# Energy determination of corn co-products fed to broiler chicks from 15 to 24 days of age, and use of composition analysis to predict nitrogen-corrected apparent metabolizable energy[1]

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**ABSTRACT** An experiment (3 trials) was conducted to determine the $AME_n$ of 15 corn co-products obtained from various wet and dry milling plants, and to develop prediction equations for $AME_n$ based on chemical composition. Co-products included distillers dried grains with solubles (DDGS, n = 6), high-protein distillers dried grains (n = 2), corn germ (n = 2), corn germ meal, corn bran with solubles, corn gluten meal, corn gluten feed, and dehulled, degermed corn. Treatments (15) consisted of 85% inclusion of the corn-soybean meal basal diet combined with a 15% inclusion of each corn co-product, as well as a control diet containing glucose·$H_2O$ (15%) at the expense of the co-product. In each trial, Ross × Ross 708 chicks (10 birds per pen) were randomly assigned to 16 dietary treatments (12 replicate pens; 4 replicate pens per trial). After a 7-d diet acclimation period from 15 to 22 d of age, a 48-h total excreta collection was conducted for the determination of $AME_n$. Co-products were analyzed for gross energy, CP, moisture, crude fat, starch, crude fiber, ash, total dietary fiber, neutral detergent fiber, and acid detergent fiber, and hemicellulose was determined by difference. Stepwise regression resulted in the following equation: $AME_n$, kcal/kg of DM = 3,517 + (46.02 × % crude fat, DM basis) − (82.47 × % ash, DM basis) − (33.27 × % hemicellulose, DM basis) ($R^2 = 0.89$; SEM = 191; $P \leq 0.01$). Removing hemicellulose from the model resulted in the following equation: $AME_n$, kcal/kg of DM = (−30.19 × % neutral detergent fiber, DM basis) + (0.81 × gross energy, kcal/kg of DM basis) − (12.26 × % CP, DM basis) ($R^2 = 0.87$; SEM = 196; $P \leq 0.01$). These results indicate that nutrient composition may be used to generate $AME_n$ prediction equations for corn co-products fed to broiler chicks.

**Key words:** broiler, co-product, distillers dried grains with solubles, energy prediction

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## INTRODUCTION

Dietary energy sources represent a major cost in poultry diets (Donohue and Cunningham, 2009). Because a portion of the supply of corn and oil for animal feed has been diverted as inputs for ethanol and biodiesel production, ingredients have reached unprecedented prices for the poultry industry (Donohue and Cunningham, 2009). Using alternative ingredients to replace a portion of the corn and soybean meal can be an attractive strategy to reduce the diet cost for poultry nutritionists. Distillers dried grains with solubles (**DDGS**) is the primary co-product of ethanol production in the United States (Rausch and Belyea, 2006). In recent years, ethanol production has experienced exponential growth, resulting in a large supply of DDGS as a feed ingredient for the livestock and poultry industries. Distillers dried grains with solubles is an acceptable ingredient for broilers, with maximum inclusion levels being 6, 12, and 18% in the starter, grower, and finisher diets, respectively (Lumpkins et al., 2004).

Dry-grind and wet milling of corn results in multiple co-products, including DDGS, corn gluten meal, corn gluten feed, crude corn oil, and corn germ meal (Rausch and Belyea, 2006). Dry-grind milling is the primary type of processing used for ethanol production in the United States (Bothast and Schlicher, 2005). In addition to conventional dry-milling, dry-mill fractionation is used in a smaller number of ethanol plants to extract starch and oil more efficiently. Because of the value of these 2 products in a variety of industries, the number of plants implementing the fractionation process may increase in the future. Dry-mill fractionation of corn is used to separate bran, germ, and endosperm based

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[1] Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by Auburn University or the USDA. The USDA is an equal opportunity provider and employer.

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on bulk density, milling, and physical characteristics. Advantages of dry-mill fractionation are that it separates corn oil from the germ for food-grade markets and generates a higher concentration of endosperm (starch without bran and germ) in the fermentation process, to enhance the yield of ethanol. As new fractionation processes develop, the resulting co-products will continue to evolve. Consequently, nutrient digestibility values are warranted for these "new generation" corn co-products because of their altered chemical composition.

Extensive nutrient variation of corn co-products can limit their use in broiler diets (Cromwell et al., 1993; Batal and Dale, 2006; Fastinger and Mahan, 2006). Information is needed to accurately predict $AME_n$ values of corn co-products to minimize adverse broiler performance associated with energy variability. Regression equations have been developed to estimate energy utilization based on chemical composition of feedstuffs for both poultry (Batal and Dale, 2006; Cozannet et al., 2010a) and swine (Noblet and Perez, 1993; Fairbairn et al., 1999; Pedersen et al., 2007; Bulang and Rodehutscord, 2009). To our knowledge, $AME_n$ prediction equations based on chemical composition for a wide range of corn co-products have not been reported in poultry. The objective of this study was to select corn co-products with a wide range of nutrient composition to develop robust equations to predict $AME_n$ in broilers based on the chemical composition of 15 corn co-products obtained from both dry-grind and wet-milling facilities.

## MATERIALS AND METHODS

The Institutional Animal Care and Use Committee at Auburn University approved all experimental protocols involving live birds.

### Bird Husbandry

Three energy balance trials were conducted in growing broilers from 15 to 24 d of age. Overall, 1,920 Ross × Ross 708 broilers were obtained from a commercial hatchery and were vaccinated for Marek's disease, Newcastle disease, and infectious bronchitis. In each trial, 640 broilers (10 per cage; 5 males and 5 females) were placed into grower battery cages (Petersime, Gettysburg, OH). Each cage (68 × 68 × 38 cm) was equipped with 1 trough feeder and 1 trough waterer. The experimental facility was a solid-sided house with temperature control. In all trials, temperature was set to 33°C at placement (decreased gradually to 27°C by the conclusion of the trial), and a 23L:1D lighting schedule was used. Broilers were fed a common starter diet until d 15.

### Dietary Treatments

Fifteen corn-co products were obtained from various wet-mill and dry-grind ethanol plants throughout the United States (Table 1). Multiple corn co-products were chosen to encompass a wide range in nutrient composition. These included DDGS (6 samples), high-protein dried distillers grains (**HP-DDG**, 2 samples), corn germ meal, corn germ (2 samples), corn bran with solubles, corn gluten meal, corn gluten feed, and dehulled, degermed (**DHDG**) corn. On d 15, birds were randomly assigned to 1 of 16 dietary treatments, which included a control diet (85% basal diet + 15% glucose·$H_2O$) and 15 test diets, each containing 15% of a single corn co-product (85% basal diet + 15% co-product; Table 2). Each treatment was represented by 12 replications (4 replicates per trial) over time. All dietary treatments were provided in mash form.

### Measurements

After a 7-d acclimation period, a 48-h energy balance assay was conducted from 22 to 24 d of age. Feed consumption and excreta weights during the 48-h collection period were used to calculate energy and nitrogen intake and excretion. From each pen, multiple subsamples were collected from the total amount of excreta on the pan under the cage; these samples were then homogenized, after which a 250-g representative sample was

**Table 1.** Sources of corn co-products

| Abbreviation[1] | Feedstuff | Vendor |
|---|---|---|
| DDGS-1 | Distillers dried grains with solubles | VeraSun Energy Corporation (Aurora, SD) |
| DDGS-2 | Distillers dried grains with solubles, oil extracted | VeraSun Energy Corporation (Aurora, SD) |
| DDGS-3 | Distillers dried grains with solubles | Ace Ethanol (Racine, WI) |
| DDGS-4 | Distillers dried grains with solubles, Dakota Gold BPX | Poet Biorefining (Groton, SD) |
| DDGS-5 | Distillers dried grains with solubles | Hawkeye Renewables (Iowa Falls, IA) |
| DDGS-6 | Distillers dried grains with solubles, Dakota Gold BPX | Poet Biorefining (Corning, IA) |
| Corn germ-1 | Corn germ, dehydrated | Poet Biorefining (Coon Rapids, IA) |
| Corn germ-2 | Corn germ, dehydrated | Poet Biorefining (Coon Rapids, IA) |
| HP-DDG-1 | High-protein distillers dried grains | Poet Biorefining (Coon Rapids, IA) |
| HP-DDG-2 | High-protein distillers dried grains | MOR Technology (Cape Girardeau, MO) |
| Gluten feed | Corn gluten feed | Tate & Lyle (Ft. Dodge, IA) |
| Gluten meal | Corn gluten meal | Archer Daniels Midland (Cedar Rapids, IA) |
| Bran | Corn bran with solubles | Poet Biorefining (Glenville, MN) |
| DHDG corn | Dehulled, degermed corn | Bunge North America (Atchinson, KS) |
| Germ meal | Corn germ meal | Cargill (Eddyville, IA) |

[1] DDGS = distillers dried grains with solubles, HP-DDG = high-protein distillers dried grains, DHDG corn = dehulled, degermed corn.

**Table 2.** Ingredient and calculated nutrient composition of the basal diet

| Item | Amount |
|---|---|
| Ingredient (%) | |
| Corn | 62.92 |
| Soybean meal (48%) | 32.88 |
| Dicalcium phosphate | 1.72 |
| Calcium carbonate | 1.13 |
| Sodium chloride | 0.52 |
| DL-Methionine | 0.28 |
| Vitamin premix[1] | 0.25 |
| Mineral premix[2] | 0.25 |
| Salinomycin[3] | 0.05 |
| Calculated nutrient composition (%)[4] | |
| $AME_n$ (kcal/kg) | 2,923 |
| CP | 20.18 |
| Digestible lysine | 0.97 |
| Digestible methionine | 0.57 |
| Digestible TSAA | 0.81 |
| Digestible threonine | 0.64 |
| Digestible valine | 0.82 |
| Digestible isoleucine | 0.75 |
| Digestible arginine | 1.21 |
| Digestible tryptophan | 0.20 |
| Ca | 0.90 |
| Nonphytate P | 0.44 |
| Na | 0.23 |

[1] Vitamin premix provided the following per kilogram of diet: vitamin A (vitamin A acetate), 8,000 IU; vitamin D (cholecalciferol), 2,000 IU; vitamin E (DL-α-tocopherol acetate), 8 IU; menadione (menadione sodium bisulfate complex), 2 mg; vitamin $B_{12}$ (cyanocobalamin), 0.02 mg; folate (folic acid), 0.5 mg: D-pantothenic acid (calcium pantothenate), 15 mg; riboflavin, 5.4 mg; niacin (niacinamide), 45 mg; thiamine (thiamine mononitrate), 1 mg; D-biotin, 0.05 mg; and pyridoxine (pyridoxine hydrochloride), 2.2 mg; choline (choline chloride), 500 mg.

[2] Mineral premix provided the following per kilogram of diet: Mn (manganous oxide), 65 mg; Zn (zinc oxide), 55 mg; Fe (iron sulfate monohydrate), 55 mg; Cu (copper sulfate pentahydrate), 6 mg; I (calcium iodate), 1 mg; Se (sodium selenite), 0.3 mg.

[3] BioCox 60 provided 60 g/907 kg of salinomycin (Alpharma, Fort Lee, NJ).

[4] Values reported as percentages unless noted otherwise. Digestible amino acid values were determined from digestible coefficients and calculated total amino acid content of the ingredients (Ajinomoto Heartland, 2004).

placed in a plastic bag for later analysis. Representative samples of feed and excreta were frozen until later analysis. Feed and excreta samples were dried at 55°C in a forced-air oven, and dried samples were ground through a mill equipped with a 1-mm screen to ensure a homogeneous mixture. Gross energy contents of feed and excreta were determined on an 0.8-g sample using an adiabatic oxygen bomb calorimeter (Parr Instruments, Moline, IA), and analysis was performed in duplicate as described in the manual of the manufacturer. Nitrogen contents of feed and excreta were determined on a 0.25-g sample with a combustion analyzer (Elementar Americas Inc., Mt. Laurel, NJ) in duplicate using a previously established method (AOAC International, 2006; method 968.06). Apparent $ME_n$ for each dietary treatment was calculated using 8.73 as the N correction factor (Titus, 1956) and subtracting the contribution of $AME_n$ from glucose·$H_2O$ (3,640 kcal/kg) from all glucose-containing diets by using the following equations: total $AME_n$ intake = [gross energy intake − gross energy excretion] − [8.73 × (nitrogen intake − nitrogen excretion)]; basal $AME_n$ intake = $AME_n$ of control diet (85% basal + 15% glucose·$H_2O$) − 3,640 kcal of ME/kg of glucose·$H_2O$ (Hill and Anderson, 1958; Sell et al., 2001); co-product $AME_n$ = (total $AME_n$ intake − basal $AME_n$ intake)/co-product intake.

All corn co-products were analyzed by a commercial laboratory (University of Missouri Agriculture Experiment Station Chemical Laboratories, Columbia; Tables 3 and 4) unless otherwise described. Particle size was determined on a 13 half-height sieve shaker (Tyler Ro-Tap, Mentor, OH) as described by Baker and Herrman (2002), with data reported as the geometric mean (μm) on an as-is basis. Bulk density was determined by using a standard weight per bushel tester (USDA, 1953), with data reported as grams per cubic centimeter on an as-is basis. Hemicellulose (**HC**) was determined by subtracting acid detergent fiber (**ADF**) from neutral detergent fiber (**NDF**). Values for ADF and NDF were expressed without residual ash, and NDF was determined after pretreatment with a thermostable amylase.

### Statistics

Data were analyzed as a randomized complete block design (SAS Institute, 2004). Pen location was the blocking factor, with the block effect being the row of cages. Each treatment was represented by 12 replications (4 replicates per trial) over time. Stepwise regression was used to determine the effect of the nutrient composition on $AME_n$. The coefficient of determination ($R^2$), SE of the regression estimate, and the Mallows statistic [**C(p)**] were used to define the equation with the best fit. In addition, full and partial correlations between $AME_n$ and nutrient composition were conducted to assist in interpreting the stepwise regression results. If, in the final prediction model, the intercept was determined to be nonsignificant, it was excluded from the model and an adjusted $R^2$ value was calculated using the NOINT option (SAS Institute, 2004). Statistical significance was considered at $P \leq 0.05$.

## RESULTS AND DISCUSSION

Corn co-products are known to be variable in amino acid, ME, and sodium composition (Cromwell et al., 1993; Batal and Dale, 2006; Fastinger and Mahan, 2006). Moreover, nutrient variability has been reported to be influenced by particle segregation and sample collection technique (Ileleji et al., 2007; Kingsly et al., 2010). The objective of the current research was to use chemical composition to develop equations for predicting $AME_n$ of corn co-products currently being produced in the United States. To develop robust and accurate prediction equations, we selected a wide range in nutrient composition of co-products, and as expected, the chemical composition among the 15 corn co-products used in the current experiment was diverse (Table 3). Gross energy of the corn co-products ranged from 4,397 to 5,811 kcal/kg of DM, CP from 8.3 to 66.3%, fat from

**Table 3.** Analyzed composition of corn co-products[1]

| Item (%) | DDGS-1 | DDGS-2 | DDGS-3 | DDGS-4 | DDGS-5 | DDGS-6 | Corn germ-1 | Corn germ-2 |
|---|---|---|---|---|---|---|---|---|
| Bulk density (g/cm$^3$) | 0.487 | 0.494 | 0.581 | 0.467 | 0.470 | 0.441 | 0.435 | 0.314 |
| Particle size geometric mean (µm) | 579 | 480 | 1,054 | 330 | 784 | 352 | 1,175 | 1,050 |
| Moisture | 13.41 | 12.64 | 6.82 | 10.87 | 9.75 | 8.2 | 9.44 | 11.27 |
| Gross energy (kcal/kg) | 5,434 | 5,076 | 5,314 | 5,547 | 5,375 | 5,174 | 5,224 | 5,021 |
| CP | 31.94 | 34.74 | 29.62 | 29.49 | 29.65 | 26.48 | 17.54 | 15.65 |
| Starch | 6.24 | 3.04 | 7.85 | 4.94 | 3.47 | 3.30 | 25.00 | 23.31 |
| Crude fiber | 7.56 | 8.69 | 7.05 | 7.95 | 7.76 | 7.01 | 4.87 | 3.72 |
| Total dietary fiber | 35.69 | 37.20 | 30.34 | 35.90 | 38.14 | 32.69 | 24.78 | 19.41 |
| Neutral detergent fiber | 40.12 | 50.96 | 34.61 | 33.41 | 40.13 | 27.72 | 27.37 | 16.70 |
| Acid detergent fiber | 14.42 | 15.82 | 11.25 | 8.62 | 10.55 | 9.75 | 6.13 | 4.72 |
| Cellulose | 11.72 | 12.72 | 10.64 | 8.21 | 10.12 | 8.04 | 5.21 | 4.39 |
| Lignin | 3.16 | 3.49 | 1.21 | 1.00 | 1.06 | 2.20 | 1.28 | 0.73 |
| Crude fat | 10.16 | 3.15 | 11.45 | 11.71 | 10.89 | 11.52 | 18.45 | 15.88 |
| Ash | 4.46 | 5.16 | 4.16 | 5.41 | 4.43 | 4.48 | 6.46 | 5.53 |
| Item (%) | HP-DDG-1 | HP-DDG-2 | Gluten feed | Gluten meal | Bran | DHDG corn | Germ meal | |
| Bulk density (g/cm$^3$) | 0.576 | 0.635 | 0.499 | 0.677 | 0.346 | 0.687 | 0.465 | |
| Particle size geometric mean (µm) | 587 | 471 | 571 | 577 | 2,166 | 477 | 483 | |
| Moisture | 5.95 | 8.3 | 4.14 | 8.51 | 9.18 | 12.78 | 10.87 | |
| Gross energy (kcal/kg) | 5,321 | 5,811 | 4,539 | 5,467 | 4,982 | 4,397 | 4,767 | |
| CP | 43.83 | 57.45 | 24.29 | 66.30 | 15.17 | 8.28 | 23.64 | |
| Starch | 7.30 | 0.51 | 12.57 | 11.08 | 25.73 | 87.96 | 15.29 | |
| Crude fiber | 9.42 | 8.14 | 8.56 | 1.44 | 4.80 | 0.60 | 10.69 | |
| Total dietary fiber | 31.28 | 28.80 | 40.07 | 9.24 | 26.65 | 2.61 | 47.76 | |
| Neutral detergent fiber | 32.00 | 43.52 | 42.66 | 12.25 | 25.21 | 4.27 | 61.05 | |
| Acid detergent fiber | 12.61 | 25.42 | 9.90 | 7.57 | 5.35 | 0.49 | 12.49 | |
| Cellulose | 12.05 | 22.55 | 9.17 | 5.95 | 5.38 | 0.77 | 11.71 | |
| Lignin | 0.95 | 3.40 | 1.05 | 2.24 | 0.55 | 0.33 | 1.22 | |
| Crude fat | 2.86 | 4.12 | 2.70 | 1.34 | 9.68 | 0.17 | 2.38 | |
| Ash | 2.05 | 1.10 | 6.81 | 3.99 | 5.31 | 0.49 | 2.70 | |

[1] Identity of individual feedstuffs is described in Table 1. All values on a DM basis except particle size, bulk densities, and moisture. Values reported on a percentage basis unless noted otherwise. DDGS = distillers dried grains with solubles; HP-DDG = high-protein dried distillers grains; DHDG corn = dehulled, degermed corn.

**Table 4.** Methods of analysis used to determine feed composition of 15 corn co-products

| Analysis[1] | Method of analysis[2] |
|---|---|
| Gross energy[3] | Isoperibol bomb calorimeter (model no. 6300, Parr Instrument Co., Moline, IL) |
| DM | AOAC official method 934.01 |
| Starch | AACC approved method 76-13. Modified: Starch Assay Kit (product code STA-20, Sigma, St. Louis, MO) |
| CP | AOAC official method 990.3 |
| Crude fat | AOAC official method 920.39 (A) petroleum ether |
| Crude fiber | AOAC official method 978.10 |
| Total dietary fiber | AOAC official method 985.20 (A–C) |
| Neutral detergent fiber | Holst (1973) |
| Acid detergent fiber | AOAC official method 973.18 (A–D) |
| Cellulose | AOAC official method 973.18 (A–D) |
| Lignin | AOAC official method 973.18 (A–D) |
| Ash | AOAC official method 942.05 |

[1] Unless otherwise noted, all methods of analysis were determined by the University of Missouri Experimental Station Chemical Laboratories (Columbia).

[2] AOAC = Association of Official Analytical Chemists; AACC = American Association of Cereal Chemists.

[3] Determined by Auburn University Laboratory (Auburn, AL).

0.2 to 18.4%, ash from 0.5 to 6.8%, NDF from 4.3 to 61.1%, ADF from 0.49 to 25.42%, and total dietary fiber (**TDF**) from 2.61 to 47.76%. The range in chemical composition of co-products was fully expected because agronomic conditions and proximate composition of original corn sources, as well as processing methods (Cromwell et al., 1993; Kim et al., 2010), can affect corn grain and, consequently, the corn co-product produced. Moreover, chemical composition of corn co-products can be influenced by the degree of starch fermentation, heat processing, proportion of solubles added back to the distillers dried grains, and drying method at a particular production facility (Martinez-Amezcua and Parsons, 2007; Martinez-Amezcua et al., 2007). In addition to chemical composition, physical measurements differed widely among co-products in the current study in that bulk density and particle size ranged from 0.314 to 0.687 g/cm$^3$ and from 330 to 2,166 μm, respectively.

We also chose to evaluate AME$_n$ instead of TME$_n$. True ME$_n$ values are often used for evaluating feed ingredients, and comparison of AME$_n$ and TME$_n$ values may be difficult. In general, TME$_n$ values for corn and DDGS are 3.5 and 20% higher than AME$_n$ values, respectively (NRC, 1994). Although the use of TME$_n$ for evaluating feed ingredients is more rapid and can prove advantageous because it accounts for metabolic fecal and endogenous urinary energy (Sibbald, 1975), our evaluation of AME$_n$ allowed ad libitum feeding of the diets containing the co-products, which would be more reflective of the broiler industry. We choose to evaluate co-products by using a corn- and soybean meal-based diet. However, it has been reported that dietary composition of the basal diet may influence AME$_n$ (Adeola and Ileleji, 2009).

Apparent ME$_n$ values among all 15 corn co-products ranged from 1,746 kcal/kg of DM in corn gluten feed to 3,495 kcal/kg of DM in corn germ (Table 5). The AME$_n$ values for the 6 DDGS samples included in the study ranged from 2,146 to 3,098 kcal/kg of DM, averaging 2,678 kcal/kg of DM (Table 5), but were lower than previously published values. Batal and Dale (2006) reported TME$_n$ values of 17 DDGS samples, which ranged from 2,490 to 3,190 kcal/kg, whereas Fastinger and Mahan (2006) reported TME$_n$ of 5 samples of DDGS varying from 2,484 to 3,047 kcal of TME$_n$/kg on an as-fed basis. The 3 high-protein co-products evaluated in the current study included 2 samples of HP-DDG and 1 sample of corn gluten meal. The AME$_n$ values of 2 HP-DDG products in the current study were 2,708 and 2,932 kcal/kg of DM. Kim et al. (2008) reported a similar energy value of 2,957 kcal of TME$_n$/kg for HP-DDG (n = 1), whereas Applegate et al. (2009) published an AME$_n$ value of 2,526 kcal/kg for HP-DDG (n = 1). In addition to using a semipurified diet, the lower value for HP-DDG reported by Applegate et al. (2009) may be attributed to the difference in fiber composition because their sample was 8.28% units higher in ADF and 3.76% units lower in NDF when compared with samples in the current study and with their use of

**Table 5.** Determined energy of corn co-products in broiler chicks[1,2]

| Ingredient | n | Gross energy | AME$_n$ |
|---|---|---|---|
| DDGS-1 | 12 | 5,434 | 2,685 |
| DDGS-2 | 12 | 5,076 | 2,146 |
| DDGS-3 | 12 | 5,314 | 2,628 |
| DDGS-4 | 12 | 5,347 | 3,098 |
| DDGS-5 | 12 | 5,375 | 2,593 |
| DDGS-6 | 12 | 5,174 | 2,903 |
| Corn germ-1 | 12 | 5,224 | 3,120 |
| Corn germ-2 | 12 | 5,021 | 3,495 |
| HP-DDG-1 | 12 | 5,321 | 2,708 |
| HP-DDG-2 | 12 | 5,811 | 2,932 |
| Gluten feed | 12 | 4,539 | 1,746 |
| Gluten meal | 12 | 5,467 | 3,182 |
| Bran | 12 | 4,982 | 3,030 |
| DHDG corn | 12 | 4,397 | 3,442 |
| Germ meal | 12 | 4,767 | 1,991 |

[1] Gross energy and AME$_n$ are expressed as kilocalories per kilogram of DM. AME$_n$ was determined by a 48-h excreta collection following a 7-d adaptation period.

[2] Identity of feedstuffs as described in Table 1. DDGS = distillers dried grains with solubles, HP-DDG = high-protein distillers dried grains, DHDG corn = dehulled, degermed corn.

**Table 6.** Pearson correlation coefficients between components of 15 samples of corn co-products[1]

| Item | $AME_n$ | Gross energy | CP | Total starch | Resistant starch | Crude fiber | TDF | NDF | ADF | Hemicellulose | Lignin | Cellulose | Crude fat | Ash |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $AME_n$ | 1.00 | | | | | | | | | | | | | |
| Gross energy | 0.214 | 1.00 | | | | | | | | | | | | |
| *P*-value | 0.44 | | | | | | | | | | | | | |
| CP | −0.053 | 0.717 | 1.00 | | | | | | | | | | | |
| *P*-value | 0.85 | 0.01 | | | | | | | | | | | | |
| Total starch | 0.446 | −0.646 | −0.545 | 1.00 | | | | | | | | | | |
| *P*-value | 0.10 | 0.01 | 0.04 | | | | | | | | | | | |
| Resistant starch | 0.131 | −0.389 | −0.238 | 0.653 | 1.00 | | | | | | | | | |
| *P*-value | 0.64 | 0.15 | 0.39 | 0.01 | | | | | | | | | | |
| Crude fiber | −0.745 | 0.192 | 0.112 | −0.681 | −0.433 | 1.00 | | | | | | | | |
| *P*-value | 0.01 | 0.49 | 0.67 | 0.01 | 0.11 | | | | | | | | | |
| TDF | −0.767 | 0.099 | −0.037 | −0.691 | −0.432 | 0.943 | 1.00 | | | | | | | |
| *P*-value | 0.01 | 0.73 | 0.90 | 0.01 | 0.11 | 0.01 | | | | | | | | |
| NDF | −0.828 | 0.139 | 0.117 | −0.624 | −0.341 | 0.914 | 0.914 | 1.00 | | | | | | |
| *P*-value | 0.01 | 0.62 | 0.68 | 0.01 | 0.21 | 0.01 | 0.01 | | | | | | | |
| ADF | −0.432 | 0.612 | 0.619 | −0.630 | −0.224 | 0.665 | 0.512 | 0.670 | 1.00 | | | | | |
| *P*-value | 0.11 | 0.02 | 0.01 | 0.01 | 0.42 | 0.01 | 0.05 | 0.01 | | | | | | |
| Hemicellulose | −0.845 | −0.130 | −0.162 | −0.483 | −0.325 | 0.838 | 0.915 | 0.932 | 0.390 | 1.00 | | | | |
| *P*-value | 0.01 | 0.64 | 0.56 | 0.07 | 0.24 | 0.01 | 0.01 | 0.01 | 0.15 | | | | | |
| Lignin | −0.215 | 0.552 | 0.605 | −0.472 | −0.036 | 0.276 | 0.213 | 0.402 | 0.758 | 0.133 | 1.00 | | | |
| *P*-value | 0.44 | 0.03 | 0.02 | 0.08 | 0.90 | 0.32 | 0.45 | 0.14 | 0.01 | 0.64 | | | | |
| Cellulose | −0.443 | 0.595 | 0.589 | −0.623 | −0.250 | 0.701 | 0.538 | 0.711 | 0.990 | 0.412 | 0.661 | 1.00 | | |
| *P*-value | 0.10 | 0.02 | 0.02 | 0.01 | 0.37 | 0.01 | 0.04 | 0.01 | 0.01 | 0.13 | 0.01 | | | |
| Crude fat | 0.388 | 0.258 | −0.377 | −0.207 | −0.303 | −0.045 | 0.109 | −0.123 | −0.220 | −0.047 | −0.149 | −0.223 | 1.00 | |
| *P*-value | 0.15 | 0.35 | 0.17 | 0.46 | 0.27 | 0.87 | 0.70 | 0.66 | 0.43 | 0.87 | 0.60 | 0.42 | | |
| Ash | −0.154 | −0.070 | −0.276 | −0.392 | −0.272 | 0.072 | 0.308 | 0.084 | −0.261 | 0.240 | −0.072 | −0.293 | 0.615 | 1.00 |
| *P*-value | 0.583 | 0.80 | 0.32 | 0.15 | 0.33 | 0.80 | 0.264 | 0.77 | 0.35 | 0.39 | 0.80 | 0.29 | 0.01 | |

[1] CP = (N × 6.25); TDF = total dietary fiber; NDF = neutral detergent fiber; ADF = acid detergent fiber.

**Table 7.** Stepwise regression, all variables included

| | Regression coefficient | | | | Statistical parameter[1] | | |
|---|---|---|---|---|---|---|---|
| $AME_n$ equation | Intercept | Hemicellulose[2] | Crude fat | Ash | SE | $R^2$ | C(p), Mallows |
| Equation 1 | 3,635 | −37.72 | — | — | 280 | 0.71 | 0.31 |
| SE | 167 | 6.61 | — | — | — | — | — |
| Estimated *P*-value | 0.01 | 0.01 | — | — | — | — | — |
| Equation 2 | 3,382 | −36.99 | 29.55 | — | 222 | 0.84 | −2.49 |
| SE | 156 | 5.22 | 9.93 | — | — | — | — |
| Estimated *P*-value | 0.01 | 0.01 | 0.01 | — | — | — | — |
| Equation 3 | 3,517 | −33.27 | 46.02 | −82.47 | 191 | 0.89 | −2.57 |
| SE | 147 | 4.79 | 11.21 | 36.28 | — | — | — |
| Estimated *P*-value | 0.01 | 0.01 | 0.01 | 0.04 | — | — | — |

[1] $R^2$ is the coefficient of determination; SE is the SE of the regression estimate, defined as the root of the mean square error; and C(p) is the Mallows statistic.

[2] Hemicellulose was calculated as the difference between neutral detergent fiber and acid detergent fiber.

$AME_n$ vs. $TME_n$. In the experiment herein, corn gluten meal was determined as 3,182 kcal of $AME_n$/kg of DM, whereas NRC (1994) reported a higher value (3,720 kcal of $AME_n$/kg). High fiber co-products in the current study included corn gluten feed, corn germ meal, corn germ (n = 2), and corn bran, with determined $AME_n$ values of 1,746, 1,991, 3,308, and 3,030 kcal/kg of DM, respectively. The 1,746 kcal of $AME_n$/kg of DM for corn gluten feed is in close agreement with 1,750 kcal of $AME_n$/kg of corn gluten feed reported previously (NRC, 1994). Corn germ in the current experiment was determined to contain 3,308 kcal of $AME_n$/kg of DM, whereas Kim et al. (2008) reported 4,336 kcal of $TME_n$/kg for dehydrated corn germ (n = 1). Although fiber content was not reported, crude fat content was 1.9% units greater and CP was 1.7% units lower in the dehydrated corn germ sample reported by Kim et al. (2008) when compared with samples evaluated in the current study. The notable difference in sample composition, as well as the difference in methodology ($TME_n$ vs. $AME_n$), may partially account for the greater value reported by Kim et al. (2008). Dehulled, degermed corn had the lowest fiber content of the 15 co-products evaluated, whereupon $AME_n$ was determined to be 3,442 kcal/kg of DM. Applegate (2005) reported DHDG corn to contain 3,364 kcal of $AME_n$/kg by using regression analysis of 5 semipurified diets containing DHDG corn from 0 to 93.38% and extrapolating $AME_n$ at 100% DHDG corn inclusion.

The use of composition analysis to predict energy values of feed ingredients for poultry is not novel (Sibbald et al., 1963; Guirguis, 1975; Coates et al., 1977). More recently, prediction equations derived from composition analysis have been developed for meat and bone meal (Adedokun and Adeola, 2005), corn DDGS (Batal and Dale, 2006), and wheat DDGS (Cozannet et al., 2010a). Batal and Dale (2006) reported that the best predictors of $TME_n$ for DDGS were fat, fiber, protein, and ash; however, the equations were suggested for use only as a general guide because of a relatively low $R^2$ of 0.45. Using a covariate model and simple linear regression, Cozannet et al. (2010a) determined that the $AME_n$ of wheat DDGS could be predicted with luminance ($P < 0.001$, $R^2 = 0.77$) and ADF ($P < 0.001$, $R^2 = 0.79$).

Pearson correlations between chemical components of corn co-products are presented in Table 6. Hemicellulose displayed the strongest correlation with $AME_n$ (r = −0.845, $P = 0.01$), followed by NDF, TDF, and crude fiber (r = −0.828, −0.767, and −0.745, respectively, $P = 0.01$). This was expected given that HC is the primary fiber type in corn co-products, making up a large portion of their total NDF, TDF, and crude

**Table 8.** Stepwise regression, hemicellulose removed from the model

| | | Regression coefficient | | | | Statistical parameter[1] | | |
|---|---|---|---|---|---|---|---|---|
| $AME_n$ equation | Intercept | NDF[2] | Gross energy | CP | Starch | SE | $R^2$ | C(p), Mallows |
| Equation 1 | 3,733 | −28.79 | — | — | — | 294 | 0.69 | 1.44 |
| SE | 194 | 5.40 | — | — | — | — | — | — |
| Estimated *P*-value | 0.01 | 0.01 | — | — | — | — | — | — |
| Equation 2 | 1,412 | −30.41 | 0.46 | — | — | 247 | 0.80 | −0.95 |
| SE | 923 | 4.57 | 0.18 | — | — | — | — | — |
| Estimated *P*-value | 0.15 | 0.01 | 0.03 | — | — | — | — | — |
| Equation 3 | NOINT | −30.19 | 0.81 | −12.26 | — | 196 | 0.87 | — |
| SE | NOINT | 3.64 | 0.03 | 3.75 | — | — | — | — |
| Estimated *P*-value | NOINT | 0.01 | 0.01 | 0.01 | — | — | — | — |

[1] $R^2$ is the coefficient of determination [an adjusted $R^2$ was calculated using the NOINT option (SAS Institute, 2004) 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.

[2] NDF = neutral detergent fiber.

fiber (NRC, 2007; Table 3). Other fibrous measures (ADF, r = 0.432, $P = 0.11$; cellulose, r = −0.443, $P = 0.10$) were not as strongly correlated. Hetland et al. (2004) indicated that fiber is generally regarded as a diluent in diets fed to poultry, and based on our data, it appears that in corn co-products, HC has the single highest effect on $\text{AME}_\text{n}$. The weak correlation of total starch (r = 0.446, $P = -0.10$) and gross energy (r = 0.214, $P = 0.44$) with $\text{AME}_\text{n}$ is likely attributed to the high fiber and low starch content observed in all the co-products, except for DHDG corn. The weak correlation of crude fat (r = 0.388, $P = 0.15$) with $\text{AME}_\text{n}$ is a bit surprising given that the 6 DDGS and 2 corn germ samples contain moderately high levels of crude fat, but apparently this was overshadowed by their high levels of HC and the low levels of crude fat in the HP-DDG, corn gluten feed, and corn germ meal.

Stepwise selection in multiple regression was used to determine the chemical components that best served as predictors of $\text{AME}_\text{n}$ for the 15 corn co-products (Table 7). With HC having the strongest correlation with $\text{AME}_\text{n}$, it was the first variable included in the multiple regression model, generating $\text{AME}_\text{n}$ (equation 1) with an $R^2$ of 0.71. The equation was improved with the stepwise addition of crude fat ($P = 0.01$) to the model, subsequently increasing $R^2$ to 0.84 (equation 2). Ash ($P = 0.04$) was the third predictor to enter the model, further improving $R^2$ to produce the final equation: [$\text{AME}_\text{n}$, kcal/kg of DM = 3,517 − (33.27 × % HC DM) + (46.02 × % crude fat DM) − (82.47 × % ash DM), $R^2 = 0.89$, SEM = 191].

Analysis for HC requires determining both ADF and NDF; therefore, measurement of HC is time consuming and laborious. In an effort to produce a more practical equation for commercial applications, multiple regression was again performed with HC omitted from the variable pool (Table 8). Neutral detergent fiber ($P = 0.01$) was the first variable included in the model, yielding an $R^2$ of 0.69 (equation 1). The model was improved by subsequent addition of gross energy [$P = 0.03$ (equation 2), $R^2 = 0.80$], and CP [$P = 0.03$ (equation 3), $R^2 = 0.87$] with the final equation: $\text{AME}_\text{n}$, kcal/kg of DM = (−30.19 × % NDF, DM basis) + (0.81 × gross energy, kcal/kg of DM basis) − (12.26 × % CP, DM basis) ($R^2 = 0.87$; SEM = 196; $P \leq 0.01$).

Similar to the findings in this study, Cozannet et al. (2010a) reported that fiber alone accounted for much of the variation of $\text{AME}_\text{n}$ content in wheat co-products. In their study, however, ADF had the strongest correlation with $\text{AME}_\text{n}$ ($R^2 = 0.79$) rather than NDF or HC. This could be a result of using wheat rather than corn co-products, as well as a difference among analytical techniques of fiber indicators. In contrast to the results of Cozannet et al. (2010a) and the current study, Batal and Dale (2006) reported that the single best indicator of $\text{TME}_\text{n}$ for corn DDGS was fat ($R^2 = 0.29$), with a final equation including fat, fiber, protein, and ash ($R^2 = 0.45$). The analysis of DDGS used by Batal and Dale (2006), however, was limited to proximate composition such that data on specific fiber indicators were not reported. Furthermore, previous research developed $\text{AME}_\text{n}$ prediction equations using only DDGS (Batal and Dale, 2006; Cozannet et al., 2010a). As a result, variation in chemical composition between samples was not as large as that observed between the diverse array of co-products used in the current study. For example, the NDF of samples used by Cozannet et al. (2010a,b) ranged from 25.1 to 33.8%, whereas NDF in the current study ranged from 4.3 to 61.1% for DHDG corn and corn germ meal, respectively.

In conclusion, wide variability of $\text{AME}_\text{n}$ existed in corn co-products produced from dry- and wet-milling plants. Using stepwise selection in multiple linear regression, the best predictors of $\text{AME}_\text{n}$ were HC, crude fat, and ash. When removing HC from the variable pool to develop a more practical equation, the best predictors of $\text{AME}_\text{n}$ were NDF, gross energy, and CP. An independent validation of the prediction equations reported herein is warranted with future research.

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