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Metabolizable Energy Requirements for Broiler Breeder in Different Environmental Temperatures

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Abstract: A 10 wk feeding experiment was conducted to develop a model for predicting the ME requirement for broiler breeder hens housed in different environmental temperatures. Three groups of 50 Cobb 500 broiler breeder hens were individually housed in breeder cages located in environmentally controlled rooms set at 15.5, 23 and 30°C. Each breeder was given an intramuscular injection of Tamoxifen (TAM) (5 mg/kg BW) in corn oil at days 1 and 4 to stop egg production. Ten breeders from each environmental temperature were sacrificed for carcass composition analysis at the beginning of the study. Breeders, during the non-laying period, housed at 15.5°C were fed 100 g providing 285 kcal MEn/b/d (2851 kcal/kg; 16%CP) and breeders housed at 23°C and 30°C were fed 93 g providing 265 kcal MEn/b/d of same diet. Five breeders were sacrificed from each environmental room after the breeders resumed egg production. The ME requirement for maintenance (ME_m) determined during the non-laying period was 104.3, 98.1 and 99.4 kcal/kg$^{0.75}$ for birds housed in 15.5, 23 and 30°C, respectively. At first egg, 136, 130 and 128 g/bird/d of same diet previously fed during the non-laying period provided 388, 371 and 365 kcal ME_n/b/d to broiler breeder hens housed at 15.5, 23 and 30°C, respectively. The egg number, egg weight and BW change for each breeder during egg production was evaluated through the remainder of the 10 wk period. At the end of the trial, all birds were sacrificed and frozen at -4°C for carcass composition analysis. Body weight data collected during the non-laying period was used to construct a single equation by plotting Metabolizable Energy (ME) against body weight change (BWΔ) for each individual hen to calculate the ME_m. Egg production and egg weights were recorded daily after egg production resumed. The ME_g and ME_e requirement for BW gain and egg production were determined for breeders in each of the environmental temperatures based on the energy content of carcass and egg mass and the respective efficiency of energy utilization. The average ME_g and ME_e for the three environmental temperatures was 5.8 kcal/g and 2.3 kcal/g, respectively. Three equations were developed from the feeding experiment to predict ME needs for breeders: Eq. 1: ($ME = BW^{0.75} [111.9 - 0.46 T] + 5.8G + 2.3EM$); Eq. 2: ($ME = BW^{0.75} [110.3 - 0.47 T + 0.055 (T - 22.5)^2] + 5.8G + 2.3EM$); Eq. 3: ($ME = BW^{0.75} [111.02 - 0.49 T + 0.049 (T - 22.07)^2] + BW\Delta (1/0.77 \times ERf + 1/0.37 \times ERp) + ECE/0.73 \times EM$), where ME = Metabolizable Energy (kcal), BW = Body Weight (kg$^{0.75}$), T = Temperature (°C), BWΔ = Body Weight change (g/d), ERf = Energy Retained as fat (kcal), ERp = Energy Retained as protein (kcal); ECE = Energy Content of Eggs (kcal/g) and EM = Egg Mass (g).

Key words: Metabolizable energy, prediction models, environmental temperature, broiler breeders

INTRODUCTION

Although energy is not a nutrient *per se*, from the biological and economic stand point, energy plays a fundamental role in formulating diets for broiler breeder hens. Feed intake of broiler breeders is regularly restricted during rearing to prevent reproduction and health problems at a later age and to assure optimal performance. Metabolizable Energy (ME) requirements for broiler breeder hens are known to be higher than for commercial layers; nevertheless, the requirements for broiler breeders is often extrapolated from studies conducted mainly with Leghorn type hens (Leeson, 2003). The factorial approach is one of the most common ways of partitioning the ME requirements into maintenance, gain and egg production (Zhang and Coon, 1994). Environmental temperature plays an important role in regulating energy requirements for poultry. Sakomura *et al.* (2011) suggests that additional environmental-nutrition research is needed to help standardize the nutritional changes that occur. The objective of the present study was to determine the energy requirement for maintenance, body weight gain and egg mass output for broiler breeder hens housed at different environmental temperatures.

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Table 1: Composition and analysis of diet fed to broiler breeder hens housed at 3 different environmental temperatures

Ingredients	Composition (%)
Corn	63.17
Soybean meal solvent ext. 47.5% protein	24.83
Choline Chloride 60%	0.07
Lysine	0.43
Dicalcium PO_4	1.87
Ethoxyquin 66%	0.02
Poultry fat	2.45
Calcium carbonate	6.43
Kemin Mold Curb 50% Propionic Acid	0.05
Salt	0.39
Trace mineral CVI Breeders[A]	0.06
CVI Breeder premix 2960[B]	0.15
Crude protein PCT	15.50
Calculated metabolizable energy (kcal/kg)	2860.00
Analyzed AME_N (kcal/kg)	2851.00
Calculated crude protein[C]	16.00
Analyzed crude protein	16.02

[A]Provides per kg of diet: Mn 120 mg; Zn 120 mg; Fe 60; Cu 12 mg; I 1.2 mg; Mg 31.8 mg and Ca 855.
[B]Provides per kg of diet: vitamin D_3 4.95 kIU; vitamin A 14.7 KIU; vitamin E 80.7 IU; niacin 94.7 mg; D-Pantothenic acid 39.2 mg; riboflavin 21.1 mg; pyridoxine 12.4 mg; thiamine 6.3 mg; folic acid 3.9 mg; biotin 0.44 mg; 29.7 MCG.
[C]Crude protein = %

MATERIALS AND METHODS

Birds and management: Three groups of 50 Cobb 500 broiler breeder hens, 32 weeks of age, were placed in individual female broiler breeder cages in three different environmentally controlled rooms (Cobb-Vantress, 2008). Cages (47 cm high, 30.5 cm wide, 47 cm deep) were each equipped with an individual feeder and nipple drinker. Birds were fed individually and provided with free access to water at all times. During a 2-week adaptation period, temperature was gradually adjusted to 15.5, 23 and 30°C before the initiation of the experiment.

The lighting regimen was 16 hr light and 8 h darkness per day. Temperature of each room was recorded each day at 08:30 in the morning throughout the experimental period.

During the non-laying period, 93 g/bird/d of breeder diet (2851 kcal AME_n/kg; 16% CP) (Table 1) provided 265 kcal ME_n/b/d for breeders housed at 23 and 30°C and 100 g/bird/d provided 285 kcal ME_n/b/d for breeders housed at 15.5°C. During the laying period, 136, 130 and 128 g/bird/d of same diet (2851 kcal AME_n/kg; 16% CP) (Table 1) provided 388, 371 and 365 kcal ME_n/b/d to broiler breeder hens housed at 15.5, 23 and 30°C, respectively.

General procedures for flock management and collection of egg and carcass samples were similar to the experimental design described by Reyes *et al.* (2011). Egg production was stopped utilizing 2 injections (5 mg/kg BW) of Tamoxifen (TAM) (estrogen antagonist) in corn oil on days 1 and 4 at the beginning of the study. Ten breeders from each environmental room were sacrificed by CO_2 inhalation and frozen at -4°C for carcass composition analysis. Five additional breeders from each environmental room were sacrificed for carcass composition analysis when the breeders resumed egg production. The remaining breeders from each environmental temperature were sacrificed for carcass composition analysis at the termination of the 10 wk period to represent the body composition of breeders at the end of laying period.

Breeder performance data, egg and body tissue samples obtained from the three environmental temperatures, egg energy content, carcass energy content, energy retained in the body, energy for egg production, energy coefficients and maintenance energy requirement were determined using the same procedures and calculations described by Reyes *et al.* (2011). Three ME requirement models for broiler breeders were developed for different environmental temperatures. The ME requirement for maintenance (ME_m) was calculated using the individual data collected during the non-laying period in order to reduce interdependence among factors involved in egg production.

Statistical analysis: Standard statistical procedures were used to obtain linear regression equations for predicting ME_m (Mendenhall and Sincich, 2003). Regression analyses and polynomial equations were fitted using the least squares procedure of JMP IN® Software (SAS Institute) (1999-2000a). Data were subjected to a one-way ANOVA using the General Linear Models procedure of SAS® (1999-2000b). When a significant F statistic was detected, means were separated using Tukey's test at 5% of probability (Freund and Wilson, 1997).

RESULTS AND DISCUSSION

Although the temperatures were mechanically kept constant for each environmental room, slight fluctuations occurred throughout the trial. The overall registered mean temperatures and standard deviations of environmentally controlled rooms were 15.5 (±0.49), 23 (±0.29) and 30 (±0.46)°C.

Egg production dropped to zero 7 days after the first TAM injection. Broiler breeder hens housed in rooms maintained at 15.5, 23 and 30°C environmental temperature reached peak egg production in 25, 20 and 22 days after last TAM injection, respectively. Hens that laid few or no eggs during the experiment were not used for calculating ME_e.

Metabolizable energy for maintenance: Data collected only during the non-laying period were used to calculate ME_m. The ME_m requirements obtained were 104.3, 98.1 and 99.4 kcal/kg$^{0.75}$ for birds housed in 15.5, 23 and 30°C, respectively (Fig. 1).

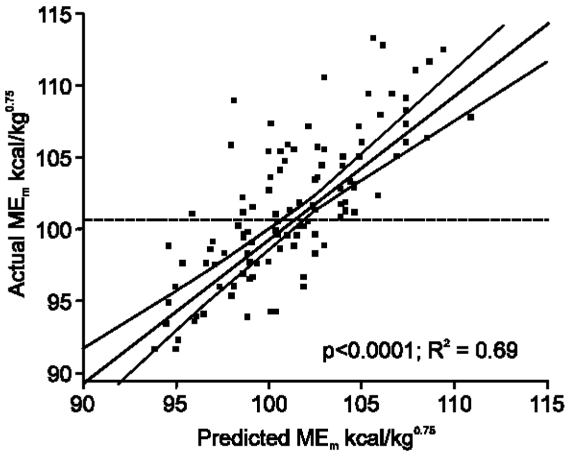

Fig. 1: Actual and predicted ME for maintenance for breeder hens housed at 15.5, 23 and 30°C

Parameter estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept (23°C)	98.06	0.450	216.06	<0.0001
BW change g/d	0.53	0.059	9.01	<0.0001
30°C	99.41	0.640	2.12	0.0366
15.5°C	104.39	0.630	10.07	<0.0001

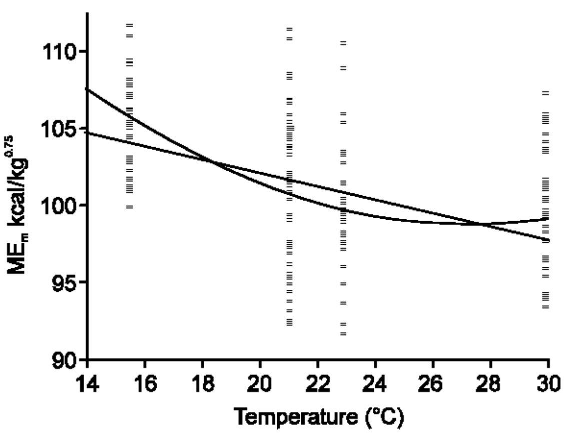

Fig. 2: ME for maintenance (ME$_m$) as a function of environmental temperature

Linear Fit:
MEm (kcal/kg$^{0.75}$) = 111.9 - 0.46 T (°C); R^2 = 0.50

Polynomial Fit Degree = 2:
MEm (Kcal/kg$^{0.75}$) = 110.3 - 0.47 T (°C) + 0.055 (T (°C) -22.5)2 T (°C); R^2 = 0.61

Temperature effects on ME$_m$ indicated a non-linear relationship between ME intake as a function of environmental temperature (Fig. 2). The data collected were utilized to estimate temperature effects on ME$_m$. The three equations used for ME$_m$ were: 1.) Me$_m$ = BW$^{0.75}$ [111.9 - 0.46 T](R^2= 0.50), 2.) ME$_m$ = BW$^{0.75}$ [110.3 - 0.47 T + 0.055 (T - 22.5)^2] (R^2 = 0.61) and 3.) ME$_m$ = BW$^{0.75}$ [111.02 - 0.49 T + 0.049 (T - 22.07)^2] (R^2 = 0.54). ME$_m$ is the requirement of ME for maintenance and T is temperature in degree Celsius.

ME$_m$ for broiler breeder hens kept at 30 and at 15.5°C environmental temperature was slightly higher (99.4 kcal/kg$^{0.75}$ and 104.3 kcal/kg$^{0.75}$, respectively) than that of breeder hens kept at 23°C (98.1 kcal/ kg$^{0.75}$). Sakomura (2001) developed prediction equations for calculating ME requirements for broiler breeder hens at different temperatures using the factorial approach. ME$_m$ requirements were obtained by comparative slaughter. ME$_m$ for broiler breeders housed at 15.5°C obtained in the present study (104. 4 kcal/kg$^{0.75}$) are in close agreement with those obtained by using the prediction equation elaborated by Sakomura (2001) (i.e. 103 kcal/kg$^{0.75}$). However, ME$_m$ for birds kept at 23 and 30°C environmental temperatures calculated in the present study (98.1 kcal/kg$^{0.75}$ and 99.4 kcal/kg$^{0.75}$, respectively) were 9% higher than that calculated by Sakomura's equation (89 kcal/kg$^{0.75}$ and 90 kcal/kg$^{0.75}$, respectively). Rabello *et al.* (2004) also evaluated the effect of environmental temperature on the metabolizable energy requirements of broiler breeder hens and reported 111.2, 91.5 and 88.5 kcal/kg$^{0.75}$/day for birds kept in cages at 13, 21 and 30°C. Rabello *et al.* (2004) reported values that were 10.9% higher for birds kept at 13°C and 6.5% lower for birds kept at 30°C. The lower ME$_m$ requirement for the breeders kept at 15.5°C in present experiment can be attributed to the 2.5°C higher temperature compared to Rabello *et al.* (2004).

An inverse linear relationship between environmental temperature and ME$_m$ has been reported in the literature. As temperature increases, energy requirements for maintenance decrease, within a broad range of temperatures (Hurwitz *et al.*, 1980; NRC, 1981). Sakomura *et al.* (2003) also observed a depression in ME requirements for maintenance at increasing temperatures in broiler breeder pullets. Sakomura (2004) indicates that a linear relationship should be considered for predicting the ME$_m$ when environmental temperatures are similar to the thermo-neutral temperature for poultry.

The present study using TAM treated hens supports a non-linear relationship between temperature and ME$_m$. Broiler breeder hens housed at 30°C had a higher ME$_m$ than broiler breeders housed at a thermo-neutral temperature (21-23°C). The ability to detect a slight increase in ME$_m$ for breeders housed at 30°C compared to 23°C may have been possible because the data was collected from individual broiler breeder hens and the environmental temperature was kept constant throughout the experiment. Broiler breeders housed in a constant 30°C temperature in present study would probably be more heat stressed than breeders housed in cyclic temperatures with same 30°C 24h mean warm temperature. Previous research with commercial layers housed in constant temperatures above 30°C show a rapid decrease in feed intake and performance compared to layers housed in similar 24 h mean temperature from cyclic temperatures ranging from 27-35°C (Zollitsch *et al*., 1996). Broiler breeders would require additional energy to dissipate heat loss compared to a commercial layer because of the additional bodyweight/surface area (kg/cm^3). The breeders in the constant 30°C warm temperature may need more ME_m to provide energy for thermoregulatory mechanisms such as panting caused by the hot environmental temperatures (Waibel and MacLeod, 1995). A quadratic effect of temperature above 27°C on requirements of ME_m has also been suggested in the literature for broiler breeder hens (Sakomura, 2004; 2001; Leeson and Summers, 1997; Rabello *et al*., 2006) and for broilers (Longo *et al*., 2006).

Metabolizable energy for body weight gain: There was a significant difference ($p<0.05$) in weight gain among hens maintained at different environmental temperatures (Table 2). Broiler breeder hens housed at 15.5, 23 and 30°C gained an average of 41.4, 12.0 and 23.1 g during the non-laying period, respectively. It is important to recall that, during the non-laying period, breeder hens housed at 15.5°C received an additional 7 g/bird/d (~20 kcal ME) more than hens housed at 23 and 30°C.

The average ME_g was 5.8 kcal/g (Table 3) in the present study and the mean efficiency for ME_g was 57%. The average ER_p and ER_f were 40 and 60.3%, respectively. Mean partial efficiencies for fat (*k*f) and protein (*k*p) for breeders were 0.77 and 0.38, respectively. These values were used to construct the prediction equation for calculating ME for broiler breeder hens.

The 5.8 kcal/g estimate of ME needed for body weight gain is similar to the value estimated by NRC (1994) (5.5 kcal/g) and by Emmans (1974) (5 kcal/g) for laying hens. Differences in ME requirements for gain could be due to differences in body composition and efficiency of energy utilization (Romero *et al*., 2009a). Romero and group indicate that linear models assume constant slopes that imply that the calculations are only applicable to birds with equal characteristics of BW gain. The Canadian researchers suggest a non-linear model instead.

Body weight changes (BWΔ) of breeders used in the present study were different among groups. The relatively low weight gain of breeders housed at 23 and 30°C (0.75 and 1.34 g/d, respectively) indicates that ME intake was only slightly above the maintenance requirement and the additional dietary energy was almost equally partitioned into body fat and protein (Table 3). The BWΔ of breeder hens housed at 15.5°C was larger since they were fed approximately 20 kcal additional ME. The body composition of the BWΔ was also different for breeders housed at 15.5°C because the breeders gained a higher percentage of fat. The results of this experiment would indicate that if breeders housed at 23 and 30°C had received a larger ME above maintenance, the ratio of protein: fat retained may have been different. Breeders seemingly become very efficient when fed lower levels of energy intake since little energy was left for body weight change.

Overall, a greater percentage of energy utilized for BWΔ was deposited as fat during the feeding study. The increased fat retention for breeders housed at 15.5°C was in agreement with the findings of Pearson and Herron (1981); Spratt and Leeson (1987); Spratt *et al.* (1990). Experiments conducted during the complete laying period with Cobb 500 broiler breeder hens housed in individual cages (Sun and Coon, 2005; Sun *et al*., 2006) showed the composition of gain for BWΔ for breeder hens was 75% fat and 25% protein. Broiler breeders that were 10-20% above a Cobb standard at the beginning of production retained more energy as fat than as protein, whereas breeders that were 10-20% below the Cobb standard retained more protein during the productive cycle (20-65 weeks).

Table 2: Body weight change and daily body weight change of broiler breeder hens during the non-laying period

	Temperatures (°C)			
Characteristics	15.5	23	30	Average
Initial body weight, kg	3.73±00.03	3.71±00.04	3.69±0.03	3.71
Final body weight, kg	3.77±00.04	3.73±00.04	3.71±0.03	3.74
Body weight gain, g	41.39±10.81	12.03±10.63	22.06±8.92	25.16
Body weight gain, g/d	2.59±00.66	0.80±0.0002	1.34±0.56	3.95

Table 3: Partial efficiencies for body weight gain, fat and protein retention and ME for body weight gain during the non-laying period

	Temperatures (°C)			
Characteristics	15.5	23	30	Average
*k*g, %	71.00	51.00	49.00	57.00
ER as DM, kcal/d	16.73±1.65	5.14±1.59	8.62±1.34	10.16
ERp, %	31.00	45.00	43.00	39.70
ERf, %	69.00	55.00	57.00	60.30
*K*f	0.96	0.61	0.73	0.77
*k*p	0.47	0.41	0.25	0.38
Meg	5.09	6.74	5.49	5.77

Boekholt *et al*. (1994) concluded that daily retention of protein and fat was linearly related to energy retention. The authors found that more fat than protein was retained when growing broilers were fed at increasing energy intakes, but when energy intakes were lower, a constant daily protein retention and a variable fat retention occurred. The findings of Boekholt *et al*. (1994) support the increased fat gain, *k*f and the observed ratio (fat: protein) of retained energy during the non-laying period especially for the breeders fed additional energy and housed at 15.5°C (Table 3, 6).

Broiler breeders housed at 15.5°C, which received an extra allocation of energy (~20 kcal/d) gained more weight and had a higher *k*g than the other breeders housed at higher temperatures (Table 3). One of two possible scenarios may have produced this result. The ME_m for broiler breeders housed at the cold temperature may have been overestimated since there was a higher percentage of the breeder population housed at 15.5°C that gained weight compared to breeder hens housed at 23°C and 30°C. A more likely explanation is the heat increment from extra feed provided the breeders during production spared the energy needed for ME_m so that more energy was available to be converted into body tissue. Zhang and Coon (1997) and MacLeod (2002) hypothesized that higher partial efficiencies of energy retention at cool temperatures are the result of the heat increment of feeding that replaces thermoregulatory heat production and therefore, the requirements for maintenance.

The estimated *k*g for broiler breeders housed at 23°C was 0.51 and slightly higher than *k*g of 0.49 for broiler breeders housed at 30°C although both groups received the same feed allowance. Additional energy would be needed to meet the demand for dissipating heat for breeders housed at 30°C resulting in a higher ME_m and a lower *k*g. An additional input of energy has been shown to be necessary to dissipate metabolic heat in chickens and turkeys housed at temperatures above 30°C (Hurwitz *et al*., 1980).

The higher retained energy as fat in breeders housed at 15.5°C may be explained either by the extra heat increment of feeding or by an overestimated ME_m. Therefore, in order to calculate the ME_g, mean efficiencies (*k*g) for the three groups of hens were used. Estimated *k*g in the present study (0.57) is 24% lower than that reported by Spratt *et al*. (1990) for broiler breeder hens and 10 and 17.5% higher than that calculated by Rabello *et al*. (2000, 2006). The variation in these data might have been caused by the method used to determine protein and fat accretion rates (respiration calorimetry or comparative slaughter) (Webster, 1989). The estimated *k*g found in the present study may have been influenced by bird age and variation of body composition within groups of broiler breeder hens. The average value of *k*g of 0.57 (Table 3) may be a better estimate for predicting the energy requirements of ME for broiler breeder hens under practical conditions.

Birds housed at 15.5°C had higher efficiencies (0.96 and 0.47) for fat and for protein synthesis than birds housed at warmer temperatures. Birds housed at 15.5°C gained approximately 2.6 g per day, 69% of which was fat gain (Table 3). These results can be compared with those reported by Spratt *et al*. (1990) who found 0.96 and 0.51 efficiency for fat and protein, respectively. Body weight gain (2.6 g/d) observed in breeders housed at 15.5°C was also similar to the 2-3 g/d gain reported by Spratt *et al*. (1990). Breeders housed at 30°C had higher *k*f (0.73) than breeders housed at 23°C (0.61). The breeders housed at 30°C retained a higher percentage of gain as fat compared to breeders housed at 23°C possibly because of lower energy requirements for fat synthesis compared to protein retention (Boekholt *et al*., 1994). Breeders housed at 23°C had a relatively low *k*f, body weight gain and ERf compared to breeders housed at 30°C, which were fed the same amount of ME. This may suggest that either there was a preference for maintaining protein retention at the expense of fat (Boekholt *et al*., 1994) or more energy was needed at 23°C to keep the birds warm (El Husseiny and Creger, 1980), leaving less energy available for storage as fat. The mean *k*p (0.37) and *k*f (0.77) (Table 3) were used to construct the factorial model in the present study.

Metabolizable energy for egg production: Temperature significantly ($p<0.05$) affected egg production, egg mass, egg weight and some egg composition measurements (Table 4 and 5).

Egg Production (EP) and Egg Mass (EM) of hens housed at 15.5 and 30°C was lower than EP and EM of hens maintained at 23°C. Egg Weight (EW) was significantly lower for breeders housed in 30°C environmental temperature compared to egg weights for breeders housed in 15.5 and 23°C. The breeders housed in 15.5°C temperatures produced eggs that were approximately 6.1 g larger than eggs for breeders housed in 30°C temperatures (Table 4). The smaller eggs for breeders housed in 30°C temperatures may have been the reason that the eggs from these breeders contained the lowest % yolk (DM), although non-significant and significantly lower % albumen (DM) (Table 5). The non-significant smaller % yolk (DM) for the breeders housed in 30°C temperatures may have also been the reason that the breeder eggs from this group contained significantly higher yolk % protein and although non-significant, highest yolk % fat (Table 5). Breeders housed in 15.5 and 23°C shown a trend for producing eggs with an increased % albumen (DM)

Table 4: Performance characteristics of broiler breeder hens maintained at 15.5, 23 and 30°C during the laying period

	Temperatures (°C)		
Characteristics	15.5	23	30
Egg weight, g	63.57[a]±0.63	61.80[a]±0.56	57.46[b]±0.93
Egg mass, g/hen/d	45.18[b]±0.71	50.47[a]±1.02	42.19[b]±1.90
Egg production, %	71.23[b]±0.0003	81.74[a]±0.0003	73.00[b]±0.0003
Initial body weight, kg	3.80±0.21	3.72±0.004	3.76±0.022
Final body weight, kg	3.84±0.022	3.75±0.004	3.78±0.022
Body weight change, g	31.85±22.96	19.84±14.08	17.60±11.30
Feed consumption above maintenance, kcal/d	99.90±2.29	108.68±1.79	96.51±1.25

[a,b]Means ± SEM within a variable with no common superscript differ significantly ($p<0.05$)

Table 5: Egg composition, gross energy, partial efficiency of egg synthesis and ME for egg mass for broiler breeder hens maintained at 15.5, 23 and 30°C during the laying period

	Temperatures (°C)			
Characteristics	15.5	23	30	Average
Albumen, %	61.92±0.39	61.22±0.56	61.12±0.32	61.42
Yolk, %	29.28±0.38	29.47±0.26	30.18±0.29	29.64
Shell, %	9.41[a]±0.09	9.37[a]±0.09	8.80[b]±0.12	9.19
Albumen DM, %	12.32[a]±0.15	12.21[ab]±0.11	11.89[ab]±0.36	12.14
Yolk DM, %	42.03±0.42	43.24±0.16	40.45±0.09	41.90
Albumen fat, % DM	0.05±0.00003	0.08±0.00003	0.08±0.00003	0.07
Albumen protein, % DM	81.8[b]±0.24	82.7[a]±0.34	81.8[b]±0.22	82.10
Yolk fat, %	56.59±0.003	56.47±0.003	58.69±0.003	57.25
Yolk protein, %	30.18[b]±0.18	29.91[b]±0.19	30.91[a]±0.24	30.33
Egg gross energy, kcal/g	1.67±0.01	1.68±0.01	1.65±0.01	1.67
*k*e	0.71±0.03	0.79±0.02	0.66±0.04	0.73
ME_e	2.32	2.11	2.54	2.32

[a,b]Means ± SEM within a variable with no common superscript differ significantly ($p<0.05$)

Table 6: Body composition of broiler breeder hens

	Temperature (°C)								
	15.5			23			30		
Measurement	Initial[1]	First egg[2]	Final[3]	Initial	First egg	Final	Initial	First egg	Final
Fat, %	14.69	15.61	15.89	15.39	15.81	15.83	15.01	14.38	15.37
Protein, %	17.43	16.50	16.73	17.46	17.87	17.47	16.69	17.01	17.23
DM, %	40.02	38.62	38.35	40.30	42.01	41.90	38.99	38.93	39.03
Fat, % as DM	37.39	38.41	38.50	38.85	37.42	37.83	38.34	38.69	39.01
Protein, % as DM	51.84	50.92	50.37	51.71	50.76	50.47	51.04	52.10	51.87
GE, kcal/g	06.43	06.48	06.50	06.44	06.50	06.47	06.47	06.44	06.45

[1]Carcass composition of breeders at the beginning of the non-laying period.

[2]Carcass composition of breeders at the end of the non-laying period.

[3]Carcass composition of breeders at end of the laying period

although the differences were not significant between environmental groups. Birds that laid few or no eggs during the laying period were excluded from the egg production analysis *k*e calculation.

The Energy Content of Eggs (ECE) collected from broiler breeder hens housed at 15.5, 23 and 30°C were 1.68, 1.67 and 1.65 kcal/ g, respectively (Table 5). The energy value is based on the entire egg weight including the shell. The average energy content of breeder eggs from present study was 1.67 kcal/g. The average energy value per g egg mass is similar to the generally accepted NRC value of 1.66 kcal/g (NRC, 1981). The Energy Content of Eggs (ECE) reported in literature range from 1.33 to 1.80 kcal/g (Sakomura, 2004; Rabello *et al*., 2006; Sibbald, 1979; Chwalibog, 1992). To calculate the ME needed per gram of egg mass (egg mass = EP x EW), the energy content of eggs was divided by the average estimated *k*e, giving a requirement of 2.3 kcal/g of egg mass.

The *k*e's for broiler breeder hens housed at 15.5 and at 23°C were higher (71 and 79%, respectively) than that of hens housed at 30°C (66%), but there were no significant differences among groups ($p<0.05$). Breeders housed at 23°C were capable of sustaining a relatively high egg production and egg mass compared to the hens housed at 15.5 and 30°C (Table 4). Johnson and Farrell (1983) concluded that a non-linear relationship "between retained energy and total ME intake from maintenance to production" in broiler breeder hens might explain the *k*e above 70%.

Estimated values of *k*e reported in the literature range between 60 and 86% (Sakomura, 2004; Rabello *et al.*, 2006; Grimbergen, 1974) depending on strain, age, egg composition, egg size, lighting pattern, nutrition and environmental factors (Chwalibog, 1992). High efficiencies for egg production have been observed when broiler breeder hens use body energy to compensate the energy shortage (Spratt *et al.*, 1990; Pearson and Herron, 1981; Attia *et al.*, 1995; Neuman *et al.*, 1998) because of the higher efficiency of using body energy versus dietary ME for egg production.

Although in the present study the mean efficiency for EM synthesis (72.9%) is between 60 and 85% reported in the literature (Sakomura, 2004; Chwalibog, 1992), the variation in *k*e values may indicate that the heat increment from the increased feed allowance during the laying period may have been used to help maintain the breeder body temperature. The reduction in energy needed for ME_m provided extra energy that was deposited in eggs.

In order to calculate the energy needed per a gram of egg mass (egg mass = EP x EW), the energy content of eggs was divided by the average estimated *k*e, giving a requirement of 2.3 kcal/g of egg mass (1.67/0.729). This value is in the range of 2.04 and 3.13 reported in the literature for broiler breeder hens (Sakomura, 2004; Rabello *et al.*, 2000; Leeson *et al.*, 1973; Waldroup *et al.*, 1976; Sakomura *et al.*, 1993; Byerly *et al.*, 1980; Rabello *et al.*, 2006; Romero *et al.*, 2009b). The value 2.3 kcal/g of egg mass was incorporated into the prediction equations developed in the present study.

Zhang and Coon (1997) determined a high *k*e in TAM treated hens housed at temperatures of 15.3°C and below. The authors suggested that energy used for maintenance was not totally independent of the energy used for egg synthesis. Part of the additional heat liberated from the increased feed intake during egg production was used to compensate the ME_m leaving a surplus of energy that produced an overestimated *k*e for laying hens housed at cooler environmental temperatures.

The present study supports similar conclusions drawn by Zhang and Coon (1997) that TAM can be effectively utilized to stop egg production and accurately determine ME_m and ME_g in individual birds. Following a short time period for the natural depletion of TAM, the efficiency of utilization of ME for egg production and ME_e can be measured in same individual hens. The use of TAM-treated broiler breeder hens in present study allowed the estimation of the coefficients needed for developing ME prediction models. The estimated coefficients and their variations can be obtained from each individual (unique) breeder. The use of non-laying broiler breeders allowed a more accurate estimation of ME_m without interaction with EP and also provided an improved opportunity to estimate an accurate value for *k*e when egg production was resumed. The use of TAM methodology made possible the use of the individual characteristics for estimating ME requirements and avoided the use of a group average value of ME_m. The use of TAM also provided an advantage of allowing the use of larger numbers of individual breeders which would be difficult with indirect or direct metabolic chamber calorimetric studies because of the availability and costs of large numbers of chambers.

Prediction models for ME requirements for broiler breeders: The 3 equations developed for predicting ME requirements for broiler breeders housed in different environmental temperatures are as follows:

Equation 1:

$$ME = BW^{0.75}[111.9 - 0.46\,T] + 5.8G + 2.3EM$$

Equation 2:

$$ME = BW^{0.75}\,[110.3 - 0.47\,T + 0.055\,(T - 22.5)^2] + 5.8G + 2.3EM$$

Equation 3:

$$ME = BW^{0.75}\,[111.02 - 0.49\,T + 0.049\,(T - 22.07)^2] + BW\Delta\,(1/0.77 \times Erf + 1/0.38 \times Erp) + ECE/0.73 \times EM$$

Where ME = Metabolizable Energy (kcal); BW = Body Weight ($kg^{0.75}$); T = Temperature (°C); BWΔ = Body Weight change (g/d); Erf = Energy retained as fat (kcal); Erp = Energy retained as protein (kcal); ECE = Energy Content of Eggs (kcal/g) and EM = Egg Mass (g).

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