RESEARCH REPORT
ANIMAL SCIENCE

Title: Effects of body weight and research conditions on the determination of the productive energy content of corn germ meal fed to growing-finishing pigs - **NPB #17-116**

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Industry Summary

Corn germ meal (CGM), a co-product of the corn wet milling industry, is an ingredient that could be used to reduce the cost of swine diets. Efficient use of any ingredient requires an accurate estimate of energy content and metabolizable energy (ME) is the standard energy measurement that is used in diet formulation in the US. However, there are few published estimates of the ME content of CGM. In addition, for ingredients high in fiber, such as CGM, using the ME system overestimates the energy available to the animal for production. An approach that has been advocated to overcome the problem with using ME is to determine the productive energy (PE) of ingredients such as CGM. This is estimated from the growth performance, in particular feed and energy efficiency, of pigs fed a diet including the test ingredient with that of pigs fed a reference diet based on a standard ingredient (e.g., a corn-soybean meal based diet). Determination of PE is relatively easy to carry out, can be conducted on commercial as well as research units, and does not require specialized facilities or equipment. However, the appropriate methodology to determine PE has not been investigated and the optimum approach to estimate PE has not been established. Therefore, the objectives of this research were to estimate the PE of CGM based on growth studies conducted at either a university research unit or a commercial production facility across various weight ranges in the growing-finishing period. In addition, these estimates of PE were compared with direct measurement of the ME of CGM using a standard metabolism study.

Four experiments were conducted; 2 growth performance evaluation studies (at either a Commercial or University research site), and 2 metabolism studies to measure the ME content of ingredients and diets used in the growth studies. Three diets were compared [a Control diet based on corn and soybean meal and 2 diets containing 20% CGM (with and without added fat)] across 4 growth periods [Early Growing (64 to 141 lb live weight), Late Growing (141 to 211 lb live weight), Finishing (141 to 280 lb live weight), and Growing-Finishing (64 to 280 lb live weight)]. A total of 3,672 and 576 barrows

and gilts housed in mixed-sex groups of 34 and 4 were used in the Commercial and University experiments, respectively, giving 12 replicates per diet for each growing period at each site. The CGM used was from a single source and a single diet phase was used in each growth period. The ME value of CGM used to formulate diets, based on previous research, was 2,548 kcal/kg. Two standard metabolism studies were carried out to directly measure the ME content of corn and CGM and also of the 3 diets that were use in the Early Growing period of the growth study, respectively.

The growth performance of pigs at the University site was more variable than at the Commercial site which was most likely the result of the larger group sizes and total numbers of animals used at the Commercial site. In addition, estimates of the PE of CGM were much more variable for the 3 diets and growth periods at the University site. Also, the PE of CGM estimated in the Finishing period at both sites was greater than estimates from the other growth periods. The ME of corn and CGM measured directly in metabolism studies were similar to estimates published by NRC (2012); however, the estimate of ME of CGM was considerably greater than the PE estimated from the growth studies. The ME of the Control diet used in the Early Growing period measured in the metabolism study was similar to the formulated value for this diet. However, the ME values for the 2 CGM diets used in the Early Growing period determined in the metabolism study were greater than the formulated values.

The results of this research suggest that the most appropriate approach to estimate PE would be using large-scale, controlled research studies carried out under commercial conditions rather than relatively small-scale studies under university conditions. Also, this research suggests that PE could be accurately determined over a relatively short period early in the growing period rather than over the entire growing-finishing period. Finally, the direct measurement of ME of CGM and of diets containing CGM from metabolism studies confirmed that this approach generally overestimates the energy available to the pig for growth which emphasizes the potential benefit of the use of the PE approach.

Key Findings:

The results of this research suggest that:

- Corn germ meal is a viable ingredient that can be used in diets for growing-finishing pigs (at least up to 20% inclusion level).
- The Metabolizable Energy value of CGM determined using a metabolism study (the conventional approach) overestimated the energy available to the pig for growth; this supports the use of the Productive Energy concept for the estimation of the energy value of corn germ meal and other fibrous ingredients.
- Estimates of Productive Energy of corn germ meal based on growth assays were:
  - Influenced substantially by the research conditions and the weight range over which the assay was conducted.
  - More consistent when measured under controlled commercial conditions and relatively early in the growing period than when measured under University research conditions and at heavier weights.
  - Were greater when measured in finishing than in growing pigs, suggesting that, in theory, a different energy value should be used for fibrous ingredients for different weights of pigs.
- The most appropriate approach to estimating PE is in large-scale controlled studies carried out under commercial conditions during the early growing period.

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Scientific Abstract:

Four experiments were carried out to investigate the energy content of corn germ meal (CGM). Experiments 1 and 2 were growth studies carried out at either a Commercial or a University site to evaluate the effect of research conditions on estimates of the productive energy (PE) content of CGM. The 2 experiments used a RCBD with 3 dietary treatments: 1) Control (corn-soybean meal-based); 2) CGM-No Fat (20% CGM; 4.8% lower ME than Control); 3) CGM+Fat (20% CGM + yellow grease; same ME as Control); and 4 growth periods: Early Growing (E-G; 29-64 kg BW), Late Growing (L-G; 64-96 kg BW), Finishing (F; 96-127 kg BW), and Growing Finishing (G-F; 29-127 kg BW). At the commercial site, the CGM+Fat diet was fed in G-F only. One diet phase was used in each of the E-G, L-G, and F periods. Diets for both experiments were made at the same feed mill using the same batches of ingredients and were formulated to the same SID lysine:ME ratio within phase, and to meet or exceed nutrient requirements proposed by NRC (2012). The ME value of CGM used to formulate diets was 2,548 kcal/kg. A total of 3,672 and 576 barrows and gilts housed in mixed-sex groups of 34 and 4 were used in Exp. 1 and 2, respectively, giving 12 replicates/diet/growing period at each site. Statistical analysis was carried out within experiment and growing period with pen as the experimental unit using PROC MIXED or PROC TTEST of SAS; the model accounted for the effects of dietary treatment and block. 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 BW gain) was calculated for each diet and growth period. The effect of dietary treatment on growth performance was relatively similar at the 2 research sites. Compared to the Control treatment, ADG was lower ($P < 0.05$) and F:G greater ($P < 0.05$) for pigs on the CGM-No Fat treatment in E-G, L-G, and G-F but not F period at the Commercial site and in L-G and G-F but not E-G and F at the University site. Pigs on the CGM+Fat treatment generally had similar ($P > 0.05$) growth performance to those on the Control treatment. There was no effect of dietary treatment on caloric efficiency in E-G, L-G, and G-F periods at the Commercial site or in E-G and F periods at the University site. Caloric efficiency for the CGM-No Fat compared to the Control diet was lower ($P < 0.05$) at the Commercial site in F (9,913 and 10,318 kcal/kg, respectively; SEM 91.2) but was greater ($P < 0.05$) in L-G (8,464 and 8,078 kcal/kg, respectively; SEM 137.9) and G-F (8,461 and 8,126 kcal/kg, respectively; SEM 95.1) at the University site. For the Commercial site, estimates of PE of CGM were similar ($P > 0.05$) for CGM-No Fat diet in E-G, L-G, and G-F periods (2,465, 2,568, and 2,439 kcal/kg, respectively) and for the CGM+Fat diet in G-F (2,508 kcal/kg); however, PE was greater ($P < 0.05$) for the F period (3,193 kcal/kg). At the University site, PE estimates were more variable than at the Commercial site, both between growth periods and between the CGM diets. For example, PE based on the CGM-No Fat treatment for E-G, L-G, and G-F was 2,455, 1,829, and 1,924 kcal/kg, respectively ($P > 0.05$), and on the CGM+Fat treatment for the same periods was 2,898, 2,215, and 2,819 kcal, respectively, ($P > 0.05$). Estimates of PE based on the F period were generally greater than those for other periods for the CGM-No Fat treatment at both the Commercial and University site (3,193 and 3,086 kcal/kg, respectively) and for the CGM+Fat treatment at the University site (3,095 kcal/kg). Experiments 3 and 4 were metabolism studies that measured the ME of corn and CGM, and of the 3 diets used in the E-G period, respectively. Measured ME of corn and CGM in Exp. 3 was 3,489 and 2,828 kcal/kg, respectively, which are similar to NRC (2012) values. Measured ME of the Control, CGM-No Fat, and CGM+Fat diets was 3,332, 3,250, and 3,442 kcal/kg, respectively, which were 36, 112, and 145 kcal/kg, respectively, greater than formulated values for these diets. These results suggest that estimating PE from large-scale, controlled research studies carried out under commercial conditions would be more appropriate than using relatively small-scale studies under university conditions. Also, PE can be accurately determined over a relatively limited weight range in the growing period rather than over the entire growing-finishing period. Finally, ME values from metabolism studies generally overestimated the energy available to the pig for growth which emphasizes the potential benefit of using the PE approach.

Introduction

Corn germ meal (CGM) is a co-product of the corn wet milling industry that produces starch and corn oil as primary products to be used in the human food industry. Corn germ meal is available in relatively large quantities in a number of areas of the US and is, potentially, an ingredient that could be used to reduce the cost of diets fed to swine. Efficient use of any ingredient in swine diets requires an accurate estimate of the energy content of that ingredient. The metabolizable energy content (ME) of ingredients is the standard measurement that is used in diet formulation in the US and most other countries in the world. However, there are very few published estimates of the ME content of CGM. In addition, CGM has a relatively high fiber content (NDF of 44%; NRC, 2012) and for such ingredients using the ME system will tend to overestimate the energy available to the animal for production. The net energy (NE) content of such ingredients would, in theory, more accurately estimate the energy available to the animal for production. However, the NE content of CGM has not been established and, also, measuring the NE of any ingredient requires specialized facilities and equipment that are not widely available.

One practical approach that has been advocated is to determine the productive energy (PE) of ingredients such as CGM. Productive energy is estimated from growth assays by comparing the energy efficiency of pigs fed a diet including the test ingredient with that of pigs fed a reference diet (e.g., a corn-soybean meal based diet). Any difference between the diets in energy efficiency is attributed to the test ingredient (e.g., CGM) and the energy content of the ingredient can be adjusted accordingly. Productive energy determinations are relatively easy to carry out and do not require specialized facilities. A significant number of pig producers have the capability to measure growth and feed intake under commercial conditions and, as such, could undertake studies to determine the PE content of any ingredient. However, the appropriate methodology to use to determine PE has not been investigated and the optimum approach to estimate PE has not been established.

The research summarized in this report provides the industry with additional estimates of the energy content of CGM, a potentially important ingredient for swine diets, but, also, for the first time provides information on the appropriate methodology to use to measure PE of CGM that could also be applied to other ingredients.

Objectives

The primary objectives of this research were to estimate the energy content of corn germ meal (CGM) and to evaluate the impact of the methodology used to carry out growth performance studies on the estimates of productive energy content of CGM when fed to growing-finishing pigs.

These objectives were achieved by addressing the following sub-objectives:

1. Compare estimates of productive energy of CGM based on growth studies conducted at a university research unit or at commercial production facilities.
2. Evaluate the impact of the weight range used for the growth study during the grow-finish period on estimates of productive energy of CGM.
3. Compare estimates of productive energy obtained in sub-objectives 1, and 2, with the metabolizable energy content of CGM measured using a standard metabolism study.

Materials & Methods

Determination of the productive energy of corn germ meal under different research conditions and weight ranges (Sub-objectives 1 and 2)

Two experiments (Exp. 1 and 2) were carried out using the same design and similar treatments at 2 different research sites to estimate the productive energy (PE) content of corn germ meal (CGM).

Locations

Experiment 1 was carried out at a Commercial Research Site (Georgia Technology Center of The Maschhoffs, located in Carlyle, IL), which is a standard commercial wean-to-finish facility equipped to collect data on BW and feed intake under typical commercial conditions. Experiment 2 was carried out at a University Research Site [Swine Research Center (SRC), University of Illinois, Urbana-Champaign, IL] under typical university research facility conditions. The experimental protocol for the experiments at both sites was approved by the University of Illinois Institutional Animal Care and Use Committee.

Experimental Design and Treatments

Both experiments used a randomized complete block design (date of start on study was the blocking factor) with 4 blocks and 12 replicates per treatment subclass.

A summary of the treatments used in the two experiments is presented in Table 1. The treatments used in both experiments involved combinations of 3 CGM dietary treatments [0 % CGM (Control; corn soybean meal based diets); 20% CGM with no added fat (CGM-No Fat); 20% CGM + added fat (CGM+Fat)] and 4 different growth periods [Early Growing (E-G; 29 to 64 kg BW); Late Growing (L-G; 64 to 96 kg BW); Finishing (F; 96 to 127 kg BW); Growing-Finishing (G-F; 29 to 127 kg BW)]. For Exp. 1, due to a limit to the number of pens available for the experiment, the CGM+Fat diet was only fed in the G-F period, giving 9 diet by growth period treatment combinations. For Exp. 2, the 3 dietary treatments were fed in all 4 growth periods giving 12 diet by growth period treatment combinations (Table 1).

Treatment No.	Growth Period	Dietary Treatment	Experiment
1		0% CGM	1 and 2
2	Early Growing	20% CGM	1 and 2
3		20% CGM + Added Fat	2
4		0% CGM	1 and 2
5	Late Growing	20% CGM	1 and 2
6		20% CGM + Added Fat	2
7		0% CGM	1 and 2
8	Finishing	20% CGM	1 and 2
9		20% CGM + Added Fat	2
10		0% CGM	1 and 2
11	Growing-Finishing	20% CGM	1 and 2
12		20% CGM + Added Fat	2

Diets

All diets were formulated to meet or exceed the requirements recommended by NRC (2012) for the weights of pigs used. 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 both experiments is shown in Table 2. Diets for both experiments were manufactured at the Carlyle Mill of

The Maschhoffs in pellet form. Three dietary phases were used, one phase for each growth period. All diets were formulated to have the same SID lysine:calorie ratio within phase. Diets for the CGM+Fat treatment were formulated to the same ME concentration as the Control treatment using yellow grease. Diets for the CGM-No Fat were formulated at a lower ME content than the other 2 diets.

The ME values for corn and soybean meal used in diet formulation were 3,403 and 3,319 kcal/kg, respectively; these were based on the values from NRC (2012) adjusted for the chemical composition of the batches of the ingredients used in diet manufacture. The ME value for CGM used to formulate the diets was 2,548 kcal/kg, which was based on the productive ME of CGM determined in previous studies (Estrada, 2017) adjusted for the chemical composition of the batches used in diet manufacture. Diet formulation and calculated and analyzed composition for E-G, L-G, and F growth periods are presented in Tables 3, 4, and 5, respectively.

Red iron oxide was included in the CGM-No Fat diet (0.04% inclusion) in all 3 growth periods to allow easy identification of diets at the farm; the corn-soybean based Control diet was much paler in color than the diets containing CGM. This step was taken to minimize the risk of pigs inadvertently receiving diets of the wrong treatment. In addition, a mycotoxin binder was included in all diets (0.05% inclusion) for the F period only due high levels of mycotoxin in the batches of corn used to manufacture those diets.

Animals

Experiment 1: A total of 3,672 commercial crossbred pigs (progeny of PIC 359 sires mated to commercial dams) housed in 108 mixed-sex pens of 34 pigs (equal numbers of barrows and gilts) were used in the study, giving 12 replicates/dietary treatment/growth period and 9 pens per replicate. Allotment was carried out at wk 8 post-weaning (28.7 ± 0.60 kg BW). For each replicate, pigs were individually weighed, sorted by sex, 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. The mean pen BW and within-pen variation in BW were calculated and, if necessary, pigs were moved between pens within a replicate to equalize these across pens. Pens were randomly allotted to treatment.

Experiment 2: A total of 576 commercial crossbred pigs (progeny of PIC 359 sires mated to Camborough or Geneporc Fertilis 25 dams) housed in 144 mixed-sex pens of 4 pigs (equal numbers of barrows and gilts) were used in the study, giving 12 replicates/dietary treatment/growth period and 12 pens per replicate. Allotment was carried out at wk 8 post-weaning (29.1 ± 2.36 kg BW). For each replicate, pigs were individually weighed, sorted by sex, 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. The mean pen BW and within-pen variation in BW were calculated and, if necessary, pigs were moved between pens within a replicate to equalize these measurements across pens. Pens were randomly allotted to treatment.

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 BW (L-G and F growth periods, respectively) to allow for any losses of pigs during the period from allotment to these pens starting on test. When the mean pen weight of pens corresponding to these treatments reached the designated start weight, pigs were weighed (individually at the University site and as a group at the Commercial site) and the extra animals (if any) were removed to achieve same number of pigs per pen with equal number of barrows and gilts and similar BW between pens within a replicate. At both sites, pigs on the L-G and F growth periods were fed the Control treatment diets from allotment to the start of the respective growth period.

Housing

Experiment 1: Pigs were housed in a wean-to-finish building that had fully slatted concrete flooring and was tunnel ventilated. Pen divisions were of horizontal metal bars. Each pen was equipped with a 4-space wet-dry feeder and 2 cup-type water drinkers. Feed and water were available *ad libitum* throughout the study period. Air temperature in the building was maintained using thermostatically controlled heaters and fan ventilation. The thermostat was set at 18.3°C throughout the study period. Under hot conditions, when the ambient room temperature reached 29.4° C, water sprinklers were used to cool the pigs. The floor space for all treatments was 0.63 m^2/pig. In the event of a mortality or removal of an animal during the study, the pen size was adjusted using a moveable pen partition to maintain a constant floor space per pig.

Experiment 2: During the study period, pigs were housed in a mechanically-ventilated building that had part-solid, part-slatted concrete floors (approximately equal area of solid and slatted floor). Each pen had a single-space dry box feeder mounted on the front gate and a nipple-type water drinker. Feed and water were available *ad libitum* throughout the study period. Pen divisions and gates consisted of vertical steel rods. The thermostat was set at 18.5°C throughout the study period and temperature was maintained using thermostatically-controlled heaters and fan ventilation. The floor space for all treatments was 0.94 m^2/pig.

Feed and Growth Measurements

For both experiments, individual weights were collected at allotment (wk 8 post-weaning) for all treatments. Subsequently, pen weights were collected at the Commercial site and individual pig weights at the University site on all pigs at the start and end of each growth period (E-G period: day 0 and 40, and day 0 and 38 for the Commercial and University sites, respectively; L-G period: day 40 and 70, and day 38 and 66, respectively; F period: day 70 and 102, and day 66 and 94, respectively).

At the Commercial site, 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. At SRC, feed was manually weighed and delivered. 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 and efficiency.

Calculation of Productive Energy of Corn Germ Meal

The calculation of PE for CGM, or any ingredient, has been described in detail by Estrada (2017). The basic concept of the approach is to compare the energetic (caloric) efficiency of a test diet that contains the test ingredient, in this case CGM, with a reference diet that contains a standard ingredient, such as corn. An implicit assumption in estimating PE is that the ME value of the standard ingredient used in the reference diet has been well established and is, therefore, accurate. The expectation is that if the estimate of ME for the test ingredient used to formulate diets was accurate then the caloric efficiency of the reference and the test diet should be the same. Consequently, any difference in caloric efficiency between the reference diet based on the standard ingredient and the diet based on the test ingredient is assumed to be due to the use of an inaccurate estimate of the ME value of the test ingredient used in diet formulation.

The steps in estimating PE start with the calculation of the caloric efficiency (F:G multiplied by the formulated ME content for the reference and test diets). An adjusted ME is calculated for the test diet by multiplying the formulated ME value of the test diet by the ratio between the caloric efficiency of the reference and test diets. If this ratio is less than 1 (i.e., the caloric efficiency of the test diet is greater than

that of the reference diet), this suggests that the original ME value used for the test ingredient was over-estimated and vice versa. The difference between the formulated and adjusted ME of the test diet is assumed to be due to error in the original ME value used for the test ingredient. This difference is adjusted by the proportion of the ingredient included in the test diet to estimate the extent to which the original ME value of the test ingredient used in formulation was over- or under-estimated and the original ME value is adjusted accordingly to estimate the PE value of the test ingredient.

Statistical Analysis

Growth performance data from the 2 experiments were tested for normality and homogeneity of variances 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. Data for the 2 research sites (Exp. 1 and 2) and for the 4 growth periods were analyzed separately as RCBC with pen as the experimental unit; the model included the fixed effect of CGM dietary treatment and the random effect of block. Productive energy was calculated for each dietary treatment and growth period based on the respective mean F:G and comparison of PE estimates between dietary treatments and growth periods was conducted using the two-sample Student's *t*-test, using the PROC TTEST procedure of SAS.

Determination of ME content of corn germ meal using a metabolism study (Sub-objective 3)

Animals, Experimental Design, and Treatments

Two experiments (Exp. 3 and 4) were carried out at the Swine Research Center of the University of Illinois to measure the ME content of diets containing CGM used in Exp. 1 and 2 (Exp. 3) and of corn, CGM, and Distillers Dried Grains with Solubles (DDGS; Exp. 4). Both experiments used a completely randomized design. The DDGS treatment was included to provide an additional reference point for comparison with corn and CGM.

Experiment 3: Diets from the 3 dietary treatments used in the E-G period in Exp. 1 and 2 (Table 3) were compared, which were as follows:

1. Control (0% CGM; corn-soybean meal based diet)
2. CGM–No Fat (20% CGM; formulated to a lower ME than Control).
3. CGM+Fat (20% CGM + yellow grease; formulated to same ME level as Control)

Experiment 4: Three diets were compared:

1. Corn based basal diet
2. Corn + 40% CGM
3. Corn + 40% DDGS

For both experiments, vitamins and minerals were included in all diets to meet or exceed current requirement estimates (NRC, 2012).

Both experiments used 24 growing pigs that were the offspring of Line 359 boars mated to Camborough sows (Pig Improvement Company, Hendersonville, TN). The average initial BW was 52.4 ± 2.86 and 28.35 ± 1.53 kg for Exp. 3 and 4, respectively. Pigs were allotted to a completely randomized design with 3 diets and 8 replicate pigs per diet.

Housing

Pigs were housed individually in metabolism crates that were equipped with a self-feeder, a nipple waterer, and a slatted floor. A screen and a urine pan were placed under the slatted floor to allow for the total, but separate, collection of urine and fecal materials.

Procedures and Measurements

For both experiments, feed was supplied in a daily amount of 3 times the maintenance energy requirement (i.e., 106 kcal of ME/kg of $BW^{0.75}$; NRC, 2012) of the smallest pig in each replicate and divided into 2 equal meals that were provided at 0800 and 1600 h. Water was available at all times. Pigs were fed experimental diets for 12 days. The initial 5 d were considered an adaptation period to the diet. Fecal markers were fed on d 6 (chromic oxide) and d 11 (ferric oxide) and fecal collections were initiated when chromic oxide appeared in the feces and ceased when ferric oxide appeared (Adeola, 2001). Feces were collected twice daily and stored at –20°C immediately after collection. Urine collections were initiated on d 6 at 1600 h and ceased on d 11 at 1600 h. Urine buckets were placed under the metabolism crates to permit total collection and buckets were emptied every morning and a preservative of 50 mL of sulfuric acid was added to each bucket when they were emptied. The collected urine was weighed and a 10% subsample was stored at –20°C. At the conclusion of the experiments, urine samples were thawed and mixed within animal and diet, and a sub-sample was lyophilized before analysis.

All samples were analyzed in duplicate. Fecal samples were thawed and mixed within pig and diet, and then dried at 65°C using a forced air drying oven. Samples were then ground through a 1-mm screen in a Wiley mill (Model 4; Thomas Scientific, Swedesboro, NJ) before analysis. Diets, ingredients, and fecal samples were analyzed for DM (method 930.15; AOAC, 2007). Ingredients, diets, fecal and urine samples were also analyzed for GE using bomb calorimetry (Model 6400; Parr Instruments, Moline, IL).

The apparent total tract digestibility (ATTD) of GE and DM was calculated for each diet. The DE and ME of corn was calculated by dividing the DE and ME of the corn diet by the inclusion rate of corn in that diet. The contribution of DE and ME from corn to the DE and ME in the diets containing CGM or DDGS was subtracted from the DE and ME of these diets, and the DE and ME of each ingredient (CGM and DDGS) was calculated by difference (Adeola, 2001). The ATTD of GE and DM in CGM and DDGS was calculated using the same procedure.

Statistical Analysis

Data were analyzed as CRD with the individual pig as the experimental unit; the model included the fixed effect of diet and the random effect of replicate. Least-squares means were separated using the PDIFF option; an α level of 0.05 was used to assess significance among means.

Results

Experiments 1 and 2: Growth Studies

These were carried out to meet Sub-Objectives 1 and 2:

1. Compare estimates of productive energy of CGM based on growth studies conducted at a university research unit or at commercial production facilities.
2. Evaluate the impact of the weight range used for the growth study during the grow-finish period on estimates of productive energy of CGM.

Diets

Analyzed composition of the major ingredients (corn, SBM, and CGM) used to manufacture the diets for the growth performance evaluation (Exp. 1 and 2) is presented in Table 2. In general, the composition of these ingredients was in line with those reported by NRC (2012). These analyzed composition values were used to formulate the experimental diets.

Diet composition and calculated and analyzed composition for the E-G, L-G, and F growth period are presented in Tables 3, 4, and 5, respectively. Formulated and analyzed values were generally similar for the 3 phases taking into account sampling and analytical variation.

Growth Performance

The growth performance results for Exp. 1 and 2 for the 4 growth periods are presented in Table 6. The CGM+Fat diet was fed in all 4 growth periods in Exp. 2 but, due to space limitations at the commercial research site, only in the G-F period in Exp. 1.

Data were analyzed separately for each growth period within each experiment and, consequently, the valid comparisons are between dietary treatments within experiment and growth period.

In general, the differences in growth performance between the 3 CGM dietary treatments within each growth period were relatively similar in the 2 experiments. However, the variation associated with the growth performance variables were considerably greater at the University site than at the Commercial site (Table 6). For example, for the G-F growth period the SEM for ADG, ADFI, and F:G were 0.0085, 0.0251, and 0.0172, respectively, for the Commercial site compared to 0.0169, 0.0474, and 0.0293, respectively, for the University site.

As expected, there were no differences ($P > 0.05$) in BW at the start of any of the growth periods in either experiment (Table 6). At the Commercial site, pigs on the CGM-No Fat treatment had lower ($P < 0.05$) ADG in E-G, L-G, and G-F compared to those on the Control treatment (3.9, 5.0, and 3.6% lower, respectively), but not ($P > 0.05$) in the F period. At the University site, ADG was numerically lower for the CGM-No Fat treatment compared to the Control in all growth periods (by 5.6, 7.5, 5.3, and 5.2% for E-G, L-G, F, and G-F, respectively); however, the treatment difference was significant ($P < 0.05$) in L-G and G-F growth periods only. Pigs on the CGM+Fat treatment had similar ($P > 0.05$) ADG to the Control treatment in all growth periods at the University site (Table 5). However, at the Commercial site the ADG of pigs on the CGM+Fat treatment in the G-F period (the only period in which this diet was fed) was lower ($P < 0.05$; 2.7%) than the Control treatment but similar ($P > 0.05$) to the CGM-No Fat treatment.

There was no effect ($P > 0.05$) of dietary treatment on ADFI in any growth period at the University site or in E-G, L-G, and F periods at the Commercial site (Table 6). However, in the G-F period at the Commercial site ADFI was greater ($P < 0.05$) for the CGM-No Fat than the CGM+Fat treatment with the Control treatment being intermediate and different ($P < 0.05$) from the other treatments.

Feed:gain was greater ($P < 0.05$) for the CGM-No Fat treatment than the Control treatment in all periods at both sites, except in the F period at both sites where F:G was similar ($P > 0.05$) for these 2 treatments (Table 6). The CGM+Fat treatment had similar ($P > 0.05$) F:G to the Control in all periods in which it was fed at both sites (Table 6), but had lower ($P < 0.05$) F:G than the CGM-No Fat treatment in G-F period at the Commercial site (4.9%) and in all periods at the University site (7.4, 7.3, 4.8, and 10.1%, for E-G, L-G, F, and G-F, respectively).

Caloric Efficiency and Productive Energy Content of CGM

The results relating to the parameters that were required to estimate PE of CGM for the 2 experiments, 3 dietary treatments, and 4 growth periods are summarized in Table 7. The results for F:G

have been discussed previously and the formulated dietary ME contents are taken from diet formulations which are presented in Tables 3, 4, and 5 for the 3 growth periods, respectively.

The results for caloric efficiency (F:G multiplied by the formulated ME values for the diet) are presented in Table 7. The expectation is that if the ME values for corn and CGM used in diet formulation were accurate then the caloric efficiency of the 2 CGM dietary treatments should be similar to the Control ($P > 0.05$). This was the case for the CGM+Fat treatment that had similar ($P > 0.05$) caloric efficiency to the Control treatment in all growth periods at the University site and in the G-F period at the Commercial site (Table 7). Similarly, there was no difference ($P > 0.05$) in caloric efficiency between the Control and the CGM-No Fat treatments in the E-G, L-G, and G-F periods at the Commercial site and in the E-G and F periods at the University site. However, caloric efficiency for the CGM-No Fat compared to the Control treatment was lower ($P < 0.05$) for the F period at the Commercial site but greater ($P < 0.05$) for the L-G and G-F periods at the University site (Table 7). In this respect, a lower caloric efficiency for the test than the control treatment suggests that the ME for the test ingredient that was used in diet formulation was underestimated and vice versa.

The estimated PE of CGM based on the 4 growth periods and the 2 CGM treatments in Exp. 1 and Exp. 2 are presented in Table 7. For Exp. 1, PE estimates based on the CGM-No Fat treatment were similar ($P > 0.05$) for E-G, L-G, and G-F periods but were substantially greater ($P < 0.05$) for F than for the other 3 growth periods (difference of 728, 625, and 754 kcal/kg for the E-G, L-G, and G-F periods, respectively). In addition, in Exp. 1, the PE estimate based on the CGM+Fat treatment in G-F was not different ($P > 0.05$) from the estimate based on the CGM-No Fat treatment (2,508 and 2,439 kcal/kg, respectively).

The PE estimates from Exp. 2, which was carried out at the University site, were generally much more variable than those from Exp. 1, which was carried out at the Commercial site (Table 7). Although there was no difference ($P > 0.05$) between the PE values based on the CGM-No Fat diet for the E-G, L-G, and G-F periods, the differences between values was considerable with the PE for the E-G period being 626 (25.5%) and 531 (21.6%) kcal/kg greater than that for L-G and G-F periods, respectively. Similarly, for the CGM+Fat treatment there was no difference ($P > 0.05$) in PE values for the E-G, L-G, and G-F periods; however, the values were considerably different (2,898, 2,215, and 2,819 kcal/kg, respectively). In addition, the PE value for the G-F period for Exp.2 was greater ($P < 0.05$) for the CGM+Fat than the CGM-No Fat diet (2,819 and 1,924 kcal/kg, respectively; Table 7). However, there was no difference ($P > 0.05$) in PE value between the 2 CGM dietary treatments for the other growth periods (Table 7).

Similar to the results of Exp. 1, the estimated PE for Exp. 2 based on the CGM-No Fat diet was greater ($P < 0.05$) for the F period than the other periods (Table 7), with the difference being 631, 1,257, and 1,162 kcal/kg for the E-G, L-G, and G-F periods, respectively. The PE estimate for the F period based on the CGM+Fat treatment in Exp. 2 was also greater ($P < 0.05$) than that for the L-G but not ($P > 0.05$) the other periods (PE values were 2,898, 2,215, 3,095, and 2,819 kcal/kg for E-G, L-G, F, and G-F periods, respectively; Table 7).

Experiments 3 and 4: Metabolism Studies

Experiment 3: The digestibility of energy and DE and ME values for the 3 dietary treatments used in the E-G period in Exp. 1 and 2 are summarized in Table 8. Diet formulations and calculated and analyzed composition are presented in Table 3; the composition of the major ingredients (corn, soybean meal, and CGM) used to formulate this diet are presented in Table 2.

Apparent total tract digestibility of GE was greater ($P < 0.05$) for the Control treatment than the CGM-No Fat diet, with the CGM+Fat treatment being intermediate and different ($P < 0.05$) than the other 2 treatments (Table 8). Values for DE and ME were greater ($P < 0.05$) for the CGM+Fat than the CGM–

No Fat treatment with the Control treatment being intermediate and different ($P < 0.05$) from the other 2 treatments.

Experiment 4: The analyzed composition of the corn, CGM, and DDGS samples evaluated in this experiment are presented in Table 9 and the ingredient and analyzed composition of the 3 experimental diets are given in Table 10. The results of the metabolism study are presented in Table 11.

The ATTD of GE and DM were greater ($P < 0.05$) for corn than CGM with DDGS being intermediate and different ($P < 0.05$) than the other 2 ingredients. The DE and ME of corn and DDGS were similar ($P > 0.05$) but were greater ($P < 0.05$) than those for CGM on both an as fed and dry matter basis (Table 11).

Discussion

Experiments 1 and 2: Growth Studies

Data were analyzed separately for each growth period within each experiment. Based on previous research, differences in growth performance between sites and growth periods were expected. However, it was not an objective of this research to evaluate differences in growth performance between sites and growth periods. Rather, the main objective was to determine if research site and the weight range over which growth performance was measured impacted the estimate of the PE of CGM, and also to identify the most appropriate BW range to use to estimate PE. On this basis, carrying out the statistical analysis within research site and growth period was the most appropriate approach to use.

An interesting feature of this research was the greater variation associated with growth performance variables at the University compared to the Commercial research site. The number of experimental units (pens) per treatment was the same at both sites; however, the number of pigs per pen was substantially greater for the commercial compared to the research site (34 compared to 4 pigs/pen, respectively). Variation between pens in growth performance would generally be expected to decrease with increasing number of pigs/pen. Consequently, although treatment differences were relatively similar across the 2 sites, they were not always statistically different for the University site.

Growth Performance

In general, at both research sites, pigs fed the diet with CGM without added fat had similar feed intake but reduced growth rate and feed efficiency compared to those fed the corn-soybean meal control diet. The exception to this was during the finishing period when growth performance was similar for these 2 treatments.

The response to including fat in the CGM diet differed between research sites. At the University site, ADG, ADFI, and F:G were similar for the CGM+Fat and the Control treatments in all of the growth periods. However, at the Commercial site during the G-F period (the only period when the CGM+Fat diet was fed) ADG and ADFI were lower for the CGM+Fat compared to the Control with F:G being similar. This result is surprising given that the diets for these 2 treatments were formulated to have the same ME content with the expectation that growth performance would be similar. However, differences in ADG and ADFI between these 2 treatments was relatively small (26g and 53g for ADG and ADFI, respectively).

The limited amount of studies carried out to evaluate the effects of feeding CGM to pigs on growth performance have generally given variable results. Some studies have shown no effect of including up to 25% CGM on growth performance (Jones, 1987; Weber et al., 2010). However, other studies have shown similar results to those of the present research. For example, Estrada (2017) carried out 2 studies in the same commercial facility used in this research over the wean-to-finish period. In one

study, there was no effect of including up to 25% CGM in the diet on ADG or ADFI, however, there was a linear reduction in G:F. In a second study, including up to 40% CGM resulted in linear reductions in ADG and G:F with no effect on ADFI. Interestingly, in the studies of Estrada (2017) the Control and CGM diets were formulated to the same ME content.

Caloric Efficiency

Caloric efficiency is defined as the amount of energy consumed per unit of body weight gain and is calculated by multiplying the F:G 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.

The expectation was that if the estimates of ME for ingredients used to formulate control and test diets were accurate then the caloric efficiency of the Control and the 2 CGM diets should be the same. An implicit assumption in estimating PE is that the ME value of the standard ingredient used in the Control diet, such as corn that was used in this study, has been well established and is, therefore, accurate. Consequently, any difference in caloric efficiency between a control diet based on the standard ingredient and the diet including the test ingredient is assumed to be due to the use of an inaccurate estimate of the ME value of the test ingredient in diet formulation. In addition, the ME values for corn and CGM used to formulate diets in this study were adjusted based on the chemical composition of the batches of the ingredients used to manufacture the diets which should have improved the accuracy of the ME estimates compared to using NRC (2012) values without this adjustment.

At the Commercial site, with the exception of the F period, caloric efficiency for the Control and CGM-No Fat diets were similar (difference between Control and CGM-No Fat diets of 35, 11, and 58 kcal/kg for E-G, L-G, and G-F, respectively, or 0.5, 0.1, and 0.7% of Control mean, respectively). In addition, caloric efficiency values for the CGM+Fat treatment in the G-F period was similar to that for the other 2 treatments (8,316, 8,374, and 8336 kcal/kg BW gain for the Control, CGM-No Fat, and CGM+Fat diets, respectively). These results suggest that the ME value used for CGM in diet formulation was relatively accurate.

However, at the University site, caloric efficiency varied relatively widely between dietary treatments within growth period, although treatment differences were only significant for the E-G and G-F periods. For example, differences in caloric efficiency between the Control and CGM-No Fat treatments for L-G, and G-F periods were 386, and 335 kcal/kg, or 4.8, and 4.1% of the control mean.

An interesting finding was the lower (improved) caloric efficiency for the CGM-No Fat treatment compared to the Control treatment at the Commercial site during the F period, which was substantial (405 kcal/kg; 3.9%). At the University site, the caloric efficiency of both CGM treatments was also lower than the Control treatment during the F period (314 and 304 kcal for CGM-No Fat and CGM+Fat treatments, respectively); however, these differences were not statistically significant. These results suggest that the ME value used to formulate the CGM diets was underestimated for finishing pigs. This may possibly be related to the greater capacity of heavier pigs to digest the fibrous fraction of the diet (Noblet et al., 1994; LeGoff and Noblet, 2001; Noblet and van Milgen, 2004; Cozzanet et al., 2010). The issue of changes in fiber digestion with increasing size of pig warrants further research.

Productive Energy of CGM

There was more variation in PE estimates for the different diets and growth periods in Exp. 2, which was carried out at the University site, than in Exp. 1 which was carried out at the Commercial site. As previously discussed, the variation in all of the growth measurements was considerably greater at the University than at the Commercial site even though the number of replicates at each site was the same. The diets used at both sites were produced at the same feed mill using the same batches of ingredients and

the research protocols used at the 2 sites were similar. The major difference between the 2 sites was in the environment that the pigs experienced and, particularly, the group sizes used. These results illustrate that controlled research under commercial conditions, with the ability to use large numbers of animals in large groups, can lead to reduced between pen variation in growth performance and, in this case, was the approach that yielded more consistent estimates of PE. Increasing the number of replicates and/or number of pigs/pen at the University site would be options to increase the probability of detecting important treatment differences. However, based on these results carrying out PE determinations under typical University swine research conditions, with small group sizes, cannot be recommended.

The PE estimates were substantially higher for the F than the other periods in both experiments and were relatively consistent across experiments. Thus, PE values were 3,193 and 3,086 kcal for CGM-No Fat treatments in Exp. 1 and 2, respectively, and 3095 kcal for the CGM+Fat diet in Exp.2. As previously discussed, there is evidence that the pig's ability to digest the fiber component of the diet increases with weight. On this basis, it has been suggested that different energy values are needed for use with lighter and heavier pigs, particularly for fibrous ingredients (Noblet and van Milgen, 2004; Noblet, 2005; NRC, 2012; Kil et al., 2013). However, the difference in PE estimates between F and the other periods was considerable; for example, for the Commercial site the difference in PE between the L-G and F periods was 625 kcal (24.3%). Further research would be needed to determine how much of this difference was due to increased digestibility of fibrous components in the CGM diet in finishing. In addition, the variation in growth performance and caloric efficiency was greater in the F period than in the other periods which suggests that studies to estimate PE should be carried either over the entire grow-finish period or earlier in the growth period. In practice, carrying out the growth evaluation over a short period of time has merit and, consequently, estimating PE in the growing period has advantages in this respect.

The ultimate use of these results, and a major objective of this research, was to derive a PE value for CGM that could be used for future diet formulation. Based on the previous discussion, the most appropriate values to use would be those derived from the Commercial site for the CGM-No Fat diet in either the E-G, L-G, or G-F periods (2,465, 2,568, and 2,439 kcal/kg, respectively) or for the CGM+Fat for the G-F period (2,508 kcal/kg). It is common practice to average estimates of ingredient energy values across studies and the average of these 4 estimates of the PE value of CGM is 2,495 kcal/kg. This is 98% of the ME value used to formulate the diets used in this study (2,548 kcal/kg) which was also derived from PE estimates from growth studies carried out in the same commercial facility as the current experiment using similar methodology.

Experiments 3 and 4: Metabolism Studies

These 2 experiments were carried out to meet Sub-Objective 3:

3. Compare estimates of productive energy obtained in sub-objectives 1, and 2, with the metabolizable energy content of CGM measured using a standard metabolism study.

The ME values for the 3 diets used in the E-G period of the growth experiments that were determined the metabolism study (Exp. 3) were 3,332, 3,250, and 3,442 kcal/kg for the Control, CGM-No Fat, and CGM+Fat diets, respectively (Table 8). The formulated ME content of these 3 diets was 3,296, 3,138, and 3,297 kcal/kg, respectively (Table 3). Thus, measured ME values were higher than formulated values for all diets. However, the difference between formulated and measured values was lower for the control than the 2 diets containing CGM (difference of 36, 112, and 145 kcal/kg for Control, CGM–No Fat, and CGM+Fat diets, respectively). Therefore, the measured ME value of the Control diet was very close to the formulated value, suggesting that ME value used to formulate the Control diet were relatively accurate. The greater difference between measured and formulated ME values for the CGM diets suggests

a greater ME for CGM than was used in diet formulation. The ME value used in diet formulation for this research was based on an estimate of the PE of CGM that was derived from a growth study carried out at the Commercial site and under similar conditions to the current growth study (Estrada, 2017). It is generally accepted that metabolism studies over-estimate the ME value of fibrous ingredients, such as CGM.

The ME content of corn and CGM measured in the metabolism study (Exp. 4) were 3,420 and 2,769 kcal/kg, respectively. These values are similar to those reported by NRC (2012) of 3,395 and 2,830 kcal/kg, respectively. There have been a limited number of studies that have measured the ME of CGM using a metabolism study, as indicated by NRC (2012). Anderson et al. (2012) reported a greater value for the ME of CGM than obtained in the current study (3,011 kcal/kg), whereas Guitierrez et al. (2014) reported a lower value (2,630 kcal/kg). However, Rojas et al. (2014), in a study carried out in the same facilities as the current experiment, reported values for the ME of corn and CGM that were similar to those found in this research (3,375 and 2,817 kcal/kg, respectively).

In summary, the results of the 2 growth experiments suggest that the conditions under which PE is measured can have a substantial influence on the values obtained. Growth performance and estimates of PE were more variable in the growth study carried out at the University site, most likely due to the smaller numbers of animals used than at the Commercial site. On this basis, the determination of PE in large-scale, controlled research studies under commercial conditions would be the most appropriate approach to use. In addition, the most consistent values for PE at the Commercial site were obtained during the growing period and over the entire grow-finish period which suggests that PE could be accurately determined over a relatively short period early in the growing period. Value for PE were consistently greater when measured in the finishing period than in the growing period which suggests that the ME value used to formulate diets should be adjusted for finishing pigs. The ME value for CGM measured directly in the metabolism study were similar to NRC (2012) estimates. In addition, the ME values of the 3 diets used in the E-G period of the growth study that were determined in a metabolism study suggest that direct measurement using this approach overestimates the ME of diets containing CGM. This emphasizes the need for alternative approaches to evaluating the energy content of fibrous ingredients such as CGM and supports the use of PE as a potentially valuable approach to use under commercial conditions.

Tables

Table 2. Analyzed composition of corn, soybean meal, and corn germ meal used to manufacture the experimental diets used in Experiment 1, 2, and 3.

Item	Corn	Soybean meal[1]	Corn germ meal[1]
Analyzed composition, % 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
ADF	2.50	6.37	12.54
NDF	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]Soybean meal and corn germ meal 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) at Ajinomoto Heartland, LLC, Chicago, IL.

Table 3. Experiment 1, 2 and 3: Diet formulation and calculated and analyzed composition for Early Growing period (29 to 64 kg BW).

	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	1.19
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]Proximate analysis was conducted by Midwest Laboratories using wet chemistry. Amino acid analysis was conducted by Ajinomoto Heartland, Inc. using High-Performance Liquid Chromatography.
[4]SID = standardized ileal digestible

Table 4. Experiment 1 and 2: Diet formulation and calculated and analyzed composition for Late Growing period (64 to 96 kg BW).

	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[3]	Calculated	Analyzed[3]	Calculated	Analyzed[3]
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]HMB = 2-hydroxy-4-(methylthio) butanoic acid
[3]Proximate analysis was conducted by Midwest Laboratories using wet chemistry. Amino acid analysis was conducted by Ajinomoto Heartland, Inc. using High-Performance Liquid Chromatography.
[4]SID = standardized ileal digestible

Table 5. Experiment 1 and 2: Diet formulation and calculated and analyzed composition for Finishing period (96 to 127 kg BW).

	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]Proximate analysis was conducted by Midwest Laboratories using wet chemistry. Amino acid analysis was conducted by Ajinomoto Heartland, Inc. using High-Performance Liquid Chromatography.
[3]SID = standardized ileal digestible

Table 6. Experiment 1 and 2: Effect of corn germ meal (CGM) dietary treatment and growth period on the growth performance of growing-finishing pigs.

	Experiment 1 (Commercial Research Site)					Experiment 2 (University Research 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	12	12	12	-	-	12	12	12	-	-
Number of pigs	408	408	408	-	-	48	48	48	-	-
Live Weight, 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

[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 ratio. Diets for Control and 'CGM+Fat' were formulated to the same ME level. Diets for 'CGM-No Fat' treatment had approximately 160 kcal/kg less ME compared to Control diets.

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

Table 7. Experiment 1 and 2: Effect of corn germ meal (CGM) dietary treatment[1] and growth period on feed:gain, formulated dietary ME content, caloric efficiency of growing-finishing pigs and estimated productive ME content of corn germ meal.

	Experiment 1 (Commercial Research Site)				Experiment 2 (University Research Site)			
	Diet[1]				Diet[1]			
Item	Control[2]	CGM-No Fat	CGM+Fat	SEM	Control[2]	CGM-No Fat	CGM+Fat	SEM
Feed:gain, kg: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
Formulated 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	-
Caloric Efficiency, kcal/kg of BW gain								
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, kcal/kg[4]								
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]	2,819[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 were formulated to the same SID lysine:ME ratio. 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. The value for the ME content of CGM used in diet formulation was 2,548 kcal/kg.

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

[3]As-fed basis

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

Table 8. Experiment 3: Apparent total tract digestibility (ATTD) of GE and concentration of DE and ME of experimental diets[1]

Item	Diet			SEM	*P* - value
	Control	CGM-No Fat	CGM+Fat		
Feed intake, kg/d	1.90	1.88	1.89	0.023	0.874
Intake of GE, kcal/d	7,281[b]	7,334[ab]	7,655[a]	91.75	0.017
GE in feces, kcal/d	732[b]	1036[a]	960[a]	33.02	<0.001
GE in urine, kcal/d	226	187	192	19.21	0.32
ATTD of GE, %[2]	89.94[a]	85.86[c]	87.47[b]	0.429	<0.001
DE, kcal/kg	3,450[b]	3,349[c]	3,544[a]	16.45	<0.001
ME, kcal/kg	3,332[b]	3,250[c]	3,442[a]	16.24	<0.001

[1]Data are means of 8 observations per diet
[2]ATTD = apparent total tract digestibility.

Table 9. Experiment 4: Analyzed composition of ingredients, as-is basis

	Corn	Corn germ meal	DDGS[1]
DM, %	85.94	88.08	83.89
CP, %	6.66	23.44	26.17
GE, kcal/kg	3,857	4,087	4,408
AEE, %	4.28	3.59	5.89
Total dietary	12.70	36.30	36.30
Ash, %	1.08	2.59	5.86

[1]DDGS = Distillers dried grains with solubles

Table 10. Experiment 4: Ingredient and analyzed composition of experimental diets, as-fed basis

	Diet		
Ingredient, %	Corn	Corn Germ Meal	DDGS
Corn	97.3	57.7	57.55
Corn germ meal	-	40	-
DDGS	-	-	40
Ground limestone	0.75	1.75	1.4
Dicalcium phosphate	1.4	0	0.5
Sodium chloride	0.4	0.4	0.4
Vit-mineral premix[2]	0.15	0.15	0.15
Analyzed composition			
DM, %	85.97	87.24	86.17
GE, kcal/kg	3,699	3,860	3,974
CP, %	6.31	14.1	15.18
AEE, %	3.84	3.65	5.48
Total dietary fiber, %	10.2	23.3	21.7
Ash, %	3.92	4.6	4.73

[1]DDGS= Distillers dried grains with solubles

[2]The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kg of complete diet: vitamin A as retinyl acetate, 11,150 IU; vitamin D_3 as cholecalciferol, 2,210 IU; vitamin E as $_{DL}$-alpha tocopheryl acetate, 66 IU; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 1.10 mg; riboflavin,6.59 mg; pyridoxine as pyridoxine hydrochloride, 1.00 mg; vitamin B_{12}, 0.03 mg; $_{D}$-pantothenic acid as $_{D}$-calcium pantothenate, 23.6 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper sulfate; Fe, 125 mg as ironsulfate; I, 1.26mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganoussulfate; Se, 0.30mg as sodium selenite and selenium yeast; and Zn, 125.1mg as zinc sulfate.

Table 11. Experiment 4: Energy concentration in of corn, corn germ meal, and distillers dried grains with solubles[1]

	Ingredient				
Item	Corn	Corn germ meal	DDGS[2]	SEM	*P*-value
ATTD of GE, %[3]	91.76[a]	67.44[c]	76.12[b]	1.70	<0.01
ATTD of DM, %	93.06[a]	71.67[c]	77.62[b]	1.45	<0.01
DE, kcal/kg, as fed	3,489[a]	2,828[b]	3,381[a]	64.36	<0.01
ME, kcal/kg, as fed	3,420[a]	2,769[b]	3,221[a]	70.10	<0.01
DE, kcal/kg DM	4,060[a]	3,210[b]	4,031[a]	74.47	<0.01
ME, kcal/kg DM	3,980[a]	3,143[b]	3,839[a]	80.92	<0.01

[a-c]Means within a row with different superscripts are different ($P < 0.05$).

[1]Data are least squares means of 8 observations per treatment.

[2]DDGS = distillers dried grains with solubles

[3]ATTD = apparent total tract digestibility.

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