



Modelling Energy Utilization for Laying Type Pullets¹

■ Author(s)

Neme R²
Sakomura NK²
Fialho FB³
Freitas ER²
Fukayama EH²

¹ Financed by FAPESP; part of thesis from the first author.

² Departamento de Zootecnia, FCAV/UNESP

³ Researcher CNPUV/EMBRAPA. Bento Gonçalves, RS.

■ Mail Address

Nilva Kazue Sakomura
Departamento de Zootecnia
UNESP/Jaboticabal.
Via de Acesso Prof. Paulo D. Castellane s/n
14.884-900. Jaboticabal, SP, Brasil.
Phone/Fax: +55 16 3209-2682

E-mail: sakomura@fcav.unesp.br

■ Keywords

Body composition, energy requirements, feather coverage, laying hens, model, temperature.

ABSTRACT

Three trials were carried out to determine energy metabolized (EM) requirement model for starting and growing pullets from different strains, at five ambient temperatures and different percentage feather coverage. In Trial I, metabolizable energy requirements for maintenance (MEM) and efficiency of energy utilization were estimated using 64 birds of two different strains, Hy-Line W36 (HLW36) and Hy-Line Semi-heavy (HLSH), from 9 to 13 weeks of age. The effects of ambient temperature (12, 18, 24, 30 and 36°C) and percentage feather coverage (0, 50 and 100%) on MEM were assessed in the second trial, using 48 birds per temperature per strain (HLSH and HLW36) from 9 to 13 weeks of age. Trial III evaluated ME requirements for weight gain (MEg) using 1,200 birds from two light strains (HLW36 and Hisex Light, HL) and two semi-heavy strains (HLSH and Hisex Semi-heavy, HSH) reared until 18 weeks of age. According to the prediction models, MEM changed as a function of temperature and feather coverage, whereas MEg changed as a function of age and bird strain. Thus, two models were developed for birds aged 1 to 6 weeks, one model for the light strain and one for the semi-heavy strain. Energy requirements (ER) were different among strains from 7 to 12 weeks, and therefore 4 models were elaborated. From 13 to 18 weeks, one single model was produced for semi-heavy birds, since ER between semi-heavy strains were not different, whereas two different models were elaborated for the light layers. MEg of light birds was higher than MEg of semi-heavy birds, independent of age.

INTRODUCTION

Temperature is the most important environmental factor in animal production and directly affects animal responses. Domestic birds are homeotherm animals and therefore must expend energy to maintain body temperature, in order to have adequate biochemical, physiological and behavioral responses (Al-Saffar, 2002). At high temperatures, the feather coverage is one of the factors that impair dissipation of the heat produced during bird metabolism. Peguri & Coon (1993) reported that the maximization of net gain in birds depends on the ability of quantifying the costs of high requirements of energy for maintenance when environmental temperature is low, as well as the costs of maintenance in high temperatures, when metabolizable energy (ME) intake is lower.

According to Fialho (1999), mathematical models of physiological systems may be used in studies with poultry and swine as a means of elaborating strategies that optimize growth, decrease losses, reduce production costs and improve carcass characteristics, as well as evaluating the potential of alternative production systems.

The present study elaborated mathematical models to determine maintenance and growth energy requirements for pullets from different



strains during the rearing phase, as a function of ambient temperature and feather coverage.

MATERIAL AND METHODS

Three trials were carried out at the poultry experimental facilities of the Department of Animal Science, at Faculdade de Ciências Agrárias e Veterinárias – FCAV/UNESP/Jaboticabal.

Trial I – Metabolizable energy requirements for maintenance and efficiency of dietary energy utilization

Energy requirements for maintenance and the efficiencies of energy utilization for maintenance (*km*) and for weight gain (*kg*) were evaluated in a trial carried out in temperature-controlled chambers at constant temperature (24°C). Sixty-four pullets from a light strain (Hy-Line W-36, HLW36) and 64 pullets from a semi-heavy strain (Hy-Line Semi-heavy, HLSH) were reared from 7 to 13 weeks of age, in a completely randomized experimental design, with 4 treatments and 4 repetitions (4 birds/parcel). Treatments for both strains consisted of 4 feeding restriction levels: *ad libitum*, 70%, 50% and 35% of *ad libitum* intake. Diets were formulated based on corn, soybean meal and wheat meal. Nutrient levels were 2,850 kcal ME/kg, 18% CP, 1% calcium, 0.45% available phosphorus, 0.9% lysine and 0.725% methionine + cystine for the light strain, whereas levels for semi-heavy strains were 2,850 kcal ME/kg, 17% CP, 1% calcium, 0.44% available phosphorus, 0.9% lysine and 0.732% methionine + cystine.

The amount of food given to the restricted birds was calculated according to the intake of *ad libitum* birds. At the end of the experiment, total feed intake and metabolizable energy intake were calculated.

The apparent metabolizable energy of the diets was determined in a metabolism trial carried out using the same restriction levels and 11-week-old birds from the two strains.

Feed was given *ad libitum* during a one-week adaptation period, after which the initial body weight was recorded, and controlled feed intake started. Four birds with body weight similar to the mean body weight of the strain were killed at the beginning of the experiment to determine initial levels of body energy. At the end of the experiment, birds were weighed, fasted for 24 hours, weighed again and killed to determine final body composition. Feather samples were analyzed separately and the defeathered birds

were frozen, sawed and entirely ground. Representative subsamples were dried for 72 hours in an oven at 55 °C and ground a second time before dry matter, ether extract, crude protein and gross energy levels were determined.

Energy retention (ER) was calculated as the difference between initial and final mean body levels of gross energy. Heat production (HP) was calculated as the difference between metabolizable energy intake (MEI) and ER. The variables MEI and ER were related according to Farrell (1974), so that the regression analysis of ER as a function of MEI was used to estimate ME requirements for maintenance (ME_m) and the efficiency of energy utilization above maintenance. The regression of the logarithm of HP on MEI determines heat production during fasting, whereas the HP antilogarithm determines heat production when MEI is extrapolated to zero.

Trial II – Ambient temperature and feather coverage effects on energy requirements for maintenance

The effects of different temperatures and feather coverage on the energy requirements for maintenance were evaluated using 480 pullets with different feather coverage percentages (100, 50 and 0% of normal feathering) in 5 temperature-controlled chambers at constant temperatures (12, 18, 24, 30 and 36°C).

Two hundred and forty replacement pullets from each strain were reared from 9 to 13 weeks of age distributed in a completely randomized design with four repetitions of 4 birds. There were 48 HLW36 and 48 HLSH birds in each chamber. Birds were fed *ad libitum* with the same diets used in Trial I.

One week before the onset of the experiment, feathers were removed using a shearing machine and scissors. Feathers were completely removed from the birds of the 0% treatment, and from the right body side of the birds of the 50% treatment.

After one week for adaptation to the different temperatures, four birds from each strain and each temperature were killed in order to determine the initial levels of body energy. At the end of the experimental period, all birds were weighed and killed to determine final body composition, as described for Trial I.

MEI and ER were calculated in order to determine the energy requirements for maintenance of the two strains, and at the two different feather coverage percentages, in each chamber. The efficiency of ME utilization for each strain, determined in Trial I, was used in this second trial as the efficiency of ME



utilization (*kg*). Metabolizable energy requirements for maintenance (MEM) were determined using the formula: $MEM = MEI - (ER/kg)$.

Statistical analyses

Statistical analyses were performed using the R program (<http://www.r-project.org>). The effects of temperature and feather coverage on MEM were evaluated according to the following linear regression models:

$$MEM = B + d * (L - T) + ei, \text{ when } T < L$$

$$MEM = B + s * (T - L) + ei, \text{ when } T \geq L$$

where:

$L = L_0 - L_1 * FI$ (L = lower critical temperature)

T = Ambient temperature ($^{\circ}C$)

FI = Feather index (0 to 1)

B, d, s, L_0 and L_1 = Model parameters

ei = random effects for observation i

Trial III – Determination of energy requirements for body weight gain

Energy requirements for body weight gain for each strain were determined using 1,200 one-day-old female chicks. Three hundred birds from each strain were placed in starting cages (1 to 6 weeks of age) and then rearing cages (7 to 18 weeks old). The birds were distributed in a completely randomized design, with four treatments and four repetitions of 75 birds per strain. The medium strains Hy-Line Semi-heavy (HLSH) and Hisex Semi-heavy (HSH), and the light strains Hy-Line W-36 (HLW36) and Hisex Light (HL) were evaluated in this trial. Birds were fed daily with diets formulated according to the requirements adequate for each strain (light or semi-heavy) in each rearing phase.

All birds were weighed weekly and the mean body weight and weight gain were calculated. Feed intake per parcel was also determined weekly. Two birds with body weight similar to the mean body weight of the parcel (eight birds per strain) were separated and then killed as described for Trial I.

Methodology to determine energy requirement for body weight gain

Net energy requirements for weight gain (*NEg*) were calculated using regression equations of the total carcass crude energy (y) as a function of the body weight (x) during the studied period for each strain, according to the allometric equation $\log y = a + b \log x$ (ARC, 1980). In order to calculate the estimates of the

energy composition of body weight gain, equations for body composition were derived, and the formula used was similar to $y = b10^a x^{(b-1)}$.

Afterwards, to determine ME for body weight gain (*MEg*), the values calculated for *NEg* were divided by the efficiency of ME utilization obtained in Trial I for light or semi-heavy strains.

Statistical analyses

Regressions and statistical analyses were performed using the software Statistica (1996). The obtained equations were compared between strains using the test for homogeneity of regression coefficients (Steel & Torrie, 1980).

RESULTS AND DISCUSSION

Trial I – Metabolizable energy requirements for maintenance

Birds restricted 50 and 35 % of *ad libitum* intake showed negative values of energy retention, indicating that pullets cannot be subjected to the same levels of food restriction that are used for broilers (Table 1). Longo (2000) reported that negative energy retention was seen only for broilers fed 30% of *ad libitum* intake and reared at 30°C. This is explained by the fact that broiler selection programs are directed to increase feed intake at levels greater than the basal energy requirement. According to Boekholt *et al.* (1994), the *ad libitum* intake in broilers is approximately 2 to 3 times the maintenance requirements. Basaglia (1999) reported that laying hens from a light strain fed 35% of *ad libitum* intake had negative energy retention at 12, 22 and 31°C. Besides, birds reared at 12°C and fed 55% of *ad libitum* intake also showed negative energy retention, because maintenance requirements increased.

Table 1 – Means of metabolizable energy intake (MEIn), energy retention (ER) and heat production (HP) in the different strains and levels of feed restriction.

Feed level	MEIn (kcal/kg ^{0.75} /day)	ER (kcal/kg ^{0.75} /day)	HP (kcal/kg ^{0.75} /day)
Hy-Line W36			
<i>Ad libitum</i>	194.67 ± 6.99	44.58 ± 5.51	150.10 ± 4.71
70%*	143.71 ± 1.16	10.24 ± 1.98	133.47 ± 1.59
50%	108.49 ± 1.91	-9.19 ± 5.57	117.68 ± 4.02
35%	78.22 ± 0.73	-24.08 ± 3.38	102.30 ± 3.09
Hy-Line semi-heavy			
<i>Ad libitum</i>	206.32 ± 1.54	46.41 ± 4.36	159.91 ± 4.41
70%*	154.12 ± 1.48	9.26 ± 4.94	144.86 ± 4.28
50%	119.82 ± 2.10	-6.85 ± 3.05	126.67 ± 4.80
35%	86.91 ± 1.13	-29.72 ± 3.41	116.63 ± 3.44

* Percentage of *ad libitum* intake.



Laying hens usually have low daily feed intake. The amount of ingested feed is adequate for a standardized development, so that weight and body composition at sexual maturity are adequate. This becomes evident in the results of the present study, when comparing the ME intake with the MEm requirements for each strain (Table 2). Therefore, light strain birds fed *ad libitum* and 70% restriction consumed only 1.59 and 1.18 times the MEm, respectively, whereas semi-heavy birds consumed 1.54 and 1.15, respectively. Thus, the lowest degree of food restriction caused significant reduction of MEI, which was only 18% higher than the basal energy costs in light birds and 15% in semi-heavy birds.

the fact that greater energy costs for maintenance are needed for tissues with high protein levels, due to the permanent cell turnover, and that the maintenance of the fat tissue requires low energy, since it is virtually a metabolically inactive tissue (Luiting, 1990).

The protein/energy ratio was 9.04% higher in semi-heavy birds compared to light birds, a value very similar to the difference of daily energy requirements between strains, which was 9.66% higher in semi-heavy birds.

Heat production (HP) in semi-heavy pullets was 9.81 kcal/kg^{0.75}/day higher than in light birds. According to Blaxter (1989), different factors influence animal metabolism, including body weight, the circadian cycle, age, nutrition, body composition, organ size, purpose of the breed and differences among species. The hens HLW36 are the birds with the lowest body weight among the light strains currently commercialized. In the present study, these birds had lower MEm and HP than HLSH birds, which might be explained mainly by differences in body composition.

The reduction in HP seen for both strains when subjected to feed restriction might be explained by the fact that birds eat less frequently (Li *et al.*, 1991), resulting in reduced feed intake (Blaxter, 1989) and digestion (Van Kampen, 1976), and lower calorogenic effect of food (Kleiber, 1961).

As shown in Table 2, the efficiency of dietary energy utilization for body weight gain was 0.59 for light birds and 0.62 for semi-heavy birds, representing a 6.78% higher efficiency for the semi-heavy strain. The efficiency of utilization of diet energy for maintenance (*Km*) was very similar between the two evaluated strains, i.e., 0.67 for light birds and 0.69 for semi-heavy birds.

Similar results have been reported in laying hens during the production phase (0.71) (Basaglia, 1999), in pullets of a light strain (0.72) (Silva, 1995) and in heavy breeders during the production phase (0.71) (Rabello, 2001). On the other hand, higher values have been reported by Silva (1999) in heavy breeders during the production phase (0.76) and by Longo (2000) in broilers (0.80). The ambient temperature in these above mentioned studies ranged between 21 and 23°C.

Trial II – Ambient temperature and feather coverage effects on the energy requirements for maintenance

There were no differences ($p > 0.05$) in the metabolizable energy requirements for maintenance between studied strains at the different temperatures and with different feather coverage. Thus, the results for both strains were analyzed together (Table 3).

Table 2 – Regression equation of energy retention (ER) and logarithm of heat production on the energy intake (MEI_n), metabolizable (MEm) and net energy (NEm) for maintenance, and efficiencies of energy utilization for maintenance (*km*) and body weight gain (*kg*).

Regression equation	R ²	Requirement (kcal/kg ^{0.75} /day)	Efficiency
Hy-Line W36			
ER = - 72.309 + 0.5919*MEI	0.99	MEm = 122.16	<i>kg</i> = 0.59
log HP = 4.3986 + 0.00325*MEI	0.97	NEm = 81.34	<i>km</i> = 0.67
Hy-Line semi-heavy			
ER = - 83.9260 + 0.6256*MEI	0.99	MEm = 133.97	<i>kg</i> = 0.62
log HP = 4.5214 - 0.0028*MEI	0.97	NEm = 91.96	<i>km</i> = 0.69

m = NEm/MEm.

It is interesting to note on Table 2 that the MEm estimated in this trial for HLW36 birds (122.16 kcal/kg^{0.75}/day) was 13.67 kcal higher than the daily energy intake of birds submitted to 50% restriction (Table 1), which explains the negative energy retention. In HLSH birds, the MEm was 133.97 kcal/kg^{0.75}/day, i.e., 14.15 kcal higher than the daily ingestion of birds restricted 50%, and also resulted in negative retention.

The MEm values reported in the present study are within the MEm range for laying hens reported by De Groote (1974), which was between 99 and 133 kcal/kg^{0.75}/day, and higher than the value of 99 kcal/kg live body weight reported for Leghorn Dekalb XL birds by Peguri & Coon (1993).

Daily MEm of semi-heavy hens was 9.67% higher than the MEm of light hens, and thus intake per day was 11.81 kcal/kg^{0.75} higher. The same response profile was seen for NEm; semi-heavy birds had requirements 13.06% higher than light birds, and energy daily intake was 10.62 kcal/kg^{0.75} higher.

Body composition analysis showed that the protein/energy ratio in HLW36 birds was smaller (1.66) than in HLSH birds (1.81), which means that the former had proportionally more body fat. The lower MEm requirements for HLW36 birds may be explained by



Table 3 – Overall means of metabolizable energy requirements for maintenance (MEM) according to temperature and feather coverage.

Feather coverage (%)	Temperature (°C)				
	12*	18*	24 ^{ns}	30 ^{ns}	36 ^{ns}
	MEM (kcal/kg^{0.75}/day)				
100%	141.80 ± 2.94	94.02 ± 10.94	93.98 ± 7.78	109.33 ± 4.82	108.75 ± 6.24
50%	152.72 ± 9.49	124.93 ± 13.74	98.84 ± 10.83	91.57 ± 6.76	99.49 ± 8.98
0%	178.28 ± 12.21	133.71 ± 8.94	95.53 ± 9.53	95.91 ± 7.36	107.07 ± 8.35

* Linear (p<0.01) ^{ns} Non-significant.

The MEM established in this trial for normally feathered birds reared at 24°C was lower than the requirements determined in Trial I for both strains. Since environmental temperature was similar in both trials, any differences are probably due to different husbandry practices. In Trial I, husbandry was more intense than in Trial II. The food remaining in the feeders was weighed daily in order to calculate the amount of food to be provided according to the restriction levels, and bird stress might have increased. Besides, the metabolism trial was carried out during the experimental period. In the second trial, feed was provided in the morning and in the afternoon, and this was the only procedure carried out daily.

Restricted birds were clearly more stressed and aggressive as a consequence of competition for food after the feeder was filled up, and energy costs were probably higher.

The effect of ambient temperature and feather coverage on MEM requirements was evaluated as a function of the lower thermoneutral limit, or lower critical temperature (LCT).

$$\text{MEM} = 92.40 + 6.73 \cdot (\text{LCT} - T), \text{ when } T < \text{LCT}$$

$$\text{MEM} = 92.40 + 0.88 \cdot (T - \text{LCT}), \text{ when } T \geq \text{LCT}$$

Coefficient of determination (R^2) = 82.21%

Where:

$$\text{LCT} = 24.54 - 5.65 \cdot \text{FI};$$

LCT = lower critical temperature (°C);

T = temperature (°C);

FI = feather index (0 to 1).

According to the equation (Figure 1), it may be observed that LCT was higher when birds had poorer feather coverage. LCT values were 18.89; 21.72 and 24.54°C for 100%, 50% and 0% of feather coverage, respectively.

LCT is related to feather coverage because it indicates which is the thermoneutral temperature for the bird, and consequently, at which temperature

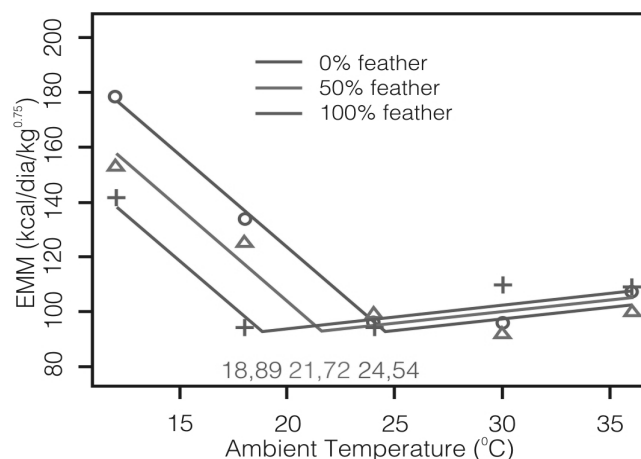


Figure 1 – Mean observed values (markers) and regression models (curves) of MEM as a function of feather coverage and ambient temperatures.

lowest energy levels must be expended for basal metabolism maintenance. According to Furlan (2002), the thermoneutral zone corresponds to an ambient temperature range within which the metabolism rate is minimal and body temperature is kept constant at lowest energy costs. Therefore, a minimal fraction of the metabolizable energy is used for thermogenesis, and net energy available for production is maximal. Thus, it might be concluded that the birds adjusted the temperature set point specifically for each temperature and each degree of feather coverage that was studied.

It is worth noting that the parameter that changed was LCT, and not MEM requirements. The requirements were similar for the different degrees of feather coverage (92.4 kcal/kg^{0.75}/day) at thermoneutral temperatures. This results from the greater heat loss in defeathered birds, mainly by non-evaporative processes (radiation, conduction and convection). Consequently, more energy was required at lower temperatures, and adaptation was better at higher temperatures, as shown in Figure 1.

Based on the produced model, maintenance requirement increases 0.88 kcal/kg^{0.75}/day for each degree of temperature above the LCT. At



temperatures above thermoneutral temperatures, higher MEM is attributed to the increase in energy expenses due to the activation of heat loss mechanisms, mainly the higher respiratory rate in order to increase evaporative heat loss.

On the other hand, temperatures lower than LCT caused maintenance requirements to increase 6.73 kcal/kg^{0.75}/day for each degree of temperature decrease.

Birds without feathers had higher MEM than normally feathered birds at 12 and 18°C, which might be due to the higher sensible heat exchanged with the environment at exposed body surfaces, evidencing the insulating ability of the feathers. Similarly, Peguri & Coon (1993) reported increase in the MEM in defeathered birds at temperatures of 12.8 and 23.9°C, whereas O'Neill & Jackson (1974) reported a 30% increase in MEM in laying birds showing poor post-molt feathering compared to the MEM of normally feathered birds.

Table 4 – Estimated metabolizable energy requirement for maintenance (kcal/kg^{0.75}/day) as a function of temperature and feather coverage.

Feather coverage (%)	Temperature (°C)				
	12	18	24	30	36
100%	138.77	98.39	96.90	102.18	107.46
50%	157.82	117.44	94.41	99.69	104.97
0%	176.79	136.41	91.92	97.20	102.48

Although no significant differences ($p > 0.05$) were seen in MEM for the different degrees of feather coverage at temperatures higher than 24°C, the requirements of defeathered birds at 30 and 36°C were numerically lower than the requirements of normally feathered birds. This finding suggests that heat exchange with the environment was improved and lower energy was required to activate the mechanisms of heat loss, which were more intensively used by normally feathered birds.

According to Hurwitz *et al.* (1980), the effects of temperature on energy metabolism are complex and sometimes responses are cubic rather than linear, as usually assumed. The authors stated that energy requirements for maintenance decrease until the temperature reaches 24°C, the rate is lower between 24 and 28°C, and requirements increase between 28 and 34°C. These observations corroborate the findings of the present study.

Trial III – Energy requirements for growth

The experimental period was divided into three different phases, according to the age of the birds, i.e., starting (1 to 7 wk), rearing I (8 to 12 wk) and rearing II (13 to 18 weeks).

Regression equations of carcass gross energy as a function of body weight were determined for each strain and growth phase (Table 5).

Table 5 – Regression equations of body gross energy levels (GEb) on the weight gain according to rearing phase and strain.

Strain	Regression	R ²	P
1 to 7 weeks			
Overall	log GEb = - 0.069 + 1.134*log BW	0.99	0.001
8 to 12 weeks			
Hy-Line semi-heavy	log GEb = - 0.836 + 1.401*log BW	0.98	0.001
Hy-Line W36	log GEb = - 0.531 + 1.313*log BW	0.95	0.001
Hisex	log GEb = - 0.108 + 1.152*log BW	0.95	0.001
13 to 18 weeks			
Other strains	log GEb = - 0.923 + 1.435*log BW	0.93	0.001
Hy-Line W36	log GEb = - 2.124 + 1.849*log BW	0.70	0.001

In the starting phase, there were no significant differences ($p < 0.05$) between the equations obtained for each strain, and the ratio between carcass gross energy and body weight was similar. Therefore, one overall equation was obtained.

In the following growth phase (8 to 12 weeks), energy deposition was different between the light and semi-heavy Hy-Line strains, but not between the light and semi-heavy birds from the Hisex strain. Thus, two different equations were determined for Hy-Line birds and one equation was determined for Hisex birds. In the last growth phase, gross energy deposition on the carcass was different only for the Hy-Line W36 birds, and thus two equations were produced, as shown in Table 5.

Body composition equations were derived in order to estimate the energy fraction of the weight gain. The coefficients of energy utilization established in Trial I were used to calculate the metabolizable energy for weight gain (MEg) for each strain.

Energy requirements for weight gain increased with age independent of strain (Table 6). Such response results from the higher protein and lipid deposition per kilogram of body weight gain with aging.

According to the starting phase results, although NE was similar between strains, MEg was different. This was probably due to different efficiencies of energy utilization. It should be noted that the MEg requirements for different strains were very similar; the requirement of light birds was 6.83% higher than for semi-heavy birds.



Table 6 – Estimated composition of the weight gain (Net Energy requirement, NEg) and metabolizable energy requirement for weight gain (MEg) according to rearing phase and strain

Strains	Equations **	Mean body weight (g)	Requirement for weight gain		
			NEg (kcal/g)	MEg (kcal/g)	
1 to 7 weeks					
Overall	$GEb = 0.97 * BW^{0.134}$	240.38	2.03	3.22	3.44
8 to 12 weeks					
Hy-Line semi-heavy	$GEb = 0.205 * BW^{0.401}$	881.09	3.11	4.94	-
Hy-Line W36	$GEb = 0.386 * BW^{0.313}$	745.45	3.06	-	5.19
Hisex	$GEb = 0.897 * BW^{0.152}$	806.52	2.48	3.94	4.20
13 to 18 weeks					
Other strains	$GEb = 0.171 * BW^{0.435}$	1389.20	3.98	6.32	6.74
Hy-Line W36	$GEb = 0.014 * BW^{0.849}$	1170.39	5.60	-	9.49

** $p \leq 0.01$; 1 - Semi-heavy; MEg = NEg / 0.63; 2 - Light; MEg = NEg / 0.59.

In the following phase, considering the semi-heavy birds, requirements for HLSH were 25.38% higher than for HSH. On the other hand, between the two light strains, requirements for HLW36 were 23.57% higher than for Hisex birds per kilogram of body weight gain. Such differences in energy requirements might be an effect of the greater protein deposition rates in Hy-Line birds compared to Hisex birds.

In the last phase, semi-heavy strains had the same daily requirement (6.32 kcal/kg); on the other hand, the requirement of HLW36 was 40.80% higher than for HL. This might be due to the higher deposition of protein (7.62%) and lipid (31.49%) on the weight gain of HLW36 birds (Table 7).

Table 7 – Composition of body weight gain as a function of strain and age.

Age	Body weight gain composition (g/g)		
	Fat	Protein	Ashes
1 to 6 weeks			
Hy-Line semi-heavy	0.080	0.222	0.031
Hisex semi-heavy	0.081	0.223	0.031
Hy-Line W36	0.101	0.238	0.031
Hisex Light	0.070	0.230	0.031
7 to 12 weeks			
Hy-Line semi-heavy	0.157	0.274	0.036
Hisex semi-heavy	0.157	0.274	0.036
Hy-Line W36	0.190	0.298	0.035
Hisex Light	0.144	0.279	0.035
13 to 18 weeks			
Hy-Line semi-heavy	0.202	0.299	0.038
Hisex semi-heavy	0.202	0.299	0.038
Hy-Line W36	0.238	0.325	0.037
Hisex Light	0.181	0.302	0.037

HLW36 Fat = $0.0072 * BW^{0.495}$; Other strains Fat = $0.0061 * BW^{0.479}$; Semi-heavy Protein = $0.0896 * BW^{0.165}$; HLW36 Protein = $0.082 * BW^{0.195}$; HLSH = $0.094 * BW^{0.165}$; Ashes = $0.0172 * BW^{0.1084}$

According to Scott *et al.* (1982), the energy requirements for weight gain in birds should be carefully evaluated, since differences in body composition, growth rate and consequently in protein

and fat deposition might exist between strains and sexes, as seen in the present study.

Prediction models for the daily ME requirements for pullets were produced based on the results of efficiency of energy utilization for light and semi-heavy strains (Trial I), metabolizable energy requirement for maintenance in the different temperatures and percentages of feather coverage (Trial II), as well as energy requirements for growth in the different rearing phases (Trial III).

CONCLUSIONS

The following models were produced to predict energy requirements for pullets from light and semi-heavy strains as a function of ambient temperature and percentage of feather coverage:

Semi-heavy strains (kcal/bird/day)		
1 to 6 wk	$ME = BW^{0.75} * 92.40 + 6.73 * (LCT - T) + 3.22 * F$	(T < LCT)
	$BW^{0.75} * 92.40 + 0.88 * (T - LCT) + 3.22 * F$	(T ≥ LCT)
Light strains (kcal/bird/day)		
1 to 6 wk	$ME = BW^{0.75} * 92.40 + 6.73 * (LCT - T) + 3.44 * F$	(T < LCT)
	$BW^{0.75} * 92.40 + 0.88 * (T - LCT) + 3.44 * F$	(T ≥ LCT)
Hy-Line semi-heavy (kcal/bird/day)		
7 to 12 wk	$ME = BW^{0.75} * 92.40 + 6.73 * (LCT - T) + 4.94 * F$	(T < LCT)
	$W^{0.75} * 92.40 + 0.88 * (T - LCT) + 4.94 * F$	(T ≥ LCT)
Hy-Line W36 (kcal/bird/day)		
7 to 12 wk	$ME = BW^{0.75} * 92.40 + 6.73 * (LCT - T) + 5.19 * F$	(T < LCT)
	$BW^{0.75} * 92.40 + 0.88 * (T - LCT) + 5.19 * F$	(T ≥ LCT)
Hisex semi-heavy (kcal/bird/day)		
7 to 12 wk	$ME = BW^{0.75} * 92.40 + 6.73 * (LCT - T) + 3.94 * F$	(T < LCT)
	$BW^{0.75} * 92.40 + 0.88 * (T - LCT) + 3.94 * F$	(T ≥ LCT)
Hisex light (kcal/bird/day)		
7 to 12 wk	$ME = BW^{0.75} * 92.40 + 6.73 * (LCT - T) + 4.20 * F$	(T < LCT)
	$BW^{0.75} * 92.40 + 0.88 * (T - LCT) + 4.20 * F$	(T ≥ LCT)
Semi-heavy strains (kcal/bird/day)		
13 to 18 wk	$ME = BW^{0.75} * 92.40 + 6.73 * (LCT - T) + 6.32 * F$	(T < LCT)
	$W^{0.75} * 92.40 + 0.88 * (T - LCT) + 6.32 * F$	(T ≥ LCT)
Hy-Line W36 (kcal/bird/day)		
13 to 18 wk	$ME = BW^{0.75} * 92.40 + 6.73 * (LCT - T) + 9.49 * F$	(T < LCT)
	$BW^{0.75} * 92.40 + 0.88 * (T - LCT) + 9.49 * F$	(T ≥ LCT)
Hisex Light (kcal/bird/day)		
13 to 18 wk	$ME = BW^{0.75} * 92.40 + 6.73 * (LCT - T) + 6.74 * F$	(T < LCT)
	$BW^{0.75} * 92.40 + 0.88 * (T - LCT) + 6.74 * F$	(T ≥ LCT)

ME = Metabolizable energy; BW = Body weight; LCT = Lower critical temperature; T = Temperature (°C); F = retained fat.



REFERENCES

- Al-Saffar AA, Rose SP. Ambient temperature and the egg laying characteristics of laying fowl. *World's Poultry Science Journal* 2002; 58(3):317-331.
- ARC - Agricultural Research Council. The nutrients requirements of ruminant livestock. London; 1980. p.351.
- Basaglia R. Equações de predição das exigências de energia e proteína para poedeiras leves [tese]. Jaboticabal (SP): Universidade Estadual Paulista; 1999.
- Blaxter K. Energy metabolism in animals and man. Cambridge: Cambridge University Press; 1989. p. 23-65.
- Boekholt HA, Van Der Grinten PH, Schreus VVAM, Los MJN, Leffering CP. Effect of dietary energy restriction on retention of protein, fat and energy in broiler chickens. *British Poultry Science* 1994; 35:603-614.
- De Groote G. Utilization of metabolizable energy. In: Morris, TR, Freeman BM, Editors. Energy requirements of poultry. Edinburgh: British Poultry Science; 1974. p.113-33.
- Farrell DJ. General principles and assumptions of calorimetry. In: Morris TR, Freeman BM, Editors. Energy requirements of poultry. Edinburgh: British Poultry Science; 1974. p.1-23.
- Fialho FB. Análise de sistemas e desenvolvimento de modelos teóricos de simulação das funções fisiológicas e bioeconômicas de suínos e aves. Concórdia, SC: Embrapa Suínos e Aves; 2002 [Acessado 15 de out. de 2002]. Disponível em: www.cnpsa.embrapa.br. 1999.
- Furlan RL, Macari M. Fisiologia aviária aplicada a frangos de corte: termorregulação. Jaboticabal: FUNEP-UNESP; 2002. p.209-228.
- Hurwitz S, Weiselberg M, Eisner UT. The energy requirements and performance of growing chickens and turkeys as affected by environmental temperature. *Poultry Science* 1980; 59:2121-2128.
- Kleiber M. The fire of life: An introduction to animal energetics. New York: Wiley; 1961. p.453.
- Li Y, Ito T, Yanamoto S. Diurnal variation of heat production related to some physical activities in laying hens. *British Poultry Science* 1991;32:821-827.
- Longo FA. Estudo do metabolismo energético e do crescimento de frangos de corte [dissertação]. Jaboticabal (SP):Universidade Estadual Paulista; 2000.
- Luiting P. Genetic variation of energy partitioning in laying hens: causes of variation in residual feed consumption. *World's Poultry Science Journal* 1990; 46:133-152.
- O'Neill SJB, Jackson N. Observations on the effect of environmental temperature and the moult on the heat production and energy requirements of hens and cockerels of a white leghorn strain. *Journal Agriculture Science* 1974; 82:553-558.
- Peguri A, Coon C. Effect of feather coverage and temperature on layer performance. *Poultry Science* 1993; 72:1318-1329.
- R program for statistical analysis. Boston, USA. Free Software Foundation. 2002. [Accessed Feb. 12, 2003]. Available from: URL: <http://www.r-project.org>
- Rabello CBV. Equações de predição das exigências de energia e proteína para aves reprodutoras pesadas na fase de produção [tese]. Jaboticabal (SP): Universidade Estadual Paulista; 2001.
- Scott ML, Nesheim MC, Young RJ. Nutrition of the chicken. 3rd ed. Ithaca: ML Scott & Ass; 1982. 562p.
- Silva R. Equações de predição das exigências de energia e proteína para matrizes pesadas na fase de crescimento [tese]. Jaboticabal (SP): Universidade Estadual Paulista; 1999.
- Silva R. Exigências de energia metabolizável para frangas de postura de 1 a 18 semanas de idade [dissertação]. Jaboticabal (SP): Universidade Estadual Paulista; 1995.
- STATISTICA. Version Release 5.1. for windows; 1996.
- Steel RGD, Torrie JH. Principles and procedures of statistics. New York: Library of Congress Cataloging in Publication; 1980.
- Van Kampen M. Activity and energy expenditure in laying hens: 2. The energy cost of exercise. *Journal Agriculture Science* 1976; 87(1):81-84.