Modeling Metabolizable Energy Utilization in Broiler Breeder Pullets[1]

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ABSTRACT The objective of this study was to determine models for ME requirements for broiler breeder pullets using the factorial method. The influence of the temperature on maintenance ME requirements was determined by experiments conducted in three environmental rooms with temperature kept constant at 15, 22, and 30°C, using the comparative slaughter technique. The energy requirements for weight gain were determined based on the body energy content and efficiency of energy utilization for weight gain. Two ME requirement models for each age were developed using the coefficients for maintenance and weight gain. The models for 3 to 8 wk were ME = $W^{0.75}$ (186.52 − 1.94T) + 2.47WG, and ME = $W^{0.75}$ (174 − 1.88T) + 2.83WG; for 9 to 14 wk, ME = $W^{0.75}$ (186.52 − 1.94T) + 2.69WG, and ME = $W^{0.75}$ (174 − 1.88T) + 2.50WG; and 15 to 20 wk, ME = $W^{0.75}$ (186.52 − 1.94T) + 2.76WG, and ME = $W^{0.75}$ (174 − 1.88T) + 3.24WG. In these equations, W is BW (kg), T is temperature (°C), and WG is daily weight gain (g). These models were compared to the breeder's recommendations in a feeding trial from 5 to 20 wk of age. Models 1 and 2 provided energy intakes that promoted BW smaller than the breeder's recommendation. However, all breeder pullets had weights above the standard recommendation. Model 2 gave the smallest ME intake and BW close to the standard recommendation and provided the best prediction of ME requirements.

(*Key words*: broiler breeder pullet, comparative slaughter technique, energy model, factorial method, metabolizable energy requirement)

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INTRODUCTION

Research conducted to determine the nutritional requirements of broiler breeder pullets has been limited. One of the main reasons is because they are fed with controlled feeding and do not grow at the maximum rate. In addition, broiler breeder research has been primarily conducted during the laying period. Therefore, the nutritional energy requirements of broiler breeder pullets have not been defined (NRC, 1994).

Energy requirements can be determined by a factorial method that combines maintenance, growth, and production requirements. The determination of factorial coefficients is an important component of developing mathematical models but may be difficult because complex techniques are often required (Sakomura, 1996).

Application of models to predict the daily nutrient requirement may be helpful for feeding broiler breeder pullets. Metabolizable energy equations for predicting the requirements have been recommended for breeders and laying hens (Emmans, 1974; Rostagno et al., 1983; Peguri and Coon, 1988; Sakomura et al., 1993; NRC, 1994). A ME model may consider factors, such as BW, daily weight gain (WG), and environmental temperature, needed to predict the maintenance, growth, and production energy requirements.

Computer programs have been developed to assist in defining nutritional requirements by using a combination of growth models and nutritional research information. Swine nutritional requirements have been developed using models for growth and reproductive phases (NRC, 1998).

The objectives of this research were to determine the optimum coefficients needed for maintenance and growth energy requirements for broiler breeder pullets, to develop models for defining ME needs of pullets, and to evaluate the models in the feeding study.

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Abbreviation Key: HP = heat production; k_g = efficiency of energy utilization for retention; k_p = efficiency of energy utilization for protein retention; k_f = efficiency of energy utilization for fat retention; k_m = efficiency of energy utilization for maintenance; MEI = ME intake; ME_m = ME requirement for maintenance; ME_g = ME requirement for growth; NE_m = net energy requirement for maintenance; NE_g = net energy requirement for weight gain; RE = retained energy; WG = daily weight gain; $W^{0.75}$ = metabolic body weight.

MATERIAL AND METHODS

Energy Requirements for Maintenance

Three hundred eighty-four Hubbard Hi-Yield broiler breeder pullets (4 wk of age) were housed in three environmental rooms with temperature kept constant at 15, 22, and 30°C (± 2°C). The breeder pullets were randomly distributed into 16 floor pens per room with the pullets divided into four treatments of four replications of eight birds each. The pullets were acclimated to the environmental temperature and facilities for 14 d, and data were collected for a continuing 38-d feeding period. The four feed intake treatments consisted of ad libitum, 54, 34, and 19% of ad libitum intake. The actual ME intake was quantified by measuring the feed residuals during the experiment.

The diet utilized for feeding the pullets was formulated according to Hubbard Hi-Yield recommendations, with 2,960 kcal ME/kg, 16% CP, 0.754% methionine + cystine, and 0.800% lysine.

An 8-d feeding trial was conducted to determine the AME_n of the experimental diet by using a total collection technique. Breeder pullets were fed with four experimental feed intake levels: ad libitum, 54, 34, and 19% of ad libitum for the AME_n assay. Each feed intake level was provided to 10 breeder pullets housed in cages with two pullets per repetition and five replications.

The ME requirements were determined by a comparative slaughter method. In order to determine retained energy (RE) in the carcass and feathers, 24 pullets of the same age, strain, BW, and feeding regimen were killed by cervical dislocation at the beginning of the feeding study. All experimental pullets were killed by cervical dislocation at the end of the controlled feeding trial. Breeder pullets were weighed, defeathered, and weighed again to determine weight of the feathers. Samples of feathers were taken and ground for later analysis. The carcasses were immediately frozen at –4°C. Frozen pullets from each pen were combined and chopped into small pieces, after which the combined pieces were passed through a grinder[3] two times. Carcass samples were dried in a drying oven (55°C) for 96 h and reground for homogeneity. Carcass and feather samples were analyzed for dry matter, nitrogen, ether extract, and ash according to Silva (1981). Gross energy was determined by using a Parr adiabatic bomb calorimeter.

Heat production (HP) was determined by the difference between the ME intake (MEI) and RE. The logarithmic relationship between HP and MEI provided the maintenance net energy requirement (NE_m), as being the HP at zero ME intake (Balnave, 1974).

The maintenance ME requirement (ME_m) was determined by two procedures. The first procedure for determining the ME_m requirement was the linear relationship between RE and MEI that provided the ME_m at the intercept with x-axis being ME intake at zero energy retained (Farrell, 1974). The ME_m requirement was also determined by a second procedure according to the following model: $ME_m = MEI - (RE/k_g)$, where ME_m = maintenance ME (kcal/kg$^{0.75}$ per d), MEI = ME intake (kcal/kg$^{0.75}$ per d), RE = retained energy (kcal/kg$^{0.75}$ per d), and k_g = efficiency of energy utilization for retention (Boekholt et al., 1994).

[3]Model 114, CAF Rio Claro—SP, Brazil.

Energy Requirement for Weight Gain

One hundred sixty 3-wk-old breeder pullets were housed in a noncontrolled environmental room at temperatures recorded from 15°C (minimum) to 30°C (maximum) and distributed among four groups of 40 birds per group.

Eight breeder pullets consisting of two birds per group were slaughtered weekly from 3 to 20 wk of age to determine energy content in the carcasses and feathers. The procedures utilized for killing pullets, preparation of samples, and carcass analysis were the same as described for the experiments to determine the ME_m.

Net energy requirement for weight gain (NE_g) was obtained by linear regression between body energy content (BE) and BW. The slope of the equation provided the net energy requirement per gram of weight gain.

The ME requirements for weight gain (ME_g) were determined considering the NE_g and k_g.

Efficiencies of Energy Utilization

The k_g for gain was determined by two procedures. The k_g was determined in procedure 1 by using the formula: $k_g = RE/MEI - ME_m$. In procedure 2 the k_g was considered the slope of linear regression of RE and MEI.

The efficiency of energy utilization retained as protein (k_p) and as fat (k_f) were determined by multiple linear regression of MEI as a function of RE as protein (RE_p) and RE as fat (RE_f) (Boekholt et al., 1994). The procedure was also utilized to determine the maintenance ME requirement as being the intercept of the model: $MEI = ME_m + 1/k_p\ RE_p + 1/k_f\ RE_f$.

ME Requirement Models

Two models for daily ME requirements of broiler breeder pullets were determined from 5 to 8, 9 to 14, and 15 to 20 wk of age. Model 1 was elaborated according to the coefficients for maintenance and for weight gain considering the k_g determined by procedure 1. For model 2, the maintenance coefficient and k_g were obtained by procedure 2.

Evaluation of ME Requirement Models

Four hundred thirty-two Hubbard Hi-Yield breeder pullets were utilized in a feeding study from 5 to 20 wk of age to evaluate the ME requirement models determined in previous studies and to compare to standard breeder recommendations for the strain.

TABLE 1. Means of ME intake, retained energy, and heat production for broiler breeder pullets by feed levels at 15, 22, and 30°C

Feeding level	ME intake[1]	Retained energy[2]	Heat production
	(kcal/kg $BW^{0.75}$ per d)		
	15°C		
Ad libitum	329 ± 11	121 ± 6.2	208 ± 9.3
54% Ad libitum	249 ± 4.3	60 ± 2.1	188 ± 3.9
34% Ad libitum	197 ± 2.6	22 ± 2.6	176 ± 5.0
19% Ad libitum	138 ± 4.3	–9 ± 3.7	147 ± 7.9
	22°C		
Ad libitum	317 ± 6.9	125 ± 2.9	192 ± 7.9
54% Ad libitum	236 ± 1.5	58 ± 0.9	179 ± 1.2
34% Ad libitum	183 ± 1.2	24 ± 2.1	159 ± 3.3
19% Ad libitum	126 ± 2.4	–7 ± 1.6	134 ± 3.8
	30°C		
Ad libitum	291 ± 4.8	107 ± 4.2	184 ± 6.6
54% Ad libitum	216 ± 1.2	50 ± 2.8	166 ± 3.9
34% Ad libitum	167 ± 2.3	17 ± 1.8	149 ± 3.6
19% Ad libitum	111 ± 3.1	–4.4 ± 3.6	115 ± 6.6

[1]The ME intake was calculated based on feed intake and the AME_n of diet determined: 2,804, 2,921, 2,999, and 3,008 kcal/kg of diet fed according to the feeding levels: ad libitum, 54, 34, and 19% of ad libitum, respectively.

[2]The retained energy was calculated considering the initial BW (540 ± 15 g), initial body energy (2,020 kcal/kg), and energy of feathers (4,172 kcal/kg).

The pullets were randomly distributed into 18 floor pens (6 m^2) and divided among three treatments consisting of six replicates with 24 pullets per replicate. The treatments were as follows: 1) a control consisting of ME being supplied according to Hubbard Hi-Yield recommendations, 2) ME supplied according to model 1, and 3) ME supplied according to model 2.

The ME requirements were determined by using data for BW, weight gain corrected weekly, and environmental temperature corrected daily in the models. One-half of the pullets of each experimental unit were individually weighed weekly to obtain the average BW. The environmental temperature was recorded thermohydrographically, and the daily average temperature was calculated by the formula: T (°C) = [(T9am + Tmin + Tmax + 2 × T9pm)/5], where T = average temperature, T9am = temperature at 9 p.m., Tmin = minimum temperature recorded, Tmax = maximum temperature recorded, and T9pm = temperature at 9 p.m. The prediction of temperature was based on temperature the previous day.

The diets were formulated weekly to assure the pullets were being fed energy levels based on the two models and were provided the same intakes of protein, minerals, and vitamins as the control pullets.

The birds from 5 to 17 wk of age were fed according to a skip-a-day feeding schedule, and the birds from 18 to 20 wk were fed according to a 5 – 2 feeding schedule (5 d on feed and 2 d off feed).

Seventy-two breeder pullets consisting of four pullets per replicate were killed at the end of the feeding study at 20 wk of age and frozen for carcass analysis. The body composition was determined by analyzing the carcasses for water, protein, ether extract, and ash. The breast

TABLE 2. Regression of retained energy (RE) and heat production (HP) as a function of ME intake (MEI), values of maintenance ME (ME_m), maintenance net energy (NE_m), efficiency of energy utilization for gain (k_g), and maintenance (k_m) for broiler breeder pullets at 15, 22, and 30°C

Regressions[1,2]	R^2	Requirements (kcal/kg $BW^{0.75}$ per d)	Efficiencies
	15°C		
RE = –108.19 + 0.6867MEI	0.98	ME_m = 157.6	k_g[3] = 0.69
HP = 118.86 $e^{0.0018.MEI}$	0.90	NE_m = 118.9	k_m[4] = 0.75
	22°C		
RE = –99.56 + 0.6925MEI	0.99	ME_m = 143.8	k_g = 0.69
HP = 109.31 $e^{0.0019.MEI}$	0.91	NE_m = 109.3	k_m = 0.76
	30°C		
RE = –80.74 + 0.6285MEI	0.97	ME_m = 128.5	k_g = 0.63
HP = 92.49 $e^{0.0025.MEI}$	0.89	NE_m = 92.5	k_m = 0.72

[1]Regressions were significantly different from zero ($P < 0.01$).

[2]e = 2.718, is the base of the natural logarithm, when MEI is zero, $e^0 = 1$ and the HP is the intercept of equation.

[3]k_g = slope of linear regression of RE as a function of ME.

[4]$k_m = NE_m/ME_m$.

TABLE 3. Body weight (g), feather (%), and carcass defeathered compositions of broiler breeder pullets from 3 to 20 wk of age

Age (wk)	Body weight (g)	Feather[3] (%)	Water[2] (%)	Ash[2] (%)	Fat[2] (%)	Protein[2] (%)	Energy[2] (kcal/g)
3	322 ± 1.5[1]	5.9 ± 0.04	70.2 ± 0.43	3.1 ± 0.02	10.2 ± 0.08	15.9 ± 0.25	1.85 ± 0.03
4	389 ± 1.0	5.5 ± 0.04	70.2 ± 0.70	3.1 ± 0.03	10.1 ± 0.28	15.8 ± 0.46	1.84 ± 0.04
5	488 ± 2.5	6.0 ± 0.05	70.9 ± 0.11	3.2 ± 0.03	9.45 ± 0.14	15.9 ± 0.16	1.76 ± 0.01
6	576 ± 3.1	4.8 ± 0.06	70.1 ± 0.62	3.2 ± 0.06	10.2 ± 0.05	15.9 ± 0.37	1.85 ± 0.02
7	678 ± 8.04	5.5 ± 0.17	71.0 ± 0.47	3.1 ± 0.02	9.6 ± 0.35	15.9 ± 0.26	1.79 ± 0.03
8	779 ± 6.9	5.1 ± 0.01	69.9 ± 1.46	3.2 ± 0.13	10.3 ± 0.36	15.8 ± 0.53	1.85 ± 0.06
9	877 ± 13.4	6.4 ± 0.34	71.4 ± 0.73	3.2 ± 0.09	9.5 ± 0.45	15.4 ± 0.28	1.75 ± 0.04
10	960 ± 17.3	5.6 ± 0.30	69.0 ± 1.54	3.2 ± 0.11	10.1 ± 0.18	16.0 ± 0.84	1.85 ± 0.06
11	1,000 ± 3.3	5.1 ± 0.01	71.6 ± 1.33	3.3 ± 0.07	9.0 ± 0.73	15.6 ± 0.48	1.73 ± 0.08
12	1,115 ± 8.4	5.7 ± 0.06	70.1 ± 0.79	3.4 ± 0.10	9.5 ± 0.48	15.9 ± 0.32	1.80 ± 0.07
13	1,236 ± 7.7	5.1 ± 0.06	71.4 ± 1.22	3.4 ± 0.18	8.8 ± 0.49	15.8 ± 0.78	1.72 ± 0.06
14	1,320 ± 9.8	5.5 ± 0.17	71.0 ± 0.12	3.5 ± 0.08	8.9 ± 0.06	15.8 ± 0.27	1.72 ± 0.02
15	1,413 ± 8.5	5.6 ± 0.15	71.4 ± 0.30	3.5 ± 0.12	8.4 ± 0.31	16.5 ± 0.33	1.71 ± 0.04
16	1,531 ± 3.9	5.6 ± 0.03	71.1 ± 1.18	3.5 ± 0.13	8.5 ± 0.82	16.2 ± 0.34	1.71 ± 0.10
17	1,681 ± 7.6	5.1 ± 0.05	71.9 ± 1.24	3.4 ± 0.12	7.7 ± 0.58	16.5 ± 0.69	1.65 ± 0.08
18	1,816 ± 7.0	5.8 ± 0.06	69.4 ± 0.61	3.4 ± 0.13	9.8 ± 0.16	16.6 ± 0.25	1.85 ± 0.03
19	1,954 ± 14.4	5.0 ± 0.41	70.4 ± 0.76	3.3 ± 0.13	9.1 ± 0.68	16.8 ± 0.50	1.81 ± 0.05
20	2,062 ± 9.0	6.3 ± 0.01	69.8 ± 1.30	3.4 ± 0.22	8.9 ± 0.59	17.3 ± 0.50	1.77 ± 0.05

[1]Mean ± SEM.

[2]Carcass defeathered composition.

[3]Feather composition = 9.03% ± 0.49 water; 0.78% ± 0.36 ash; 1.39% ± 0.50 fat; 93.4% ± 1.50 protein; 4.574 kcal/g ± 0.87.

percentages (breast weight/BW expressed in percentage) of pullets were determined.

The statistical analyses were processed by the Statistical and Genetic Analyses System according to Euclydes (1982). The means were compared using the Tukey's test at 5% probability.

RESULTS AND DISCUSSION

Maintenance Energy Requirements

The ME intake, body RE, and HP for each feeding level and temperature, expressed as metabolic BW per day ($W^{0.75}$/d), are presented in Table 1. The NE_m, ME_m, and efficiency of utilization of ME for growth (k_g) determined for each temperature, according to procedure 1, are presented in Table 2.

The ME_m requirements were reduced with each temperature increase. The effect of temperature on ME_m was expressed by the following linear equation: $ME_m = W^{0.75}$ (186.52 − 1.94T), $r^2 = 0.99$, where W = BW (kg), and T = environmental temperature (°C). Similar results of ME_m were obtained using procedure 2: 146.92 ± 3.55, 130.92 ± 3.43, and 118.58 ± 3.97 kcal/kg$W^{0.75}$ per d for 15, 22, and 30°C, respectively. An equation representing the ME_m data developed from procedure 2 was as follows: $ME_m = W^{0.75}$ (174.15 − 1.88T), $r^2 = 0.92$. Both models were similar to the NRC (1994) prediction model for laying hens, which is $ME_m = W^{0.75}$ (173.1 − 1.95T).

The temperatures 15 and 22°C did not affect efficiencies of energy utilization for maintenance (k_m) and gain (k_g), but the efficiencies of utilization for maintenance and gain were reduced at 30°C (Table 2). The pullets might have used part of the dietary energy to dissipate additional body heat in the 30°C environment. The k_m values that ranged from 72 to 76% are similar to k_m values of 66.2 to 78.1% reported by Balnave (1974). The k_m values reported herein and the values reported by Balnave (1974) are less than k_m values of 85% reported by De Groote (1974) for adult and growing birds and 80% for growing birds weighing 0.3 to 1.2 kg reported by Chwalibog and Thorbek (1989).

The data of ME_m, NE_m and k_m for broiler breeder pullets are limited, and reported values are conflicting. The ME_m requirements of 128.5, 143.8, and 157.6 kcal/kg $BW^{0.75}$ per d for pullets housed in environmental temperatures of 30, 22, and 15°C, respectively, are similar to the results determined by Balnave (1974) at 25°C temperature. Balnave (1974) reported values of 112.9 kcal/kg $BW^{0.75}$ per d from 7 to 8 wk of age and 138.2 kcal/kg $BW^{0.75}$ per d from 11 to 12 wk of age. Chwalibog (1991) listed the ME_m from 76 to 115 kcal/kg $BW^{0.75}$per

TABLE 4. Allometric relationships of the water, protein, fat and ash contents, and carcass weight of broiler breeder pullets

Component	Equation	R^2
Water	Water = 1.8801 + 0.7043BW	0.99
Protein	Protein = −9.0706 + 0.1710BW	0.99
Fat	Fat = 6.9778 + 0.0845BW	0.96
Ash	Ash = −1.4593 + 0.0348BW	0.99

TABLE 5. Linear regression of body energy (BE) as a function of BW, net energy requirements for gain (NE_g), efficiency, and ME requirements for gain (ME_g) of broiler breeder pullets from 3 to 8, 9 to 14, and 15 to 20 wk of age

Regression[1]	R^2	NE_g (kcal/g)	Efficiency (%)	ME_g (kcal/g)
	3 to 8 wk of age			
BE = 7.618 +1.950BW	0.99	1.950	79[2]	2.47
			69[3]	2.83
	9 to 14 wk of age			
BE = 205.17 + 1.725BW	0.94	1.725	64[2]	2.69
			69[3]	2.50
	15 to 20 wk of age			
BE = –568.06 + 2.239BW	0.94	2.239	81[2]	2.76
			69[3]	3.24

[1]Regressions were significantly different from zero ($P < 0.01$).
[2]k_g = retained energy/(ME intake – ME for maintenance).
[3]k_g = Slope of regression (retained energy = –99.56 + 0.6925.ME intake, $r^2 = 0.99$).

d for chickens from 0.3 to 2.0 kg on experiments with different feeding levels.

The basal metabolic HP of 92.5, 109.3, and 118.9 kcal/kg $BW^{0.75}$ per d at 30, 22, and 15°C, respectively, were higher than HP of 88.2 kcal/kg $BW^{0.75}$ per d for birds from 11 to 12 wk of age (Balnave 1974), HP of 85.32 kcal/kg $BW^{0.75}$ per d for chickens from 0.3 to 1.2 kg (Chwalibog and Thorbek, 1989), and HP of 71.24 kcal/kg $BW^{0.75}$ per d for pullets (Silva et al., 1997). The HP results for pullets housed at 15°C reported herein were similar to 125.0 kcal/kg $BW^{0.75}$ per d suggested by De Groote (1974).

The variation in these data might have been caused by a lack of standardization of methods used to determine energy balance. The energy studies might have been determined with respiration chambers, calorimetry, carbon and nitrogen balance, and comparative slaughter. Fuller et al. (1983) reported that HP values obtained by calorimetry technique and comparative slaughter may differ by as much as 3 to 12%, and the HP values obtained with a calorimeter are usually lower.

The genetic strain and type of chicken (meat or egg), BW, breeder system (floor or cage), environmental temperature, and energy levels of diets could each affect the data variability for HP and energy utilization.

Energy Requirement for Growth

The data of body composition of pullets from 3 to 20 wk old are presented in Table 3. The percentage water is the largest part of body composition with substantially less carcass protein, fat, and ash. There were no specific trends of changing body composition with age that could be determined.

The allometric relationships among body protein, water, fat and ash, and BW are presented in Table 4. The results show a linear relationship of nutrient deposition with BW increase. The allometric relationships provide a means of calculating the body composition according to variations in BW (Bennett and Leeson, 1990a).

The ME requirements for growth were determined from 3 to 8, 9 to 14, and 15 to 20 wk of age. The linear regression among body energy and BW, ME, and NE requirements for growth are presented in Table 5.

The ME requirements for growth ranged from 2.47 to 3.24 kcal/g. This variation was due to differences in net

TABLE 6. Multiple linear regression of retained energy as protein (RE_p) and retained energy as fat (RE_f) in function of ME intake (MEI), maintenance requirements (ME_m) and efficiencies for protein retention (k_p) and fat retention (k_f) of broiler breeder pullets at 15, 22, and 30°C

Regressions[1,2]	R^2	k_p[3] (%)	k_f[4] (%)	ME_m (kcal/kg $BW^{0.75}$ per d)
		15°C		
MEI = 161.91 + 1.73RE_P + 1.04RE_f	0.96	57.8	96.2	161.91
		22°C		
MEI = 131.56 + 2.45RE_P + 0.92RE_f	0.99	40.8	108.7	131.56
		30°C		
MEI = 123.07 + 2.50RE_p + 0.93RE_f	0.97	40.0	107.5	123.07
Average	—	46.2	104.1	—

[1]MEI, RE_P, and RE_F are expressed in kilocalories per $kilogram^{0.75}$ per day.
[2]Regressions were significantly different from zero ($P < 0.01$).
[3]$k_p = 1/1.73$.
[4]$k_f = 1/1.04$.

TABLE 7. Metabolizable energy intake of broiler breeder pullets from 5 to 8, 9 to 14, and 15 to 20 wk of age according to treatment

	ME intake (kcal/pullet per period)[1]			
Treatment	5 to 8	9 to 14	15 to 20	5 to 20
Control	3,617[c]	7,092[a]	9,857[a]	20,566[a]
Model 1	3,836[a]	7,084[a]	9,403[b]	20,324[ab]
Model 2	3,762[b]	6,934[a]	9,368[b]	20,068[b]
F^2	70.92**	1.63[NS]	12.51**	5.04**
CV (%)	0.75	2.04	1.97	1.36

[a–c]Means within a column lacking a common superscript differ ($P < 0.05$).

[1]Data are means of six pens of 24 breeder pullets.

[2]Values of F followed NS ($P > 0.05$).

**Significant ($P < 0.01$).

energy body content that ranged from 1.950 to 2.239 kcal/g and the differences in k_g that ranged from 64 to 81%. These results are close to the suggested values of 1 to 3 kcal/g of BW for growing birds reported by Scott et al. (1982) and 2 kcal/g of BW for broiler breeder pullets reported by Bornstein et al. (1979). Scott (1982) suggested the rationale for the ME requirements for growth ranging from 1 to 3 kcal/g of BW for growing birds was due to differences in protein and fat deposition during growth. The ME required for growth is also largely affected by the efficiency of energy retention. De Groote (1974) has reported that efficiency of energy retention ranges from 37 to 85% for birds from 1 to 18 wk of age.

Chwalibog (1991) has reported that the validity of different models for estimating energetic efficiency of growth are based on the assumption that the efficiency of ME utilization for protein and fat formation are identical ($k_p = k_f$), but if this is not the case, the proportion between energy retained in protein and fat should be constant during the experiment.

The efficiency of RE as protein and fat and the ME_m requirement are presented in Table 6. The results of ME_m were similar to those determined by other procedures. The effect of environmental temperature also was observed on the ME_m requirements.

The temperature effect on the efficiencies of energy retained as protein (k_p) or as fat (k_f) was small for 22 and 30°C, but notable changes occurred at 15°C. The k_p at 22 and 30°C were approximately the same, and the k_f for the two temperatures were the same. The k_p at 15°C was approximately 18 percentage points higher than k_p at 22 and 30°C, and k_f at 15°C was 11 to 13 percentage points lower than k_f at 22 and 30°C. The higher k_p for the cooler environmental temperature indicated a lower energetic cost for energy deposition as protein and a higher energetic cost for energy deposition as fat.

The k_p and k_f values presented in the literature are quite varied because of the differences in genetic strains, gender, age, diets, and methodologies utilized for determining RE. MacLeod (1990) determined the k_p and k_f of female broilers to range from 47 to 57% and 102 to 103%, respectively. Nieto et al. (1995) determined k_p values for male broilers between 40.5 and 57.8% and k_f values between 64.5 and 127.0%. The researchers justified the higher efficiency for energy retention as fat compared to protein based on lower energetic cost for energy retention as fat. Boekholt et al. (1994) reported that the energy retained as fat was 85% of total energy retained at higher levels of ME intake, whereas the energy retained as protein was 15%.

Assuming a protein caloric value of 5.686 kcal/g, and considering the average energy efficiency for protein retention of 46.2% (Table 6), 12.31 kcal of ME is necessary for 1 g of protein deposition. Assuming a caloric value of fat of 9.385 kcal/g, and considering the average energy

TABLE 8. Body weight of broiler breeder pullets at 8, 14, and 20 wk of age according to treatment

	BW (g)[1]		
Treatment	8 wk	14 wk	20 wk
Control	821[a]	1,374[a]	2,100[a]
Model 1	827[a]	1,391[a]	2,059[ab]
Model 2	824[a]	1,381[a]	2,022[b]
F^2	1.06[NS]	1.28[NS]	13.07**
CV (%)	1.78	2.24	1.54

[a,b]Means within a column lacking a common superscript differ ($P < 0.05$).

[1]Data are means of six pens of 24 breeder pullets, body weight initial at 5 wk of age was 390 g.

[2]Values of F followed NS ($P > 0.05$).

**Significant ($P < 0.01$).

TABLE 9. Breast percentage, protein, and fat body composition of 20-wk-old broiler breeder pullets

Treatment	Breast[1,2] (%)	Protein[1,3] (%)	Fat[1,3] (%)
Control	23.48[a]	17.78[b]	9.65[a]
Model 1	23.76[a]	18.35[ab]	8.22[a]
Model 2	23.96[a]	18.98[a]	8.28[a]
F^4	0.76[NS]	3.70*	2.25[NS]
CV (%)	3.00	3.71	11.84

[a,b]Means within a column lacking a common superscript differ ($P < 0.05$).
[1]Data are means of six repetitions of 4 breeder pullets.
[2]Breast weight per body weight, expressed as a percentage.
[3]Carcass defeathered composition.
[4]Values of F followed NS ($P > 0.05$).
*Significant ($P < 0.05$).

efficiency for fat retention of 104.1% (Table 6), 9.02 kcal of ME is necessary for 1 g of fat deposition.

According to Emmans (1989) and Chwalibog (1991), the energy requirements for 1 g of protein gain are 11.95 and 11.47 kcal/g and 13.38 kcal/g for 1 g fat gain. However, the requirement can be expressed as units of protein and fat gain only if the efficiencies are constant (Emmans, 1995).

ME Requirement Models

Two models were developed for determining the ME daily requirements (kcal/bird per d) for each growth phase, according to the coefficients determined for maintenance and weight gain. The models consider (W), WG, and environmental temperature (T) as follows:

3 to 8 wk

1. ME = $W^{0.75}$ (186.52 − 1.94T) + 2.47WG.
2. ME = $W^{0.75}$ (174.15 − 1.88T) + 2.83WG.

9 to 14 wk

1. ME = $W^{0.75}$ (186.52 − 1.94T) + 2.69WG.
2. ME = $W^{0.75}$ (174.15 − 1.88T) + 2.50WG.

15 to 20 wk

1. ME = $W^{0.75}$ (186.52 − 1.94T) + 2.76WG.
2. ME = $W^{0.75}$ (174.15 − 1.88T) + 3.24WG.

Evaluation of Models

Average values of ME intake are presented in Table 7, and BW of breeder pullets are in Table 8. According to the results, model 2 provided lower ME intake ($P \leq 0.01$), which was reflected in the lower BW at 20 wk ($P \leq 0.01$) compared to the control treatment. The performance of pullets fed according to model 1 was similar to that for the control treatment; however, these treatments increased BW at 20 wk of age compared to BW of pullets recommended for Hubbard-Hi-Yield.

The BW recommended by Hubbard-Hi-Yield at 8, 14, and 20 wk of age are 793, 1,318, and 1,932 g, respectively. All treatments provided increased BW compared to breeder recommendations. However, if a range of 5% below and above the weight can be considered acceptable, at 20 wk of age BW can range from 1,835 to 2,029 g. The pullets fed according to model 2 ranged in BW from 1,856 to 2,029 g. Model 2 also provided less ME intake than the breeder's recommendation. Variations of BW (Table 8) reflected the effect of different ME intake levels (Table 7), considering that the intakes of other nutrients, protein, amino acids and minerals were the same for all treatments.

Bennett and Leeson (1990b) tested the effect of ME levels of 2,550, 2,800, and 3,080 kcal/kg fed to broiler breeder pullets and observed the same relationship between BW and the highest ME intake observed in this study. An increase in energy intake can be damaging to the BW of broiler breeder hens (Waldroup and Hazen, 1976; Bornstein et al., 1979; Kuana, 1986; Spratt and Leeson, 1987), because BW excess can be prejudicial to the egg production and fertility rates. Therefore, it is

TABLE 10. Means of predicted and observed daily weight gain, differences between these values, and percentage of ME for maintenance (ME_m) and for gain (ME_g)

Age (wk)	Predicted gain (g/d)	Observed gain (g/d)	Observed predicted (g/d)	ME_m (kcal/d)	ME_g (kcal/d)	ME_m (%)	ME_g (%)
			Model 1				
5 to 8	14	16	2	100	34	75	25
9 to 14	3	13	10	162	7	96	4
15 to 20	4	16	12	217	11	95	5
			Model 2				
5 to 8	14	15	1	92	40	70	30
9 to 14	7	13	6	148	17	90	10
15 to 20	9	15	6	199	27	88	12

necessary to control the BW before sexual maturity, which is related to energy intake control after 4 wk of age. However, Robinson and Robinson (1991) observed that the performance of broiler breeders with higher BW at 21 wk of age was superior to those birds with lower BW; according to these authors, the BW at sexual maturity age should be adequate to support good performance.

Average values for breast percentage and carcass fat and protein percentage at 20 wk of age are presented in Table 9. The breast and carcass fat percentages were not affected by treatments ($P > 0.05$). On the other hand, the control treatment provided a lower protein carcass percentage than other treatments ($P < 0.05$). The higher ME intake of this treatment (Table 7) provided less protein deposition and increased fat deposition. This result indicates that excess energy intake above maintenance and lean gain tissue requirements was used for fat deposition, which is more efficient than for protein deposition (De Groote, 1974).

The body composition represents an important parameter in evaluation of feeding programs for the growing of broiler breeders, because BW is not always the best strategy. Nevertheless, the ideal body composition of pullets at first egg has not yet been established.

Predicted WG, which were applied to the models in order to predict energy requirements, the observed WG data, and the differences between predicted and observed data, are presented in Table 10. The maintenance and weight gain energy requirements and their respective percentages of total energy requirements are also presented (Table 10).

According to these results, for broiler breeder pullets from 5 to 8 wk of age, the application of models 1 and 2 showed that 72.5% of total feed energy was used for maintenance and 27.5% for weight gain. From 9 to 20 wk of age, model 1 estimated 95 to 96% of ME total intake was used for maintenance, which was higher than the 88 to 90% observed for model 2.

The differences between predicted and observed weight gain were relatively small from 5 to 8 wk, being 2 g/d for model 1 and 1 g/d for model 2. However, for the following ages, the differences were accentuated between model 1 and 2. The differences between observed and predicted weight gains were 10 and 12 g, respectively, for model 1 and 6 g for model 2. Model 1 seems to have overestimated the maintenance requirements, and the excess of energy produced additional weight gain. This observation could be verified by the greater difference between observed and predicted weight gains by model 1 compared to model 2.

In conclusion, model 2 was more precise for predicting the ME requirements for broiler breeder pullets. In addition, breeder pullets gained more weight when fed the energy intake recommended by the breeder guide. It may be necessary to re-evaluate breeder recommendations for ME requirements for broiler breeder pullets.

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REFERENCES

Balnave, D. 1974. Biological factors affecting energy expenditure. Pages 25–46 in Energy Requirements of Poultry. T. R. Morris and B. M. Freeman, ed. British Poultry Science, Edinburgh.

Bennett, C. D., and S. Leeson. 1990a. Body composition of the broiler breeder pullets. Poult. Sci. 69:715–720.

Bennett, C. D., and S. Leeson. 1990b. Influence of energy intake on development of broiler breeder pullets. Can. J. Anim Sci. 70:259–266.

Boekholt, H. A., P. H. Van Der Grinten, V. V. A. M. Schreus, M. J. N. Los, and C. P. Leffering. 1994. Effect of dietary energy restriction on retention of protein, fat and energy in broiler chickens. Br. Poult. Sci. 35:603–614.

Bornstein, S., S. Hurwitz, and Y. Lev. 1979. The amino acid requirements of broiler breeder hens. Poult. Sci. 58:109–116.

Chwalibog, A. 1991. Energetics of Animal Production. Acta Agric. Scand. 41:147–160.

Chwalibog, A., and G. Thorbek. 1989. Fasting heat production in chickens. Arch. Geflugelkd. 53:54–57.

De Groote, G. 1974. Utilization of metabolizable energy. Pages 113–133 in Energy Requeriments of Poultry. T. R. Morris and B. M. Freeman, ed. British Poultry Science, Edinburgh.

Emmans, G. C. 1974. The effect of temperature on performance of laying hens. Pages 79–90 in Energy Requirements of Poultry. T. R. Morris and B. M. Freeman, ed. British Poultry Science, Edinburgh.

Emmans, G. C. 1995. Problems in modelling the growth of poultry. World's Poult. Sci. J. 51:77–89.

Emmans, G. C. 1989. The growth of turkeys. Pages 135–166 in Recent Advances in Turkey Science. C. Nixey and T. C. Grey, ed. Butterworths, London.

Euclydes, R. F. 1982. SAEG—Sistema de análises estatísticas e genéticas. Universidade Federal de Viçosa, imprensa Universitária, Vicosa, Brazil.

Farrell, D. J. 1974. General principles and assumptions of calorimetry. Pages 1–23 in Energy Requirements of Poultry. T. R. Morris and B. M. Freeman, ed. British Poultry Science, Edinburgh.

Fuller, H. L., N. Dale, and M. Smith. 1983. Comparison of heat production of chickens measured by energy balance and by gaseous exchange. J. Nutr. 113:1403–1408.

Kuana, S. 1986. Exigências nutricionais de energia metabolizável, metionina + cistina e de lisina para matrizes pesadas. M.S. Thesis. Universidade Federal de Vicosa, Viçosa, Brazil.

MacLeod, M. G. 1990. Energy and nitrogen intake, expenditure and retention at 20C in growing fowl given diets with range of energy and protein contents. Br. J. Nutr. 64:625–637.

National Research Council. 1994. Nutrient Requirements of Poultry. 9th rev. ed. National Academy Press, Washington, DC.

National Research Council. 1998. Nutrient Requirements of Swine. 10th rev. ed. National Academy Press, Washington, DC.

Nieto, R., C. Prieto, I. Fernandez-Figares, and J. F. Aguilera. 1995. Effect of dietary protein quality on energy metabolism in growing chickens. Br. J. Nutr. 74:163–172.

Peguri, A., and C. N. Coon. 1988. Development and evaluation of models for metabolizable energy and true metabolizable

energy intake for Dekalb XL-Link White Leghorn hen. Pages 199–211 in 49th Minnesota Nutrition Conference and Degussa Technol. Symp., Bloomington, MN.
Robinson, F. E., and A. Robinson. 1991. Reproductive performance, growth rate and body composition of broiler breeder hens differing in body weight at 21 weeks of age. Can. J. Anim. Sci. 71:1233–1239.
Rostagno, H. S., D. J Silva, P. M. A. Costa, J. B. Fonseca, P. R. Soares, J. A. A. Pereira, and M. A. Silva. 1983. Composição de alimentos e exigências nutricionais de aves e suínos (*Tabela Brasileira*). Viçosa, Universidade Federal de Viçosa, Imprensa Universitaria, Viçosa, Brazil.
Sakomura, N. K. 1996. Exigências nutricionais das aves utilizando o modelo fatorial. Pages 361–388 in Anais do Simpósio Internacional Sobre Exigências Nutricionais de Aves e Suínos, Viçosa, Brazil.
Sakomura, N. K., H. S. Rostagno, P. R. Soares, and G. Sanches. 1993. Determinação das equações de predição da exigência nutricional de energia para matrizes pesadas e galinhas poedeiras. Rev. Soc. Bras. Zoot. 22:723–731.
Scott, M. L., M. C. Nesheim, and R. J. Young. 1982. Nutrition of the Chicken. 3rd ed. M. L. Scott, Ithaca, NY.
Silva, D. J. 1981. Análise de alimentos: Métodos químicos e biológicos. Universidade Federal de Viçosa, imprensa Universitária, Viçosa, Brazil.
Silva, R., N. K. Sakomura, K. T. Resende, R. Basaglia. 1997. Exigências de energia metabolizável para frangas de postura de 1 a 18 semanas de idade. Rev. Soc. Bras. Zoot. 26:111–120.
Spratt, R. S., and S. Leeson. 1987. Effect of protein and energy intake of broiler breeder hens on performance of broiler chicken offspring. Poult. Sci. 66:1489–1494.
Waldroup, P., and K. R. Hazen. 1976. The comparison of daily energy needs of the normal and dwarf broiler breeder hen. Poult. Sci. 55:1383–1393.