NON RUMINANT NUTRITION

Energy values of triticale or sorghum distillers' dried grains with solubles and rye fed to broiler chickens

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Abstract

The current experiments were conducted to determine ileal digestible energy (IDE), metabolizable energy (ME), and nitrogen-corrected ME (ME_n) of triticale distillers' dried grains with solubles (TDDGS), sorghum distillers' dried grains with solubles (SDDGS), or rye for broiler chickens using the regression method. Five diets including a corn-soybean meal reference diet and four assay diets, prepared by adding TDDGS or SDDGS at 10% or 20% of the diet to partly replace energy-yielding ingredients in the reference diet, were used. Each of the five diets was fed to eight replicate cages of six birds per replicate cage from day 14 to 21 post-hatching. Similarly in experiment 2, corn-soybean reference diet and two assay diets in which rye at 20% or 40% replaced energy-yielding sources in the reference diet and each of the three diets was fed to eight replicate cages of eight birds per replicate cage from day 18 to 23 post-hatching. Excreta samples were collected twice daily from day 18 to 20 in experiment 1 or day 20 to 22 in experiment 2, and ileal digesta were collected on day 21 (experiment 1) or day 23 (experiment 2). The IDE, ME, and ME_n (kcal/kg DM) of TDDGS or SDDGS were derived from the regressions of TDDGS-, SDDGS-, or rye-associated, IDE, apparent ME, and apparent ME_n intake in kilocalories against the intake of TDDGS, SDDGS, or rye (X, kg DM), respectively. For diets with TDDGS substitution, regression equations were $IDE = 12.3 + 3,288X$, $ME = -3.0 + 2,800X$, and $ME_n = -0.4 + 2,647X$. The equations for the SDDGS diets were $IDE = -4.8 + 3,247X$, $ME = -7.6 + 3,210X$, and $ME_n = -7.0 + 3,072X$; and those for the rye diets were $IDE = 9.5 + 3,002X$, $ME = 6.3 + 3,053X$, and $ME_n = 4.8 + 2,928X$. The IDE contents did not differ between TDDGS and SDDGS whereas the ME and ME_n contents were greater ($P < 0.05$) in the SDDGS than in the TDDGS. In conclusion, the current study provided energy values of the DDGS sources and rye using the regression method. The regression-derived IDE for TDDGS, SDDGS, or rye were 3,288, 3,247, or 3,002 kcal/kg DM, respectively; corresponding ME were 2,800, 3,210, or 3,053 kcal/kg DM. The respective regression-derived ME_n for TDDGS, SDDGS, or rye were 2,647, 3,072, or 2,928 kcal/kg DM for broiler chickens.

Key words: broiler chicken, distillers' dried grains with solubles, ileal digestible energy, metabolizable energy, regression method, rye

Introduction

In recent years, increased demand for ethanol as biofuel (Windhorst, 2007) has led to the production of a large amount of coproducts such as distillers' dried grains with solubles (DDGS) as a good source of energy for formulating practical poultry diets (Swiatkiewicz and Koreleski, 2008). However, nutrient

and energy contents in DDGS are highly variable depending on several factors including nutritive values of original grains used, the method of fermentation process, and the amount of solubles blended with distillers' grains (Stein and Shurson, 2009). Therefore, available energy and nutrient contents in DDGS samples must be evaluated for use for poultry diets.

Abbreviations

DDGS	distillers' dried grains with solubles
DM	dry matter
IDE	ileal digestible energy
ME	metabolizable energy
ME _n	nitrogen-corrected metabolizable energy
N	nitrogen
SDDGS	sorghum distillers' dried grains with solubles
SBM	soybean meal
TDDGS	triticale distillers' dried grains with solubles

Corn and wheat have been the major cereal grains used for ethanol production because they have greater fermentable starch contents compared with other grains. However, recent expansion in bioethanol industry has led producers to look for alternative grains such as sorghum and triticale for ethanol production. Nutritive contents in sorghum or triticale are comparable to those of corn or wheat, respectively. Moreover, both alternative ingredients are grown in areas unsuitable for corn or wheat. Therefore, their use is less competitive than other ingredients for human food (Cerisuelo et al., 2012). Taken together, there is an increase in the potential use of triticale DDGS (TDDGS) or sorghum DDGS (SDDGS) in poultry diet.

There is limited research on nutrients and energy values of TDDGS, SDDGS, or rye fed to broiler chickens. Oryschak et al. (2010) have reported the apparent ileal digestibility of nutrients or gross energy in TDDGS fed to broiler chickens from day 21 to 28 using the difference method. Barekattain et al. (2014) have reported metabolizable energy (ME) and net energy in broiler diets containing 30% SDDGS using comparative slaughter or indirect calorimetry method. However, there is a dearth of information about the ileal digestible energy (IDE), ME, and nitrogen-corrected ME (ME_n) in individual non-corn DDGS sources and rye for broiler chickens. Due to the challenges in the poultry industry of feed costs and the potential benefits of using alternative ingredients in broiler chicken diets, more data on the IDE, ME, and ME_n are needed to optimize diet formulation. Therefore, the objective of the current study was to determine IDE, ME, and ME_n of TDDGS or SDDGS fed to broiler chickens using the regression method.

Materials and methods

All experimental protocols were reviewed and approved by the Purdue University Animal Care and Use Committee.

Animals

Male broiler chicks (Ross 308; Aviagen, Huntsville, AL) were obtained from a local hatchery at day old. Chicks were individually tagged with identification numbers and reared in electrically heated battery cages (model SB 4 T; Alternative Design Manufacturing & Supply, Siloam Springs, AR) kept at 35 °C, 32 °C, and 28 °C from day 0 to 7, day 7 to 14, and day 14 to 22, respectively, in an environmentally controlled room. Birds had ad libitum access to water and a standard broiler starter diet from day 0 to 14 or 18. Birds in experiment 1 were weighed individually on day 14, 240 birds in eight replicate cages of 6 birds per cage were allotted to five diets on the basis of body weight in a randomized complete block design and given ad libitum access to water and experimental diets from day 14 to 21. A total

of 192 broiler chickens in eight replicate cages of 8 birds per cage were assigned to three diets in a randomized complete block design on day 18 in experiment 2. Birds were given ad libitum access to water and experimental diets from day 18 to 23 post-hatching. Diets were randomly allocated to cages within blocks in each of the experiments 1 and 2.

Experimental diets

Dietary treatments consisted of a reference diet and four assay diets in experiment 1. A corn-soybean meal (SBM) diet was prepared as a reference diet in which corn, SBM, corn starch, and soybean oil were used as energy-yielding sources (Table 1). Four assay diets were prepared by supplementing the reference diet with TDDGS or SDDGS at 10% or 20%, respectively, to partly replace energy-yielding sources in the reference diet. Similarly, in experiment 2, the corn-SBM diet was prepared as a reference diet in which corn, SBM, and soybean oil were used as energy-yielding sources and rye at 20% or 40% replaced energy-yielding sources in the reference diet (Table 2). These dietary inclusion levels were based on previous studies with DDGS (experiment 1) and pilot studies with rye in which significant reductions in feed intake were seen with 60% rye. In each of experiments 1 and 2, chromic oxide was included at 0.5% as an indigestible index for the calculation of ileal digestibility and total tract retention. Minerals and vitamins were added to all diets according to requirement estimates (NRC, 1994).

Sample collection and chemical analysis

From day 18 to 20 in experiment 1 or day 20 to 22 in experiment 2, excreta samples were collected, which are at different ages due to logistics. During the collection period, waxed papers were placed in trays beneath the cages. Excreta samples on the paper were collected twice daily. They were pooled within a cage over the 2 d period and stored in a freezer at -20 °C until further analysis. On day 21 in experiment 1 or day 23 in experiment 2, all birds were euthanized via carbon dioxide asphyxiation. Ileal digesta samples were collected from the distal two-thirds of the ileum defined as extending from Meckel's diverticulum to the ileocecal junction. The content in the ileum was rinsed with distilled water, pooled per cage of six or eight birds (experiment 1 or experiment 2, respectively), and stored in a freezer at -20 °C until further analysis.

At the end of the experiment, ileal digesta and excreta samples were thawed and placed in a forced-air oven at 55 °C for 96 h. Dried samples were ground using a mill grinder (Retsch ZM 100; Retsch GmbH & Co., Haan, Germany). Gross energy contents in the diets, excreta samples, and ileal digesta samples were determined using an isoperibol oxygen bomb calorimeter (Parr 1261; Parr Instruments Co., Moline, IL) with benzoic acid as a calibration standard. Dry matter (DM) analysis of samples was conducted by drying samples in an oven at 105 °C for 24 h (method 934.01; AOAC, 2005). Nitrogen (N) in the samples was determined using the combustion method (Model FP2000; Leco Corp., St. Joseph, MI) with EDTA as a calibration standard. Chromium concentrations in the diets, ileal samples, and excreta samples were determined using a method described by Fenton and Fenton (1979).

Calculations and statistics

The index method with chromic oxide was used to determine the apparent ileal digestibility and metabolizability coefficients of DM, N, and energy in the experimental diets (Kong and Adeola, 2014). The IDE and apparent ME contents of experimental diets were then calculated as the product of respective coefficients

Table 1. Ingredient composition of diets used in experiment 1

Item	Reference diet	TDDGS, %		SDDGS, %	
		10	20	10	20
Ingredients, %					
Corn	50.34	45.05	39.77	45.05	39.77
Soybean meal	38.20	34.19	30.18	34.19	30.18
TDDGS	0	10.00	20.00	0	0
SDDGS	0	0	0	10.00	20.00
Corn starch	0.70	0.42	0.13	0.42	0.13
Soybean oil	4.00	3.58	3.16	3.58	3.16
DL-Methionine	0.30	0.30	0.30	0.30	0.30
L-Lysine HCl	0.11	0.11	0.11	0.11	0.11
Monocalcium phosphate	1.75	1.75	1.75	1.75	1.75
Limestone	1.40	1.40	1.40	1.40	1.40
Salt	0.40	0.40	0.40	0.40	0.40
Corn starch–chromic oxide premix ¹	2.50	2.50	2.50	2.50	2.50
Vitamin–mineral premix ²	0.30	0.30	0.30	0.30	0.30
Calculated composition					
Crude protein (N × 6.25), %	22.81	22.98	23.16	23.00	23.19
Ca, %	0.93	0.91	0.90	0.92	0.91
P, %	0.75	0.71	0.68	0.71	0.68
Analyzed composition					
Crude protein (N × 6.25), %	22.87	22.20	23.44	21.76	23.65
Gross energy, kcal/kg	4,196	4,301	4,394	4,241	4,344

¹Prepared as 1 g of chromic oxide mixed with 4 g of corn starch.

²Supplied the following per kilogram of diet: vitamin A, 5,484 IU; vitamin D₃, 2,643 IU; vitamin E, 11 IU; menadione sodium bisulfite, 4.38 mg; riboflavin, 5.49 mg; D-pantothenic acid, 11 mg; niacin, 44.1 mg; choline chloride, 771 mg; vitamin B₁₂, 13.2 µg; biotin, 55.2 µg; thiamine mononitrate, 2.2 mg; folic acid, 990 µg; pyridoxine hydrochloride, 3.3 mg; I, 111 µg; Mn, 66.06 mg; Cu, 4.44 mg; Fe, 44.1 mg; Zn, 44.1 mg; Se, 300 µg.

and the GE of diets (kcal/kg). Apparent ME_n was calculated by correction of apparent ME to zero N retention using the factor of 8.22 kcal/g of N (Hill and Anderson, 1958). The IDE, ME, and ME_n of test ingredients (TDDGS, SDDGS, or rye) were then estimated using the regression method described by Bolarinwa and Adeola (2012). The energy of assay diets was corrected for non-energy-yielding fractions. The IDE, ME, and ME_n of the experimental diets were then corrected for substitution rates of the energy-yielding ingredients. Test ingredient IDE, ME, or ME_n for each level of substitution in the assay diets were calculated using the difference procedure as previously described (Adeola, 2001). Intake of dry TDDGS, SDDGS, or rye at each level of substitution was calculated as the product of test ingredient substitution rate and DM intake. The product of TDDGS, SDDGS, or rye intake at each level of substitution and test ingredient IDE, ME, or ME_n for each level of substitution in the assay diets is the test ingredient-associated IDE, ME, or ME_n intake in kilocalories. Data for ileal digestibility and metabolizability of energy were analyzed using PROC GLM of SAS (SAS Institute Inc., Cary, NC). Dietary treatments and blocks were included in the model as independent variables. The experimental unit was a cage. In each experiment, multiple linear regression of the test ingredient-associated IDE, ME, or ME_n intake in kilocalories against kilograms of test ingredient intake for cage of birds was conducted using the following SAS statements: Proc GLM; Class TI; Model Y = TI*DMintake/solution; the solution option was used to generate intercept and slopes. Y is test ingredient-associated IDE, ME, or ME_n intake in kilocalories; TI is test ingredient (coded as TDDGS or SDDGS in experiment 1; rye in experiment 2); DMintake is test ingredient intake in kilograms of DM, which is used as a regressor. The

slope from the regression equation is the actual energy value of the test ingredient. Statistical significance was considered when P-value was less than 0.05.

Results

The analyzed nutrient and energy compositions of TDDGS and SDDGS used in the current study are presented in Table 3. TDDGS and SDDGS have similar nutritive contents, except for ether extract and fiber fraction. Respective lysine and valine concentrations in SDDGS were 159% and 132% of those in TDDGS. The growth performance of birds on diets containing TDDGS or SDDGS in experiment 1 or rye in experiment 2 is given in Table 4. The test diets containing TDDGS or SDDGS at 10% or 20% did not affect the growth performance of birds from day 14 to 21 post-hatching. The 7-d weight gain or feed efficiency from day 14 to 21 post-hatching was not affected by TDDGS or SDDGS substitution at 10% to 20% in experiment 1 with the average initial BW, 7-d weight gain, feed intake, and gain/feed at 389 g, 344 g, 516 g, and 665 g/kg, respectively. Replacement of energy-yielding ingredients in the reference diet with 20% to 40% rye resulted in linear reductions ($P < 0.01$) in 5-d weight gain and gain/feed from 396 to 283 g and 660 to 522 g/kg during the day 18 to 23 post-hatching period in experiment 2 (Table 4).

As given in Table 5, there were linear reductions ($P < 0.01$) in ileal digestibility and retention of DM as dietary TDDGS or SDDGS (experiment 1) or rye concentration in the test diets increased from 0 to 20% (experiment 1) or to 40% (experiment 2). Ileal digestibility of N was not affected by replacement of part of the reference diet with TDDGS, SDDGS, or rye. Whereas N retention increased ($P < 0.01$) with rye addition in experiment 2, TDDGS or

Table 2. Ingredient composition of diets used in experiment 2

Item	Reference diet	Rye, %	
		20	40
Ingredients, %			
Corn	52.52	41.04	29.57
Soybean meal	35.50	28.03	20.56
Rye	0	20.00	40.00
Soybean oil	5.00	3.95	2.89
DL-Methionine	0.38	0.38	0.38
L-Lysine HCl	0.29	0.29	0.29
L-Threonine	0.11	0.11	0.11
Monocalcium phosphate	1.50	1.50	1.50
Limestone	1.50	1.50	1.50
Salt	0.40	0.40	0.40
Corn–chromic oxide premix ¹	2.50	2.50	2.50
Vitamin–mineral premix ²	0.30	0.30	0.30
Calculated composition			
Crude protein (N × 6.25), %	22.57	20.39	18.21
Ca, %	0.93	0.91	0.90
P, %	0.69	0.67	0.66
Analyzed composition			
Crude protein (N × 6.25), %	22.98	20.03	19.04
Gross energy, kcal/kg	4,285	4,344	4,387

¹Prepared as 1 g of chromic oxide mixed with 4 g of corn.

²Supplied the following per kilogram of diet: vitamin A, 5,484 IU; vitamin D₃, 2,643 IU; vitamin E, 11 IU; menadione sodium bisulfite, 4.38 mg; riboflavin, 5.49 mg; D-pantothenic acid, 11 mg; niacin, 44.1 mg; choline chloride, 771 mg; vitamin B₁₂, 13.2 µg; biotin, 55.2 µg; thiamine mononitrate, 2.2 mg; folic acid, 990 µg; pyridoxine hydrochloride, 3.3 mg; I, 111 µg; Mn, 66.06 mg; Cu, 4.44 mg; Fe, 44.1 mg; Zn, 44.1 mg; Se, 300 µg.

SDDGS addition did not affect N retention in experiment 1. Ileal digestibility of energy tended to linearly decrease ($P < 0.10$) and metabolizability of energy linearly decreased ($P < 0.05$) as dietary concentration of SDDGS in experiment 1 (Table 5). Ileal digestibility and metabolizability of energy linearly decreased ($P < 0.05$) as dietary concentration of TDDGS (experiment 1) or rye (experiment 2) increased in the test diets (Table 5). Apparent ME or ME_n of diets was not affected by dietary concentration of TDDGS or SDDGS in experiment 1. Apparent ME or ME_n of diets linearly decreased ($P < 0.01$) in experiment 2 as dietary rye increased from 0 to 40% (Table 5).

Table 6 depicts the IDE, ME, and ME_n concentrations of TDDGS and SDDGS in experiment 1 and rye in experiment 2 for broiler chickens. The regression of IDE, apparent ME, and apparent ME_n intake associated with TDDGS, SDDGS, or rye against the substituted DDGS or rye (X, kg DM) were for the diet with TDDGS substitution: IDE = $12.3 + 3,288X$, ME = $-3.0 + 2,800X$, and ME_n = $-0.31 + 2,647X$; for the diet with SDDGS substitution: IDE = $-4.9 + 3,247X$, ME = $-7.5 + 3,210X$, and ME_n = $-7.0 + 3,072X$; and for the diet with rye substitution: IDE = $9.5 + 3,002X$, ME = $6.3 + 3,053X$, and ME_n = $4.8 + 2,928X$. The comparisons of slopes and intercepts for IDE, ME, and ME_n regressions between the TDDGS and SDDGS diets are given in Table 6. The ME and ME_n slopes for the SDDGS were greater ($P < 0.01$) than those for TDDGS. However, slopes for IDE were not different between the two DDGS sources. The regression-derived IDE for TDDGS,

Table 3. Analyzed nutrient compositions (on a DM basis, except DM) of TDDGS, SDDGS, and rye used in experiments 1 and 2

Item	TDDGS	SDDGS	Rye
DM, %	92.74	91.18	91.22
Gross energy, kcal/kg	5,298	5,295	4,945
Crude protein (N × 6.25), %	27.72	28.63	13.21
Ether extract, %	6.55	10.16	2.43
Crude fiber, %	8.26	6.97	3.23
Neutral detergent fiber, %	37.11	30.27	14.23
Acid detergent fiber, %	11.72	14.69	4.87
Calcium, %	0.10	0.08	0.12
Phosphorus, %	0.60	0.64	0.36
Indispensable amino acid, %			
Arginine	1.15	1.31	0.82
Histidine	0.56	0.72	0.29
Isoleucine	0.98	1.28	0.37
Leucine	2.07	3.36	0.90
Lysine	0.71	1.13	0.48
Methionine	0.42	0.46	0.22
Phenylalanine	1.19	1.31	0.51
Threonine	0.85	1.12	0.44
Tryptophan	0.19	0.14	0.13
Valine	1.35	1.78	0.59
Dispensable amino acid, %			
Alanine	1.34	2.25	0.45
Aspartic acid	1.42	1.86	0.82
Cysteine	0.45	0.45	0.27
Glutamic acid	4.46	3.75	3.21
Glycine	1.06	1.12	0.55
Proline	2.21	1.93	1.87
Serine	0.96	1.16	0.44
Tyrosine	0.70	0.84	0.28

¹Values presented are from one replicate analysis for amino acids and means of duplicate analyses for the other nutrients (Adeola et al., 2010).

SDDGS, or rye was 3,288, 3,247, or 3,002 kcal/kg DM, respectively (Table 6). The respective ME and ME_n were 2,800 and 2,647 kcal/kg DM for TDDGS; 3,210 and 3,072 kcal/kg DM for SDDGS; and 3,053 and 2,928 kcal/kg DM for rye (Table 6).

Discussion

On a DM basis, the gross energy contents in TDDGS, SDDGS, and rye were within the range reported in the literature (Oryschak et al., 2010; NRC, 2012; Barekattain et al., 2013). The analyzed crude protein (CP) contents in the TDDGS (27.7%) and rye (13.2%) were comparable to the values (27.4% and 13%, respectively) reported in NRC (2012). However, the analyzed CP (28.6%) in SDDGS was slightly less than that (30.8%) reported in NRC (2012). Ether extract in TDDGS used in the current study was slightly greater than values reported in literature (Oryschak et al., 2010; NRC, 2012; Adeola and Kong, 2014), whereas the ether extract contents of SDDGS and rye are within the range in previous studies (Urriola et al., 2009; Cerisuelo et al., 2012; NRC, 2012; Barekattain et al., 2014).

The objective of the current experiments was to determine the energy value of TDDGS, SDDGS, and rye for broiler chickens. As these feed ingredients may be formulated into the diets of broiler chickens, knowledge of their energy value is crucial for cost-effective diets. The concentrations of TDDGS, SDDGS, or rye in the test diets are not levels likely to be used in practical diet formulation for broiler chickens. Formulating TDDGS, SDDGS, or

Table 4. Growth performance of birds on diets containing TDDGS or SDDGS in experiment 1¹, or rye in experiment 2²

Item	0	TDDGS, %		SDDGS, %		SEM ³	P-value			
		10	20	10	20		L ⁴	Q ⁴	L ⁵	Q ⁵
Experiment 1										
Initial weight, g	389	389	389	389	389	0.4	0.939	0.668	0.818	0.471
Final weight, g	710	719	728	746	737	17.2	0.479	0.988	0.286	0.291
Weight gain, g/bird	321	330	339	357	348	17.1	0.478	0.994	0.286	0.296
Feed intake, g/bird	483	491	503	541	529	17.2	0.431	0.915	0.070	0.112
Gain/feed, g/kg	666	661	674	662	662	25.1	0.823	0.772	0.903	0.941
	0	Rye, %		SEM ³	P-value					
		20	40		Linear	Quadratic				
Experiment 2										
Initial weight, g	650	650	650	43.8	0.681	0.766				
Final weight, g	1,046	989	933	42.4	<0.001	0.339				
Weight gain, g/bird	396	338	283	17.1	<0.001	0.654				
Feed intake, g/bird	661	566	542	22.8	0.682	0.129				
Gain/feed, g/kg	660	598	522	20.5	<0.001	0.339				

¹Birds in experiment 1 were on the diets for 7 d from day 14 to 21 post-hatching.²Birds used in experiment 2 were on the diets for 5 d from day 18 to 23 post-hatching.³Standard error of the mean.⁴Linear (L) and quadratic (Q) contrasts for TDDGS.⁵Linear (L) and quadratic (Q) contrasts for SDDGS.**Table 5.** DM, energy, and N digestibility and utilization of broilers fed experimental diets containing TDDGS or SDDGS in experiment 1¹, or rye in experiment 2²

Item	0	TDDGS, %		SDDGS, %		SEM ³	P-value			
		10	20	10	20		L ⁴	Q ⁴	L ⁵	Q ⁵
Experiment 1										
Ileal DM digestibility, %	70.6	70.0	68.2	69.5	68.9	0.4	<0.001	0.193	0.003	0.656
DM retention, % of DM intake	67.1	64.5	62.7	65.1	63.9	0.4	<0.001	0.386	<0.001	0.487
Ileal N digestibility, %	82.6	82.6	81.8	81.4	82.0	0.4	0.152	0.425	0.259	0.099
N retention, % of N intake	56.5	53.7	55.9	54.5	54.5	0.7	0.602	0.111	0.072	0.296
Ileal energy digestibility, %	72.4	72.6	71.1	71.5	71.4	0.4	0.043	0.102	0.090	0.486
Energy metabolizability, % intake	72.7	70.7	69.2	71.5	71.4	0.3	<0.001	0.597	0.014	0.209
Ileal digestible energy, kcal/g DM	3,365	3,470	3,473	3,356	3,398	38	0.453	0.475	0.144	0.213
Apparent ME, kcal/g DM	3,384	3,318	3,270	3,357	3,411	34	0.384	0.496	0.219	0.286
Apparent ME _n , kcal/g DM	3,194	3,139	3,108	3,172	3,219	32	0.216	0.437	0.194	0.214
	0	Rye, %		SEM ³	P-value					
		20	40		L ⁶	Q ⁶				
Experiment 2										
Ileal DM digestibility, %	72.1	71.4	70.3	0.3	<0.001	0.239				
DM retention, % of DM intake	69.2	67.3	64.5	0.3	<0.001	0.395				
Ileal N digestibility, %	83.2	83.9	84.5	0.3	0.152	0.542				
N retention, % of N intake	50.9	56.6	57.5	0.5	<0.001	<0.001				
Ileal energy digestibility, %	75.1	72.1	71.5	0.3	<0.001	0.212				
Energy metabolizability, % intake	74.5	71.8	69.1	0.2	<0.001	0.097				
Ileal digestible energy, kcal/g DM	3,553	3,448	3,331	14	<0.001	0.075				
Apparent ME, kcal/g DM	3,529	3,434	3,340	12	<0.001	0.096				
Apparent ME _n , kcal/g DM	3,375	3,285	3,196	11	<0.001	0.093				

¹Birds in experiment 1 were on the diets for 7 d from day 14 to 21 post-hatching.²Birds used in experiment 2 were on the diets for 5 d from day 18 to 23 post-hatching.³Standard error of the mean.⁴Linear (L) and quadratic (Q) contrasts for TDDGS.⁵Linear (L) and quadratic (Q) contrasts for SDDGS.⁶Linear (L) and quadratic (Q) contrasts for rye.

rye into the test diets reduced the ileal digestibility and retention of DM. Linear reductions in ileal digestibility and retention of DM were observed with increasing inclusion levels of barley

and DDGS produced from wheat, corn, or sorghum (Cozannet et al., 2010; Adeola and Zhai, 2012; Bolarinwa and Adeola, 2012; Adebiyi and Olukosi, 2015). Dietary fiber reduces DM retention in

Table 6. IDE, ME, and ME_n contents of TDDGS and SDDGS in experiment 1, and rye in experiment 2 for broiler chickens

Item	Intercept, kcal	Slope, kcal/kg DM	r ²
Experiment 1			
IDE			
TDDGS	12.3	3,288	0.87
SDDGS	-4.8	3,247	0.87
SEM	5.7	79	
P-value	0.054	0.718	
ME			
TDDGS	-3	2,800	0.86
SDDGS	-7.6	3,210	0.87
SEM	5.7	82	
P-value	0.575	0.003	
ME _n			
TDDGS	-0.4	2,647	0.87
SDDGS	-7.1	3,072	0.88
SEM	4.9	74	
P-value	0.348	0.001	
Experiment 2			
IDE			
Rye	9.5	3,002	0.91
SEM	4.6	53	
ME			
Rye	6.3	3,053	0.92
SEM	3.7	49	
ME _n			
Rye	4.8	2,928	0.93
SEM	3.5	37	

broiler chickens due to its low digestibility (Adeola et al., 2010). The increase in dietary fiber associated with increasing rye, or TDDGS, or SDDGS concentrations in the test diets may explain the reductions in ileal digestibility and retention of DM noted in the current study. Furthermore, the addition of TDDGS or SDDGS negatively affected digestibility and metabolizability of energy, which is consistent with the findings of Cozannet et al. (2010) and Barekattain et al. (2014) for sorghum DDGS as well as Bolarinwa and Adeola (2012) and Adebisi and Olukosi (2015) for wheat DDGS. Because the addition of DDGS had no effect on N utilization, the reduction in energy metabolizability with the increase in dietary DDGS is not attributable to energy expenditure for excretion of excess N. A linear reduction in utilization of energy occurred with rye in experiment 2. Consequently, linear decreases in diet IDE, ME, and ME_n were observed with increasing levels of rye from 0 to 40% of the diet, which may be due to viscosity arising from its high concentration of pentosans. Adeola and Bedford (2004) observed that high viscosity in wheat-based diets reduced fat, starch, N, and energy digestibility. Feeding a rye-soybean meal diet containing 58% rye to broiler chickens from day 4 to 22 post-hatching, Mathlouthi et al. (2002) reported that the rye-based diet reduced weight gain, feed efficiency, crude fat, and protein digestibility as well as apparent ME compared with the corn-based diet. Furthermore, villus length, width, and surface were decreased in broiler chickens fed the rye-based diet compared with those fed the corn-based diet suggesting reduced digestive and absorptive capacity.

The reference diet used in experiment 1 and given in Table 1 was formulated to contain 3,382 kcal ME/kg DM. The analyzed ME was 3,420 kcal/kg DM, in Table 5, which is very close and approximately 38 kcal/kg more than formulated or 101% of formulated ME. For experiment 2, the formulated ME of the

reference diet was 3,440 kcal/kg DM. The analyzed ME at 3,529 kcal/kg DM, depicted in Table 5, is approximately 89 kcal/kg more than formulated or 103% of formulated ME. Utilization of energy in feeds is affected by protein quality, which calls for correcting ME for nitrogen retention that occurred during the assay period. In experiment 1, nitrogen correction resulted in a 6% reduction in the ME of diets and respective 4% and 5% reductions in the ME values of TDDGS and SDDGS. Nitrogen correction resulted in a 4% reduction in the ME of diets as well as the ME concentration of rye. The range of reductions in ME values with nitrogen correction was in the bounds previously observed (McNabb and Blair, 1988; Adebisi and Olukosi, 2015; Zhong and Adeola, 2019). The linear reduction in energy metabolizability with increasing level of test ingredient supplementation did not appear to follow ME values of the test diets due perhaps to increasing gross energy of the test diets with increasing level of test ingredient supplementation.

Incorporating DDGS into diets generally results in increased dietary fiber and reduced nutrient digestibility of diet (Stein and Shurson, 2009; Adeola and Zhai, 2012). In a study with added dietary TDDGS from 0 to 30%, Oryschak et al. (2010) observed a linear decrease in nutrient and energy digestibility with increasing TDDGS. Negative effects on nutrient utilization were also observed in a study conducted with SDDGS by Barekattain et al. (2013), where N digestibility in experimental diets fed to 21-d-old broilers decreased when the levels of dietary SDDGS increased from 0 to 30%. In the current study, the calculated fiber content in the experimental diets increased as the TDDGS or SDDGS inclusion level increased. However, the negative effect of DDGS inclusion on ileal energy digestibility was marginal. In addition, the IDE content in the diet increased as the dietary DDGS inclusion level increased. These discrepancies between the current study and other studies might be attributed to several factors, including bird variation (age, gender, or strain), DDGS source (Bolarinwa and Adeola, 2012), and method (index vs. total collection) used for determining energy digestibility (Barekattain et al., 2014).

The apparent ME content of experimental diets did not change with the addition of TDDGS or SDDGS. This result was unexpected as there were linear reductions in energy metabolizability with an increasing level of DDGS supplementation. This might be due to increasing gross energy of the test diets with increasing level of DDGS, the inclusion level of DDGS, or the method for determining energy utilization. In the current study, chromic oxide was used as the indigestible index to determine the metabolizability of energy in experimental diets. Barekattain et al. (2014) observed that the inclusion of 30% SDDGS in broiler diets could significantly reduce ME calculated by total collection in calorimetric chambers. However, this effect was not observed when the index method was used in the same study. In their study in which diets containing graded replacement of wheat with rye from 0 to 70% were fed to broiler chickens from day 7 to 17 post-hatching, Friesen et al. (1992) observed a 25% reduction in weight gain and a decrease in ME_n from 3,380 to 2,352 kcal/kg from 0 to 35% rye substitution.

Despite the absence of difference between TDDGS and SDDGS in IDE in the current study, the ME and ME_n of SDDGS were greater than those of TDDGS. The reason for this is unknown. Speculatively, different levels and types of fibrous contents might have contributed to such a difference in ME values. It has been reported that apparent ME_n was negatively correlated with neutral detergent fiber when prediction equations for apparent ME_n in broiler chickens were developed using nutrient and apparent ME_n contents in 15 corn DDGS samples (Meloche et al.,

2013). In addition, microbes in the ceca of broiler chickens are capable of fermenting undigested dietary fiber entering from the ileum into short-chain fatty acids such as acetate, butyrate, and propionate. To the best of our knowledge, no study has evaluated energy digestibility or metabolizability of SDDGS for broiler chickens. However, in our previous growing pig study, the DE, apparent ME, and apparent ME_n of SDDGS were 3,520, 3,355, and 3,228 kcal/kg, respectively, which are greater than those of SDDGS evaluated in the current study (Adeola and Kong, 2014). There is also a dearth of publication reporting energy utilization of broilers fed TDDGS. Oryschak et al. (2010) reported that the IDE of TDDGS has a range from 2,014 to 2,077 kcal/kg using the difference method, which is less than the value in the current study. Such difference in IDE might be due to different DDGS sources. Bolarinwa and Adeola (2012) have reported that there was about 400 kcal/kg difference in the ME of two wheat DDGS samples with similar chemical compositions. From the data presented by Barekattain et al. (2014) on the measured NE and ME of diets formulated with SDDGS, the ME of SDDGS is estimated at 2,700 kcal/kg, which is lower than in the current study. There is also a paucity of information on the energy value of rye for broiler chickens. NRC (1994) has the ME of rye at 2,985 kcal/kg DM, which is only 68 kcal/kg DM lower than the regression-derived ME for rye in the current study.

In conclusion, the current study provided energy values of TDDGS and SDDGS using the regression method. The IDE in two DDGS samples evaluated was not different, whereas the ME and ME_n of the TDDGS were about 400 kcal/kg less than those of SDDGS. In addition, the current study showed that TDDGS and SDDGS could be used as potential energy sources for broiler chickens. The IDE, ME, and ME_n of TDDGS evaluated in the current study were 3,288, 2,800, and 2,647 kcal/kg of DM, respectively; the corresponding values for SDDGS were 3,247, 3,210, and 3,072 kcal/kg of DM. The respective IDE, ME, and ME_n for rye evaluated in the current study were 3,002, 3,053, and 2,928 kcal/kg DM.

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Conflict of interest statement

The authors have no conflict of interest.

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