Metabolizable energy value of dried corn distillers grains and corn distillers grains with solubles for 6-week-old broiler chickens

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ABSTRACT The objective of this study was to determine the ileal digestible energy (IDE), ME, and ME_n contents of corn distillers grains (DDG) and corn distillers grains with solubles (DDGS) for 6-wk-old broiler chickens using a multiple linear regression method. The DDG and DDGS were incorporated into a corn-soybean meal-based reference diet at 3 levels (0, 300, or 600 g/kg) by replacing the energy-yielding ingredients. These 5 diets were fed to 120 male Ross 308 broilers from d 35 to 42 posthatch with 3 birds per cage and 8 replicate cages per diet in a randomized complete block design. The birds were fed a standard broiler starter diet from d 1 to 22 posthatch and a standard broiler grower diet from d 22 to 35 posthatch. The inclusion of DDG and DDGS linearly ($P < 0.001$) decreased ileal digestibility of DM, energy, and IDE. Supplementation of DDG (linearly and quadratically; $P < 0.05$) or DDGS (linearly; $P < 0.05$) decreased metabolizability of DM, N, energy, N-corrected energy, and ME and ME_n. By regressing the DDG and DDGS-associated IDE intake in kilocalories against kilograms of DDG and DDGS intake, the IDE regression equation was Y = −19 + 2,428 × DDG + 2,922 × DDGS, $r^2 = 0.97$, which indicates IDE values of 2,428 kcal/kg of DM for DDG and 2,922 kcal/kg of DM for DDGS. Similarly, the ME regression equation was Y = −24 + 2,279 × DDG + 2,800 × DDGS, $r^2 = 0.98$, which implies ME values of 2,279 kcal/kg of DM for DDG and 2,800 kcal/kg of DM for DDGS. For ME_n, the regression equation was Y = −20 + 2,176 × DDG + 2,688 × DDGS, $r^2 = 0.98$, which suggests ME_n values of 2,176 kcal/kg of DM for DDG and 2,688 kcal/kg of DM for DDGS. The IDE, ME, and ME_n values of DDGS were higher ($P < 0.01$) than those of DDG. From these values, we calculated the advantages in IDE, ME, and ME_n of DDGS over DDG used in this study to be 20, 23, and 24%, respectively.

Key words: broiler chicken, corn distillers grains, corn distillers grains with solubles, ileal digestible energy, metabolizable energy

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INTRODUCTION

Wet grains and solubles are 2 intermediate products from grain processing into ethanol. After drying, wet grains turn into dried distillers grains (**DDG**), whereas dried distillers grains with solubles (**DDGS**) contain some or all of the solubles added back to wet grains and dried (Bregendahl, 2008). With all of the solubles added back, the fat content increased from 8% in the corn DDG to 10.5% in the corn DDGS (Stein and Shurson, 2009). However, the fermentation and drying, which concentrates nutrients in corn approximately 3-fold, also exacerbates the variability in the nutrients concentration in addition to the varied ratio of blending the distillers solubles with the residual grains (Belyea et al., 2004; Stein and Shurson, 2009).

The ME values for feed ingredients that are traditionally determined with adult roosters often extends its application to other types of birds. However, Lopez and Leeson (2007) found that roosters provide a good estimate of AME but not nitrogen-corrected AME_n for broiler chickens. This is based on the assumption that dietary energy utilization does not change with advancing age of broiler chickens, which has been challenged by the findings that ME_n value increased from d 0 to 14 of age with New Hampshire × Columbian chicks while the increase in ME_n lasted until d 21 of age with the commercial chicks in the study of Batal and Parsons (2002). Lopez and Leeson (2008) also asserted that there was evidence that AME and AME_n values varied with the age of the birds. So it is reasonable to abort our one-size-fits-all concept and to associate ME values for feed ingredients with the age of birds, that is, their ability to extract energy from feedstuffs.

In previous studies, we determined ME and ME_n of DDG to be 2,315 and 2,132 kcal/kg of DM (Adeola et al., 2010) and ME and ME_n of DDGS to be 2,904

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and 2,787 kcal/kg of DM (Adeola and Ileleji, 2009) for 3-wk-old broilers. In the current study, we compared ileal digestible energy (**IDE**), ME, and ME_n of DDG and DDGS for 6-wk-old broiler chickens.

MATERIALS AND METHODS

Birds and Diets

Animal procedures were approved by the Purdue University Animal Care and Use Committee. Male Ross × Ross 308 birds were fed a standard broiler starter diet (Table 1) from d 1 to 22 posthatch and a standard broiler grower diet (Table 1) from d 22 to 35 posthatch. The DDG and DDGS were incorporated into a corn-soybean meal-based reference diet at 3 levels (0, 300, or 600 g/kg) by replacing the energy-yielding ingredients. The ingredient composition of the 5 diets (reference diet, DDG 300, DDG 600, DDGS 300, and DDGS 600) is shown in Table 2. Energy-yielding ingredients, including corn, soybean meal, soy oil, and cornstarch, were replaced by DDG and DDGS in such a way that the same ratio of corn, soybean meal, soy oil, and cornstarch across the experimental diets were maintained. These ratios were 11.852:4.444:0.481:1 for corn:soybean meal:soy oil:cornstarch for all of the diets in Table 2. This substitution method is crucial for separating the energy contribution of basal ingredients to the assay diets (diets in which a portion of the basal diet is substituted with the test ingredient) from that of the test ingredients (DDG and DDGS) when using the regression method in energy utilization studies (Adeola and Ileleji, 2009).

Experimental Procedures

On d 35 posthatch, 120 birds were sorted by BW and assigned to 8 cages per diet with 3 birds per cage in such a way that the average initial BW was similar across diets. Cages were divided into 8 blocks of 5 diets, and diets were randomly assigned to cages within each block. Birds were provided ad libitum access to water and dietary treatments from d 35 to 42 posthatch.

Excreta were collected twice daily on d 39, 40, and 41 posthatch. During collection, waxed paper was placed in trays under the cages and excreta on the waxed paper were collected. The collected excreta were pooled per cage over the 3 d and stored at −20°C. For chemical analyses, excreta samples were dried in a forced-air oven at 55°C and then ground to pass through a 0.5-mm screen using a mill grinder (Retsch ZM 100, GmbH & Co. K.C., Cologne, Germany). On d 42 posthatch, feeders and birds were weighed to determine weight gain and feed intake, followed by asphyxiating the birds using carbon dioxide. Ileal digesta from the Meckel's diverticulum to about 2-cm cranial to the ileocecal junction were collected. Ileal contents from birds in the same cage were flushed with distilled water into 1 plastic container and stored at −20°C until freeze-dried and ground for further analyses.

Analyses

Ileal digesta, excreta, and diet samples were analyzed in duplicate for gross energy (**GE**) to determine the IDE, ME, and ME_n. Gross energy contained in digesta, excreta, or diets was determined in a bomb calorimeter (Parr 1261 bomb calorimeter, Parr Instruments Co., Moline, IL) using benzoic acid as a calibration standard. Dry matter was determined by placing samples in a drying oven (Precision Scientific Co., Chicago, IL) at 105°C for 24 h. Nitrogen was determined using the combustion method (Leco model FP-2000 N analyzer, Leco Corp., St. Joseph, MI; method 990.03; AOAC International, 2000) using EDTA as a calibration standard. The chromium concentration was determined using the method of Fenton and Fenton (1979). Proximate analyses [methods 920.39 (for crude fat), 978.10 (for crude fiber), 973.18 (A, B, C, D; for neutral detergent fiber and

Table 1. Ingredient composition of starter (d 1 to 22) and grower (d 22 to 35) diets

Item	Starter	Grower
Ingredient, g/kg		
Corn	542.2	606.5
Soybean meal	360	307.5
Soybean oil	50	50
Dicalcium phosphate[1]	20	14.5
Limestone (38% Ca)	13	13.5
Salt	4	4
Vitamin-mineral premix[2]	3	3
DL-Met	3.8	1
L-Lys·HCl	2.9	—
Thr	1.1	—
Total	1,000	1,000
Calculated nutrient content		
Protein, g/kg	226.4	201.7
ME, kcal/kg	3,207.7	3,202.1
Ca, g/kg	10.0	9.0
P, g/kg	7.5	6.3
Ca:P	1.4	1.4
Nonphytate P, g/kg	4.9	3.8
Total indispensable amino acids, g/kg		
Arg	14.6	13.0
His	5.9	5.3
Ile	9.2	8.3
Leu	18.9	17.6
Lys	14.3	10.7
Met	7.2	4.2
Met + Cys	10.8	7.5
Phe	10.5	9.5
Phe + Tyr	19.1	17.3
Thr	9.4	7.5
Trp	3.0	2.6
Val	10.2	9.3

[1]20% Ca, 18.5% P.

[2]Supplied the following per kilogram of diet: vitamin A, 5,484 IU; vitamin D_3, 2,643 ICU; vitamin E, 11 IU; menadione sodium bisulfate, 4.38 mg; riboflavin, 5.49 mg; D-pantothenic acid, 11 mg; niacin, 44.1 mg; choline chloride, 771 mg; vitamin B_{12}, 13.2 µg; biotin, 55.2 µg; thiamine mononitrate, 2.2 mg; folic acid, 990 µg; pyridoxine hydrochloride, 3.3 mg; I, 1.11 mg; Mn, 66.06 mg; Cu, 4.44 mg; Fe, 44.1 mg; Zn, 44.1 mg; and Se, 300 µg.

Table 2. Ingredient composition of experimental diets

Item	Reference diet	Test ingredient, g/kg: Corn dried distillers grains (DDG) 300	600	Corn dried distillers grains with solubles (DDGS) 300	600
Ingredient, g/kg					
Corn	640.0	440.0	240.0	440.0	240.0
Soybean meal (47.5%)	240.0	165.0	90.0	165.0	90.0
Soybean oil	26.0	17.9	9.8	17.9	9.8
Dicalcium phosphate[1]	10.5	10.5	10.5	10.5	10.5
Limestone	15.0	15.0	15.0	15.0	15.0
NaCl	4.0	4.0	4.0	4.0	4.0
Cornstarch[2]	34.0	17.1	0.3	17.1	0.3
Chromic oxide premix[3]	25.0	25.0	25.0	25.0	25.0
Vitamin-mineral premix[4]	3.0	3.0	3.0	3.0	3.0
DL-Met	2.5	2.5	2.5	2.5	2.5
DDG/DDGS	0.0	300.0	600.0	300.0	600.0
Total	1,000.0	1,000.0	1,000.0	1,000.0	1,000.0
Calculated nutrients and energy[5]					
Protein, g/kg	179.0	206.5	233.9	205.3	231.5
ME, kcal/kg	3,160.3	2,739.4	2,318.5	2,891.8	2,623.3
Ca, g/kg	8.3	8.3	8.4	8.5	8.8
P, g/kg	4.7	5.1	5.5	6.1	7.4
Ca:P	1.7	1.6	1.5	1.4	1.2
Nonphytate P, g/kg	3.0	3.8	4.7	3.8	4.7
Total amino acids, g/kg					
Arg	10.8	10.3	9.9	10.4	9.9
His	4.5	5.0	5.4	5.1	5.7
Ile	6.9	7.7	8.5	7.8	8.6
Leu	15.4	19.6	23.8	17.2	19.0
Lys	8.8	8.4	8.0	8.3	7.8
Met	5.3	5.6	5.9	6.2	7.1
Met + Cys	8.1	8.3	8.5	9.4	10.6
Phe	8.0	8.4	8.7	9.1	10.2
Phe + Tyr	14.6	15.4	16.2	15.9	17.1
Thr	6.3	5.8	5.3	7.1	7.9
Trp	2.2	2.1	2.0	2.1	2.0
Val	7.9	9.0	10.0	9.3	10.8

[1]20% Ca, 18.5% P.

[2]Adjusted cornstarch level to accommodate cornstarch in the chromic oxide premix.

[3]Prepared as 1 g of chromic oxide added to 4 g of cornstarch.

[4]Supplied the following per kilogram of diet: vitamin A, 5,484 IU; vitamin D_3, 2,643 ICU; vitamin E, 11 IU; menadione sodium bisulfate, 4.38 mg; riboflavin, 5.49 mg; D-pantothenic acid, 11 mg; niacin, 44.1 mg; choline chloride, 771 mg; vitamin B_{12}, 13.2 µg; biotin, 55.2 µg; thiamine mononitrate, 2.2 mg; folic acid, 990 µg; pyridoxine hydrochloride, 3.3 mg; I, 1.11 mg; Mn, 66.06 mg; Cu, 4.44 mg; Fe, 44.1 mg; Zn, 44.1 mg; and Se, 300 µg.

[5]The respective reference diet (RD), RD + 300 g DDG/kg, RD + 600 g DDG/kg, RD + 300 g DDGS/kg, and RD + 600 g DDGS/kg were analyzed to contain 884, 898, 912, 894, and 901 g of DM/kg; 4,407, 4,576, 4,797, 4,587, and 4,667 kcal of GE/kg; and 177, 212, 266, 210, and 243 g of CP/kg, respectively.

acid detergent fiber), 985.01 (A, B, C; for Ca and P), and 982.30 E (a, b, c) (for amino acid); AOAC International, 2000] of the DDG and DDGS were conducted at the University of Missouri Experiment Station Chemical Laboratories, Columbia.

Calculations and Statistical Analysis

Ileal digestible energy, ME, and ME_n in diets, DDG, and DDGS were calculated as described previously (Adeola et al., 2010). The coefficients (C) of ME for assay diets, the basal diet, and the test ingredient are Cad, Cbd, and Cti, respectively. The proportional contribution of energy by the basal diet and test ingredient to the assay diet are Pbd and Pti, respectively; by definition Pbd + Pti = 1 or Pbd = 1 − Pti. The assumption of additivity in diet formulation implies that: Cad = (Cbd × Pbd) + (Cti × Pti); solving for Cti gives Cti = [Cad − (Cbd × Pbd)] ÷ Pti; substituting 1 − Pti for Pbd gives Cti = {Cbd + [(Cad − Cbd) ÷ Pti]}. The product of Cti at each level of test ingredient substitution rate (300 or 600 g/kg), kilograms of dry test ingredient intake (product of 0.3 or 0.6 and dry feed intake), and the GE of the test ingredient is the test ingredient-associated ME, or ME_n intake. Growth performance and digestibility data were analyzed using the GLM procedures of SAS Institute (2006) in a randomized complete block design. The effects of increasing levels of DDG or DDGS in assay diets were compared using linear and quadratic contrasts.

The regression of DDG- or DDGS-associated IDE, ME, or ME_n intake in kilocalories against kilograms of

Table 3. Analyzed gross energy and chemical composition of the corn dried distillers grains (DDG) and corn dried distillers grains with solubles (DDGS) on an as-fed basis[1]

Item	DDG	DDGS
DM, g/kg	921	901
Gross energy, kcal/kg	4,879	4,762
CP (N × 6.25), g/kg	315	287
Crude fat, g/kg	94.6	101.3
Crude fiber, g/kg	94.8	59.3
Neutral detergent fiber, g/kg	495.6	248.3
Acid detergent fiber, g/kg	179.1	84.5
Ca, g/kg	0.19	0.3
P, g/kg	4.8	6.3
Indispensable amino acids, g/kg		
Arg	12.9	12.4
His	8.8	7.7
Ile	12.9	9.4
Leu	43.6	32.6
Lys	9.3	7.9
Met	6.7	5.1
Phe	17.2	9.1
Thr	11.6	11.5
Trp	2.0	2.1
Val	17.2	14.2
Dispensable amino acids, g/kg		
Ala	25.0	19.2
Asp	20.1	16.8
Cys	6.0	4.9
Glu	52.2	47.9
Gly	11.7	9.3
Pro	25.7	22.4
Ser	13.2	9.5
Tyr	13.1	8.3

[1]Values presented are from one replicate analysis for amino acids and means of duplicate analyses for the other nutrients.

DDG and DDGS intake for cage of birds was conducted using multiple linear regression (Littell et al., 1995). The solution option was used to generate intercept and slopes using GLM procedures of SAS Institute (2006). Also, DDG and DDGS-associated IDE, ME, and ME_n intake in kilocalories was regressed against corresponding kilograms of DDG and DDGS intake for each block to generate intercepts for each of the 8 blocks. The slope data were analyzed using the paired *t*-test to compare IDE, ME, and ME_n between DDG and DDGS. Statistical significance was determined at an α level of 0.05.

RESULTS

The corn DDG and DDGS used in this study were analyzed to contain 4,879 and 4,762 kcal of GE/kg, 315 and 287 g of CP/kg, and 921 and 901 g DM/kg, respectively (Table 3). The substitution of either DDG or DDGS increased DM, GE, and CP concentration compared with the reference diet in a substitution rate-dependent fashion. Crude fat, crude fiber, neutral detergent fiber, and acid detergent fiber were determined to be 94.6 vs. 101.3 g/kg, 94.8 vs. 59.3 g/kg, 495.6 vs. 248.3 g/kg, and 179.1 vs. 84.5 g/kg for DDG and DDGS, separately (Table 3).

There were both linear and quadratic effects ($P < 0.05$) of DDG substitution on final weight, weight gain, and feed intake (Table 4). Also, with the inclusion of DDG, feed efficiency was linearly decreased ($P < 0.05$) while the quadratic effect tended to be significant ($P = 0.054$). The inclusion of DDGS only linearly decreased ($P < 0.05$) feed intake.

There were linear ($P < 0.001$) decreases in the digestibility of DM and energy and in IDE with increases in supplementation of DDG or DDGS to the reference diet (Table 5). With ileal N digestibility, there was a quadratic effect ($P < 0.05$) of DDG. On the total tract level, the inclusion of DDG decreased metabolizability of DM, N, energy, N-corrected energy, and ME and ME_n both linearly ($P < 0.001$) and quadratically ($P < 0.05$), whereas there were only linear ($P < 0.001$) effects of DDGS on these measurements (Table 5).

Regression equations relating test ingredient-associated energy intake to intake of corn DDG and DDGS in the determination of IDE, ME, and ME_n of corn DDG and DDGS are presented in Table 6. The IDE regression equation was $Y = -19 + 2{,}428 \times DDG + 2{,}922 \times DDGS$, $r^2 = 0.97$, which indicates IDE values of 2,428 kcal/kg of DM for DDG and 2,922 kcal/kg of DM for DDGS. Similarly, the ME regression equation was $Y = -24 + 2{,}279 \times DDG + 2{,}800 \times DDGS$, $r^2 = 0.98$, which implies ME values of 2,279 kcal/kg of DM for DDG and 2,800 kcal/kg of DM for DDGS. For ME_n, the regression equation was $Y = -20 + 2{,}176 \times DDG + 2{,}688 \times DDGS$, $r^2 = 0.98$, which alludes to ME_n

Table 4. Initial and final weights, weight gain, feed intake, and feed efficiency of birds offered experimental diets for 7 d[1]

	Diet[2]						*P*-value			
		DDG, g/kg		DDGS, g/kg						
Item	Reference	300	600	300	600	SD	L[3]	Q[3]	L[4]	Q[4]
Initial weight, g	2,226	2,225	2,223	2,230	2,229	12.0	0.608	0.990	0.681	0.704
Final weight, g	2,618	2,707	2,439	2,634	2,620	164.4	0.038	0.018	0.981	0.824
Weight gain, g	391	404	216	405	315	100.4	0.002	0.028	0.142	0.244
Feed intake, g	1,007	1,016	804	937	868	121.7	0.002	0.045	0.030	1.000
G:F, g:kg	372	396	261	432	367	91.2	0.022	0.054	0.914	0.126

[1]Data are means of 8 replicate cages with 3 birds per cage.

[2]DDG = corn dried distillers grains; DDGS = corn dried distillers grains with solubles.

[3]Linear (L) and quadratic (Q) contrasts for DDG.

[4]Linear (L) and quadratic (Q) contrasts for corn DDGS.

Table 5. Ileal digestibility and total tract utilization of DM, nitrogen, and energy by birds offered experimental diets[1]

Item	Diet[2]						*P*-value			
		DDG, g/kg		DDGS, g/kg						
	Reference	300	600	300	600	SD	L[3]	Q[3]	L[4]	Q[4]
Ileal digestibility coefficient										
DM	0.59	0.48	0.41	0.53	0.46	0.045	<0.001	0.270	<0.001	0.969
Nitrogen	0.73	0.69	0.72	0.72	0.72	0.031	0.307	0.034	0.322	0.823
Energy	0.66	0.58	0.50	0.60	0.54	0.043	<0.001	0.191	<0.001	0.854
IDE,[5] kcal/kg	3,282	2,841	2,659	3,105	2,825	214.112	<0.001	0.172	<0.001	0.583
Total tract metabolizability coefficient										
DM	0.64	0.50	0.41	0.54	0.44	0.024	<0.001	0.035	<0.001	0.969
Nitrogen	0.42	0.29	0.27	0.35	0.28	0.048	<0.001	0.017	<0.001	0.927
Energy	0.72	0.58	0.51	0.63	0.55	0.018	<0.001	0.002	<0.001	0.954
N-corrected energy	0.69	0.54	0.49	0.61	0.53	0.017	<0.001	0.002	<0.001	0.915
ME, kcal/kg	3,566	2,974	2,666	3,244	2,851	94.535	<0.001	0.002	<0.001	0.390
ME_n, kcal/kg	3,455	2,884	2,563	3,137	2,752	86.192	<0.001	0.002	<0.001	0.385

[1]Data are means of 8 replicate cages with 3 birds per cage. There were 7 replicate cages for ileal nitrogen digestibility coefficient for DDGS 300 due to inadequate ileal digesta amount for nitrogen analysis.

[2]DDG = corn dried distillers grains; DDGS = corn dried distillers grains with solubles.

[3]Linear (L) and quadratic (Q) contrasts for DDG.

[4]Linear (L) and quadratic (Q) contrasts for DDGS.

[5]IDE = ileal digestible energy.

values of 2,176 kcal/kg of DM for DDG and 2,688 kcal/kg of DM for DDGS. The IDE, ME, and ME_n of DDGS were higher ($P < 0.05$) than those of DDG.

DISCUSSION

Distillers solubles and DDG are the main parent stream products for DDGS. Distillers solubles are extremely viscous and pose difficulty in reducing water content when containing 50% solids, so it is usually added back to DDG to produce DDGS (Belyea et al., 1998). Distillers solubles are a rich source of fat. When all of the solubles were added back, the fat content increased from 8% in the corn DDG to 10.5% in corn DDGS (Stein and Shurson, 2009). Starch removal during fermentation reduced starch from 71.4 to 5.1% and increased the crude fat from 4.2% in corn to 11.9% in corn DDGS (Belyea et al., 2004). However, both distillers solubles and DDGS are highly variable in their chemical compositions. Belyea et al. (1998) reported values of 187 to 223 g of CP and 5.8 to 15.2 g of fat per kg of DM distillers grains, which was sampled from different batches of the same corn wet milling plant. The variation in corn DDGS is probably due to processing strategies (Belyea et al., 2004), including the ratio of distillers solubles and DDG blended. All of these potential variations might have contributed to the higher GE in DDG compared with DDGS used in the current study (as-is basis: 4,879 vs. 4,762 kcal/kg; DM basis: 5,299 vs. 5,285 kcal/kg, respectively).

Increasing substitution of the ingredients supplying energy in the reference diet with DDG or DDGS from 0 to 600 g/kg of diet reduced ileal digestibility of nitrogen and energy as well as metabolizability of DM, N, and energy during the 7-d study in 6-wk-old broiler chickens. The decrease in ileal digestibility of and total tract utilization of nitrogen and energy utilization observed with increasing substitution was less pronounced with DDGS than with DDG. This is mirrored in the reduction in weight gain, feed intake, and feed efficiency of birds fed diets containing increasing levels of DDGS when compared with DDG. These observations are consistent with a lower fiber concentration in DDGS compared with DDG and the generally greater IDE, ME, and ME_n in DDGS when compared with DDG. In previous studies of wheat DDGS, Thacker and Widyaratne (2007) also observed lower digestibility of nutrients in the diets due to wheat DDGS incorporation. The culprit for lower digestibility of nutrients in DDG or DDGS is usually recognized as the higher fiber content (Thacker and Widyaratne, 2007; Adeola et al., 2010) for its low digestibility in itself and its negative influence on digestion of other nutrients. In a 6-wk broiler study, Waldroup et al. (1981) concluded that up to 25% DDGS could be used in broiler diets by replacing corn and soybean meal (**SBM**). From the same laboratory, 15 to 20% levels of new generation DDGS were recognized as usable (Wang et al., 2007). With lysine supplementation, up to 40% replacement

Table 6. Regression equations relating test ingredient-associated energy intake to intake of corn dried distillers grains (DDG) or corn dried distillers grains with solubles (DDGS)[1]

Item	Regression equation	r^2	SD
IDE[2]	Y = −19 (32) + 2,428 (87) × DDG + 2,922 (87) × DDGS	0.97	109
ME	Y = −24 (27) + 2,279 (73) × DDG + 2,800 (73) × DDGS	0.98	91
ME_n	Y = −20 (25) + 2,176 (66) × DDG + 2,688 (66) × DDGS	0.98	83

[1]Values in parentheses are SE.

[2]IDE = ileal digestible energy.

of DDGS into SBM could be used (Parsons and Baker, 1983), and another new generation DDGS with high protein could be used up to 50% replacement for the level of SBM inclusion (Applegate et al., 2009). Therefore, nutrient composition would have an influence on the suggested inclusion level of DDGS. Also, the age of the broilers should be taken into account. Lumpkins et al. (2004) suggested 12 to 15% DDGS substitution into corn and SBM in the grower and finisher periods versus 6% in the starter period.

Considering that the objective of this study was to determine the IDE, ME, and ME_n contents of corn DDG and DDGS using the regression method, substituting the test ingredients at relatively higher levels in the assay diets is crucial (Adeola et al., 2010). This is corroborated by the larger variance of the calculated AME or AME_n when regressing against lower substitutions of the test ingredient versus higher substitutions in the study by Lopez and Leeson (2008).The ME value of DDG evaluated in the current study is 2,279 kcal/kg of DM, compared with 2,315 kcal/kg of DM for the same DDG (Adeola et al., 2010) previously reported using similar experimental procedures and facilities, with the primary difference being that this study employed 6-wk-old birds whereas 3-wk-old birds were used in the previous study. The ability of extracting energy from a single diet for broilers exhibited a quadratic trend over time with ME and ME_n values peaking at d 35 (Lopez and Leeson, 2007). Also, both ME and ME_n values were higher for broilers on the same diet at d 21 than at d 42 in the study of Lopez and Leeson (2007). The ME value of DDGS evaluated in the current study is 2,800 kcal/kg of DM compared with 2,904 kcal/kg of DM for a different DDGS for 3-wk-old broilers (Adeola and Ileleji, 2009) previously reported using similar experimental procedures and facilities. In addition to the difference in the age of the broiler chickens, the DDGS in this study contained 4,762 kcal of GE/kg compared with 4,811 kcal/kg in the study by Adeola and Ileleji (2009). Furthermore, there could be differing changes in N retention when substituting the reference diet with a test ingredient of dissimilar protein quality and content based on the finding that substituting the test ingredient in a reference diet of similar protein quality and content appears to be the only method of producing consistent values for the N-uncorrected ME values of test ingredients (Leeson et al., 1977). The ME difference between DDG and DDGS could be explained by a higher concentration of fat and residual starch in condensed solubles and the lower concentration of neutral detergent fiber and acid detergent fiber in DDGS than in DDG (Adeola et al., 2010).

Nitrogen correction partially adjusted for the effect of differences in protein retention across birds in any assay (Lopez and Leeson, 2007). Also, it can reduce the variability in estimates of ME (Leeson et al., 1977; Lopez and Leeson, 2007), which was also shown in this study by the reduced SE with estimated ME_n than that with ME. We determined ME_n of DDG and DDGS to be 2,176 and 2,688 kcal/kg of DM, respectively, which are approximately 4.5 and 4.0% lower than the corresponding ME values. So the N-correction-induced penalty imposed on DDG is slightly higher than DDGS, which is consistent with the finding by Leeson et al. (1977) that smaller disparity between the protein content of the test ingredient and the reference diet resulted in a decreased penalty. Compared with the 8% reduction in ME content of DDG in the study by Adeola et al. (2010) using 3-wk-old broilers, the 4.5% reduction is lower partially because of decreased efficiency of N retention with advancing age of the broiler chickens.

The IDE represents energy available to birds from a feed ingredient before microbial fermentation of energy substrates in the ceca and the relatively short colon and was determined to be 2,428 and 2,922 kcal/kg of DM for DDG and DDGS, respectively, which are approximately 6 and 4% higher than their ME. Considering that IDE reflects energy digested and absorbed in the gastrointestinal tract only up to the ileum, energy utilization in the distal section of the gastrointestinal tract is negative. This is primarily due to the energy-containing compounds excreted postileum into the digestive tract from the urinary duct, based on the result that conventional roosters were able to extract more energy in DDGS than cecectomized (Parsons, 1985). Even though all of the IDE of our experimental diets were lower than their ME, the discrepancy between IDE and ME was decreased from 284 kcal/kg of DM for the reference diet to 7 and 26 kcal/kg of DM for the assay diets with 600 g of DDG and DDGS/kg, respectively. This implies that IDE of DDG or DDGS should be higher than their ME. However, consistently higher IDE than ME in experimental diets were reported in a similar study conducted by Adeola et al. (2010) using 3-wk-old instead of the 6-wk-old broiler chickens in this study. Therefore, both feedstuff property and the age of the birds might have influenced the difference between IDE and ME values. More in-depth investigations are required in this area.

In summary, the respective IDE, ME, and ME_n values of the DDG sample evaluated were 2,428, 2,279, and 2,176 kcal/kg of DM with corresponding values for DDGS sample to be 2,922, 2,800, and 2,688 kcal/kg of DM. The IDE, ME, and ME_n values were 20, 23, and 24% higher than those of DDG, respectively.

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