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Determination and prediction of digestible and metabolizable energy from chemical analysis of corn co-products fed to finishing pigs[1]

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ABSTRACT: Twenty corn co-products from various wet- and dry-grind ethanol plants were fed to finishing pigs to determine DE and ME, and to generate equations predicting DE and ME based on chemical analysis. A basal diet was composed of corn (97.05%), limestone, dicalcium phosphate, salt, vitamins, and trace minerals. Twenty test diets were formulated by mixing the basal diet with 30% of a co-product, except for dried corn solubles and corn oil, which were included at 20 and 10%, respectively. There were 8 groups of 24 finishing gilts (n = 192; BW = 112.7 ± 7.9 kg). Within each group, gilts were randomly assigned to 1 of 5 test diets or the basal diet for a total of 4 replications per diet per group. Two groups of gilts were used for each set of co-products, resulting in 8 replications per co-product and 32 replications of the basal diet. The experiment was conducted as a completely randomized design. Gilts were placed in metabolism crates and offered 3 kg daily of their assigned test diet for 13 d with total collection of feces and urine during the last 4 d. Ingredients were analyzed for DM, GE, CP, ether extract (EE), crude fiber, NDF, ADF, total dietary fiber (TDF), ash, AA, and minerals, and in vitro OM digestibility was calculated for each ingredient. Gross energy was determined in the diets, feces, and urine to calculate DE and ME for each ingredient. The DE and ME of the basal diet were used as covariates among groups of pigs. The DE of the co-products ranged from 2,517 kcal/kg DM (corn gluten feed) to 8,988 kcal/kg DM (corn oil), and ME ranged from 2,334 kcal/kg DM (corn gluten feed) to 8,755 (corn oil) kcal/kg DM. By excluding corn oil and corn starch from the stepwise regression analysis, a series of DE and ME prediction equations were generated. The best fit equations were: DE, kcal/kg DM = -7,471 + (1.94 × GE) – (50.91 × EE) + (15.20 × total starch) + (18.04 × OM digestibility) with $R^2 = 0.90$, SD = 227, and $P < 0.01$; and ME, kcal/kg DM = (0.90 × GE) – (29.95 × TDF) with $R^2 = 0.72$, SE = 323, and $P < 0.01$. Additional equations for DE and ME included NDF in the instance that TDF data are not available. These results indicate that DE and ME varied substantially among corn co-products, and that various nutritional components can be used to accurately predict DE and ME in corn co-products for finishing pigs.

Key words: corn co-products, DE, ingredient analysis, ME, pigs, prediction equations

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INTRODUCTION

Dietary energy is an expensive component of swine diets. In the United States, corn is the principal cereal grain used in swine diets because it is widely grown in the United States, has highly available energy, and is generally economical. For similar reasons, and particularly because of the high starch concentration in corn, the biofuels industry uses corn for the production of ethanol. Currently, 202 wet- and dry-grind plants are operational in the United States with only 11 of these plants not using corn as their major feedstock for fuel production (Renewable Fuels Association, 2011). In the United States, the majority of ethanol is produced by dry-grind production processes, which generate co-products such as distillers dried grains with solubles (**DDGS;** Bothast and Schlicher, 2005). Distillers dried grains with solubles is a moderately high-fiber product widely used in cattle diets, but historically has had limited inclusion in swine diets because of the limited capacity for fiber utilization in pigs (Stein and Shurson, 2009).

Current developments in the ethanol industry increase the efficiency of starch, oil, and ethanol extraction, thereby, generating "new" co-products that may have potential use in the swine industry. Energy values for these "new" corn co-products do not exist in the literature, and as a result, further research in this area is warranted. Prediction equations to estimate DE and ME in feed ingredients based on chemical composition can be a useful tool in feed ingredient evaluation, but such equations are currently available only for complete diets (Just et al., 1984; Noblet and Perez, 1993), barley (Fairbairn et al., 1999), corn-DDGS (Pedersen et al., 2007), and wheat-DDGS (Cozannet et al., 2010). The objectives of this study were to: (1) determine the DE and ME concentration of 20 corn co-products fed to finishing pigs, and (2) generate prediction equations for DE and ME for corn co-products based on nutrient composition and in vitro OM digestibility.

MATERIALS AND METHODS

The Institutional Animal Care and Use Committee at Iowa State University approved all experimental protocols (12-07-6480-S).

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General Procedures

Gilts used in this research were offspring from PIC Camborough 22 sows × L337 boars (Pig Improvement Company, Hendersonville, TN). Metabolism trials were conducted over a 7-mo period at the Iowa State University Swine Nutrition Farm in Ames, IA. Twenty corn-co products from US wet-mills, dry-mills, and dry-grind ethanol plants were obtained (Table 1). The co-products used in this study included: DDGS (6 samples), high protein distillers dried grains (**HP-DDG**, 3 samples), corn bran (with and without added solubles), corn germ, corn germ meal, oil extracted-DDGS (**OE-DDGS**), corn gluten meal, corn gluten feed, dehulled-degermed corn, corn dried solubles, corn starch, and corn oil. Within the DDGS samples, one DDGS product was obtained using an alternative drying method (microwave technology; Cellencor Inc., Ames, IA) to evaluate the impact of drying process on energy digestibility. Although samples were not perfectly balanced for fat, fiber, and protein levels among the 'major' groups of corn co-products, the selection of co-products were relatively well balanced with our use of 6 'conventional' DDGS products, 4 high protein products, and 4 high fiber products.

There were 8 groups of 24 finishing gilts (n = 192; BW = 112.7 ± 7.9 kg) housed individually in metabolism crates (1.2 × 2.4 m) that allowed for separate, but total collection of feces and urine. Crates were equipped with a stainless steel feeder and a nipple waterer, to which the pigs had ad libitum access. Gilts were randomly assigned to 1 of 5 test diets or the basal diet for a total of 4 replications per diet per group. Two groups of gilts were used for each set of ingredients, resulting in 8 replications per test diet (4 replications/group × 2 groups/test diet) and 32 replications of the basal diet (4 replications/group × 8 groups).

Gilts were fed a standard corn-soybean meal diet prior to experimentation and were weighed at the beginning and end of the experiment. The basal diet contained 97.05% corn and vitamins and minerals with corn being the sole energy containing ingredient (Table 2). Twenty test diets were also formulated. Eighteen of these diets contained 70% of the basal diet and 30% of each test ingredient. However, test diets containing dried corn solubles and corn oil were formulated by mixing 80% basal diet and 20% dried corn solubles and 90% basal diet and 10% corn oil, respectively. All diets were fed in a meal form. Test ingredients were not ground to

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a constant particle size, but were added to the diets at their original particle size as would be fed commercially. The actual particle size ranged from 330 to 2,166 um (Table 3). The corn co-products were included in the test diet at a level of 30% (70% basal diet) for several reasons: 1) to include as much of the test ingredients as possible to improve DE and ME estimate accuracy; 2) to reduce the risk of considerable feed refusals; and 3) to use dietary inclusion levels that are representative of what is used in the swine industry. Feed was provided to the gilts once daily at a level of 3 kg during the 9 d of adaptation and the 4 d collection period. Total feed offered and residual feed wasted were weighed and recorded at the end of the 4 d collection period. If pigs refused > 20% of their diets, they were removed from the study.

During the time-based 4 d total fecal and urine collection period, stainless steel wire screens were placed under each metabolism crate for total fecal collection, while stainless steel buckets containing 30 mL of 6*N* HCl were placed under each crate for the total urine collection. Feces and urine were collected once daily and stored at 0˚C until the end of the collection period. At the end of the collection period, feces were pooled over the 4 d period, dried in a 70˚C forced air oven, weighed, ground through a 1-mm screen, and a subsample was taken for analysis. Likewise, urine samples were pooled over the 4 d period, thawed at the end of the collection period, weighed, and a subsample collected for analysis.

Chemical Analysis

All corn co-products were ground through a 1-mm screen prior to chemical analysis. Samples were analyzed for DM and nutrient composition at a laboratory (University of Missouri Agriculture Experiment Station Chemical Laboratories, Columbia, MO; Tables 3 and 4) unless otherwise described. Gross energy of the feedstuffs, feces, and urine samples were determined at the USDA-ARS laboratory in Ames, by analyzing duplicate samples using an isoperibol bomb calorimeter (Model Number 1281; Parr Instrument Co., Moline, IL) with benzoic acid used as a standard. One milliliter of filtered subsample urine was added to 0.5 g of dried cellulose and subsequently dried at 50˚C for 24 h. Urine addition and subsequent drying was repeated 3 times, for a total of 3 mL of filtered urine, over a 72 h period prior to urinary energy determination. The energy in cellulose was also determined and urinary energy was calculated by subtracting the energy in cellulose from the

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energy in the samples containing both urine and cellulose. Particle size was determined on a 13 half-height sieve shaker (Tyler RoTap, Mentor, OH) as described by Baker and Herrman (2002) with data reported as μm on an as-is basis. Bulk density was determined by utilizing the USDA standard weight per bushel tester (USDA, 1953) with data reported as g/cm^3 on an as-is basis.

Organic Matter Digestibility

A modified 3-step enzymatic assay as described by Boisen and Fernandez (1997) was used to determine in vitro OM digestibility (**OMD**). Prior to the in vitro assay, all samples were ground to 1 mm and weighed out to 0.5 g (± 0.1 g) per flask. Samples were analyzed in triplicate in groups of 24, and within each group, a blank and a control (corn) were analyzed in triplicate in each group. Two modifications to the Boisen and Fernandez (1997) method were made. The pepsin product described in the Boisen and Fernandez (1997) procedure was characterized as 'porcine, 2000 FIP-U/g, Merck No 7190', which is a product that is readily accessible in Europe, but is not available in the United States or Canada. For the current study, a pepsin product that closely resembled the activity level, as indicated in the publication by Boisen and Fernandez (1997), was utilized (porcine, 2,500 to 3,500 units/mg protein, reference #7012; Sigma Chemical Co., St. Louis, MO). Because the activity level of the pepsin products were not expressed in the same units, the pepsin activity utilized in our study may have been slightly different from that described by Boisen and Fernandez (1997). In addition, the current study used an incubated orbital shaker instead of a shaking water bath as described by Boisen and Fernandez (1997). Incubated orbital shakers are commonly used in microbiology laboratories, and we are confident that there is no difference between the 2 shakers as long as the desired temperature remains constant throughout incubation. In vitro OMD was calculated by determining the amount of OM digested by the enzymatic assay, after correcting for the OM in the blank, as a percentage of the total OM in the original sample (OM = 100 - % ash).

Calculations

Gross energy intake was calculated as the product of GE content of the treatment diet and the actual feed intake over the 4-d collection period. The DE and ME of each test ingredient was calculated by subtracting the

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DE or ME contributed by the basal diet from the DE or ME of the diet containing that particular test ingredient and then dividing the result by the inclusion rate of the test ingredient in the diet. Because corn was the only energy containing ingredient in the basal diet, the energy concentration of corn was calculated by dividing the DE or ME of the basal diet by 0.9705. All energy values are reported on a DM basis.

Statistical Analysis

Using the individual pig as the experimental unit, data were subjected to ANOVA with group and treatment in the model (SAS Inst. Inc., Cary, NC), and treatment means are reported as least-square means. The experiment was conducted as a completely randomized design with DE and ME of the basal diet used as a covariate to determine DE and ME values, respectively, among all groups of pigs. Stepwise regression was used to determine the effect of the feedstuff composition on apparent DE, ME, and DE:ME with variables having *P*-values ≤ 0.15 being retained in the model. The R^2, the SE of the estimate, SE, and the Mallows statistic, C(p), were used to define the best fit equation. If the intercept was determined to be non-significant in the final prediction model, it was excluded from the model and an adjusted R^2 value was calculated using the NOINT option of SAS.

RESULTS AND DISCUSSION

In the current study, all co-products were included in the diet at a level of 30% with the exception of dried solubles and corn oil, which were included in the diet at 20 and 10%, respectively. We chose these levels to reflect the co-product inclusion levels that we expected to be used in the industry. Dried solubles were initially included in the diet at 30%, but within 2 d of adapting to this treatment, however, most pigs developed diarrhea, potentially because of the level of minerals in the dried solubles. The decision was made to reduce the inclusion of dried solubles to 20% of the diet for an additional 9 d of adaptation, whereupon no further problems with diarrhea were noted. Corn oil was included in the diet at 10% because of the high energy concentration of the feedstuff. Although levels of feed intake vary widely in energy balance experiments (Kerr et al., 2009), we believe that it is important to use a feeding level as close to ad libitum access as possible, which is the feeding

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practice commonly used in commercial pork production in the United Sates. Overall, diets containing corn co-products were acceptable to the pigs with minimal feed refusal across treatments, thereby, confirming that our feeding rate of 3 kg/d during the course of the trial was at, or near, their maximum feed intake capacity (NRC, 1998). Two pigs fed the DDGS-WI treatment refused greater than 20% of total feed offered and were subsequently removed from the study and in the final analysis; feed intake did not differ by treatment ($P >$ 0.10). Overall, a total of 7 pigs were not included in the statistical analysis for reasons such as greater than 20% total feed refused, lost fecal collections, or contaminated urine samples. As shown in Table 5, most treatments had 8 observations with exception of DDGS-WI (6 observations), OE-DDGS (6 observations), corn germ meal (7 observations), and the corn basal diet (30 observations).

DE and ME Estimates

The objective of this study was to evaluate a wide variety of corn co-products in an effort to generate a robust prediction equation for DE and ME, and to evaluate and compare the energy content of various corn co-product samples. The nutrient composition of the corn co-products varied substantially (Table 3), and it is worthwhile to describe the variation in concentrations of selected nutrients among co-products evaluated in this study, and compare DE and ME values to those from similar corn co-products recently reported in the literature. In this study, most ingredients were obtained from various dry-grind ethanol plants with the exception of corn gluten meal, corn gluten feed, and corn germ meal, which were obtained from corn wet mills. Dehulled-degermed corn is a co-product from the corn dry-milling industry. Corn starch and corn oil were obtained from corn co-product refinery industries to compare our determined DE and ME values with published (NRC, 1998) energy values. These ingredients were, however, not analyzed for concentrations of other nutrients (Table 3) because of their high purity and lack of other chemical constituents. Ingredients included in the current study were: low in fiber (corn starch, corn oil, dried corn solubles, and dehulled-degermed corn), moderate in protein and fiber (DDGS, n = 6) and OE-DDGS (n = 1), high in protein (corn gluten meal, n = 1; HP-DDG, n = 3), and high in fiber (corn bran co-products, n = 2), as well as corn germ, corn germ meal, and corn gluten feed.

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On a DM basis, the concentration of CP among co-products ranged from 8.3% in dehulled-degermed corn to 66.3% in corn gluten meal. Total starch (**ST**) ranged from 0.5% in HP-DDG (MOR) to 100% in corn starch. Crude fiber ranged from 0.08% in dried corn solubles to 11.5% in corn bran without solubles. Total dietary fiber (**TDF**) ranged from 2.6% in dehulled-degermed corn to 53.6% in corn bran without solubles. Neutral detergent fiber ranged from 2.3% in dried corn solubles to 61.1% in corn germ meal. Acid detergent fiber ranged from 0.5% in dehulled-degermed corn and dried corn solubles to 25.4% in HP-DDG (MOR). Cellulose ranged from 0.8% in dehulled-degermed corn to 22.6% in HP-DDG (MOR). Lignin ranged from 0.3% in dried corn solubles to 3.5% in OE-DDGS. Crude fat (ether extract, **EE**) ranged from 0.2% in dehulled-degermed corn to 18.5% in corn germ. Ash ranged from 0.5% in dehulled-degermed corn to 14.08% in dried corn solubles. The range in nutrient composition noted is like data published in the literature for DDGS (Spiehs, et al., 2002; Fastinger and Mahan, 2006; Robinson et al., 2008), high protein DDG (Widmer et al., 2007; Kim et al., 2009), and other corn co-products (Moeser et al., 2002; Muley et al., 2007).

Distillers dried grains with solubles is a valuable feedstuff for swine (Stein and Shurson, 2009), yet it has a reputation of variable nutrient composition (Spiehs, et al., 2002; Stein et al., 2006; Pedersen et al., 2007), which has limited its use in swine feed formulations. The DDGS sources selected for this study included differences in nutrient composition, but also drying processes. The cost of drying distiller's grain is an expensive process and rotary drum drying, which is traditionally used, has potential to cause overheating, burning, and Malliard reactions (Pahm et al., 2009), thereby reducing palatability and the availability of nutrients and energy to the animal (Cromwell et al., 1993; Pahm et al., 2009). To partially evaluate the impact of drying process on energy digestibility, a DDGS source produced by using an alternative drying method involving (microwave technology, Cellencor Inc., Ames, IA) was included in our sample collection and evaluation, and was obtained at the same location where a rotary drum-dried product was obtained. Extracting oil from DDGS is becoming a popular method in the dry-grind ethanol industry to market high value crude corn oil. We obtained an OE-DDGS, in which the majority of the oil was removed using hexane extraction to

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produce a DDGS with only 3.2% EE compared with traditional DDGS that contains between 8 and 11% EE (Spiehs et al., 2002).

With the wide range in corn co-product composition, DE and ME varied substantially among ingredients ($P < 0.01$, Table 5). Low fiber co-products (corn starch, corn oil, dried corn solubles, and dehulled-degermed corn) contained between 4,082 and 8,988 kcal DE/kg DM and 4,080 and 8,755 kcal ME/kg DM. The 6 DDGS samples contained between 3,705 and 4,332 kcal DE/kg DM and 3,414 and 4,141 kcal ME/kg. The high protein co-products (corn gluten meal and 3 sources of HP-DDG) contained between 3,994 and 5,047 kcal DE/kg DM and 3,676 and 4,606 kcal ME/kg DM. The remaining fibrous feed ingredients (the 2 sources of corn bran, corn gluten feed, and corn germ meal) contained between 2,517 and 3,889 kcal DE/kg DM and 2,334 and 3,692 kcal ME/kg DM.

Only a few energy values for the corn co-products evaluated in this study could be compared with published data. The NRC (1998) lists energy values for corn (DE = 3,961 kcal/kg DM; ME = 3,843 kcal/kg DM), corn starch (DE = 4,040 kcal/kg DM; ME = 4,025 kcal/kg DM), and corn oil (DE = 8,755 kcal/kg; ME = 8,405 kcal/kg). In comparison, the respective DE and ME values determined in this study were 3,883 and 3,805 kcal/kg DM for corn, 4,082 and 4,080 kcal/kg DM for starch, and 8,988 and 8,755 kcal/kg for oil. Our values were remarkably similar to NRC (1998) values for corn and corn starch, but slightly greater than that listed for corn oil. Our DE value of 3,883 kcal/kg DM for corn (as calculated from the basal diet) agrees with the value of 3,845 kcal/kg DM reported by Stein et al. (2006), but slightly less than the DE values of 3,949, 4,088, 4,056, 4,002, and 4,181 kcal/kg DM for corn reported by Moeser et al. (2002), Pedersen et al. (2007), Widmer et al. (2007), Kim et al. (2009), and Stein et al. (2009), respectively. Likewise our ME value of 3,805 kcal/kg DM for corn (calculated from the basal diet) is also slightly less than the ME values of 3,929, 3,989, 3,972, 3,921, and 4,103 kcal/kg DM for corn by Moeser et al. (2002), Pedersen et al. (2007), Widmer et al. (2007), Kim et al. (2009), and Stein et al. (2009), respectively. All of these values are in agreement with the average DE (3,872 kcal/kg DM) and ME (3,810 kcal/kg DM) of 3 high-oil corn varieties reported by Adeola and Bajjalieh (1997). The fact that we obtained DE and ME values for corn, cornstarch, and corn oil that are in agreement with

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published data indicates that our experimental and laboratory approaches give accurate results. This gives us confidence that the DE and ME we determined for the test ingredients are also accurate.

Relative to other estimates of DE and ME for corn co-products, the DE and ME values for corn gluten meal of 5,047 and 4,598 kcal/kg DM, respectively, obtained in this study are slightly greater than the NRC (1998) values of 4,694 and 4,255 kcal/kg DM, respectively. In contrast, the DE and ME values determined for corn gluten feed (2,517 and 2,334 kcal/kg DM, respectively) are less than the NRC (1998) values of 3,322 and 2,894 kcal/kg DM, respectively. Our DE and ME values for corn gluten feed are also less than those reported by Honeyman and Zimmerman (1991), although they utilized sows which were heavier (181 kg) and consumed less feed (2.6 kg/d) than pigs used in our study, which are factors known to affect energy digestibility (Noblet and Shi, 1993; Le Goff et al., 2002; Kerr et al., 2009).

The 6 DDGS samples selected for this study varied substantially in nutrient composition and processes used to produce them. In the current study, DE for DDGS ranged from 3,705 (SD-BPX) to 4,332 kcal/kg DM (DDGS-WI) with an average of 4,029 kcal/kg DM. On average, our results compared favorably to data reported by Stein et al. (2006), Pedersen et al. (2007), and Stein et al. (2009) who reported average DE values of 3,556, 4,140, and 4,072 kcal/kg DM, respectively. In the current study, ME value for DDGS ranged from 3,414 kcal/kg DM (SD-BPX) to 4,141 kcal/kg DM (DDGS-WI) with an average of 3,790 kcal/kg DM. Our ME values concur with the average ME of 3,897 and 3,750 kcal/kg DM reported by Pedersen et al. (2007) and Stein et al. (2009), respectively. There was not a large difference in DE (100 kcal/kg DM) or ME (163 kcal/kg DM) between the rotary drum-dried or microwave-dried DDGS samples obtained from the same plant.

Moeser et al. (2002) determined that the DE and ME values for dehulled-degermed corn fed to growing pigs was 4,063 and 4,009 kcal/kg DM, respectively, which are less than our values of 4,401 and 4,316 kcal/kg DM, respectively. Differences in these obtained values, however, may be due to various differences in experimental design (Kerr et al., 2009) and animal BW (Noblet and Shi, 1993; Le Goff et al., 2002). Moeser et al. (2002) utilized 27-kg growing barrows compared to the 112.7-kg finishing gilts used in the current study, and Moeser et al. (2002) included the test co-product at 96.4% of the diet compared to our level of 30% of the

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diet. Nevertheless, the magnitude of the difference in ME determined between our study and the values reported by Moeser et al. (2002) is surprising given that the composition of the co-products used in the 2 experiments was relatively similar, and because dehulled-degermed corn is a highly digestible product, which are affected little by pig BW or dietary inclusion level (Fernandez et al., 1986; Le Goff et al., 2002; Kerr et al., 2009).

Jacela et al. (2011) determined the DE of OE-DDGS to be 3,100 kcal/kg DM, which is less than the 3,868 kcal/kg DM determined in the current study. They did not directly measure ME. In the current study, the average DE and ME of the 3 HP-DDG samples was 4,386 and 4,035 kcal/kg DM, respectively. These values were less than the 4,763 and 4,476 kcal/kg DM of DE and ME, respectively, reported by Widmer et al. (2007), and the 5,043 and 4,690 kcal/kg DM of DE and ME, respectively, reported by Kim et al. (2009), but greater than the 3,703 kcal DE/kg DM reported by Jacela et al. (2010). The DE of 3,889 kcal/kg DM and ME of 3,692 kcal/kg DM for corn germ in the current study is slightly less than the DE and ME of 3,979 and 3,866 kcal/kg DM, respectively, reported by Widmer et al. (2007).

In the current study, the basal diet contained 97.05% corn and was not balanced for AA. It is well known that AA contributes to the energy in a diet and imbalances in AA can lead to reduced feed intake, as well as poor growth and performance (Batterham, 1984, 1992; Lewis, 2001). Realizing this relationship, the ME values in the current study could be underestimated because N excretion in the urine may have been increased relative to a balanced diet. Our experimental design, however, is similar to that used by others (Moeser et al., 2002; Widmer et al., 2007). During N balance studies, urinary N can volatilize as ammonia if the N is not stabilized by utilizing acid or storing at cold temperatures to avoid N loss, thereby leading to inaccurate and inflated ME values (van Kempen et al., 2003). In our study, 6*N* HCl was added to the stainless steel buckets to stabilize N excretion and prevent bacterial growth. In addition, urine was collected daily, and stored frozen until subsequent laboratory analysis.

Another factor that may affect the DE and ME values, and consequently the ME:DE, are the impact of dietary fiber on N loss. Typically, N is excreted as urea in the urine. However, in the presence of high dietary fiber, there is a shift in N loss from the urine to the feces in the form of microbial N (Cahn et al., 1997). As a

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result, the net effect would be a decrease in urinary N loss and an increase in fecal N loss, thereby reducing the DE value relative to the ME value.

DE and ME Prediction Equations

Development and use of prediction equations to estimate energy content in feeds is not a new concept (Just et al., 1984; Noblet and Perez, 1993; Cozannet et al., 2010). However, we believe that it is important to establish equations specifically for corn co-products currently produced in the United States. We also believe that it is important to provide the composition and the determined DE and ME of each corn co-product so that readers can subdivide the data into different protein or fiber-level classifications and generate their own prediction estimates or they can modify the equations to reflect their analytical capability. Because corn starch and corn oil are highly refined products, we elected not to include them in our regression analysis to avoid introducing bias in the regression equations. We elected to maintain the default *P*-value of 0.15 for the purpose of selection and elimination of regression variables in stepwise regression. Prediction estimates for DE and ME in barley (Fairbairn et al., 1999), meat and bone meal (Adedokun and Adeola, 2005; Olukosi and Adeola, 2009), and DDGS (Pedersen et al., 2007) have all utilized regression, but the level of significance utilized in PROC REG was not defined in those reports. Consequently, we assumed that the default value was utilized for statistical analysis in these studies, and did likewise in the current experiment. In addition, we have provided the SE and *P*-value associated with each regression coefficient parameter along with the model statistical parameters. The prediction of DE in wheat DDGS (Cozannet et al., 2010) did not utilize multiple regression, but instead used a covariance procedure where the selection of the variable having the highest correlation coefficient was followed by linear regression. For the current results, a y-intercept was initially included in all statistical models, but if the y-intercept was not significant ($P > 0.15$) in the final model, it was removed and the equation was redefined and the subsequent R^2 was adjusted accordingly. We also did not allow the equation to contain multiple fiber measures because fiber measurement methods are not independent of each other.

Using stepwise regression and chemical analysis, a series of prediction equations for DE were generated (Table 6). The initial regression included hemicellulose (**HC**) as the most important component to predict DE,

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but with the addition and deletion of additional parameters to the regression model via stepwise regression, the final best fit equation was Eq. 6 (Table 6): DE, kcal/kg DM = -7,471 + (1.94 × GE) – (50.91 × EE) + (15.20 × ST) + (18.04 × in vitro OMD) with R^2 = 0.90 and SD = 227. Because analyzing for TDF, ST, and in vitro OMD are relatively costly, time consuming, less automated, and can produce highly variable results, we elected to delete ST and in vitro OMD from the model (i.e., Eq. 4, Table 6) and use NDF instead of TDF (Eq. 4b, Table 7). As expected, the resultant equation [DE, kcal/kg DM = -2,161 + (1.39 × GE) – (20.70 × NDF) - (40.30 × EE), R^2 = 0.77, SD = 337] provided a SD of the estimate that was increased and a R^2 that was decreased by this modification. However, this equation still provides an acceptable equation from which to predict the DE of corn co-products for finishing pigs, albeit slightly poorer than that reported for corn DDGS (Pedersen et al., 2007) or barley (Fairbairn et al., 1999), but slightly better than that for wheat DDGS (Cozannet et al. (2010).

A series of prediction equations for ME were also generated (Table 8). Similar to the prediction equations for DE, the initial regression included HC as the most important component to predict DE, but with the addition and deletion of additional parameters to the regression model via stepwise regression, the final best fit equation was Eq. 3 (Table 8): ME, kcal/kg DM = (0.90 × GE) – (29.95 × TDF) with R^2 = 0.72 and SD = 323. In a similar manner as described for DE, we elected to use NDF instead of TDF with the subsequent equation exhibiting a lower R^2 (0.58 vs. 0.72), which was improved when ash was included in the model, resulting in Eq. 3c (Table 9): ME, kcal/kg DM = (0.94 × GE) – (23.45 × NDF) - (70.23 × ash) with R^2 = 0.68 and SD = 359. This equation is also acceptable for predicting the ME of corn co-products for finishing pigs, albeit slightly poorer than described by others (Noblet and Perez, 1993; Fairbairn et al., 1999; Pedersen et al., 2007), but similar to, or better than that for meat and bone meal (Adedokun and Adeola, 2005; Olukosi and Adeola, 2009).

When DE was included as a parameter to predict ME, the R^2 improved (Table 10). Other factors included in this equation were the negative effects of CP and EE and positive effects of NDF. A possible explanation for these mathematical relationships is that including DE as a parameter initially overestimated ME content such that a negative y-intercept, CP, and EE values are needed to correct for this overestimation. The

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average ME of corn co-products that were used this experiment (except corn starch and corn oil) was 94.1% (Table 5) and agrees closely with values published by others (Honeyman and Zimmermann, 1991; Noblet and Perez, 1993; Adeola and Bajalieh, 1997; NRC, 1998; Pedersen et al., 2007). Although small, CP had a negative effect on ME (Table 10), which was expected (Noblet and Perez, 1993).

Experimental determination of DE or ME values is expensive, time consuming, and labor intensive, and values are difficult to compare among laboratories because of the differences in analytical procedures (Cromwell et al., 1999, 2000, 2003; Kerr et al., 2009) and in nutrient concentration, depending the laboratory analysis used (Hall, 2003; Mertens, 2003; Palmquist and Jenkins, 2003). Given these challenges, however, prediction equations are a useful tool in estimating energy values of co-products utilized in the livestock industry. To our knowledge, no such equations have been generated for this diverse group of corn co-products. Data presented herein indicate that for the corn co-products evaluated in this study, GE and TDF are key parameters to estimate DE and ME in finishing pigs. In addition, NDF can be used as a substitute for TDF for corn co-products, but some degree of accuracy will be lost.

LITERATURE CITED

AACC International. 1976. Approved Methods of Analysis. AACC International. St. Paul, MN.

Adedokun, S. A., and O. Adeola. 2005. Metabolizable energy value of meat and bone meal for pigs. J. Anim. Sci. 83:2519-2526.

Adeola, O., and N. L. Bajjalieh. 1997. Energy concentration of high-oil corn varieties for pigs. J. Anim. Sci. 75:430-436.

AOAC. 2005. Official Methods of Analysis. 18th ed. Assoc. Offic. Anal. Chem. Arlington, VA.

Baker, S., and T. Herrman. 2002. Evaluating feed particle size. Bulletin MF-2051. Kansas State Agricultural Experiment Station and Cooperative Extension Service, Manhattan, KS.

Batterham, E. S. 1984. Utilization of free lysine by pigs. Pig News Information 5:85-88.

Batterham, E. S. 1992. Availability and utilization of amino acids for growing pigs. Nutr. Res. Rev. 5:1-18.

Downloaded from jas.fass.org at Magrath Library, Serials Department on December 7, 2011

Boisen, S., and J. A. Fernandez. 1997. Prediction of the total tract digestibility of energy in feedstuffs and pig diets by in vitro analyses. Anim. Feed Sci. Technol. 68:277-286.

Bothast, R. J., and M. A. Schlicher. 2005. Biotechnological processes for conversion of corn into ethanol. Appl. Microbial. Biotechnol. 67:19-25.

Canh, T. T., M. W. A. Verstegen, A. J. A. Aarnink, and J. W. Schrama. 1997. Influence of dietary factors on nitrogen partitioning and composition of urine and feces of fattening pigs. J. Anim. Sci. 75:700-706.

Cozannet, Y., C. Primot, C. Gady, J. P. Metayer, M. Lessire, F. Skiba, and J. Noblet. 2010. Energy value of wheat distillers grains with solubles for growing pigs and adult sows. J. Anim. Sci. 88:2382-2392.

Cromwell, G. L., J. H. Brendemuhl, L. I. Chiba, T. R. Cline, T. D. Crenshaw, C. R. Dove, R. A. Easter, R. C. Ewan, K. C. Ferrell, C. R. Hamilton, G. M. Hill, J. D. Hitchcock, D. A. Knabe, E. T. Kornegay, A. J. Lewis, G. W. Libal, M. D. Lindemann, D. C. Mahan, C. V. Maxwell, J. C. McConnell, J. L. Nelssen, J. E. Pettigrew, L. L. Southern, T. L. Veum, and J. T. Yen. 2003. Variability in mixing efficiency and laboratory analyses of a common diet mixed at 25 experiment stations. J. Anim. Sci. 81:484-491.

Cromwell, G. L., C. C. Calvert, T. R. Cline, J. D. Crenshaw, T. D. Crenshaw, R. A. Easter, R. C. Ewan, C. R. Hamilton, G. M. Hill, A. J. Lewis, D. C. Mahan, E. R. Miller, J. L. Nelssen, J. E. Pettigrew, L. F. Tribble, T. L. Veum, and J. T. Yen. 1999. Variability among sources and laboratories in nutrient analyses of corn and soybean meal. NCR-42 Committee on Swine Nutrition. North Central Regional-42. J. Anim. Sci. 77:3262-3273.

Cromwell G. L., T. R. Cline, J. D. Crenshaw, T. D. Crenshaw, R. A. Easter, R. C. Ewan, C. R. Hamilton, G. M. Hill, A. J. Lewis, D. C. Mahan, J. L. Nelssen, J. E. Pettigrew, T. L. Veum, and J. T. Yen. 2000. Variability among sources and laboratories in analyses of wheat middlings. NCR-42 Committee on Swine Nutrition. J. Anim. Sci. 78:2652-2658.

Cromwell, G. L., K. L. Herkelman, and T. S. Stahly. 1993. Physical, chemical, and nutritional characteristics of distillers dried grains wit solubles for chicks and pigs. J. Anim. Sci. 71:679-686.

Downloaded from jas.fass.org at Magrath Library, Serials Department on December 7, 2011

Fairbairn, S. L., J. F. Patience, H. L. Classsen, and R. T. Zijlstra. 1999. The energy content of barley fed to growing pigs: characterizing the nature of its variability and developing prediction equations for its estimation. J. Anim. Sci. 77:1502-1512.

Fastinger, N. D., and D. C. Mahan. 2006. Determination of the ileal amino acid and energy digestibilities of corn distillers dried grains with solubles using grower-finisher pigs. J. Anim. Sci. 84:1722-1728.

Fernandez, J. A., H. Jørgensen, and A. Just. 1986. Comparative digestibility experiments with growing pigs and adult sows. Anim. Prod. 43:127-132.

Hall, M. B. 2003. Challenges with nonfiber carbohydrate methods. J. Anim. Sci. 81:3226-3232.

Holst, D. O. 1973. Holst filtration apparatus for Van Soest detergent fiber analysis. J. AOAC. 56:1352-1356.

Honeyman, M. S., and D. R. Zimmerman. 1991. Metabolizable energy of corn (maize) gluten feed and apparent digestibility of the fibrous components for gestating sows. Anim. Feed Sci. Technol. 35:131-137.

Jacela, J. Y., J. M. Derouchey, S. S. Dritz, M. D. Tokach, R. D. Goodband, J. M. Nelssen, R. C. Sulabo, R. C. Thaler, L. Brandts, D. E. Little, and D. J. Prusa. 2011. Amino acid digestibility and energy content of deoiled (solvent extracted) corn dried distillers grains with solubles for swine and its effects on growth performance and carcass characteristics. J. Anim. Sci. 89:1817–1829.

Jacela, J. Y., H. L. Frobose, J. M. DeRouchey, M. D. Tokach, S. S. Dritz, R. D. Goodband, and J. L. Nelssen. 2010. Amino acid digestibility and energy concentration of high-protein corn dried distillers grains and high-protein sorghum dried distillers grains with solubles for swine. J. Anim. Sci. 88:3617-3623.

Just, A., H. Jørgensen, and J. A. Fernandez. 1984. Prediction of metabolizable energy for pigs on the basis of crude nutrients in the feeds. Livest. Prod. Sci. 11:105-128.

Kerr, B. J., P. V. Anderson, and G. C. Shurson. 2009. Ethanol corn co-product assessment opportunities and challenges in the swine industry. J. Anim. Sci. 87(E-Suppl. 3):142. (Abstr.)

Kil, D. Y., F. Ji, R. B. Hinson, A. D. Beaulieu, L. L. Stewart, G. L. Allee, J. F. Patience, J. E. Pettigrew, and H. H. Stein. 2009. Comparison of measured values for NE in diets and ingredients fed to pigs and values predicted from European energy systems. J. Anim. Sci. 87 (E-Suppl. 3):200. (Abstr.)

Downloaded from jas.fass.org at Magrath Library, Serials Department on December 7, 2011

Kim, B. G., G. I. Petersen, R. B. Hinson, G. L. Allee, and H. H. Stein. 2009. Amino acid digestibility and energy concentration in a novel source of high-protein distillers dried grains and their effects on growth performance of pigs. J. Anim. Sci. 87:4013-4021.

Lewis, A. J. 2001. Amino acids in swine nutrition. Pages 131-150 in Swine Nutrition. 2nd ed. A.J. Lewis and L.L. Southern, ed. CRC Press, Boca Raton, FL.

Le Goff, G., L. Le Groumellec, J. van Milgen, S. Dubois, and J. Noblet. 2002. Digestibility and metabolic utilisation of dietary energy in adult sows: influence of addition and origin of dietary fibre. Br. J. Nutr. 87:325-335.

Mertens, D. R. 2003. Challenges in measuring insoluble dietary fiber. J. Anim. Sci. 81:3233-3249.

Moeser, A. J., I. B. Kim, E. van Heugten, and T. A. T. G. Kempen. 2002. The nutritional value of degermed, dehulled corn for pigs and its impact on the gastrointestinal tract and nutrient excretion. J. Anim. Sci. 80:2629-2638.

Muley, N. S., E. van Heugten, A. J. Moeser, K. D. Rausch, and T. A. T. G. van Kempen. 2007. Nutritional value for swine of extruded corn and corn fractions obtained after dry milling. J. Anim. Sci. 85:1695-1701.

Noblet, J., and J. M. Perez. 1993. Prediction of digestibility of nutrients and energy values of pig diets from chemical analysis. J. Anim. Sci. 71:3389-3398.

Noblet, J., and X. S. Shi. 1993. Comparative digestibility of energy and nutrients in growing pigs fed ad libitum and adult sows fed at maintenance. Livest. Prod. Sci. 34:137-152.

Noblet, J., H. Fortune, X. S. Shi, and S. Dubois. 1994. Prediction of net energy value of feeds for growing pigs. J. Anim. Sci. 72:344-354.

NRC. 2007. Nutrient Requirements of Horses. 6th rev. ed. Natl. Acad. Press, Washington, DC.

NRC. 1998. Nutrient Requirements of Swine. 10th rev. ed. Natl. Acad. Press, Washington, DC.

Olukosi, O. A., and O. Adeola. 2009. Estimation of the metabolizable energy content of meat and bone meal for swine. J. Anim. Sci. 87:2590-2599.

Downloaded from jas.fass.org at Magrath Library, Serials Department on December 7, 2011

Pahm, A. A., C. Pedersen, and H. H. Stein. 2009. Standardized ileal digestibility of reactive lysine in distillers dried grains with solubles fed to growing pigs. J. Agric. Food Chem. 57:535-539.

Palmquist, D. L., and T. C. Jenkins. 2003. Challenges with fats and fatty acid methods. J. Anim. Sci. 81:3250-3254.

Pedersen, C., M. G. Boersma, and H. H. Stein. 2007. Digestibility of energy and phosphorus in ten samples of distillers dried grains with solubles fed to growing pigs. J. Anim. Sci. 85:1168-1176.

Renewable Fuels Association. 2011. Biorefinery Locations. Accessed Oct. 9, 2011. http://www.ethanolrfa.org/bio-refinery-locations/.

Robinson, P. H., K. Karges, and M. L. Gibson. 2008. Nutritional evaluation of four co-product feedstuffs from the motor fuel ethanol distillation industry in the Midwestern USA. Anim. Feed Sci. Technol. 146:345-352.

Spiehs, M. J., M. H. Whitney, and G. C. Shurson. 2002. Nutrient database for distillers dried grains with solubles produced from new plants in Minnesota and South Dakota. J. Anim. Sci. 80:2639-2645.

Stein, H. H., and G. C. Shurson. 2009. The use and application of distillers dried grains with solubles in swine diets. J. Anim. Sci. 87:1292-1303.

Stein, H. H., S. P. Cannot, and C. Pedersen. 2009. Energy and nutrient digestibility of four sources of distillers dried grains with solubles produced from corn grown within a narrow geographical area and fed to growing pigs. Asian-Aust. J. Anim. Sci. 22:1016-1025.

Stein, H. H., M. L. Gibson, C. Pedersen, and M. G. Boersma. 2006. Amino acid and energy digestibility in ten samples of distillers dried grain with solubles fed to growing pigs. J. Anim. Sci. 84:853-860.

USDA. 1953. The test weight per bushel of grain: Method of use and calibration of the apparatus. Circular No. 921. U.S. Government Printing Office, Washington, DC.

van Kempen, T. A., D. H. Baker, and E. van Heugten. 2003. Nitrogen losses in metabolism trials. J. Anim. Sci. 10:2649-2650.

Widmer, M. R., L. M. McGinnis, and H. H. Stein. 2007. Energy, phosphorus, and amino acid digestibility of high-protein distillers dried grains and corn germ fed to growing pigs. J. Anim. Sci. 85:2994-3003.

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Table 1. Origin of corn co-products

Abbreviation	Feedstuff identification[1]	Origin
Gluten feed	Corn gluten feed	Tate & Lyle, Ft. Dodge, IA
Bran	Corn bran	ICM/Lifeline Foods, St. Joseph, MO
Bran with solubles	Corn bran with solubles	Poet Biorefining, Glenville, MN
DDGS (WI)	DDGS	Ace Ethanol, Racene, WI
DDGS(MNdm)	DDGS – drum dry	Cellencor, Heron Lake, MN
DDGS(MNmc)	DDGS – microwave dry	Cellencor, Heron Lake, MN
DDGS (IA)	DDGS	Hawkeye Renewables, Iowa Falls, IA
DDGS (BPX)	DDGS- Dakota Gold BPX	Poet Biorefining, Groton, SD
DDGS (SD)	DDGS	VeraSun Energy Corportation, Aurora, SD
OE-DDGS	Oil extracted-DDGS	VeraSun Energy Corporation, Aurora, SD
Gluten meal	Corn gluten meal	Archer Daniels Midland, Cedar Rapids, IA
HP-DDG (ICM)	HP-DDG	ICM/Lifeline Foods, St. Joseph, MO
HP-DDG (MOR)	HP-DDG	MOR Technology, Cape Girardeau, MO
HP-DDG (IA)	HP-DDG	Poet Biorefining, Coon Rapids, IA
Corn germ	Corn germ	Poet, Coon Rapids, IA
Germ meal	Corn germ meal	Cargill, Eddyville, IA
Dried solubles	Corn dried distillers solubles	Pulse Combustion Systems, Payson, AZ
DHDG corn	Dehulled, degermed corn	Bunge North America, Atchison, KS
Starch	Corn starch	Archer Daniels Midland, Clinton, IA
Oil	Corn oil	Mazola, ACH Food Co., Memphis, TN

[1]DDGS, distillers dried grains with solubles; and HP-DDG, high protein-distillers dried grains.

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Table 2. Ingredient composition of corn basal diet, as-fed basis

Ingredient	Concentration, %
Corn	97.05
Dicalcium phosphate	1.22
Limestone	0.73
Sodium chloride	0.40
Vitamin mix[1]	0.35
Trace mineral mix[2]	0.25

[1]Provided the following per kilogram of diet: vitamin A, 7,716 IU; vitamin D_3, 1,929 IU; vitamin E, 39 IU; vitamin B_{12}, 0.04 mg; riboflavin, 12 mg; niacin, 58 mg; and pantothenic acid, 31 mg.

[2]Provided the following per kilogram of diet: Cu (oxide), 35 mg; Fe (sulfate), 350 mg; I (CaI), 4 mg; Mn (oxide), 120 mg; Zn (oxide), 300 mg; and Se (Na_2SeO_3), 0.3 mg.

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Table 3. Characteristics of corn co-products, DM basis[1]

Item	DDGS (WI)	DDGS (IA)	DDGS (SD)	OE-DDGS	DDGS (BPX)	DDGS (MNdm)	DDGS (MNmc)	Dried solubles	Gluten feed
Bulk density, g/cm^3	0.581	0.470	0.487	0.494	0.467	0.530	0.396	0.330	0.499
Particle size, µm	1,054	784	579	480	330	568	866	WNP	571
Moisture, %	6.82	9.75	13.41	12.64	10.87	11.43	12.95	22.3	4.14
OM digestibility, %	74.22	62.25	64.7	57.14	65.43	63.85	62.97	93.48	60.99
GE, kcal/kg	5,314	5,375	5,434	5,076	5,347	5,550	5,502	5,476	4,539
CP, %	29.62	29.65	31.94	34.74	29.49	32.69	34.12	23.75	24.29
AA, %									
Ala	2.07	2.09	2.38	2.48	2.09	2.38	2.47	1.47	1.52
Arg	1.33	1.46	1.49	1.44	1.37	1.47	1.55	1.20	1.13
Asp	1.87	1.96	2.11	2.19	1.93	2.24	2.22	1.48	1.45
Cys	0.53	0.57	0.60	0.61	0.59	0.64	0.61	0.39	0.52
Glu	4.41	4.50	5.20	5.43	4.70	5.11	5.33	2.79	3.70
Gly	1.18	1.24	1.34	1.39	1.22	1.38	1.38	1.26	1.03
His	0.77	0.83	0.90	0.89	0.82	0.90	0.94	0.60	0.72
Ile	1.06	1.14	1.19	1.25	1.11	1.23	1.29	0.68	0.70
Leu	3.47	3.45	3.90	4.12	3.37	3.88	4.08	1.58	2.03
Lys	1.03	1.21	1.19	1.00	1.10	1.20	1.29	1.09	0.67
Met	0.56	0.58	0.65	0.64	0.54	0.64	0.65	0.32	0.30
Phe	1.29	1.61	1.48	1.51	1.31	1.48	1.55	0.53	0.77
Pro	2.08	2.23	2.52	2.54	2.29	2.44	2.57	1.29	1.87
Ser	1.37	1.32	1.52	1.58	1.30	1.47	1.53	0.90	0.88
Thr	1.11	1.10	1.22	1.26	1.09	1.25	1.26	0.81	0.78
Trp	0.21	0.19	0.20	0.18	0.21	0.23	0.23	0.21	0.13
Tyr	1.04	1.17	1.19	1.22	1.05	1.16	1.22	0.62	0.65
Val	1.49	1.57	1.69	1.76	1.53	1.73	1.80	1.08	1.11
Total starch, %	7.85	3.47	6.24	3.04	4.94	2.12	1.05	6.34	12.57
Crude fiber, %	7.05	7.76	7.56	8.69	7.95	7.93	8.35	0.08	8.56
Total dietary fiber, %	30.34	38.14	35.69	37.20	35.90	35.38	43.18	16.07	40.07
NDF, %	34.61	40.13	40.12	50.96	33.41	44.87	49.12	2.33	42.66
ADF, %	11.25	10.55	14.42	15.82	8.62	13.16	14.66	0.49	9.90
Cellulose, %	10.64	10.12	11.72	12.72	8.21	11.95	13.37	0.79	9.17
Lignin, %	1.21	1.06	3.16	3.49	1.00	1.72	1.92	0.31	1.05
Crude fat, %	11.45	10.89	10.16	3.15	11.71	12.10	11.98	11.81	2.70
Ash, %	4.16	4.43	4.46	5.16	5.41	4.55	4.04	14.08	6.81
Mineral, mg/kg									
Ca	204	248	475	652	663	240	230	1699	683
Cu	6	6	5	8	6	5	5	9	8
Fe	81	72	125	288	90	104	132	129	125
Mg	3,485	3,023	3,456	3,986	3,710	3,736	3,125	11,389	5,192
Mn	21	13	16	23	15	20	18	40	34
P	7,913	8,582	7,527	8,373	9,613	8,377	7,394	24,356	11,979
K	11,465	10,974	10,069	11,232	13,140	11,758	10,172	38,597	19,862
Se	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Na	172	1,287	2,414	3,776	2,659	1,361	1,324	4,259	364
S	8,475	7,940	7,616	9,772	11,087	7,288	6,982	18,069	4,907
Zn	63	55	59	67	89	82	75	95	120

[1]DDGS = distillers dried grains with solubles; DDGS (WI) = DDGS, Racene, WI; DDGS (IA) = DDGS, Iowa Falls, IA; DDGS (SD) = DDGS, Aurora, SD; OE-DDGS = oil extracted-DDGS, Aurora, SD; DDGS (BPX) = DDGS, Gorton, SD; DDGS (MNdm) = DDGS, drum dried, Heron Lake, MN; DDGS (MNmc) = DDGS, microwave dried, Heron Lake, MN; OM = in vitro OM digestibility; BDL = below detection limit (< 2.25 mg/kg); and WNP = would not pass through screens. All values based on a DM basis except particle size and bulk densities, which are based on an as-is basis.

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Table 3. (continued)

Item	DHDG corn	Germ	Germ meal	Bran	Bran with solubles	Gluten meal	HP-DDG (MOR)	HP-DDG (IA)	HP-DDG (ICM)
Bulk density, g/cm[3]	0.687	0.435	0.465	0.158	0.346	0.677	0.635	0.576	0.604
Particle size, µm	477	1,175	483	2,166	1,841	577	471	587	783
Moisture, %	12.78	9.44	10.87	12.62	9.18	8.51	8.3	5.95	12.31
OM digestibility, %	93.15	75.54	56.98	32.32	73.32	79.95	61.46	71.54	54.36
GE, kcal/kg	4397	5224	4767	4847	4982	5467	5811	5321	5464
CP, %	8.28	17.54	23.64	10.94	15.17	66.30	57.45	43.83	39.98
AA, %									
Ala	0.66	1.05	1.41	0.78	1.04	5.54	4.65	3.49	2.92
Arg	0.28	1.31	1.67	0.65	0.77	2.38	2.26	1.63	1.68
Asp	0.48	1.35	1.68	0.81	1.02	4.23	3.75	2.82	2.44
Cys	0.17	0.34	0.37	0.22	0.30	1.08	1.13	0.81	0.74
Glu	1.74	2.47	3.22	1.67	1.95	13.51	10.88	7.88	6.84
Gly	0.25	0.91	1.31	0.55	0.77	1.93	1.93	1.51	1.46
His	0.22	0.51	0.72	0.31	0.44	1.41	1.36	1.17	1.07
Ile	0.31	0.53	0.84	0.38	0.50	2.83	2.33	1.86	1.53
Leu	1.25	1.27	1.91	1.10	1.30	10.67	8.57	6.37	5.12
Lys	0.17	0.97	1.17	0.58	0.62	1.39	1.58	1.33	1.20
Met	0.16	0.28	0.42	0.18	0.23	1.41	1.44	0.94	0.81
Phe	0.45	0.66	1.02	0.50	0.55	4.14	3.13	2.37	1.96
Pro	0.77	1.07	1.20	0.82	1.08	5.59	4.77	3.79	3.06
Ser	0.39	0.68	1.00	0.53	0.65	2.91	2.86	2.02	1.68
Thr	0.26	0.57	0.88	0.50	0.61	2.12	2.14	1.61	1.33
Trp	0.06	0.17	0.20	0.06	0.09	0.24	0.29	0.14	0.19
Tyr	0.25	0.53	0.71	0.37	0.41	3.16	2.61	1.77	1.46
Valine	0.38	0.86	1.37	0.56	0.76	3.18	2.88	2.32	2.02
Total starch, %	87.96	25.00	15.29	23.25	25.73	11.08	0.51	7.30	5.10
Crude fiber, %	0.60	4.87	10.69	11.54	4.80	1.44	8.14	9.42	7.87
Total dietary fiber, %	2.61	24.78	47.76	53.60	26.65	9.24	28.80	31.28	36.75
NDF, %	4.27	27.37	61.05	56.86	25.21	12.25	43.52	32.00	51.09
ADF, %	0.49	6.13	12.49	13.14	5.35	7.57	25.42	12.61	15.11
Cellulose	0.77	5.21	11.71	12.78	5.38	5.95	22.55	12.05	14.25
Lignin, %	0.33	1.28	1.22	0.89	0.55	2.24	3.40	0.95	1.44
Crude fat, %	0.17	18.45	2.38	5.14	9.68	1.34	4.12	2.86	6.97
Ash, %	0.49	6.46	2.70	2.33	5.31	3.99	1.10	2.05	2.09
Mineral, mg/kg									
Ca	13	159	359	164	314	6,408	173	114	78
Cu	1	7	36	5	5	18	6	4	4
Fe	15	90	122	54	98	242	102	53	61
Mg	268	5,626	1,905	1,675	3,277	1,039	456	1,110	936
Mn	1	22	11	15	17	25	17	6	5
P	879	15,187	6,496	4,379	7,578	6,318	2,486	4,185	5,029
K	1,449	16,593	4,093	6,464	13,682	4,596	1,700	4,389	3,028
Se	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Na	115	83	839	63	4,270	1,029	231	1,260	563
S	1,048	2,141	3,274	1,460	9,506	9,051	7,178	9,034	7,002
Zn	5	85	77	39	195	42	71	28	37

[1]DHDG corn = dehulled, degermed corn, Atchison, KS; HP-DDG = high protein-dried distillers grains; HP-DDG (MOR) = HP-DDG, Cape Girardeau, MO; HP-DDG (IA) = HP-DDG, Coon Rapids, IA; HP-DDG (ICM) = HP-DDG, St. Joseph, MO; OM = in vitro OM digestibility; BDL = below detection limit (< 2.25 mg/kg); and WNP = would not pass through screens. All values based on a DM basis except particle size and bulk densities, which are based on an as-is basis.

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Table 4. Methods of analysis used to determine feed composition of corn co-products

Analyte[1]	Method of analysis
AA	AOAC official method 982.30 E (a,b,c)
ADF	AOAC official method 973.18 (A-D)
Ash	AOAC official method 942.05
Cellulose	AOAC official method 973.18 (A-D)
CP	AOAC official method 990.03
Crude fat	AOAC official method 920.39 (A) petroleum ether
Crude fiber	AOAC official method 978.10
DM	AOAC official method 934.01
Lignin	AOAC official method 973.18 (A-D)
Minerals	AOAC official method 985.01 (A-D)
NDF	Holst, 1973.
Total dietary fiber	AOAC official method 985.20 (A-C)
Total starch	AACC International (1976; approved method 76-13.01); modified: Sigma Starch Assay Kit (Kit STA-20, St. Louis, MO)
Bulk density[2]	USDA, 1953
GE[2]	Isoperibol bomb calorimeter (Model No. 1281, Parr Instrument Co., Moline, IL)
In vitro OM digestibility[2]	Boisen and Fernandez, 1997
Particle size[2]	Baker and Herrman, 2002

[1]Unless otherwise noted, analysis were conducted by the University of Missouri Experimental Station Chemical Laboratories, Columbia, MO.
[2]Determined by USDA-ARS NSRIC Laboratory, Ames, IA.

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Table 5. Gross energy, DE, and ME of corn and corn co-products fed to finishing pigs (kcal/kg DM)

Ingredient[1]	n	GE	DE[2]	ME[2]
Corn	30	4,268	3,883	3,805
SD	-	105	93	100
DDGS (IA)	8	5,375	3,841	3,659
DDGS (SD)	8	5,434	4,164	3,937
DDGS (BPX)	8	5,347	3,705	3,414
DDGS (MNdm)	8	5,550	4,116	3,876
DDGS (MNmc)	8	5,502	4,016	3,713
DDGS (WI)	6	5,314	4,332	4,141
OE-DDGS	6	5,076	3,868	3,650
HP-DDG (MOR)	8	5,811	4,955	4,606
HP-DDG (ICM)	8	5,464	3,994	3,676
HP-DDG (IA)	8	5,321	4,210	3,823
Bran	8	4,847	3,004	2,957
Bran with solubles	8	4,982	3,282	3,031
Germ meal	7	4,767	3,521	3,417
Germ	8	5,224	3,889	3,692
Gluten feed	8	4,539	2,517	2,334
Gluten meal	8	5,467	5,047	4,598
DHDG corn	8	4,397	4,401	4,316
Dried solubles	8	5,476	4,762	4,525
Starch	8	3,952	4,082	4,080
Corn oil	8	9,323	8,988	8,755
SD	-	-	363	413

[1]DDGS = distillers dried grains with solubles; DDGS (IA) = DDGS, Iowa Falls, IA; DDGS (SD) = DDGS, Aurora, SD; DDGS (BPX) = DDGS, Gorton, SD; DDGS (MNdm) = DDGS, drum dried, Heron Lake, MN; DDGS (MNmc) = DDGS, microwave dried, Heron Lake, MN; DDGS (WI) = DDGS, Racene, WI; OE-DDGS = oil extracted-DDGS, Aurora, SD; HP-DDG (MOR) = HP-DDG, Cape Girardeau, MO; HP-DDG (ICM) = HP-DDG, St. Joseph, MO; HP-DDG (IA) = HP-DDG, Coon Rapids, IA; DHDG corn = dehulled, degermed corn, Atchison, KS; and HP-DDG = high protein-dried distillers grains.

[2]The DE and ME of each co-product was calculated using the DE and ME of the basal diet as a covariate.

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Table 6. Stepwise regression equations for DE of corn co-products

	Regression coefficient parameter[1]						Statistical parameter[2]		
Item	Intercept[3]	HC	GE	TDF	EE	ST	OMD	SE	R^2	C(p)
Equation 1	4,808	-32.08	-	-	-	-	-	496	0.44	36.25
SE	261	9.26	-	-	-	-	-	-	-	-
P-value	0.01	0.01	-	-	-	-	-	-	-	-
Equation 2	-23	-28.67	0.91	-	-	-	-	367	0.71	13.78
SE	1,295	6.94	0.24	-	-	-	-	-	-	-
P-value	0.99	0.01	0.01	-	-	-	-	-	-	-
Equation 3	-520	-	1.06	-32.38	-	-	-	308	0.80	6.13
SE	1,057	-	0.20	5.85	-	-	-	-	-	-
P-value	0.63	-	0.01	0.01	-	-	-	-	-	-
Equation 4	-1,358	-	1.26	-30.91	-33.14	-	-	273	0.85	3.32
SE	1,009	-	0.20	5.23	14.75	-	-	-	-	-
P-value	0.20	-	0.01	0.01	0.04	-	-	-	-	-
Equation 5	-4,144	-	1.71	-21.47	-36.97	11.23	-	256	0.88	2.89
SE	1,889	-	0.32	7.40	14.02	6.59	-	-	-	-
P-value	0.05	-	0.01	0.01	0.02	0.11	-	-	-	-
Equation 6	-7,174	-	1.94	-	-50.91	15.20	18.04	227	0.90	1.31
SE	1,191	-	0.24	-	12.27	4.75	4.78	-	-	-
P-value	0.01	-	0.01	-	0.01	0.01	0.01	-	-	-

[1]HC = hemicellulose, TDF = total dietary fiber, EE = ether extract (crude fat), ST = starch, and OMD = in vitro OM digestibility. Equations based on analyzed nutrient content expressed on DM basis. Units for GE and DE are kcal/kg DM, and are in % for HC, TDF, EE, ST, and OMD.

[2]An adjusted R^2 was calculated using the 'NOINT' option only in the final equation when the intercept was excluded from the model ($P > 0.15$), SE is the SE of the regression estimate defined as the root of the mean square error, and C(p) is the Mallows statistic.

[3]The intercept coefficient, SE and *P*-value are shown. However, if the *P*-value of the estimate was greater than 0.15, then the SE of the regression estimate represents the adjusted value.

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Table 7. Stepwise regression equations for DE of corn co-products

	Regression coefficient parameter[1]				Statistical parameter[2]		
Item	Intercept	GE	NDF	EE	SE	R^2	C(p)
Equation 4b	-2,161	1.39	-20.70	-49.30	337	0.77	3.64
SE	1,222	0.24	4.86	18.10	-	-	-
P-value	0.10	0.01	0.01	0.02	-	-	-

[1]EE = ether extract (crude fat). Equations based on analyzed nutrient content expressed on DM basis. Units for GE and DE are kcal/kg DM; and are % for NDF and EE.

[2]An adjusted R^2 was calculated using the 'NOINT' option only in the final equation when the intercept was excluded from the model ($P > 0.15$), SE is the SE of the regression estimate defined as the root of the mean square error, and C(p) is the Mallows statistic.

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Table 8. Stepwise regression equations for ME of corn co-products

	Regression coefficient parameter[1]				Statistical parameter[2]		
Item	Intercept[3]	HC	GE	TDF	SE	R^2	C(p)
Equation 1	4,495	-29.81	-	-	464	0.43	16.7
SE	244	8.66	-	-	-	-	-
P-value	0.01	0.01	-	-	-	-	-
Equation 2	621	-26.50	0.73	-	383	0.63	7.7
SE	1,354	7.25	0.25	-	-	-	-
P-value	0.65	0.01	0.01	-	-	-	-
Equation 3	167	-	0.87	-30.11	333	0.72	2.9
SE	1,144	-	0.22	6.34	-	-	-
P-value	0.89	-	0.01	0.01	-	-	-
Equation 3-NOINT	NOINT	-	0.90	-29.95	323	0.72	-
SE	NOINT	-	0.04	6.04	-	-	-
P-value	NOINT	-	0.01	0.01	-	-	-

[1]HC = hemicellulose, TDF = total dietary fiber. Equations based on analyzed nutrient content expressed on DM basis. Units for GE and ME are kcal/kg DM and % for HC and TDF.

[2]An adjusted R^2 was calculated using the 'NOINT option only in the final equation when the intercept was excluded from the model ($P > 0.15$), SE is the SE of the regression estimate defined as the root of the mean square error, and C(p) is the Mallows statistic.

[3]The intercept coefficient, SE and *P*-value are shown. However, if the *P*-value of the estimate was greater than 0.15, then the SE of the regression estimate represents the adjusted value.

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Table 9. Stepwise regression equations for ME of corn co-products

	Regression coefficient parameter[1]				Statistical parameter[2]		
Iem	Intercept[3]	GE	NDF	Ash	SE	R^2	C(p)
Equation 3b	-288	0.90	-18.41	-	411	0.58	5.85
SE	1,400	0.27	5.93	-	-	-	-
P-value	0.84	0.01	0.01	-	-	-	-
Equation 3c	-223	0.98	-23.33	-70.09	371	0.68	3.54
SE	1,263	0.24	5.83	33.23	-	-	-
P-value	0.86	0.01	0.01	0.05	-	-	-
Equation 3c- NOINT	NOINT	0.94	-23.45	-70.23	359	0.68	-
SE	NOINT	0.06	5.60	32.13	-	-	-
P-value	NOINT	0.01	0.01	0.05	-	-	-

[1]Equations based on analyzed nutrient content expressed on a DM basis. Units for GE and ME are kcal/kg DM and % for NDF and ash.

[2]An adjusted R^2 was calculated using the 'NOINT' option only in the final equation when the intercept was excluded from the model ($P > 0.15$), SE is the SE of the regression estimate defined as the root of the mean square error, and C(p) is the Mallows statistic.

[3]The intercept coefficient, SE and *P*-value are shown. However, if the *P*-value of the estimate was greater than 0.15, then the SE of the regression estimate represents the adjusted value.

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Table 10. Stepwise regression equations for ME and ME/DE of corn co-products

	Regression coefficient parameter[1]					Statistical parameter[2]		
Item	Intercept[3]	DE	CP	NDF	EE	SE	R^2	C(p)
ME	-261	1.05	-7.89	2.47	-4.99	43	0.99	-1.87
SE	109	0.03	1.07	0.83	2.20	-	-	-
P-value	0.03	0.01	0.01	0.01	0.04	-	-	-
ME, % of DE	97.26	-	-0.10	-	-	1.70	0.46	-3.03
SE	0.95	-	0.03	-	-	-	-	-
P-value	0.01	-	0.01	-	-	-	-	-

[1]EE = ether extract (crude fat). Equations based on analyzed nutrient content expressed on a DM basis. Units for DE and ME are kcal/kg DM and % for CP, NDF, and EE.

[2]An adjusted R^2 was calculated using the 'NOINT' option only in the final equation when the intercept was excluded from the model ($P > 0.15$), SE is the SE of the regression estimate defined as the root of the mean square error, and C(p) is the Mallows statistic.

[3]The intercept coefficient, SE and *P*-value are shown. However, if the *P*-value of the estimate was greater than 0.15, then the SE of the regression estimate represents the adjusted value.

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