.872^{ab}	2.920^{a}	2.781^{b}	0.0464	0.05
Growing-Finishing	2.508^{b}	2.647^{a}	2.517^{b}	0.0172	<0.001	2.454^{b}	2.685^{a}	2.415^{b}	0.0293	<0.001
Caloric efficiency, kcal/kg of BW										
Early Growing	6,600	6,635	-	54.9	0.52	6,547	6,586	6,411	71.3	0.14
Late Growing	8,503	8,492	-	72.5	0.88	$8,078^{b}$	$8,464^{a}$	$8,244^{ab}$	137.9	0.03
Finishing	$10,318^{a}$	$9,913^{b}$	-	91.2	0.01	9,534	9,220	9,230	152.4	0.15
Growing-Finishing	8,316	8,374	8,336	54.8	0.57	$8,126^{b}$	$8,461^{a}$	$7,955^{b}$	95.1	0.004

[a,b]Means within row and within Experiment with different superscripts are different ($P \leq 0.05$).

[1]All diets were formulated to the same SID lysine:ME. Diets for Control and 'CGM + Fat' were formulated to the same ME level. Diets for 'CGM - No Fat' treatments had approximately 160 kcal/kg less ME compared to Control diets.

[2]Control diet = corn-soybean meal based diet.

[3]Pigs allotted to Early and Late Growing periods were taken off-test at a fixed time of 38 and 29 d for the Early and Late Growing periods, respectively. Pigs on Growing-Finishing and Finishing periods were taken off-test at a fixed weight basis (at 126.5 ± 1.86 kg).

Table 4.6. Effects of Corn Germ Meal (CGM) inclusion in growing-finishing diets[1] on feed:gain ratio and caloric efficiency, and estimation of productive ME of CGM.

	Experiment 1 (Commercial site)				Experiment 2 (University site)			
Item	Control[2]	CGM - No Fat	CGM + Fat	SEM	Control[2]	CGM - No Fat	CGM + Fat	SEM
Feed:gain, kg								
Early growing	2.003^{b}	2.114^{a}	-	0.0170	1.986^{b}	2.099^{a}	1.944^{b}	0.0219
Late growing	2.568^{b}	2.694^{a}	-	0.0225	2.440^{b}	2.685^{a}	2.490^{b}	0.0429
Finishing	3.015	3.013	-	0.0277	2.872^{ab}	2.920^{a}	2.781^{b}	0.0464
Growing-Finishing	2.508^{b}	2.647^{a}	2.517^{b}	0.0172	2.454^{b}	2.685^{a}	2.415^{b}	0.0293
Dietary ME, kcal/kg[3]								
Early growing	3,296	3,138	3,297	-	3,296	3,138	3,297	-
Late growing	3,311	3,152	3,311	-	3,311	3,152	3,311	-
Finishing	3,320	3,158	3,320	-	3,320	3,158	3,320	-
Growing-Finishing	3,311	3,151	3,311	-	3,311	3,151	3,311	-
ME of CGM, kcal/kg[3]	2,548	2,548	2,548	-	2,548	2,548	2,548	-
Caloric Efficiency, kcal/kg of BW								
Early growing	6,600	6,635	-	54.9	6,547	6,586	6,411	71.3
Late growing	8,503	8,492	-	72.5	$8{,}078^{b}$	$8{,}464^{a}$	$8{,}244^{ab}$	137.9
Finishing	$10{,}318^{a}$	$9{,}913^{b}$	-	91.2	9,534	9,220	9,230	152.4
Growing-Finishing	8,316	8,374	8,336	54.8	$8{,}126^{b}$	$8{,}461^{a}$	$7{,}955^{b}$	95.1
Productive ME of CGM[4], kcal/kg								
Early growing	-	$2{,}465^{y}$	-	-	-	$2{,}455^{y}$	$2{,}898^{xy}$	-
Late growing	-	$2{,}568^{y}$	-	-	-	$1{,}829^{y}$	$2{,}215^{y}$	-
Finishing	-	$3{,}193^{x}$	-	-	-	$3{,}086^{x}$	$3{,}095^{x}$	-
Growing-Finishing	-	$2{,}439^{y}$	2,508	-	-	$1{,}924^{b,y}$	$2{,}904^{a,xy}$	-

[a,b]Means within row and within Experiment with different superscripts are different ($P \leq 0.05$).

[x,y]Means within column and within Experiment with different superscripts are different ($P \leq 0.05$).

[1]All diets diets were formulated to the same SID lysine:ME. Diets for Control and 'CGM + Fat' were formulated to the same ME level. Diets for ‘CGM - No Fat' treatments had approximately 160 kcal/kg less ME compared to Control diets.

[2]Control diet = corn-soybean meal based diet.

[3]As-fed basis

[4]Productive energy was calculated using the lsmeans values of caloric efficiency for each treatment.

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