Energy values of copra meal and cornstarch for broiler chickens

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ABSTRACT Two studies were conducted with broiler chickens to determine the ileal digestible energy (**IDE**), ME, and MEn in copra meal (**CM**) and cornstarch using the regression method. On day 15 and 16 for experiments 1 and 2, respectively, 192 male birds were individually weighed and allotted into 3 dietary treatments with 8 replicate cages and 8 birds per cage in a randomized complete block design with the BW as a blocking factor in each experiment. Dietary treatments consisted of 3 inclusion levels of test ingredients (i.e., 0, 100, or 200 g/kg) in corn-soybean meal–based diets using CM or cornstarch as test ingredients for experiment 1 or 2, respectively. Titanium dioxide was added as an indigestible marker to determine the ileal digestibility and utilization of energy by the index method. Experiments lasted 5 d, and excreta collection was conducted during the last 3 d of each experiment. At the end of experiments, birds were euthanized by CO_2 asphyxiation, and ileal digesta samples were collected. Data were analyzed by the ANOVA using the GLM procedure. In experiment 1, the apparent ileal digestibility (**AID**) of DM and gross energy (**GE**) and IDE in test diets linearly decreased ($P < 0.05$) with substitution of CM in test diets. In experiment 2, there were quadratic increases ($P < 0.01$) in the AID of DM and GE and IDE in diets as the concentration of cornstarch in test diets increased. In addition, linear increases ($P < 0.05$) in the apparent total tract utilization of DM, N, and GE and ME and MEn in test diets were observed. The estimates of IDE, ME, and MEn in CM were 2,493, 3,727, and 3,546 kcal/kg DM, respectively, whereas respective values of cornstarch were estimated at 4,181, 3,992, and 3,946 kcal/kg DM, respectively. In conclusion, inclusion of CM in diets may reduce the digestibility of GE, whereas the digestibility and utilization of GE may increase when adding cornstarch into diets for broiler chickens.

Key words: broiler, copra meal, cornstarch, energy, regression

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INTRODUCTION

The unstable price of major feed ingredients during the last decade has increased the importance of alternative feed ingredients, which can be used to partially replace corn and soybean meal (**SBM**) in diets for broiler chickens. Byproducts from food productions can be used as alternative feed ingredients as a form of decreasing the amount of waste. To appropriately use such ingredients in diets with the least cost formulation, an accurate determination of nutrients and energy utilization by broiler chickens are necessary.

Copra meal (**CM**) is a byproduct of oil extraction from dried coconut kernel. The use of CM as a feed ingredient in diets for broiler chickens can be beneficial in countries where the production of coconut is abundant. However, CM contains high concentration of dietary fiber, mostly consisting of mannan, which increases the viscosity of digesta and reduces the digestibility of nutrients (Sundu et al., 2009; Shastak et al., 2015). The composition of nutrients and energy values vary among sources of CM mainly due to differences in storage conditions or extraction and drying processes.

Starch is the most energy-yielding component in corn and therefore is the main source of energy in broiler diets (Carré, 2004; Svihus, 2014). Purified cornstarch has been widely used in experimental diets because of its high energy-yielding property and purity by solely containing polymers of glucose. In previous studies conducted to evaluate the nutrient digestibility in feed ingredients, cornstarch has been used to formulate experimental diets in which a test ingredient is a sole source of the nutrient of interest (Adeola and Ileleji, 2009; Park et al., 2019). To control the potential errors from formulating and feeding experimental diets, it is necessary to use the accurate energy values of cornstarch. Therefore, two experiments were conducted to determine the ileal digestible energy (**IDE**), ME, and MEn in CM

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(experiment 1) and cornstarch (experiment 2) for broiler chickens using the regression method.

MATERIALS AND METHODS

All protocols used in the study were approved by the Purdue University Animal Care and Use Committee (West Lafayette, IN).

Birds, Management, and Sample Collection

Male broiler chicks (Cobb 500; Cobb-Vantress Inc., Siloam Springs, AR) with an average initial BW of 41 g, supplied by a local hatchery, were individually tagged on the neck with identification numbers on day 0 after hatching. Birds were reared in electrically heated battery brooders (model SB 4T, Alternative Design Manufacturing, Siloam Springs, AR). The temperature was controlled to decrease 1°C for every 2 d from 35°C on day 0 after hatching. Light was provided 23 h per day throughout the study. Birds received a standard mash starter diet prepared to meet or exceed nutrient requirements recommended by NRC (1994) before the initiation of experiments. Metabolism trials in experiments 1 and 2 were based on the methodology suggested in Kong and Adeola (2014). On day 15 and 16 after hatching in experiments 1 and 2, respectively, 192 birds for each experiment were individually weighed and allotted to 3 treatments consisting of 8 replicate cages, with 8 birds per cage in a randomized complete block design with the BW as a blocking factor. Excreta collection was conducted during the last 3 d of the experimental period by lining collection pans with waxed paper. After 5 d of feeding the experimental diets, all birds were euthanized by asphyxiation using CO_2, weighed individually, and dissected to excise the ileum, which was estimated as the portion of distal small intestine from the Meckel's diverticulum to ileocecal junction. Ileal digesta samples were collected from distal two-thirds of the ileum 2 cm proximal to the ileocecal junction by flushing contents with distilled water. Collected ileal digesta samples were pooled within cages and immediately stored at −20°C. The BW gain (**BWG**) and feed intake (**FI**) [g/bird] during the experimental periods were recorded, and the gain to feed ratio (**G:F**) (g/kg) of each cage was calculated.

Test Ingredients and Experimental Diets

A corn-SBM–based diet was used for both experiments 1 and 2 (Table 1). Calcium salt of fatty acids (Essentiom, Church & Dwight Co. Inc., Ewing Township, NJ) was added at 50 g/kg in the reference diets instead of vegetable oil to increase the homogeneity of feed ingredients in experimental diets. Crystalline amino acids including L-lysine·HCl, DL-methionine, and L-threonine were added to provide limiting amino acids in the reference diet. The reference diet was prepared to meet or exceed the nutrient requirements recommended by the NRC (1994). Copra meal was used as a test

Table 1. Ingredient and analyzed nutrient composition of experimental diets, g/kg as-fed basis.

Item	Starter diet	Reference diet	Copra meal, g/kg		Cornstarch, g/kg	
			100	200	100	200
Ingredient						
Ground corn	545.2	532.5	475.1	417.7	475.1	417.7
Soybean meal, 48% CP	360.0	360.0	322.6	285.2	322.6	285.2
Soybean oil	50.0	0.0	0.0	0.0	0.0	0.0
Copra meal	0.0	0.0	100.0	200.0	0.0	0.0
Cornstarch	0.0	0.0	0.0	0.0	100.0	200.0
Fatty acids[1]	0.0	50.0	44.8	39.6	44.8	39.6
Ground limestone	15.0	6.0	6.0	6.0	6.0	6.0
Monocalcium phosphate	15.0	15.0	15.0	15.0	15.0	15.0
Salt	4.0	4.0	4.0	4.0	4.0	4.0
L-Lysine·HCl	2.9	1.0	1.0	1.0	1.0	1.0
DL-Methionine	3.8	2.5	2.5	2.5	2.5	2.5
L-Threonine	1.1	1.0	1.0	1.0	1.0	1.0
Vitamin-mineral premix[2]	3.0	3.0	3.0	3.0	3.0	3.0
Titanium dioxide premix[3]	0.0	25.0	25.0	25.0	25.0	25.0
Total	1,000	1,000	1,000	1,000	1,000	1,000
Analyzed nutrient						
DM	-	875	878	884	872	874
GE, kcal/kg	-	4,024	4,093	4,197	3,960	3,922
CP	-	213	220	207	199	179
Calculated nutrient						
Ca	9.0	10.4	9.9	9.4	9.8	9.2
Total P	7.0	7.2	7.4	7.5	6.8	6.4
Nonphytate P	5.0	4.7	4.9	5.0	4.5	4.4

[1]Calcium salt of fatty acids (Essentiom, Church & Dwight Co. Inc., Ewing Township, NJ).

[2]Provided the following quantities per kg of complete diet: vitamin A, 5,145 IU; vitamin D_3, 2,580 IU; vitamin E, 17.15 IU; menadione, 4.38 mg; riboflavin, 5.49 mg; D-pantothenic acid, 11.0 mg; niacin, 44.1 mg; choline chloride, 771 mg; vitamin B12, 0.01 mg; biotin, 0.06 mg; thiamine mononitrate, 2.20 mg; folic acid, 0.99 mg; pyridoxine hydrochloride, 3.30 mg; I, 1.11 mg; Mn, 107 mg; Cu, 4.44 mg; Fe, 73.5 mg; Zn, 179 mg; Se, 0.43 mg.

[3]Prepared as 1-g titanium dioxide added to 4 g of ground corn.

ingredient in experiment 1, whereas cornstarch was used as a test ingredient in experiment 2. In both experiments 1 and 2, 2 test diets were prepared to contain 100 or 200 g/kg test ingredient by replacing the energy-yielding ingredients (i.e., corn, SBM, and fatty acids). The ratio of corn, SBM, and fatty acids was maintained at 11.1:7.2:1 for all diets. Titanium dioxide was added as an indigestible index marker at 5 g/kg of diet in the form of a premix with ground corn.

Chemical Analysis

Excreta and ileal digesta samples were placed in a forced-air drying oven at 55°C until constant weight. Feed ingredients, experimental diets, excreta, and ileal digesta samples were ground (<0.75 mm) using a centrifugal grinder (ZM 200; Retsch GmbH, Haan, Germany). Ground samples were analyzed for DM by drying at 105°C overnight in a forced-air drying oven (Precision Scientific Co., Chicago, IL; method 934.01; AOAC, 2006), gross energy (**GE**) by an isoperibol bomb calorimeter (Parr 6200; Parr Instrument Co., Moline, IL), and nitrogen (**N**) using the combustion method (TruMac N; LECO Corp., St. Joseph, MI; method 990.03; AOAC, 2000). Titanium concentration in experimental diets, ileal digesta, and excreta samples was analyzed by Myers et al. (2004). In addition, feed ingredients were analyzed for ether extract (**EE**; method 945.16; AOAC, 2000), ash (method 942.05; AOAC, 2006), crude fiber (method 978.10; AOAC, 2006), acid detergent fiber (**ADF**; method 973.18 (AD); AOAC, 2006), and neutral detergent fiber (**NDF**; Van Soest et al., 1991) (Table 2).

Calculations and Statistical Analysis

The apparent ileal digestibility (**AID**, %) and apparent total tract utilization (**ATTU**, %) of DM, GE, and N in experimental diets were calculated as described by Kong and Adeola (2014):

$$\text{AID or ATTU } (\%) = 100 - [(\text{Ti}_i \times \text{E}_o) / (\text{Ti}_o \times \text{E}_i) \times 100],$$

where Ti_i and Ti_o represent titanium concentrations (g/kg DM) in diets and ileal digesta or excreta output, respectively; E_i and E_o represent DM (g/kg DM), GE (kcal/kg DM), or N (g/kg DM) concentrations in diets and ileal digesta or excreta output, respectively. The IDE and ME (kcal/kg DM) in experimental diets were calculated as the product of the GE concentration and the AID and ATTU of GE, respectively. The MEn (kcal/kg DM) in experimental diets was calculated by correcting ME concentration to a 0 N retention using the correction factor of 8.22 kcal/g N retention (Hill and Anderson, 1958):

$$\text{N retention (g / kg)} = \text{N}_i \times \text{ATTU of N};$$

$$\text{MEn(kcal / kg DM)} = \text{ME} - (8.22 \times \text{N retention}),$$

where N_i represents the concentration of N (g/kg DM) in diets.

The IDE (kcal/kg DM) in test ingredients was calculated by the difference procedure using the equation suggested by Adeola (2001) as follows:

$$\text{IDE}_{ti}(\text{kcal / kg DM}) = [\text{IDE}_{td} - (\text{IDE}_{rd} \times \text{P}_{rd}) / \text{P}_{ti}],$$

where IDE_{ti}, IDE_{td}, and IDE_{rd} represent the IDE (kcal/kg DM) in the test ingredient, test diet, and reference diet, respectively; P_{rd} and P_{ti} represent the proportion of the reference diet and test ingredient in the test diet, respectively. The ME and MEn (kcal/kg DM) in test ingredients were calculated using the same equation by replacing IDE with ME and MEn, respectively.

For the regression analysis, test ingredient intake (**DMI_{ti}**; g DM/bird) of each cage was calculated by the product of DM intake and proportion of test ingredients in test diets. In addition, test ingredient–associated IDE intake (**IDEI_{ti}**; kcal/bird) of each cage was calculated by multiplying the test ingredient intake and IDE in test ingredient determined in each cage and regressed against the DMI_{ti} by the following model:

$$\text{IDEI}_{ti}(\text{kcal/bird}) = \text{a} \times \text{DMI}_{ti},$$

where a is the slope of regression model that represents the estimated IDE in test ingredient, and the intercept of the model is set at 0 based on the DMI_{ti} of birds fed

Table 2. Analyzed nutrient composition of feed ingredients, g/kg DM basis.

	Ingredient				
Item	Copra meal	Cornstarch	Ground corn	SBM	Fatty acids[1]
DM	907	873	863	883	957
Gross energy, kcal/kg DM	5,356	4,162	4,537	4,568	7,985
CP	229	-	83.3	479	-
Ether extract	229	-	40.9	31.9	15.5
Crude fiber	116	-	15.8	40.3	-
Ash	49.6	-	11.1	69.3	142
Neutral detergent fiber	436	-	88.6	100	-
Acid detergent fiber	274	-	21.5	58.9	-

Abbreviation: SBM, soybean meal.
[1]Calcium salt of fatty acids (Essentiom, Church & Dwight Co. Inc., Ewing Township, NJ).

the reference diet. The ME and MEn in test ingredients were estimated using the same regression model by replacing IDE with ME and MEn, respectively.

Data were analyzed using GLM procedure of SAS (SAS Inst. Inc., Cary, NC). The model included diet and block as independent variables. Orthogonal polynomial contrast was conducted to determine the linear and quadratic effects of increasing levels of test ingredients. Regression analysis between the test ingredient–associated IDE, ME, or MEn intake and DMI_{ti} was conducted using the GLM procedure of SAS with solution I option to generate the prediction equation as described by Bolarinwa and Adeola (2012). The experimental unit was individual cage, and statistical significance was determined at α level of 0.05.

RESULTS

In experiment 1, substituting CM into the reference diet did not affect the growth performance of broiler chickens during the experimental period except for a quadratic effect ($P = 0.030$) observed on G:F of birds (Table 3). There were linear decreases ($P < 0.01$) in the AID of DM and GE and IDE in diets as the concentration of CM in diets increased. There were no effects of dietary CM inclusion on ATTU of DM, GE, or N as well as ME and MEn in diets. The estimated IDE, ME, and MEn in CM by regression method were 2,493, 3,727, and 3,546 kcal/kg DM, respectively (Table 4; Figure 1).

In experiment 2, growth performance including the final BW, BWG, and G:F of broiler chickens linearly decreased ($P < 0.01$) with increasing concentration of cornstarch in experimental diets (Table 3). There was a quadratic effect ($P = 0.018$) on the FI of birds when the dietary cornstarch concentrations increased. Substitution of cornstarch into diets resulted in quadratic increases ($P < 0.01$) in the AID of DM and GE as well as IDE in experimental diets. The ATTU of DM, GE, and N increased linearly, along with ME and MEn ($P < 0.05$) as the concentration of cornstarch in diets increased. The IDE, ME, and MEn in cornstarch were estimated at 4,181, 3,992, and 3,946 kcal/kg DM, respectively, based on the slope of regression analysis (Table 4; Figure 2).

DISCUSSION

Utilization of alternative feed ingredients in poultry diets rely on, among other things, accurate nutrient digestibility and energy utilization data. Among various alternative feed ingredients, CM has a potential as an effective alternative feed ingredient because of its considerable CP concentration (Sundu et al., 2009); however, research conducted to evaluate the nutritional values in CM is relatively scarce. To provide more data on energy utilization of CM, the present study was conducted to determine the IDE, ME, and MEn of CM for broiler chickens. Together with energy values, determination of nutrient digestibility, such as amino acids or phosphorus, is also required for the appropriate use of CM in diets for broiler chickens. Conventional methodologies to determine nutrient digestibility involve the use of cornstarch as a major component of semipurified diets (Kong and Adeola, 2014). However, there is also a lack of information regarding the energy values in cornstarch which is prerequisite for an accurate formulation of experimental diets. Therefore, experiment 2 was designed to determine the energy values in cornstarch, and future research to determine the nutrient digestibility in CM

Table 3. Growth performance, apparent ileal digestibility (%), total tract utilization (%) of DM, gross energy (GE), and nitrogen (N) and energy values in experimental diets containing increasing concentration of copra meal (CM) and cornstarch fed to broiler chickens.[1]

	Experiment 1[2]						Experiment 2[3]					
		CM, g/kg			P-value[4]			Cornstarch, g/kg			P-value[4]	
Item	RD	100	200	SEM	L	Q	RD	100	200	SEM	L	Q
Initial BW, g	441	441	441	0.2	-	-	541	543	543	1.2	-	-
Final BW, g	739	741	727	6.1	0.201	0.331	874	843	790	5.2	<0.001	0.122
BW gain, g/bird	297	305	286	5.3	0.144	0.066	334	300	248	4.8	<0.001	0.132
Feed intake, g/bird	396	393	389	6.2	0.406	0.928	459	445	402	4.5	<0.001	0.018
G:F, g/kg	754	785	740	13.0	0.468	0.030	727	675	616	8.1	<0.001	0.785
Ileal digestibility												
DM	70.2	67.1	62.6	0.47	<0.001	0.209	70.5	74.8	75.8	0.32	<0.001	0.001
Gross energy	71.3	68.5	65.3	0.69	<0.001	0.828	72.8	76.6	77.7	0.36	<0.001	0.007
IDE[5], kcal/kg DM	3,282	3,194	3,102	32.2	0.001	0.958	3,345	3,479	3,485	16.4	<0.001	0.007
Total tract utilization												
DM	72.7	71.6	71.0	1.08	0.300	0.860	74.8	76.3	78.7	0.34	<0.001	0.236
Gross energy	75.5	74.6	74.1	1.02	0.353	0.868	78.5	79.5	81.5	0.33	<0.001	0.309
Nitrogen	64.9	67.6	66.4	1.71	0.546	0.360	69.4	70.0	72.4	0.76	0.015	0.332
ME, kcal/kg DM	3,472	3,476	3,517	48.1	0.512	0.752	3,605	3,610	3,656	15.1	0.032	0.283
MEn, kcal/kg DM	3,290	3,280	3,337	43.9	0.459	0.546	3,401	3,427	3,485	13.7	<0.001	0.337

[1]In both experiments 1 and 2, each least squares mean represents 8 observations.
[2]Birds were fed experimental diets for 5 d from day 15 to 19 after hatching.
[3]Birds were fed experimental diets for 5 d from day 16 to 20 after hatching.
[4]L = linear effect of test ingredient; Q = quadratic effect of test ingredient.
[5]IDE = ileal digestible energy.

Table 4. Parameters of regression analysis between test ingredient intake (kg DM/bird) and test ingredient–associated energy intake (kcal/bird) of broiler chickens.[1]

	Slope			Intercept			Statistical parameter		
Item	Parameter	SE	*P*-value	Parameter	SE	*P*-value	SD	R^2	*P*-value
Experiment 1[2]									
IDE[4], kcal/kg DM	2,493	195.4	<0.001	0.542	8.7060	0.951	27.1	0.881	<0.001
ME, kcal/kg DM	3,727	255.2	<0.001	1.567	11.3696	0.892	35.4	0.907	<0.001
MEn, kcal/kg DM	3,546	233.3	<0.001	−0.196	10.3959	0.985	32.4	0.913	<0.001
Experiment 2[3]									
IDE[4], kcal/kg DM	4,181	144.4	<0.001	7.868	6.6976	0.253	20.4	0.974	<0.001
ME, kcal/kg DM	3,992	124.4	<0.001	−2.488	5.7673	0.670	17.5	0.979	<0.001
MEn, kcal/kg DM	3,946	110.6	<0.001	−1.986	5.1302	0.702	15.6	0.983	<0.001

[1]In both experiments 1 and 2, regression analysis was conducted with 24 observations.
[2]Birds were fed experimental diets for 5 d from day 15 to 19 after hatching.
[3]Birds were fed experimental diets for 5 d from day 16 to 20 after hatching.
[4]IDE = ileal digestible energy.

would use energy values determined in experiment 2. In both experiments 1 and 2, the methodology of experiments was based on the study by Kong and Adeola (2014), which has been widely used to determine the energy values in various feed ingredients for broiler chickens (Bolarinwa and Adeola, 2012; Ravindran et al., 2014; Adeola and Kong, 2020).

Copra meal is composed of the residues of coconut after the extraction of oil, drying, and grinding; therefore, it comprises high fiber content. Reportedly, the NDF and ADF concentrations vary, respectively, from 551 to 683 and 277 to 357 g/kg DM (Sundu, 2008; Sundu et al., 2009; NRC, 2012; Son et al., 2012; Stein et al., 2015; Rostagno et al., 2017; Son et al., 2017). However, the CM used in this study presented 436 and 274 g/kg DM of NDF and ADF, respectively (Table 2). Moreover, the analyzed concentration of crude fiber in CM was within the range of values, from 70 to 150 g/kg, reported by Sundu et al. (2009).

The EE content was 229 g/kg DM in CM, by contrast previous studies reported values ranging from 19.0 to 84.0 g/kg DM (NRC, 1994; Sundu et al., 2009; NRC, 2012; Son et al., 2012; Stein et al., 2015; Rostagno et al., 2017; Son et al., 2017). This may be due to the differences in oil extraction process during the production of CM. Panigrahi (1992) found that CM expelled twice during oil extraction contained 75 g/kg EE, whereas CM pressed once contained 220 g/kg EE. Because of the high EE, GE was also higher than the previously reported values between 4,539 and 4,781 kcal/kg DM (Sundu et al., 2009; NRC, 2012; Son et al., 2012; Stein et al., 2015; Rostagno et al., 2017; Son et al., 2017). The concentration of CP in the CM used in the present study was 229 g/kg DM; this is consistent with previous studies that reported CP between 209 and 243 g/kg DM (NRC, 1994; Sundu et al., 2009; NRC, 2012; Son et al., 2012; Rostagno et al., 2017; Son et al., 2017). The composition of CM presented higher EE and GE and

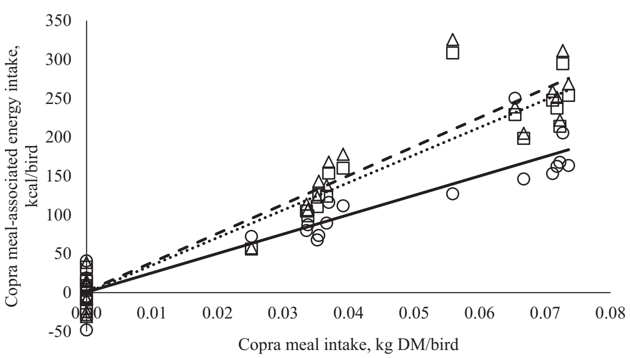

Figure 1. Regression analyses between copra meal intake (kg DM/bird) and copra meal–associated energy intake (kcal/bird) of broiler chickens in experiment 1. The ileal digestible energy (IDE; circle and solid line), ME (triangle and dashed line), and MEn (square and dotted line) were estimated by the slope of regression analyses, and dependent variables of the models were respective energy intake associated with copra meal. The estimated IDE, ME, and MEn in copra meal were 2,493, 3,727, and 3,546 kcal/kg DM, respectively, based on the models as follows: IDE, y = 2,493x (SE = 195.4) + 0.542 (R^2 = 0.881, SD = 27.1, $P < 0.001$); ME, y = 3,727x (SE = 255.2) + 1.567 (R^2 = 0.907, SD = 35.4, $P < 0.001$); MEn, y = 3,546x (SE = 233.3)–0.196 (R^2 = 0.913, SD = 32.4, $P < 0.001$).

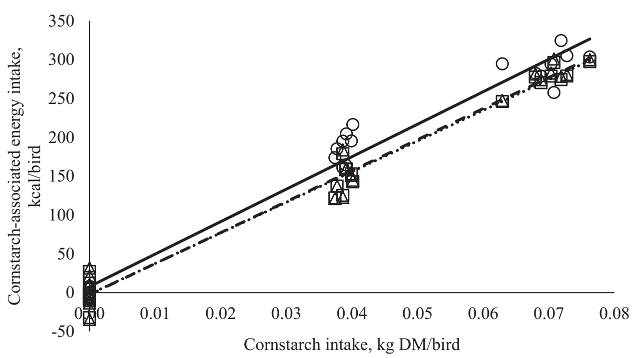

Figure 2. Regression analyses between cornstarch intake (kg DM/bird) and cornstarch-associated energy intake (kcal/bird) of broiler chickens in experiment 2. The ileal digestible energy (IDE; circle and solid line), ME (triangle and dashed line), and MEn (square and dotted line) were estimated by the slope of regression analyses, and dependent variables of the models were respective energy intake associated with cornstarch. The estimated IDE, ME, and MEn in cornstarch were 4,181, 3,992, and 3,946 kcal/kg DM, respectively, based on the models as follows: IDE, y = 4,181x (SE = 144.4) + 7.868 (R^2 = 0.974, SD = 20.4, $P < 0.001$); ME, y = 3,992x (SE = 124.4)–2.488 (R^2 = 0.979, SD = 17.5, $P < 0.001$); MEn, y = 3,946x (SE = 110.6)–1.986 (R^2 = 0.983, SD = 15.6, $P < 0.001$).

lower NDF and ADF than previously reported values, suggesting that the increase in fat content substituted part of the fibrous and less digestible content that was expected to be present in CM.

The increased concentration of dietary fiber in the diet containing 200 g/kg CM may have been responsible for the quadratic response in G:F of birds fed increasing concentration of CM in experimental diets. However, the BWG and FI were not significantly affected by CM inclusion, contrary to the findings of Sundu et al. (2006), that reported a decrease in the BWG and FI of broiler chickens fed corn-SBM–based diets from day 4 to day 14, with gradually increasing CM inclusion from 0 to 500 g/kg. This may be due to the age difference, considering that older birds have a greater intake and fiber digestion capacity. In addition, dietary treatments were prepared to estimate the energy values of CM by regression analysis in the present study, and therefore, the structure of treatment as well as nutrient and ingredient composition of experimental diets were not designed for growth performance of broiler chickens fed diets containing CM. Further research is needed to estimate the optimal concentration of CM in diets for broiler chickens.

Replacing portions of the reference diet with CM linearly decreased the AID of DM and GE and IDE in experimental diets, which may be due to increased dietary fiber concentration and antinutritional factors from CM in experimental diets. The major antinutritional factor in CM is mannan, which is a class of nonstarch polysaccharide that has negative effects on nutrient digestibility by encapsulating starch and protein in the cereal endosperm and increasing digesta viscosity (Sundu et al., 2009; Shastak et al., 2015). Shastak et al. (2015) reported that the mannan concentration in CM was 250 g/kg, whereas those in corn and SBM were 0.8 and 13 g/kg, respectively. Graded substitution of CM had no effect on ATTU of DM, GE, and N or on ME and MEn. Thus, the difference between AID and ATTU increased with the inclusion of CM, suggesting that cecal fermentation of fiber and production of volatile fatty acids maintained the energy metabolizability level throughout the treatments.

The ME and MEn in CM estimated in the present study were greater than the values reported in previous studies, 1,658 kcal/kg DM of MEn (NRC, 1994), 2,413 kcal/kg DM of ME (Sundu, 2008), and 2,122 kcal/kg DM of ME (Rostagno et al., 2017). The greater EE and GE combined with lower fiber content in the CM used in this study may explain this discrepancy when compared with nutrient composition of CM in other studies.

Because diets used in experiment 2 were prepared to estimate the energy values of cornstarch using regression method, the inclusion of cornstarch in diets resulted in a reduction in dietary CP from 213 to 179 g/kg and the concentration of several amino acids to be below the requirements suggested in NRC (1994). This contributed to the linear or quadratic decrease in the BWG, FI, and G:F of birds. In addition, the small particle size of cornstarch resulted in a lower particle size of the test diets, which perhaps reduced the FI and BWG due to selective FI of birds to the coarser particles (Nir et al., 1994; Amerah et al., 2007; Abadi et al., 2019). Moreover, the greater ME and MEn in the test diets containing cornstarch may have contributed to a lower FI because of the appetite being regulated primarily by the ME in diets (Hill and Dansky, 1954).

Starch in corn is predominantly found in the endosperm as amylose and amylopectin, and its digestibility for poultry is generally greater than 95% depending on various factors such as the age of birds and processing of diets (Moran, 1982; Carré, 2004; Cowieson et al., 2018). In the present study, increasing the concentration of cornstarch in experimental diets resulted in quadratic increases of the AID of DM and GE and IDE, along with linear increases of the ATTU of DM and GE in experimental diets. In addition, the ATTU of N in diets linearly increased with increasing concentration of cornstarch, which may be due to the increased efficiency of dietary N utilization in the test diets arising from reduced concentration of indigestible N (Bregendahl et al., 2002; van Harn et al., 2019; Hilliar et al., 2020). Notwithstanding, it is noteworthy that the concentration of several amino acids in the test diets were below the requirement estimates as discussed earlier.

The estimated ME in cornstarch was consistent with the ME value published by Rostagno et al. (2017) at 3,986 kcal/kg DM. However, the MEn in cornstarch used in experiment 2 was lower than the MEn value of starch suggested by the NRC (1994) at 4,070 kcal/kg on an as-is basis, which may be due to the different methodologies used. The MEn value was based on projections from the digestion of starches from different sources submitted to different treatments (Naber and Touchburn, 1969). The low variability in the energy values of cornstarch may be due to a high homogeneity of the product, as its DM is composed of almost completely starch. Furthermore, the absence of N in cornstarch resulted in similarity between ME and MEn values.

In conclusion, the estimated IDE, ME, and nitrogen-corrected ME in CM were 2,493, 3,727, and 3,546 kcal/kg DM, respectively. The study showed that energy values for CM were variable in contrast with other studies, emphasizing the importance of energy values estimates to better consider its inclusion in diet formulations for broiler chickens. In addition, inclusion of CM in diets may reduce the digestibility of GE, whereas the digestibility and retention of GE may increase when adding cornstarch into diets for broiler chickens. The present study also provided regression-derived IDE, ME, and nitrogen-corrected ME of purified cornstarch at 4,181, 3,992, and 3,946 kcal/kg DM, respectively, which are valuable in formulating experimental diets for broiler chicken studies.

DISCLOSURES

The authors declare no conflict of interest.

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