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A New Precision–Fed Chick Assay for Determining True Metabolizable Energy Values of some Poultry Feed Ingredients for Broiler Chickens

Research Article

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ABSTRACT

Two experiments were conducted to determine: first, the best time of excreta collection after force feeding of broilers to yield the maximal amount of excreta, and second, nitrogen-corrected true metabolizable energy contents of some poultry feedstuffs including yellow corn, soybean meal, corn gluten meal, canola meal and poultry by-product meal by a new precision-fed chick assay using 3-week-old broiler chicks. In experiment one, thirty-five 21-d-old male broiler chicks, with the same body weight were randomly assigned in to 7 experimental groups with 5 birds per each. Seven experimental treatments were designed with different excreta collection times. All chicks were precision-fed with 10 g of corn-soybean meal (60:40) mixture. Excreta were collected at 2, 4, 6, 8, 10, 12, and 14 h after precision feeding. In experiment two, thirty 21-d old male broiler chicks with 5 chicks per each feed ingredients were precision-fed by 10 g of experimental feedstuffs and 5 chicks fasted for determining endogenous energy losses. The maximum time of excreta collection for 3-week-old male broiler chicks was approximately 12 h after precision feeding. The average nitrogen-corrected true metabolizable energy values of yellow corn, soybean meal, corn gluten meal, canola meal and poultry by-product meal, were 3527.55, 2572.4, 4183.25, 1806.38 and 2678.06 kcal/kg, respectively. In conclusion, nitrogen-corrected true metabolizable energy values of feedstuffs can be determined in 3-week-old broiler chicks by using a precision-fed assay. This research suggests using energy values obtained on young broiler chicks in formulating diets for the same birds.

KEY WORDS broiler chicks, nitrogen-corrected true metabolizable energy, precision-fed.

INTRODUCTION

For the purpose of accurate formulation of diets in poultry nutrition, it is necessary to have information about ingredients and nutritive values of feedstuffs (De Leon *et al.* 2010). Evaluation of energy values of diets is crucial factor in aspects of practical and research on animal nutrition. One of the main causes is that energy content has a key role in the control of feed intake. This means that the intake of individual substances is intensely affected by the ratio of nutrients to energy.

The energy requirements of birds and the availability of energy from feedstuffs are the basic foundations for the accurate formulation of a diet in order to obtain the biologically, economically or environmentally optimal intakes of specific nutrients (MacLeod, 2002). There is a high rate of incongruity in the methods for the determination of energy values of feedstuffs for poultry. Metabolizable energy (ME) is a concept used to characterize the nutritional value of poultry feedstuffs and can be indicated as either apparent metabolizable energy (AME) or true metabolizable energy (TME).

Currently, AME is one of the most widely used methods for evaluation of available energy content of feedstuffs in poultry. Since Sibbald (1976) developed a bioassay to evaluation TME values of feedstuffs, a noticeable amount of research has been conducted in order to study the assay's applicability. Generally, AME assays have been done with young (meat-type) chickens (Hill and Anderson, 1958) while TME assays have been conducted with adult males single comb white Leghorn (SCWL) (Sibbald, 1976). The TME assays have several advantages in comparison with AME assays. It is simple, rapid, less expensive and corrected for metabolic fecal energy (FE_m) plus endogenous urinary energy (UE_e) losses. Besides its reported reproducibility, flexibility and data quality (Sibbald, 1976), the bioassay for TME can be extended to measure bioavailable amino acid (Sibbald, 1979b) and lipids (Sibbald and Kramer, 1980) in feedstuffs. Various studies on both roosters and chickens recommend differences in nutrient metabolism between them that should be considered in formulation of diets for chickens (Freitas *et al.* 2006). Freitas *et al.* (2006) showed that the nitrogen-corrected apparent metabolizable energy (AMEn) obtained by chicks should be considered in diet formulation from 1 to 21 days, and after this age, it is recommended to formulate diets based on nitrogen-corrected apparent metabolizable energy (AMEn) or nitrogen-corrected true metabolizable energy (TMEn) obtained by roosters. Due to the fact that digestive capacity varies with the age of birds, so any increase in nutrient utilization values occurring with age and development of the digestive system and accessory organs (Moran, 1958).

Gurbuz *et al.* (2009) indicate higher contents of ME in birds with their increasing age. The results showed that the TMEn values of corn, soybean meal and canola meal obtained by 4-week-old white leghorn male chicks and adult roosters were 3760 and 3880 kcal/kg; 2850 and 2870 kcal/kg and 1990 and 2240 kcal/kg, respectively (Shires *et al.* 1980).

Kato *et al.* (2011) cited that the energy contents of corn were significantly lower in the pre-initial phase (1-7 days). Same studies has found that there was good agreement in the nitrogen-corrected true metabolizable energy (TMEn) values of yellow corn, soybean meal, corn gluten meal and poultry by-product meal between leghorn roosters, 6-week-old male broiler and 6-week-old male turkey poults. It was also observed that the value for broiler tended to be slightly lower compared with roosters or poults. A precision-fed assay using 3-week-old broiler chicks can be used for determining ileal digestible energy of amino acid (AA) (Kim *et al.* 2011), but it may appropriate for determining ME or TME if excreta were collected instead of ileal digesta. Therefore, the aim of this study was to determine the optimal excreta collection time after force feeding of broilers and TMEn values of corn, soybean meal, corn gluten meal, canola meal and poultry by-product meal by precision-fed assay using 3-week-old broiler chicks.

MATERIALS AND METHODS

Chemical analysis

Five samples of feedstuffs including yellow corn (YC), soybean meal (SBM), corn gluten meal (CGM), canola meal (CM) and poultry by-product meal (PBPM) were randomly obtained from commercial feed suppliers. All samples were grounded by a 1 mm screen, stored in plastic bags and maintained in -20 ˚C until chemical composition analysis and biological assays.

Chemical compositions of feedstuffs were measured according to the Association of Official Analytical Chemists methods (AOAC, 2005). Dry matter (DM) was determined by oven drying the samples at 135 ˚C for 2 h. Ash content was measured in a muffle furnace at 500 ˚C for 6 h and crude protein (CP) was determined by the Kjeldahl method (Kjeldahl Foss 2300). Ether extract (EE) was determined by soxhlet method and crude fiber (CF) was determined by using a fibertec system (Foss 1010). Gross energy (GE) content of samples was measured by a Parr adiabatic bomb calorimeter (Zarei *et al.* 2014).

Data collection and sampling procedure

In this study, two experiments were conducted by the 21-d-old male Ross 308 broilers chicken. The aim of experiment one was to determine the best excreta collection time and experiment two was conducted to measure the TME content of feeding stuffs. For experiment one, thirty-five 21-d-old male broiler chicks and experiment two, thirty 21-d-old male broiler chicks were used which were obtained from a local commercial hatchery. Hatched one-day-old chicks were feather sexed. Birds were raised in a starter battery and were fed a basal diet from day 1 to 21 that met all Brazilian recommended nutrients (Rostagno *et al.* 2011) with 21.5% crude protein (CP) and 2966 kcal/kg of ME. The composition and nutrient contents of basal diet are shown in Table 1.

Experiment 1

Determining the best excreta collection time

Thirty five 21-d-old Ross 308 male broiler chicks, with similar body weight (940±57 g), were randomly assigned into 7 groups of 5 birds per each and were kept in individual wire metabolic cages (27.94×21.59×20.96 cm) and were deprived of feed for 10 hours to empty feed residues from alimentary canals (Kim *et al.* 2011), but water was available *ad libitum*. The initial temperature of the room was 32 ˚C and this was reduced to 24 ˚C at the end of the period.

Table 1 Ingredients and nutrient contents of of basal diet

Ingredient (%)	**Measurement**
Corn	54.62
Soybean meal (44% CP)	38.39
Soybean oil	3.00
Calcium carbonate	1.03
Dicalcium phosphate	1.73
Sodium bicarbonate	0.09
Vitamin-mineral premix[1]	0.50
DL-methionine	0.20
L-lysine	0.13
L-threonine	0.06
Salt	0.25
Total	100.00
Calculated nutrient content (%)	
Nitrogen-corrected apparent metabolisable energy (kcal/kg)	2966
Crude protein	21.5
Calcium	0.87
Available phosphorus	0.44
Na	0.16
K	0.97
Cl	0.20
Digestible lysine	1.15
Digestible methionine	0.50
Digestible methionine + cysteine	0.87
Digestible arginine	1.29
Digestible threonine	0.77
Digestible isoleucine	0.84
Digestible leucine	1.70
Digestible tryptophan	0.23
Digestible valine	0.91

[1] Vitamin-mineral premix provided per kilogram of diet: vitamin A: 8250 IU; vitamin D_3: 1000 IU; vitamin E: 11 IU; vitamin B_{12}: 0.012 mg; vitamin K: 1.1 mg; Niacin: 53 mg; Choline: 1020 mg; Folic acid: 0.75 mg; Biotin: 0.25 mg; Riboflavin: 5.5 mg; Mn: 55 mg; Zn: 50 mg; Fe: 80 mg; Cu: 5 mg; Se: 0.1 mg; I: 0.36 mg and Na: 1.6 g.

Room humidity was 50% and lighting program was 23 hours. Seven experimental treatments were designed with different excreta collection times after precision-feeding to determine optimum time of excreta collection. All chicks were precision-fed with 10 g of corn-soybean meal (60:40) basal diet. The precision-feeding of the chicks was followed by the methodology developed by Kim *et al.* (2011). The intubation equipment was made according to the recommendation of Kim *et al.* (2011) with slightly modified. Stainless steel funnel is used with a stem 23.5 cm long and an internal diameter of 0.64 cm. The plunger consists of a 0.58 cm diameter steel rod with a length of 23.5 cm. The stainless steel rod was extended 10 cm at the top (formed as a handle) to allow the intended sample to be pushed into the crop which a 3.0 cm diameter spherical knob is attached. The steel rod was equipped with a metal washer at 23.5 cm from the end of the rod for preventing the rod from being pushed beyond the lower part of the feeding tube inside the crop (Figure 1). Excreta were collected every 2 hours for the entire 14-h (at 2, 4, 6, 8, 10, 12 and 14-h post-feeding), frozen at -20 ˚C until further analysis. Then excreta samples were oven-dried at 70 ˚C and weighted for each individual chick (Kim *et al.* 2011).

Finally, best excreta collection time with considering the maximum amount of excreta was determined.

Figure 1 Stainless steel funnel with plungers
Note metal washer on plunger which controls penetration beyond the end of the funnel

Experiment 2
Determining the true metabolizable energy content of feedstuffs

A total of thirty 21-d-old broiler chicks were used for determination of the TMEn content of five feedstuffs including: YC, SBM, CGM, CM and PBPM. All birds of similar body weight (968±67 gm) were randomly divided into 6 groups and 5 birds per each and housed in individual wire metabolic cages in an environmentally controlled room. All birds were fasted for 10 hours to clear feed residues from alimentary canals (Kim *et al*. 2011), but water was available *ad libitum*.

After 10 hours, five chicks in each group were precision-fed 10 g of each grounded feedstuffs as described in experiment 1. Five birds of similar body weight were used for determination endogenous energy (FE_m+UE_e) losses. Based on the results of experiment 1, excreta were collected 12 h after precision-feeding and stored at -20 ˚C until further analysis. Then excreta samples were oven-dried at 70 ˚C for 24 hours, weighed and grounded.

The DM and CP content of excreta were analyzed as described above. The GE content of excreta was measured using a parr adiabatic oxygen bomb calorimeter (Zarei *et al.* 2014).

Finally, TMEn values of each feedstuff were calculated as follow (Sibbald, 1982):

$$TMEn= [((F_i \times GE_f) - (E \times GE_e)) - (NR \times K)] + [(FE_m+UE_e) + (NR_0 \times K)] / Fi$$

Where:

NR: $(F_i \times N_f)$ - $(E \times N_e)$.

Fi: feed intake (g).

E: excreta (g).

GE_f: gross energy of feed sample (kcal/g).

GE_e: gross energy of excreta (kcal/g).

FE_m: metabolic feacal energy (kcal/g).

UE_e: indigenous urinary energy (kcal/g).

NR: nitrogen retention (g).

N_f: feed nitrogen (%).

N_e: faecal nitrogen (%).

NR_0: nitrogen retention at zero level for control group (g).

K: nitrogen retention corrected coefficient (8.22 kcal/g $N_{retained}$)

Statistical analysis

Statistical analysis of the data from the experiment one was accomplished using the UNIVARITE and ANOVA procedures (SAS, 2003) according to completely randomized design. Differences between means were analyzed with Duncan's multiple tests. Statistical significance was considered as P < 0.05.

RESULTS AND DISCUSSION

The best excreta collection time

The results from the best excreta collection time (experiment one) were shown in Table 2. The amount of excreta increased up to 12 h post-feeding. After 12 h, a significant decrease was observed in excreta (P<0.01). The removal of feed for 12 h after precision-feeding was found to be an adequate time for 3-week-old broiler chicks to ensure that their gastrointestinal tracts would be empty of feed residues (Figure 2).

True metabolizable energy

The results of chemical composition, TMEn, TME, TMEn/GE, apparent metabolizable dry matter (AMDM) and true metabolizable dry matter (TMDM) of YC, SBM, CGM, CM and PBPM and also FE_m + UE_e were presented in Tables 3 and 4.

Yellow corn (YC)

The CP values of YC ranged from 7.56 to 8.19%, the EE contents varied from 3.65 to 3.82% and the GE values ranged from 3910.48 to 4088.95 kcal/kg. In the present study, the TMEn values of YC varied from 3407.1 to 3660.4 kcal/kg.

Soybean meal (SBM)

The amount of CP, EE, CF and TMEn contents of SBM varied from 44.81 to 45.75%, 1.35 to 1.49%, 4.24 to 4.38% and 2435.54 to 2745.9 kcal/kg, respectively.

Corn gluten meal (CGM)

The results of chemical composition and TMEn values of CGM obtained in this study ranged from 60.87 to 62.19% (CP), 2.72 to 2.9% (EE), 1.12 to 1.3% (CF) and 5505.51 to 5622.75 kcal/kg (GE). The amount of TMEn values found in this study ranged from 4140.25 to 4233.18 kcal/kg.

Canola meal (CM)

The CP values of CM varied from 32.25 to 33.56%, the EE contents ranged from 3.42 to 3.6% and the CF values of CM ranged from 13.28 to 13.48 kcal/kg. The TMEn values of CM ranged from 1610.98 to 1976.3 kcal/kg.

Poultry by-product meal (PBPM)

The GE values of PBPM obtained in this study ranged from 3871.66 to 4193.2 kcal/kg, the EE contents were between 18.02 to 18.2%, the amount of CP varied from 61.12 to 62.37% and the ash contents from 8.8 to 9%. The TMEn values of PBPM in the present study ranged from 2510.4 to 2778.3 kcal/kg.

The best excreta collection time

Based on corn-soybean meal diet, the disposal of excreta for 12 h is sufficient for the gastrointestinal tract to empty, but this time may vary based on the type of diet (Kim *et al.* 2011). Kim *et al.* (2011) indicated that 10 h of starvation was enough in 3-week-old broiler chicks to empty their gastrointestinal tracts.

Table 2 Mean value of excreta weight voided at different times for 21-d-old broiler chicks (g)

Time (hour)	2	4	6	8	10	12	14	SEM	P-value
Withdrawal of excreta	0.212[e]	0.752[ed]	1.563[cd]	2.51[ab]	2.084[cb]	3.2[a]	2.649[ab]	0.309	0.0001

The means within the same row with at least one common letter, do not have significant difference (P>0.01).
SEM: standard error of the means.

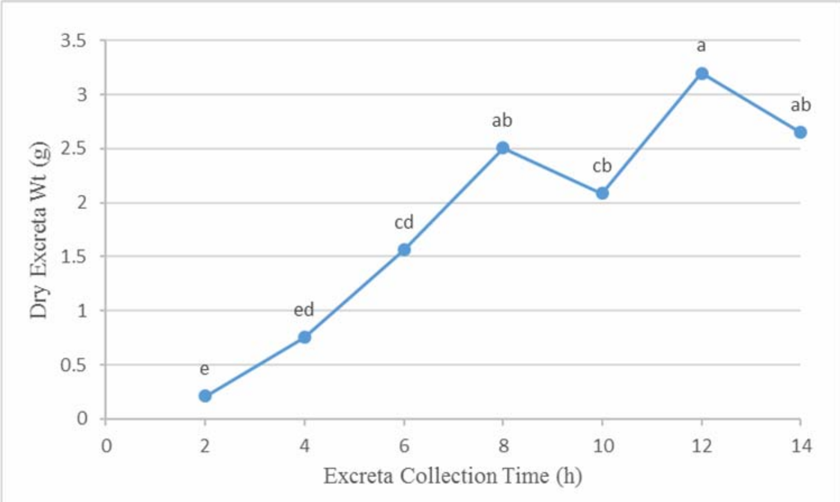

Figure 2 Mean excreta weights of broiler chicks (21-d-old) after precision-feeding of 10 g corn-soybean
Data point with no common superscripts (a-e) are significantly different (P<0.01)

Table 3 Chemical composition of yellow corn (YC), soybean meal (SBM), corn gluten meal CGM), canola meal (CM) and poultry by-product meal (PBPM) (Average±SD, as feed basis)

Feedstuffs	N	Chemical composition					
		DM %	CP %	Ash %	EE %	CF %	GE kcal/kg
YC	4	89.62±0.09	7.86±0.26	1.14±0.04	3.76±0.07	2.18±0.09	3995.59±79
SBM	4	90.7±0.05	45.31±0.40	6.0±0.07	1.42±0.06	4.3±0.06	4147.36±95
CGM	4	91.5±0.05	61.44±0.56	2.1±0.06	2.8±0.07	1.2±0.08	5557.99±55
CM	4	92.3±0.24	33.0±0.55	7.2±0.07	3.5±0.08	13.4±0.08	4473.45±107
PBPM	4	90.2±0.41	61.62±0.53	8.9±0.08	18.09±0.07	1.94±0.06	4030.89±157

DM: dry matter; CP: crude protein; EE: ether extract; CF: crude fiber and GE: gross energy.

Table 4 Energy values of yellow corn (YC), soybean meal (SBM), corn gluten meal (CGM), canola meal (CM) and poultry by-product meal (PBPM) (Average±SD, as fed basis) and FE_m + UE_e (kcal/kg) in unfed 21-d-old chicks

Item	Feedstuffs*					Unfed 21-d-old chicks
	YC	SBM	CGM	CM	PBPM	
TMEn	3527.55±94	2572.4±116	4183.25±33	1806.38±162	2678.06±112	-
TME	3432.17±103	2558.45±125	4270.12±45	1830.14±178	2711.95±124	-
TMEn/GE	88.29±2.36	62.02±2.81	75.26±0.6	40.38±3.62	66.44±2.8	-
AMDM	64.73±3.09	40.66±4.15	58.99±6.06	35.10±3.97	50.72±9.5	-
TMDM	73.85±3.09	49.74±4.16	68.11±6.06	44.22±3.97	63.75±9.5	-
FE_m + UE_e	-	-	-	-	-	3799.26±67

* Five replications were used for each feedstuff.
TME_n: true metabolizable energy corrected to zero nitrogen balance; TME: true metabolizable energy; GE: gross energy; AMDM: apparent metabolizable dry matter; TMDM: true metabolizable dry matter and FE_m + UE_e: metabolic fecal energy (FE_m) plus endogenous urinary energy (UE_e) losses.

The results of a study on adult roosters showed that while corn and soybean meal residues removed from the alimentary canal in 24 h, meat meal required about 30 h (Sibbald, 1979a). The form of feedstuffs can affect the excreta collection time. It was observed that alfalfa, fish meal and wheat fed as pellets produced higher amount of excreta than when fed as meals. Pelleted form of feedstuffs appeared to have the higher rate of passage through the alimentary canal. The results indicate that alfalfa and fish meal needed more than 24 h to pass through the digestive tract.

Rotter *et al*. (1990) showed that the 48 h collection time of excreta was considered to be sufficient for determination of TMEn contents of barley and corn samples. Therefore, based on the results of this study, the optimal time of feed withdrawal would be 12 h after precision-feeding of 3-week-old broiler chicks.

True metabolizable energy

Yellow corn

Lee *et al*. (2016) showed that the CP value of corn ranged from 7.12% (Brazil) to 7.60% (China), the EE content varied from 3.30% (United States) to 3.87% (Brazil) and the GE values ranged from 3836 kcal/kg (Ukraine) to 3995 kcal/kg (Brazil). The CP and EE values of YC reported by NRC (1994) and Rostagno *et al*. (2011) were (8.5 and 3.8%), (7.88 and 3.65%), respectively. In the present study, the mean value of TMEn (3527.55 kcal/kg) was lower than the values reported by Dale and Fuller (1979) in 6-week-old male broiler, Kato *et al*. (2011) in 15-21-d-old broiler chicks, Shires *et al*. (1980) in 4-week-old chicks (3720, 3823 and 3760 kcal/kg, respectively). The TMEn content of corn in the present study was consistent with the values noted by NRC (1994) (3470 kcal/kg) and Rostagno *et al*. (2011) (3500 kcal/kg).

Kato *et al*. (2011) by studying the effect of the birds' age on ME contents of corn hybrids indicate that the energy values of corn were significantly lower in the pre-initial phase (1-7 days). Brumano *et al*. (2006) found that younger birds (21 to 30 days) have less capacity of nutrient digestion and absorption in comparison with older birds (41 to 50 days).

Also, they found energy values by 13% higher for birds from 21 to 30 days compared with birds from 41 to 50 days old. The TME value of YC was 3432.17 kcal/kg. The TME contents of YC reported by Shires *et al*. (1980) were 3930 and 3980 kcal/kg in white leghorn male chicks and adult roosters, respectively.

Colovic *et al*. (2015) showed the effect of CP, EE, GE, CF, Ash and enzyme digestibility of organic matter on the prediction of TME contents of feedstuffs for broilers. The results showed that corn containing 4.86 to 5.25% EE had TME ranging between 3800 to 4270 kcal/kg as against 3670 kcal/kg of corn with 2.78% EE (Sibbald, 1986). Sibbald (1986) indicate that corn containing 4.87% EE yield 4540 kcal/kg GE as against 4280 kcal/kg in the case of corn with 2.78% EE. At the present study, the highest value of AMDM and TMDM were shown in YC (64.73 and 73.85 kcal/kg, respectively).

Probably, this could be attributed to low levels of CF in YC in comparison with CM. In conclusion, the results showed no differences in TMEn value of corn investigated in the present study compared with NRC (1994) and Rostagno *et al*. (2011). Thus, continuous evaluation of feedstuffs is necessary to enhance estimates of nutrient values and metabolizable energy which are applied to the poultry diets.

Soybean meal

The CP contents of SBM reported by NRC (1994), Rostagno *et al*. (2011) and Stefanello *et al*. (2016) were 48.5, 45.22 and 45.77%, respectively. The EE values obtained from other studies were NRC (1994) (1.0%), Rostagno *et al*. (2011) (1.69%). NRC (1994) and Rostagno *et al*. (2011) reported CF contents for SBM 3.9 and 5.3%, respectively. Some tables of ingredient composition generally provide nutrient profiles for this ingredient based on its CP, EE and CF contents (NRC, 1994; Rostagno *et al*. 2011).

For the SBM evaluated in the current study, the mean content of TMEn was 2572.4 kcal/kg. Dale and Fuller (1979) in 6-week-old broiler males, Shires *et al*. (1980) in 4-week-old chicks, NRC (1994), Rostagno *et al*. (2011) and Gheisari *et al*. (2014) in 5-week-old broiler chickens reported TMEn contents for soybean meal 2950, 2850, 2485, 2506 and 2551 kcal/kg, respectively. It can be observed that, the metabolizable energy content of SBM is influenced by varieties, indigestible carbohydrates such as oligosaccharides (Stefanello *et al*. 2016), processing methods (Karr-Lilienthal *et al*. 2005), chemical composition and age of the birds. For SBM case, the TME value was lower than those resulted by Yaghobfar (2013) in 21-d-old broilers, Shires *et al*. (1980) in 4-week-old chicks and adult roosters. A greater amount of TMEn was observed in high-protein SBM in comparison with conventional SBM. The higher TME value was observed for SBM containing 50 and 53% CP (Sibbald, 1986).

Sub (1988) cited lower values of TME for SBM containing 45 and 42% CP. Generally, factors such as genotype, planting area, type of soil, agricultural practices, environmental factors, storage and processing methods of SBM can influence the chemical composition (Karr-Lilienthal *et al*. 2004) and consequently the amount of CP, fiber, sugars, mineral and also the nutritive value of the SBM (Ravindran *et al*. 2014).

Corn gluten meal

NRC (1994), Rostagno *et al.* (2011), and Hassanzadeh Seyedi and Hosseinkhani (2014) reported EE contents for CGM 2.5, 2.3 and 2.9%, respectively. The GE contents of CGM noted by Rostagno *et al.* (2011) and Hassanzadeh Seyedi and Hosseinkhani (2014) were 5010 and 5509 kcal/kg, respectively. The CP values obtained by Dale and Fuller (1979), Nadeem *et al.* (2005) and Hassanzadeh Seyedi and Hosseinkhani (2014) were 55.03, 63.82 and 60.44%, respectively. The mean amount of TMEn found in this study (4183.25 4270.12 kcal/kg) was higher than the value reported by NRC (1994) (3811 kcal/kg) and Rostagno *et al.* (2011) (3868 kcal/kg). The results of study on adult roosters indicated that TMEn contents of CGM samples ranged from 4132.87 to 4157.13 kcal/kg (Hassanzadeh Seyedi and Hosseinkhani, 2014). Shires *et al.* (1980) noted that good agreement found in the results of TME values of CGM between roosters, broilers and poults, also the values for broilers were slightly lower than the values obtained by roosters or poults. Therefore, TMEn values obtained with adult roosters can be used in the formulation of diets for young growing broiler chicks (Shires *et al.* 1980). In this study, the mean value of TME was 4270.12 kcal/kg. Nadeem *et al.* (2005) reported that, the TME value of CGM (60% CP) was 3980 kcal/kg. Higher TME value as 4130 kcal/kg had been noted by Sub (1988). Sibbald (1986) indicated higher TME value (4400 kcal/kg) in 11 samples of CGM, which contained 67% CP. So, chemical composition and TMEn values of CGM can be affected by the variety of corn, production conditions of CGM, physical and chemical properties of soils, agronomic and climatologies conditions of corn cultivation.

Canola meal

NRC (1994), Nadeem *et al.* (2005), Rostagno *et al.* (2011) and Yaghobfar (2013) reported CP values of CM 38, 40.11, 37.97 and 35.7% and EE 3.8, 2.03, 1.21 and 4.6%, respectively. The CF values cited by NRC (1994), Nadeem *et al.* (2005) and Rostagno *et al.* (2011) were 12, 12.78 and 11.20%, respectively. The mean content of TMEn found in this study (1806.38 kcal/kg) was lower than the value cited by NRC (1994) (2070 kcal/kg), Shires *et al.* (1980) (1990 kcal/kg) in 4-week-old chicks and Rostagno *et al.* (2011) (1900 kcal/kg). Considerable variation has been found in metabolizable energy contents of CM. March *et al.* (1973) obtained ME values of 1465 and 1510 kcal/kg for CM fed to White Leghorn and broiler chicks, respectively and showed the relationship between ME and age of the birds. The results of this experiment indicated that the TME value of CM was lower than those resulted in adult cockerels (Yaghobfar, 2013; Shires *et al.* 1980).

The ME values of two different varieties of CM for 4-week-old male broiler chicks were 1755 and 1860 kcal/kg (March *et al.* 1975).

High TME value (2660 kcal/kg) had been noted by Jones and Sibbald (1979) in high-protein CM (53%) in comparison to those that contain low levels of CP (35%) with 2100 kcal/kg ME (Sub, 1988). Higher EE content in CM seems to be the reason for higher TMEn value. Fats, also called lipids, can be expected to enhance both the GE and ME values of the CM due to the fact that it contains more calories per gram and thus more energy than carbohydrates or proteins (Bell, 1993). Seth and Clandinin (1973) found that hull and fiber decreased the ME value of CM. Seed size, composition and color of the hull, ratio of hull to embryo may affect the level and nature of the fiber and thus the energy value (Bell, 1993). In the current study, the AMDM and TMDM of CM varied from 30.07 to 39.64 and 39.19 to 48.76 kcal/kg, respectively. The lowest dry matter digestibility of CM was due to its high levels of CF. Therefore, less metabolizable energy is expected. It is concluded that varieties, crude protein, crude fiber, residual oil in the meal and processing methods affected metabolizable energy values of CM (Karr-Lilienthal *et al.* 2005).

Poultry by-product meal (PBPM)

Kalvandi *et al.* (2011), Rostagno *et al.* (2011) and Zarei *et al.* (2014) reported GE values for PBPM 5481, 4750 and 6119 kcal/kg, respectively. The EE values of PBPM noted by NRC (1994), Kalvandi *et al.* (2011), Rostagno *et al.* (2011) and Zarei *et al.* (2014) were 13, 19.16, 14.17 and 21.75%, respectively. The CP values obtained from other studies were NRC (1994) (60%), Kalvandi *et al.* (2011) (53.11%), Rostagno *et al.* (2011) (57.68%), and Zarei *et al.* (2014) (62.8%). Robbins and Firman (2006), Rostagno *et al.* (2011) and Zarei *et al.* (2014) reported ash contents for PBPM 16.49, 15.19 and 5.2%, respectively. In the current study, the mean value of TMEn (2678.06 kcal/kg) was lower than the values reported by NRC (1994) (3120 kcal/kg), Rostagno *et al.* (2011) (3546 kcal/kg) and also was in agreement with Robbins and Firman (2006) (2690 kcal/kg).

The average value of TME (2711.95 kcal/kg) was lower than TME value reported by Zarei *et al.* (2014). Han and Parsons (1990) indicated that the TME values of PBPM were between 2863 and 3390 kcal/kg. Dale *et al.* (1993) reported that the TME values of PBPM ranged between 3626 and 5247 kcal/kg. This difference may due to used biological methods of ME evaluation. Generally, factors such as birds age, amount of experimental feed used in practical or purified diets and type of feed presentation can cause variation in methods.

Robbins and Firman (2006) cited that there were no considerable differences in any methodology used to determine the ME values of PBPM samples. Robbins and Firman (2006) reported that the observed results in roosters and chickens can be used in broilers and turkeys as well. Some studies cited similar results among roosters, turkeys and broilers.

Sibbald (1986) observed higher values of TME (3520-4480 kcal/kg) for PBPM containing 13-30% EE, 47-67% CP, and 13-16% ash compared with PBPM having 18, 56, and 11%, EE, CP and Ash, respectively. So this difference in TME values is certainly because of the variability and nutrient composition of PBPM samples. The type of raw-materials and storage time, processing methods and temperature could cause great variation in TMEn content of PBPM (Janmohammadi *et al.* 2009). So each sample should naturally be analyzed continuously before using in the formulation of poultry diets.

CONCLUSION

The optimum time of excreta collection for 3-week-old male broiler chicks was approximately 12 h after force feeding. TMEn values of feedstuffs can be determined in 3-wk-old broiler chicks by using precision-fed chick assay. TMEn values of cereal grain (corn), meals (soybean meal, corn gluten meal and canola meal) and animal by-products (poultry by-product meal) can be influenced by their chemical composition. Due to the role of energy as one of the expensive sections of diets in poultry nutrition, accurate knowledge about energy availability of feedstuffs is very important in the formulation of low-cost and economical diets in order to achieve profitable production.

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