Energy and phosphorus evaluation of poultry meal fed to broiler chickens using a regression method

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ABSTRACT Two experiments were conducted to determine energy (Exp. 1) and P (Exp. 2) utilization in poultry meal (**PM**) for broiler chickens. A total of 192 birds were allotted to 3 experimental diets in a randomized complete block design with BW as a blocking factor on d 15 and 16 post hatching in Exp. 1 and 2, respectively. Each diet was fed to 8 replicate cages with 8 birds per cage in both experiments. Initial BW of birds in Exp. 1 and 2 were 438 ± 76.9 g and 543 ± 50.2 g, respectively. Three corn-soybean meal-based diets were prepared to contain 0, 80, or 160 g/kg in Exp. 1 and 0, 50, or 100 g/kg in Exp. 2. In Exp. 1, the addition of PM to the reference diet linearly decreased ($P < 0.01$) the apparent ileal digestibility of DM and gross energy (**GE**), as well as the apparent total tract utilization (**ATTU**) of DM, GE, and N in diets; but did not affect the ileal digestible energy, ME, and MEn of diets. The ileal digestible energy, ME, and MEn of PM estimated by the regression method were 4,002, 3,756, and 3,430 kcal/kg DM, respectively, representing 58 to 68% of the GE in PM. In Exp. 2, graded concentration of PM in the reference diet linearly decreased ($P < 0.05$) ATTU of DM but linearly increased ($P < 0.01$) ATTU of P and quadratically increased ATTU of Ca in diets. The true ileal digestibility and true total tract utilization of P in PM estimated by the regression method were 77.5 and 79.0%, respectively. In conclusion, these results showed that inclusion of poultry meal in the diets of broiler chickens reduced the digestibility of GE but increased the utilization of P. The regression-estimated energy values and P digestibility of PM in the current studies may be used in diet formulation.

Key words: broiler, energy, phosphorus, poultry meal, regression

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INTRODUCTION

Poultry feed in the United States is mostly based on corn and soybean meal (**SBM**), with SBM being the foremost plant protein source. More than 70% of soybeans produced in the United States are used for livestock feed production, and hence there is a lot of dependence on SBM (USDA, 2015). Intensive research has been conducted to investigate nutritional value of alternative source of ingredients that could be cost-effective and enhance sustainable production.

Poultry meal (**PM**) is an animal protein by-product produced via rendering process, which contains high concentration of CP. Therefore, using PM in poultry diets reduces the dependence on SBM and promotes sustainability by reducing the amount of waste produced by the poultry industry. The nutritional composition of PM tends to differ based on the quality of raw material used and rendering process implemented.

Metabolizable energy or MEn of diets are major components, which drives cost and profit in poultry production. In addition, diets with inadequate energy could result in poor animal performance or nutrient wastage via excretion (Kong and Adeola, 2014). Therefore, an accurate determination of energy value of feed ingredients is necessary for cost-effective production of broiler chickens. In addition to energy, P is an important macromineral required for major biochemical pathways and energy metabolism. Investigating the true utilization of P in feed ingredients would lead to optimal concentration of P in diets, thereby influencing effective production and reducing excretion of nutrients into the environment.

An accurate evaluation of energy and nutrient utilization in PM for broiler chickens is necessary for precision nutrition with the least cost formulation. To the best of our knowledge, there is limited research on energy values and P utilization of PM for broiler chickens. Therefore, the objective of this study was to determine the ileal digestible energy (**IDE**), ME, and MEn (Exp. 1); and true ileal digestibility (**TID**) and true total tract

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utilization (**TTTU**) of P (Exp. 2) in PM using the regression method.

MATERIALS AND METHODS

The animal procedures used in the current studies were approved by the Purdue University Animal Care and Use Committee (West Lafayette, IN).

Birds, Management, and Sample Collection

A total of 480 zero-day-old male broiler chicks (Cobb 500; Cobb-Vantress Inc., Siloam Springs, AR) were obtained from a commercial hatchery and individually tagged with identification numbers. Birds were reared in electrically heated battery brooders (model SB 4 T, Alternative Design Manufacturing, Siloam Springs, AR). Temperature was set at 35°C on d 0 post hatching and gradually decreased by 1°C every 2 d. A 23L:1D photo-period schedule was used during the experimental period. Birds were fed a standard starter diet prior to being fed experimental diets. On d 15 or 16 post hatching, birds were individually weighed, and 192 birds with initial BW of 438 ± 76.9 g or 543 ± 50.2 g were selected for Exp. 1 or 2, respectively. Within experiment, birds were assigned to 3 experimental diets in a randomized complete block design with BW as a blocking factor, resulting in 8 blocks per treatment. Each experimental diet contained 8 replicate cages with 8 birds per cage. Birds were fed experimental diets for 5 or 3 d in Exp. 1 or 2, respectively. Waxed paper was placed under each cage and excreta was collected over a 3-d period in Exp. 1 and over a 2-d period in Exp. 2, pooled within cage, and stored in the freezer at -20°C. On d 20 or 19 post hatching in Exp. 1 or 2, respectively, all birds were euthanized by CO_2 asphyxiation and weighed individually. Feed consumption during the experimental period was also recorded. Ileal digesta content in the distal two-thirds of the ileum (i.e., from Meckel's diverticulum to approximately 2 cm anterior to the ileocecal junction) was flushed with distilled water into plastic containers, pooled within cage, and stored in the freezer at -20°C.

Experimental Diets

In Exp. 1, a reference diet was prepared based on corn, SBM, and calcium salt of fatty acids (Essentiom, Church & Dwight Co. Inc., Ewing Township, NJ) as energy-contributing ingredients (Tables 1 and 2). Calcium salt of fatty acids was added to the diets rather than vegetable oil to increase homogeneity in mixing of feed ingredients. Poultry meal was added to the reference diet at 80 or 160 g/kg by replacing the energy-contributing ingredients with maintaining the ratio among corn, SBM, and calcium salt of fatty acids. In Exp. 2, another reference diet was prepared based on corn and SBM as the sole source of P. Poultry meal was added to the reference diet at 50 or 100 g/kg at the expense of cornstarch and ground limestone in the reference diet. Limestone was added to supply Ca in the diet. In both experiments, crystalline amino acids including L-lysine·HCl, DL-methionine, and L-threonine were added to reference diet in order to supply limiting amino acids, in addition L- tryptophan was added to the reference diet in Exp. 2. Chromic oxide was added as an indigestible index marker at 5 g/kg of diet.

Table 1. Ingredient and analyzed nutrient composition of experimental diets containing poultry meal (PM), g/kg as-fed basis.

	Exp. 1			Exp. 2		
		PM, g/kg			PM, g/kg	
Item	RD[1]	80	160	RD	50	100
Ingredient						
Ground corn	532.5	486.6	440.7	476.0	476.0	476.0
Cornstarch	0.0	0.0	0.0	156.7	109.3	61.9
Soybean meal	360.0	330.1	300.2	170.0	170.0	170.0
Gelatin	0.0	0.0	0.0	100.0	100.0	100.0
PM	0.0	80.0	160.0	0.0	50.0	100.0
Soybean oil	0.0	0.0	0.0	50.0	50.0	50.0
Fatty acid[2]	50.0	45.8	41.7	0.0	0.0	0.0
Ground limestone	6.0	6.0	6.0	6.4	3.7	1.1
Monocalcium phosphate	15.0	15.0	15.0	0.0	0.0	0.0
Salt	4.0	4.0	4.0	4.0	4.0	4.0
L-Lysine HCl	1.0	1.0	1.0	3.0	3.0	3.0
DL-Methionine	2.5	2.5	2.5	3.5	3.5	3.5
L-Threonine	1.0	1.0	1.0	2.0	2.0	2.0
L-Tryptophan	0.0	0.0	0.0	0.5	0.5	0.5
Vitamin-mineral premix[3]	3.0	3.0	3.0	3.0	3.0	3.0
Chromic oxide premix[4]	25.0	25.0	25.0	25.0	25.0	25.0
Total	1,000	1,000	1,000	1,000	1,000	1,000
Analyzed energy or nutrient						
Gross energy, kcal/kg	4,064	4,163	4,256	-	-	-
CP (N × 6.25)	222	240	266	-	-	-
Ca	-	-	-	4.25	4.58	5.84
P	-	-	-	2.65	3.88	5.11

[1]RD = reference diet.
[2]Calcium salt of fatty acids (Essentiom; Church & Dwight Co. Inc., Ewing Township, NJ).
[3]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 B_{12}, 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; and Se, 0.43 mg.
[4]5 g chromic oxide plus 20 g ground corn.

Chemical Analysis

Excreta and ileal digesta samples from both Exp. 1 and 2 were dried at 55°C in a forced-air drying oven until constant weight. Feed ingredients, experimental diets, and excreta samples were ground (<0.75 mm) by a centrifugal grinder (ZM 200; Retsch GmbH, Haan, Germany) while ileal digesta samples were ground using an electric coffee grinder. Ground ingredients, experimental diets, excreta, and ileal digesta samples were analyzed for DM by drying at 105°C for 24 h 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.,

Table 2. Analyzed nutrient composition of feed ingredients, g/kg as-is basis.

Item	Ingredient			
	Poultry meal	Ground corn	Soybean meal[1]	Fatty acids[2]
DM	917	866	881	961
Gross energy, kcal/kg	5,411	3916	4,033	7,642
CP	528	71.9	422.5	-
Ca	36.9	-	-	-
P	15	-	-	-
Acid-hydrolyzed ether extract	261	-	-	-
Ash	143	-	-	-

[1]Solvent-extracted soybean meal with hulls.
[2]Calcium salt of fatty acids (Essentiom, Church & Dwight Co. Inc., Ewing Township, NJ).

Moline, IL), and N by a combustion method (TruMac N; LECO Corp., St. Joseph, MI; method 990.03; AOAC, 2000). The concentration of CP was calculated by multiplying 6.25 by the analyzed concentration of N in samples. Chromium concentrations in diets, ileal digesta, and excreta samples were determined using a spectrophotometer (Spark 10 M; Tecan Group Ltd., Männedorf, Switzerland) after a wet-ash digestion described by Fenton and Fenton (1979). In Exp. 2, P concentrations in diets, ileal digesta, and excreta samples were determined from digested samples, while P concentration in PM was determined from dry-ash-digested sample, by spectrophotometry, with absorbance read at 630 nm. Calcium concentrations in samples were determined by flame atomic absorption spectrometry using Varian Spectr.AA 220FS (Varian Australia Pty Ltd., Victoria, Australia).

Calculations and Statistical Analysis

The apparent ileal digestibility (**AID**) of nutrients and GE in experimental diets was calculated by the following equation (Kong and Adeola, 2014):

$$\text{AID}\ (\%) = [1 - (\text{Cr}_i/\text{Cr}_o) \times (\text{N}_o/\text{N}_i)] \times 100,$$

where Cr_i and Cr_o represent the concentration of Cr (g/kg DM) in experimental diets and ileal digesta, respectively; N_i and N_o represent the concentration of nutrients (g/kg DM) or GE (kcal/kg DM) in experimental diets and ileal digesta, respectively. The apparent total tract utilization (**ATTU**) of nutrients and GE in experimental diets were calculated by replacing the concentration of Cr, nutrients, and GE in ileal digesta with those in excreta.

Based on the AID of GE and ATTU of GE and N in Exp. 1, the IDE, ME, and retainable N in experimental diets were calculated as follows:

$$\text{IDE}\ (\text{kcal/kg DM}) = \text{GE}_i \times (\text{AID}/100);$$

$$\text{ME}\ (\text{kcal/kg DM}) = \text{GE}_i \times (\text{ATTU}/100);$$

$$\text{retainable N}\ (\text{g/kg DM}) = \text{N}_i \times (\text{ATTU}/100),$$

where GE_i and N_i represent the concentration of GE (kcal/kg DM) and N (g/kg DM) in experimental diets, respectively. The MEn in experimental diets were calculated by correcting ME for zero N retention using a factor of 8.22 kcal/g (Hill and Anderson, 1958):

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

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

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

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

The test ingredient intake and test ingredient-associated IDE intake were calculated as follows:

$$\text{TI}_i\ (\text{g DM/bird}) = \text{FI} \times \text{P}_{ti};$$

$$\text{IDEI}_{ti}\ (\text{kcal DM/bird}) = \text{TI}_i \times \text{IDE}_{ti},$$

where TI_i is test ingredient intake (g DM/bird); FI is feed intake (kg DM/bird); IDEI_{ti} is test ingredient-associated IDE intake. The IDE in PM was estimated by regression analysis between TI_i and IDEI_{ti}:

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

where a is the slope of regression model, which represents the estimated IDE (kcal/g DM) in test ingredient, and the intercept of the model is set at 0 based on the TI_i of birds fed the reference diet. The ME or MEn in PM was estimated by replacing IDE with ME or MEn using the same regression model.

In Exp. 2, the TID of P in PM was estimated by regression analysis as follows:

$$\text{P}_{AID} = \text{a} \times \text{PI} + \text{b},$$

where PI is P intake, which is the product of feed intake (kg DM/bird) and the concentration of P in the diets (g/kg DM); P_{AID} is apparent ileal digestible P intake (g/bird), which is the product of PI and AID of P (%); a is the slope of regression model, which represents the estimated TID of P in PM, and b represents the intercept of the model. The TTTU of P in PM was estimated by replacing P_{AID} with total tract utilizable P intake.

Data were analyzed by ANOVA using GLM procedure of SAS (SAS Inst. Inc., Cary, NC). Model included diet and block as independent variables. Linear and quadratic effects of graded concentration of PM were determined by orthogonal polynomial contrast. Regression analysis was conducted by GLM procedure of SAS. Regression equation was generated by SOLUTION I option. Experimental unit was the cage, and statistical significance was declared at $P < 0.05$.

RESULTS

Experiment 1

In Exp. 1, inclusion of PM in experimental diets linearly increased the gain-to-feed ratio (**G:F**; Table 3). The AID of DM and GE linearly decreased ($P < 0.01$) with increasing concentration of PM in experimental diets. The addition of PM to the reference diet linearly decreased ($P < 0.01$) the ATTU of DM, GE, and N in diets. There was no statistically significant effect of inclusion of PM on IDE, ME, and MEn of diets. The IDE, ME, and MEn of PM determined by the regression method were 4,002, 3,756, and 3,430 kcal/kg DM, respectively (Table 4).

Experiment 2

Supplementation of PM to diets in Exp. 2 linearly increased ($P < 0.05$) the final BW, BW gain, total P intake and G:F (Table 5). Graded concentration of PM in the reference diet linearly decreased ($P < 0.05$) ATTU of DM but linearly increased ($P < 0.01$) ATTU of P in diets (Table 5). The ATTU of Ca in diets quadratically increased ($P < 0.05$) as the concentration of PM in diets increased. The apparent ileal digestible and total tract utilizable phosphorus

Table 4. Regression equation relating poultry meal-associated energy intake (kcal/bird) to poultry meal (PM) intake (kg DM/bird) in Exp. 1; and apparent ileal digestible or total tract utilizable P intake (g/bird) to P intake (g/bird) from PM in Exp. 2.[1]

Item	Regression equation	R^2	SD	P-value
Exp. 1				
IDE[2]	Y = 4,002 (162) × PM + 4.69 (5.72)	0.965	17.72	< 0.001
ME[2]	Y = 3,756 (197) × PM + 5.01 (6.97)	0.943	21.56	< 0.001
MEn[2]	Y = 3,430 (171) × PM + 5.28 (6.08)	0.948	18.81	< 0.001
Exp. 2				
TID[3]	Y = 0.775 (0.05) × PM - 0.061 (0.04)	0.921	0.06	< 0.001
TTTU[3]	Y = 0.790 (0.04) × PM - 0.159 (0.03)	0.952	0.04	< 0.001

[1]Regression analysis was conducted with 24 observations.
[2]IDE = ileal digestible energy; values in parentheses are SE; the energy values (i.e., IDE, ME, MEn) were estimated as the slope of regression equation.
[3]TID = true ileal digestibility; TTTU = true total tract utilization; values in parentheses are SE; TID and TTTU of P were estimated as the slope of regression equation and multiplied by 100 for 77.5% and 79% respectively.

Table 3. Growth performance, apparent ileal digestibility and total tract utilization of DM, gross energy, N, and energy values in experimental diets fed to broiler chickens from d 15 to 20 post hatching in Exp. 1[1,2].

Item	RD	Poultry meal, g/kg			P-value[3]	
	0	80	160	SEM	L	Q
Growth performance						
Initial BW, g	438	438	438	0.2	0.758	0.953
Final BW, g	740	759	758	6.0	0.054	0.178
BW gain, g/bird	302	321	319	6.0	0.056	0.182
Feed intake, g/bird	392	398	385	8.2	0.553	0.354
G:F, g/kg	773	810	835	10.6	0.001	0.660
Apparent ileal digestibility						
DM	76.4	75.3	73.1	0.40	< 0.001	0.291
Gross energy	77.9	77.3	75.6	0.39	0.001	0.279
IDE, kcal/kg DM	3,602	3,654	3,652	18.2	0.070	0.246
Apparent total tract utilization						
DM	77.7	76.7	73.7	0.40	< 0.001	0.063
N	74.1	70.2	66.3	0.91	< 0.001	0.999
Gross energy	79.6	78.6	76.1	0.46	< 0.001	0.170
ME, kcal/kg DM	3,682	3,718	3,673	22.0	0.775	0.149
MEn, kcal/kg DM	3,466	3,497	3,441	19.7	0.380	0.092

[1]Data are least square means of 8 replicates cages with 8 birds per cage.
[2]RD = reference diet; G:F = gain-to-feed ratio; IDE = ileal digestible energy.
[3]Linear (L) and quadratic (Q) contrasts.

Table 5. Growth performance, apparent ileal digestibility and total tract utilization of DM, phosphorus, and calcium in experimental diets fed to birds from d 16 to 19 posthatching in Exp. 2.[1,2]

Item	RD	Poultry meal, g/kg			P-value[3]	
	0	50	100	SEM	L	Q
Growth performance						
Initial BW, g	543	543	543	0.2	0.621	0.774
Final BW, g	687	716	730	4.5	< 0.001	0.214
BW gain, g/bird	144	173	186	4.6	< 0.001	0.175
Feed intake, g/bird	212	223	221	3.4	0.073	0.136
Total P intake, g/bird	0.6	0.8	1.1	0.02	< 0.001	0.733
G:F, g/kg	681	776	840	11.7	< 0.001	0.294
Apparent ileal digestibility, %						
DM	81.8	80.8	80.3	0.63	0.123	0.762
P	66.1	70.4	72.8	2.57	0.087	0.755
Ca	74.2	73.1	76.8	1.51	0.255	0.213
Apparent total tract utilization, %						
DM	76.2	74.9	74.0	0.66	0.033	0.780
P	50.3	60.7	65.1	1.69	< 0.001	0.171
Ca	38.3	45.3	60.9	1.60	< 0.001	0.045
Ileal digestible P, g/bird	0.4	0.6	0.8	0.02	< 0.001	0.775
Utilizable P, g/bird	0.3	0.5	0.7	0.02	< 0.001	0.992

[1]Data are least square means of 8 replicates cages with 8 birds per cage.
[2]RD = reference diet; G:F = gain-to-feed ratio.
[3]Linear (L) and quadratic (Q) contrasts.

linearly increased ($P < 0.01$) with substitution of PM in the reference diet. The TID and TTTU of P in PM estimated by the regression method were 77.5 and 79.0%, respectively (Table 4).

DISCUSSION

Poultry meal is an animal protein by-product used in livestock production, with nutritional composition subject to the type of raw material used in its production, hence robust information is needed on its nutritional composition and digestibility of energy and nutrients. The analyzed GE of PM used in this experiment was greater than the values reported in poultry by-product meal (**PBM**) by Pesti et al. (1986) and Cao and Adeola (2016) and in poultry by-products reported by NRC (2012). Poultry meal is a good source of protein and the CP content of PM used in this study is close to the average CP of 26 samples of PBM reported by Dozier et al. (2003) but lower than other sources of PBM in previous studies (Pesti et al. 1986; NRC, 1994; Kirkpinar et al., 2004; Cao and Adeola, 2016). Moreover, the analyzed Ca and P contents of PM used in this study are within the range or close to the values reported by Waldroup and Adam (1994) and Dozier et al. (2003), but lower than the reported values by NRC (1994) for PBM. The differences observed in GE and nutrient composition of PM used in the current study compared to other studies can be due to variation in rendering sources. Both poultry meal and PBM are poultry by-products and their major difference has been reported to be dependent on the processing source (Firman, 2006). Furthermore, the nutrient composition and quality of PM and PBM vary due to the type of raw material used, variety of processing residues, time for processing, and the conditions of rendering residues (Dozier et al., 2003; Ribeiro et al., 2019). Poultry by-product meal is made from necks, feet, undeveloped eggs, and viscera while PM is made from only skin, bone, and trimmings (Meeker and Hamilton, 2006; Hicks and Verbeek, 2016). However, due to enormous variability in raw material and production practices among manufacturers, it can be presumed that there is no factual difference in nutrient composition between PM and PBM. Satterlee et al. (1971) reported that as skin content increased in deboned poultry meat, fat content increased while protein content decreased. Poultry meal containing higher proportion of leg and rib bones, could have high bone marrow content, which tends to increase the fat composition thereby contributing to the GE content and reduction of CP in PM. Also, the bone marrow lipid content of chicken was reported at approximately 46.5% (Moerck and Ball 1973). Therefore, the amount of skin and the type of bone used during the rendering process may have increased the fat content and could be the reason for the higher GE and lower CP of PM used in this study compared to some previous studies. In addition, because bone is mainly composed of inorganic matter, which mostly consists of Ca and P, variation in the Ca and P content of PM used in different studies would be dependent on the amount of bone used during rendering process.

There was no detectable effect of inclusion of PM on growth performance parameters except the linear effect observed in G:F in Exp. 1, which is consistent with reports by Cao and Adeola (2016). The linear increase in G:F might be due to the increased amino acid profile in the diets containing PM compared to the reference diet containing corn and SBM. Kirkpinar et al. (2004) reported that there is no detectable effect of adding PBM at 0, 25, or 40 g/kg in diets on BW and feed efficiency of male and female broiler chickens from d 21 to d 42 post hatching. This is partly consistent with findings in this study, but differences observed might be due to the age and sex of broiler chickens used in the study or because the current experiment was not designed as a growth performance study.

Cao and Adeola (2016) reported that the addition of PBM linearly decreased AID and ATTU of DM and GE, but no effect was observed in IDE, ME, and MEn of test diets, all of which are consistent with the findings in this study. They also reported both linear and quadratic responses for ATTU of N, which is similar with the linear effect observed in the current study. The observed linear decrease in AID and ATTU of DM suggest that PM has a lower AID and ATTU of DM compared to corn and SBM, and this might be due to the higher bone content of PM. While the linear reduction in AID and ATTU of GE observed in this study might be due to the lower energy source in PM compared to corn and SBM with starch being the main energy source in corn. In addition, diets containing PM had greater GE concentration compared to the reference diet. This probably increased the energy intake and resulted in increased excretion of energy because IDE, ME, and MEn of diets were not statistically different among each other. Meat and bone meal made from mammalian tissue is another important animal protein source used in the poultry industry. Adeola et al. (2018) reported quadratic effects for both AID and ATTU of DM and GE of MBM as opposed to linear effects observed in this study. In addition, linear and quadratic effects were observed for IDE and ME of test diets. Apart from the difference in the source of animal by-product between PM and MBM, the MBM used had lower GE and CP, and higher Ca and P compared to PM used in this study. Despite the linear reduction in ATTU of DM and GE observed in the current study, all test diets had similar IDE, ME, and MEn, inferring that PM can partly substitute some energy and protein ingredients in the diet of broiler chickens.

In Exp. 1, regression analysis was used to estimate the IDE, ME, and MEn in PM with the difference procedure to reduce the standard errors for estimated values (Park et al., 2021). In addition, Bolarinwa and Adeola (2016) reported that there is no difference in DE and ME values between regression and direct procedures. The MEn of PM determined by regression method in the present study was greater than MEn reported by NRC (1994), and this is probably due to high fat content of PM used in the current study. The MEn of PBM reported by Pesti et al. (1986) is close to that determined in the current study. Cao and Adeola (2016) reported a lower IDE at 3,537 kcal/kg DM, but ME at 3,805 kcal/kg DM and MEn at 3,278 kcal/kg DM, which is close to that observed in the current study. The 4,002 kcal IDE/kg DM, 3,756 kcal ME/kg DM, and 3,430 kcal MEn/kg DM are 68, 64, and 58%, respectively, of the GE (5,901 kcal/kg DM) in PM.

There was no detectable difference in feed intake but there was a linear increase in final BW, BW gain, total P intake and G:F as PM in diets increased from 0 to 100 g/kg in Exp. 2. This might be as a result of low concentration of Ca and P in the reference diet. The inclusion of PM in the diet increased concentration of Ca and P, which coincided with improvement in growth performance.

Inclusion of PM linearly decreased the ATTU of DM in diets, which is consistent with findings of Exp. 1. There was a linear increase in the ATTU of P as dietary P concentration increased. This could be due to the reduction in the proportion of endogenous loss collected in the excreta. It is also possible that the addition of PM increased the available P in the diets as compared to the reference diet, which contained only plant source of P that can be in phytate form. It is reported that about 60 to 80% of P in cereals are in phytate form (Skoglund et al., 2009). Also, Nelson (1976) observed that 0 and 3% of P in phytate form where digested by broiler chickens at 4 and 9 wk of age respectively, when fed diet containing corn as the sole source of grain. Supplementation of PM in the diets linearly increased apparent ileal digestible and total tract utilizable phosphorus, which is due to the linear increase observed in the total P intake.

Animal proteins such as PBM and MBM are good sources of Ca and P in the poultry industry and are utilized due to their nutritional composition (Waldroup and Adam, 1994). Meat and bone meal tend to contain more Ca and P compared to PM (NRC, 1994), probably as a result of its bone content. In addition, the bioavailability of P in PM and MBM are comparable with mono-dicalcium phosphate (Meeker and Hamilton, 2006). Waldroup and Adam (1994) also reported no difference in bioavailability of P when 6 samples of PBM and eleven samples of MBM were compared with monocalcium phosphate. Although van Harn et al. (2017) reported that P digestibility of feed ingredients of animal sources was lower compared to inorganic phosphate sources. Mutucumarana et al. (2015) fed MBM from 3 different rendering plants using semi-purified diets and reported TID of P at 69.3, 60.8 and 42%, which is low compared to the TID of P for PM obtained in the current study. Also, Mutucumarana et al. (2015) observed no effect of inclusion of MBM from 2 rendering plants on AID of P while a quadratic effect was seen with inclusion of MBM from the third rendering plant, which shows that rendering process and source can affect digestibility of P in animal proteins. van Harn et al. (2017) observed a prececal P digestibility of bone meal of 78.2%, which is comparable with that observed in this study, probably due to similar Ca-to-P ratio in test diets used in both studies. Rodehutscord et al. (2017) determined the prececal P digestibility of SBM across 17 stations, despite using the same experimental diets across all stations and analyzing samples in the same laboratory, a wide range of difference were reported among stations ranging from 19-51%. This shows the complexity in comparison of P digestibility among different studies. Therefore, comparing digestibility of feed ingredients across different studies can sometimes be ambiguous due to variability in source of ingredient, composition of diet, age and breed of animals, and analysis criteria among others. The TID and TTTU of P in PM estimated in this study seems comparably, which could be due to the low level of P supplied in the diets. Rodehutscord et al. (2012) reported similar estimate for both retention and prececal digestibility of P when P supplied is below the requirement.

In conclusion, the current studies showed that inclusion of PM in the diet of broiler chickens reduced the digestibility of GE. However, diets that contained PM had similar IDE, ME, and MEn compared with the corn-soybean meal reference diet. In addition, formulating poultry meal into the diet of broiler chickens increased utilization P. The IDE, ME, and MEn of PM determined by the regression method in the current study were 4,002, 3,756, and 3,430 kcal/kg DM, respectively, representing 58 to 68% of the GE in poultry meal. The TID and TTTU of P in PM estimated by the regression method were 77.5 and 79.0%, respectively. Energy and P utilization values generated in the 2 studies may possibly be used in diet formulation for broiler chickens.

DISCLOSURES

The authors declare no conflict of interest.

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