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# Modeling Energy Utilization in Broiler Breeders, Laying Hens and Broilers

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## ABSTRACT

The factorial approach has been used to partition the energy requirements into maintenance, growth, and production. The coefficients determined for these purposes can be used to elaborate energy requirement models. These models consider the body weight, weight gain, egg production, and environmental temperature to determine the energy requirements for poultry. Predicting daily energy requirement models can help to establish better and more profitable feeding programs for poultry. Studies were conducted at UNESP-Jaboticabal to determine metabolizable energy (ME) requirement models for broiler breeders, laying hens, and broilers. These models were evaluated in performance trials and provided good adjustments. Therefore, they could be used to establish nutritional programs. This review aims to outline the results found at UNESP studies and to show the application of models in nutritional programs for broiler breeders, laying hens, and broilers.

## INTRODUCTION

The accurate prediction of energy intake is important to formulate diets for poultry and to make economic decisions. Several models have been suggested to predict the metabolizable energy (ME) intake. Among those, the ME partitioning model has been the most promising for imminent application.

The factorial approach has been used to partition the ME requirements into maintenance, growth, and production and can be expressed by the model: $MEI = aW^b(T) + c\Delta W + dEM$, where MEI is ME daily intake, $W^b$ is metabolic body weight, $\Delta W$ is body weight change, EM is egg mass output, T is environmental temperature, a, c, and d are the maintenance, growth and production requirement coefficients, respectively. These coefficients are important to elaborate mathematical models in order to estimate energy requirements. The application of predicting daily nutrient requirement models can help to establish better and more profitable feeding programs for poultry.

Nowadays, swine recommendations by the National Research Council (1998) are based on mathematical models for growth and reproduction phases. These models are not only easy to use, but also structurally simple, so users can understand them. These models are a simple structured method to develop factorial estimations of nutrient requirements. They estimate the amount of a nutrient used for each major function of the body (e.g., maintenance, protein accretion, and milk production) and sum them to estimate a total daily requirement (NRC, 1998). However, for poultry, basically only energy models have been developed for laying hens (Emmans, 1974; Peguri & Coon, 1988; Sakomura *et al.*, 1993; NRC, 1994).

Several studies were conducted at Universidade Estadual Paulista-UNESP, in Jaboticabal, São Paulo, Brazil, with broiler breeders pullets (Sakomura *et al.*, 2003), broiler breeder hens (Rabello, 2001), laying-type pullets (Neme, 2004), laying hens (Sakomura *et al.,* in press, a) and broiler chicks (Sakomura *et al.*, in press, b and Longo *et al.*, in press), aiming to determine energy requirement coefficients for maintenance, growth, and egg production, elaborate energy requirement models, and evaluate these models in performance trials.

This review aims to outline the results obtained in these studies and to show the application of energy requirement models in nutritional programs for broiler breeders, laying hens, and broilers.

## Energy partitioning into maintenance, growth, and production

The conventional method to represent energy utilization has been the partition of metabolizable energy intake. According to Birkett & Lange (2001), the simplest approach to partition the ME intake is in terms of its use by animal for production, as retained energy (RE), and an amount associated with maintenance (MEm), as the following: ME = MEm + $(1/k_g)$RE. However, different energetic efficiencies are associated with production, for instance for growth ($k_g$), as compared with maintenance purposes. The simple model fails because it does not take into account the differences in energy retention as fat or protein. In order to model energy utilization more accurately for varying fat:protein ratios in the RE, Kielanowski (1966) subdivided the RE into RE in fat (REF) and in protein (REP), as ME = MEm + $(1/k_f)$REF + $(1/k_p)$REP.

In addition, the ME requirements for laying and breeder hens can be partitioned into maintenance, growth, and production and expressed by the model: MEI = $aW^b(T) + c\Delta W + dEM$, where MEI is ME daily intake, $W^b$ is metabolic body weight, $\Delta W$ is body weight change, EM is egg mass output, T is environmental temperature, a, c, and d are the maintenance, growth and production requirement coefficients (Emmans, 1974; Peguri & Coon, 1988; Sakomura *et al.*, 1993; NRC, 1994). The accuracy of these models depends on the estimation of those coefficients. Unfortunately, they vary greatly in the literature. Besides the difference in genetics and environmental conditions, the limitations in the methodologies employed also have an influence on the varied estimated coefficients in the literature (Chwalibog, 1991, 1992 ).

## Maintenance energy requirement

The classical definition of maintenance describes maintenance as the state "in which there is neither gain or loss of nutrient by the body" (Blaxter, 1972). Therefore, the ME requirement for maintenance has been defined as the amount of energy required to balance anabolism and catabolism, giving an energy retention around zero. According to Chwalibog (1991), this definition is acceptable for adult and not for producing animals. However, for producing animals, energetic equilibrium never occurs. In this case, Chwalibog (1985) defines the ME maintenance requirement as being the amount of ME to maintain a dynamic equilibrium of protein and fat turnover, to maintain body temperature and a normal level of locomotor's activity.

National Research Council (1998) defines ME requirement for maintenance as the needs of all body functions and moderate activity. These requirements are usually expressed on a metabolic body weight basis, which is defined as body weight raised to the 0.75 power ($BW^{0.75}$).

Energy maintenance requirement has been determined in feeding trials or by calorimetric measurements, and by using regression equation of energetic balance components. The energetic balance components can be determined by direct calorimetry using calorimeters, indirect calorimetry, and by the carcass analysis. The indirect calorimetry method, according to Blaxter (1989), measures the heat production (HP) by determining the $O_2$ consumed and $CO_2$ produced in respiration chambers, and has been used in several studies (Grimberger, 1970; Van Es *et al.*, 1970; Spratt *et al.*, 1990). The comparative slaughter method estimates the HP by the difference of ME intake and body energy retained (ER). The ER is determined by animal samples slaughtering at the beginning and at the end of trials. This method is based on the premise that the body composition of poultry can be estimated using average samples of these birds (Wolynetz & Sibbald, 1987). The criterion for defining and prepare the whole body samples is important to avoid error and to have accurate results.

The maintenance energy requirement has been determined by the linear regression of energy balance measurements. The maintenance metabolizable energy requirement (MEm) is determined by the linear relationship between RE and ME intake (MEI), where the intercept on the x axis provided the MEm, as being MEI at zero energy retention (Farrel, 1974). The logarithmic relationship between heat production and metabolizable energy intake provided the maintenance net energy requirement (NEm), as being the fasting heat production (Lofgreen & Garret, 1968).

Several factors can affect the energy metabolism, such as animal age, body weight, body composition, size of organs, and growing or production stages (Blaxter, 1989).

The UNESP studies were conducted to determine the MEm and NEm, and the efficiencies of energy utilization in broiler breeders, laying hens and broiler chickens at below and above the critical temperature. In these studies, the method of comparative slaughter was used to determine the energy balance compounds. The MEm was estimated according to procedure described by Farrel (1974), and the NEm by Lofgreen & Garret (1968) approach, which findings are presented in Table 1.

As illustrated in Table 1, the ME maintenance requirements of poultries vary widely. Thus, assuming a constant requirement is an oversimplification of reality. This variation could be attributed to genetic differences between broilers and laying hens, which exhibit different growth potential and body composition. The MEm of growing birds, broiler chicks and broiler breeder pullets, was higher than those of laying and broiler breeder hens. This can be explained by changes in body composition. The increment in fat deposition in mature birds provided a decrease in MEm because the metabolic ratio in fat tends to be lower than in other tissues. In addition, growing animals have higher MEm because of high-energy expenditures involved in protein synthesis (Blaxter, 1989). As for the efficiency of energy utilization for maintenance ($k_m$), it varied from 0.67 to 0.80, and above maintenance ($k_g$) from 0.57 to 0.69. Temperature, genetic and age of poultry did not affect the efficiencies. Since diet composition is the main factor that affects the efficiency of ME utilization, a small variation in this parameter was observed because the same diet (based on corn and soybean meal) was utilized in the assays with broiler breeders, laying hens and broiler chicks.

Other important result is the difference between MEm for broiler breeder raised in cages and on the ground. The requirement of breeders raised on the ground was 20% higher than that on cages. This is due to higher energy spent for activities. The hens raised on the ground showed higher heat production (144.18, 135.18, 136.56 kcal/kg$^{0.75}$/day) than those raised in cages (77.83, 65.20, 59.19 kcal/kg$^{0.75}$/day) at 13, 21 and 30 $^{o}$C, respectively. These results are important because of the maintenance energy requirement for broiler breeders have been studied in metabolic chambers or cages, which underestimate the requirements for breeders raised on the ground. Johnson and Farrell (1983) and Spratt *et al.* (1990) found for broiler breeder hens in metabolic chambers at 21 $^{o}$C, 87.24 and 87.71 kcal/kg$^{0.75}$/day, respectively. Similar result (91 kcal/kg$^{0.75}$/day) was observed by Rabelo *et al.* (in press) for breeders in cages at 21 $^{o}$C, while for those raised on the ground was 113 kcal/kg/day.

Austic & Nesheim (1990) reported that the energy requirement for activities is about 50% of basal metabolism and is influenced by raising conditions. Birds in cages present lower activity and heat production, about 30% of basal metabolism. The expenditure of energy for activities of laying hens is about 20 to 25% of heat production (MacLeod *et al.,* 1982).

According to Wenk (1997), the physical activity in growing farm animals kept under practical conditions, counts for almost 20% of maintenance requirements. Under restricted room conditions, often in respiration chambers, lower MEm values are found, so they must be corrected to compensate this difference.

Measurement of total heat production includes the energy required for maintenance, and energy spent in response to changes in the environment. The major environmental factor that influence heat production is temperature. Cold thermogenesis influences energy requirements when the ambient temperature is below the critical temperature. The critical temperature is the point below which an animal must increase heat production to maintain body temperature. Below the critical temperature the animal must increase its rate of metabolic heat production to maintain homeothermy (NRC, 1981).

Based on the data shown in Table 1, Sakomura *et al.*, (2003), Rabelo *et al.,* (in press), Longo *et al.,* (in press) and Neme (2004) determined regression equations of MEm in function of ambient temperature (T), as shown in Table 2. The difference observed between the genetic and bird's age are probably due to variations in body weight and body composition. A linear decrease of MEm with increase of temperature was observed for laying hens and broiler breeder pullets. On the other hand, a quadratic effect was observed for broiler chicks and broiler breeder hens. There was a decrease on MEm when the temperature increased up to 26 $^{o}$C; and above that temperature the MEm turn to increase. According to Leeson & Summers (1997), a small variation is observed in heat production of birds from 19 to 27 $^{o}$C, but below the lower critical limit temperature, birds need to produce heat to maintain

**Table 1** - Maintenance metabolizable energy requirement (MEm), maintenance net energy requirement (NEm), efficiency of energy utilization above maintenance (kg), and for maintenance (km) according to ambient temperatures, and poultry type determined at UNESP studies[1].

| Poultry type | Temperature (°C) | Requirements (kcal/kg$^{0.75}$/day) | | Efficiency | |
|---|---|---|---|---|---|
| | | MEm | NEm | Kg | Km |
| Laying-type pullets (cage) | 12 | 142 | - | - | - |
| Laying hens (cage) | 12 | 138 | 100 | 0.66 | 0.72 |
| Broiler breeder pullet (ground) | 15 | 158 | 119 | 0.69 | 0.75 |
| Broiler (ground) | 13 | 158 | 119 | 0.63 | 0.76 |
| Broiler breeder hen (ground) | 13 | 13 | 131 | 111 | - |
| Broiler breeder hen (cage) | 78 | - | 0.61 | - | 0.70 |
| Laying-type pullets (cage) | 24 | 94 | 0.59 | 0.67 | |
| Laying hens (cage) | 22 | 112 | 80 | 0.62 | 0.71 |
| Broiler breeder pullet (ground) | 22 | 144 | 109 | 0.69 | 0.76 |
| Broiler breeder hen (ground) | 21 | 21 | 113 | 91 | - |
| Broiler breeder hen (cage) | 65 | - | 0.60 | - | 0.71 |
| Broiler (ground) | 23 | 112 | 90 | 0.59 | 0.80 |
| Laying-type pullets (cage) | 30 | 109 | - | - | - |
| Laying hens (cage) | 31 | 93 | 69 | 0.69 | 0.74 |
| Broiler breeder pullet (ground) | 30 | 128 | 92 | 0.62 | 0.72 |
| Broiler breeder hen (ground) | 30 | 30 | 111 | 88 | - |
| Broiler breeder hen (cage) | 59 | - | 0.57 | - | 0.67 |
| Broiler (ground) | 32 | 127 | 96 | 0.66 | 0.76 |

1 - Sakomura *et al.*, 2003; Neme, 2004; Rabelo *et al.* (in press); Longo *et al.* (in press); Sakomura *et al.* (in press,a).

**Table 2 -** Effect of temperature on MEm for broiler breeders, laying hens and broilers determined at UNESP studies[1].

| Poultry type | Regression of Temperature on MEm | $R^2$ |
|---|---|---|
| Laying-type pullets[2] | MEm = 92.40 + 6.73 (LCT – T), (T < LCT) | 0.82 |
| | MEm = 92.40 + 0.88 (T – LCT), (T ≥ LCT) | 0.82 |
| Laying hen | MEm = $W^{0.75}$ (165.74 – 2.37.T) | 0.99 |
| | MEm = $W^{0.75}$ (163.67 – 2.09.T) | 0.85 |
| Broiler breeder pullet | MEm = $W^{0.75}$ (186.52 – 1.94.T) | 0.99 |
| | MEm = $W^{0.75}$ (174.15 – 1.88.T) | 0.92 |
| Broiler breeder hen – ground | MEm = $W^{0.75}$ (192.76 - 6.32.T + 0.12.T$^2$) | 0.72 |
| Broiler breeder hen – cage | MEm = $W^{0.75}$ (191.21 – 8.15.T + 0.16.T$^2$) | 0.85 |
| Broiler | MEm = $W^{0.75}$ (307.87 – 15.63.T + 0.31.T$^2$) | 0.93 |

MEm = maintenance ME requirement (kcal/bird/day), W = body weight (kg), T = ambient temperature (°C). 1 - Sakomura *et al.*, 2003; Neme, 2004; Rabelo *et al.* (in press); Longo *et al.* (in press); Sakomura *et al.* (in press). 2 - For laying-type pullets, it was determined the effect of temperature (12, 18, 24 and 36 °C) and feathering (0, 50 and 100% of feathers cover) on MEm. Two equations were elaborated, for temperatures above and below low critic temperature (LCT), which is in function of feathering degree, LCT = 24.54 – 5.65F, F is feathering score (0 to 1).

the body temperature, and above 27 °C require energy to dissipate heat. However, these temperature limits are not the same for all birds because body weight, feed intake, feathering, and activities can affect bird response to temperature changes.

The majority of equations to predict energy requirements for laying hens and broiler breeders involve a linear effect of temperature over energy requirements (Combs, 1968; Emmans, 1974; Waldroup *et al.*, 1976; Rostagno *et al.*, 1983; Sakomura & Rostagno, 1993; NRC, 1994). However, the linear relationship should be considered for temperatures close to that which would provide a thermally comfortable environment.

Another factor that should be taken into account in maintenance energy requirement is the feathering. Several studies have shown that feathering affects heat production. O'Neill *et al.* (1971) found that the energy for maintenance in feathered roosters declined by 2.0 kcal/kg/day/°C, while in non-feathered roosters declined 6.3 kcal/kg/day/°C, from 15 to 34°C. Studies of Lee *et al.* (1983) showed higher heat production (123 cal/kg of $W^{0.75}$/min) in poor-feathered chicken compared to normally feathered (116 cal kg of $W^{0.75}$/min).

In the UNESP studies, Neme (2004) verified the effect of temperatures (12, 18, 24, 30, and 36 °C) and feathering (0, 50, and 100%) on MEm of laying-type pullets. The lower critical temperatures (LCT) changed according to feathering levels (19, 22, and 24°C for 100, 50 and 0% of feathering, respectively). According to the equation MEm = $W^{0.75}$ 92.40 + 6.73(LCT–T), below LCT, the MEm increased 6.73 kcal/$W^{0.75}$/d for each increment of 1°C. Another equation was determined for temperatures above LCT (MEm = $W^{0.75}$92.40 + 0.88 (T–LCT)), where MEm increased 0.88 kcal/$W^{0.75}$/d for each increment of 1°C.

### Energy requirement for growing and egg production

Although maintenance and growth are parallel and continuous in the process of nutrient metabolism, the two processes have been split traditionally by nutritional scientists (Black, 2000). Most models, which simulate metabolism, consider the maintenance requirements to be the first to be met on the list of requirements, followed by protein growth and, finally, fat growth. Tissue deposition only occurs if there are sufficient nutrients available to promote growth after the maintenance requirements are met. If the readily available nutrients are not sufficient to account for the maintenance requirements, body tissue must be catabolized to supply the necessary nutrients (Pomar *et al.,* 1991).

In the studies conducted at UNESP, the energy requirements for growing were determined by the slaughter method. The birds were slaughtered weekly to quantify the energy of carcass and feathers. Net energy requirement for weight gain (NEg) was obtained by regression between body energy and body weight. The ME requirements for weight gain were calculated from the NEg and the efficiency of energy utilization. For broilers, the ME requirement was determined for protein and fat deposition.

Net energy body content (kcal/gram body weight) changed according to genetic and age of poultry, due to variations in protein and fat body composition (Table 3). An increment in body energy was observed as poultry age advanced, because of greater fat deposition. The efficiencies of energy deposition change from 47% for broiler breeder hens to 69% for broiler breeder pullets. These results promoted differences on ME requirements for growth from 2.50 kcal/g for broiler breeder pullet to 9.49 kcal/g for laying-type pullets.

Variations on ME requirements for growth have been reported (Combs, 1968 - 3.26 Kcal/g; Davis *et al.*, 1972 - 4.41 Kcal/g; Emmans, 1974 - 5.00 Kcal/g and NRC, 1981 - 5.50 Kcal/g) and can be associated to the differences in body composition.

The utilization of ME intake above maintenance depends on the partition of energy into protein and lipid synthesis and the respective efficiencies which can be estimated with a factorial approach, where the ME intake is in function of protein and lipid deposition, as the model suggested by Kielanowski (1965). This model is important because body composition changes with genetic, age, body weight, and diet. In this way, it is possible to consider body composition to determine the energy requirements.

**Table 3 -** Net energy requirement (NEg), metabolizable energy requirement (MEg) for growing and efficiencies of energy utilization (kg) determined at UNESP studies[1].

| Age (weeks) | | NE g (kcal/g) | Efficiency (kg) (%) | ME g (kcal/g) |
|---|---|---|---|---|
| **Laying-type pullets** | | | | |
| | | 2.03 | | 3.44 |
| White-Egg-Laying strain | 8 to 12 | 3.06 | 59 | 5.19 |
| | 13 to 18 | 5.60 | | 9.49 |
| | 1 to 7 | 2.03 | | 3.22 |
| Brown-Egg-Laying strain | 8 to 12 | 3.11 | 63 | 4.94 |
| | 13 to 18 | 3.98 | | 6.32 |
| | 3 to 8 | 1.950 | 69 | 2.83 |
| Broiler breeder pullet | 9 to14 | 1.725 | | 2.50 |
| | 15 to 20 | 2.239 | | 3.24 |
| | 1 to 3 | 2.190 | 59 | 3.72 |
| Male broiler | 4 to 6 | 2.479 | | 4.21 |
| | 7 to 8 | 2.657 | | 4.51 |
| | 1 to 3 | 2.341 | 59 | 3.97 |
| Female broiler | 4 to 6 | 2.316 | | 3.93 |
| | 7 to 8 | 4.148 | | 7.04 |
| Laying hen | 20 to 36 | 4.340 | 65 | 6.68 |
| Broiler breeder hen | 26 to 33 | 3.580 | 47 | 7.62 |

1 - Sakomura *et al.,* 2003; Neme, 2004; Rabelo, 2001; Longo *et al.* (in press); Sakomura *et al.* (in press, a).

Sakomura *et al.* (2003) and Sakomura *et al.* (in press, b) used this approach in the studies with broiler breeder pullets and broilers. According to our results presented in Table 4, the efficiencies of energy deposition as protein ($k_p$) and fat ($k_f$) change with the ambient temperature. The $k_p$ obtained in broilers (0.45) and broiler breeders (0.46) were similar. Based on the values of the $k_p$ and gross energy content of body protein (5.66 kcal/g), the results of ME requirements per gram of protein deposited were 12.59 kcal/g for broiler and 12.57 kcal/g for breeder pullets. However, the $k_f$ was higher for broiler breeder (1.04) than that for broiler chick (0.69). This can be explained by the difference on the feeding programs; broilers were fed *ad libitum* and broiler breeders received controlled feeding. Based on the gross energy of body fat (9.37 kcal/g) and $k_f$, the ME requirements per gram of fat deposited were 13.52 kcal/g for broilers and 9.04 kcal/g for breeder pullets.

Tess *et al.* (1984) reported a wide range of values for both energy cost of protein (7.41 to 16.01 kcal/g protein) and lipid (9.56 to 16.25 kcal/g lipid) synthesis in pigs.

The majority of researchers take into account the efficiency for growth and for egg production together due to the difficulty in determining partial efficiencies for laying and broiler breeder hens. However, Sakomura *et al.* (in press, a) and Rabello (2001) determined partial efficiencies for energy utilization for growing (65 and

47%) and egg production (62 and 64%) for laying hens and broiler breeder hens, respectively.

**Table 4 -** Effect of ambient temperature on efficiencies of ME utilization for deposition as fat ($k_f$) and protein ($k_p$) and ME requirement for protein (ME/gp) and fat (ME/gf) depositions for broilers and broiler breeder pullets.

| Temperature (°C) | $k_f$ | ME/gf[1] | $k_p$ | ME/gp[2] |
|---|---|---|---|---|
| **Broiler[3]** | | | | |
| 13 | 0.92 | 10.21 | 0.36 | 15.85 |
| 23 | 0.55 | 16.96 | 0.58 | 9.74 |
| 32 | 0.70 | 13.40 | 0.47 | 12.17 |
| Means | 0.69 | 13.52 | 0.45 | 12.59 |
| **Broiler breeder pullet[4]** | | | | |
| 15 | 0.96 | 9.76 | 0.58 | 9.76 |
| 22 | 1.09 | 8.60 | 0.41 | 13.80 |
| 30 | 1.07 | 8.76 | 0.40 | 14.15 |
| Means | 1.04 | 9.04 | 0.46 | 12.57 |

1- Requirement determined based on fat caloric content per gram (9.37 kcal/g). 2 - Requirement determined based on protein caloric content per gram (5.66 kcal/g). 3 - Longo *et al.* (in press). 4 - Sakomura *et al.* (2003).

Rabello (2001) and Sakomura *et al.* (in press, a) found similar egg energy content in the broiler breeder's (1.54 kcal/kg of egg) and laying hens' eggs (1.49 kcal/kg). Similarly, the same authors found the efficiencies of ME utilization for energy deposition in eggs of broiler breeder (64%) and laying hens (62%). In this way, the ME requirements for egg production were similar to broiler breeder (2.40 kcal/g) and laying hens (2.40 kcal/g of egg). Thus, the same coefficient (2.40 kcal/g) can be used to determine the energy requirement for egg production for broiler breeder and laying hens. As previously reported, the energy content of eggs ranges from 1.33 kcal/g (Sibbald, 1979) to 1.79 kcal (Chwalibog, 1992). On the other hand, the energy efficiency range from 60 to 85% (Luiting *et al.*, 1990; Chwalibog, 1995). Consequently, the ME requirement ranges from 1.92 to 3.15 kcal/g of egg.

## Metabolizable Energy requirement models

Based on a factorial approach and considering the coefficients determined in the studies performed at UNESP, ME requirement models were elaborated for broiler breeders, laying hens, and broilers (Table 5).

The ME requirement models were developed according to coefficients determined for ME maintenance requirement per metabolic body weight (kcal/$W^{0.75}$), for daily body weight gain (kcal/g) and for daily egg mass production (kcal/g).

**Table 5** - Metabolizable energy requirement models for broiler breeders, laying hens, and broilers.

| Birds age (weeks) | Models |
|---|---|
| | **Broiler breeder pullet[1]** |
| 3 to 8 | $ME = W^{0.75}(174 - 1.88.T) + 2.83.WG$ |
| 9 to14 | $ME = W^{0.75}(174 - 1.88.T) + 2.50.WG$ |
| 15 to 20 | $ME = W^{0.75}(174 - 1.88.T) + 3.24.WG$ |
| | **Broiler breeder hen[2]** |
| | $ME = W^{0.75}(192.76 - 6.32.T + 0.12.T^2) + 7.62.WG + 2.40.EM$ |
| | **Laying-type pullet[3]** |
| | **White-egg-laying strains** |
| 1 to 6 | $ME=W^{0.75}92.40+6.73(LCT-T)+3.44WG(T<LCT)$ |
| 7 to 12 | $ME=W^{0.75}92.40+0.88(T-LCT) + 3.44WG\ (T \geq LCT)$ |
| 3 to 18 | $ME=W^{0.75}92.40+6.73(LCT-T) + 5.19WG\ (T<LCT)$ |
| 1 to 6 | $ME=W^{0.75}92.40+0.88(T-LCT) + 5.19WG\ (T\geq LCT)$ |
| 7 to 12 | $ME=W^{0.75}\ 92.40+6.73(LCT-T) + 9.49WG\ (T<LCT)$ |
| 13 to 18 | $ME=W^{0.75}\ 92.40+0.88(T-LCT) + 9.49WG\ (T\geq LCT)$ |
| | **Brown-egg-laying strains** |
| | $ME=W^{0.75}92.40+6.73(LCT-T)+3.22WG(T<LCT)$ |
| | $ME=W^{0.75}92.40+0.88(T-LCT) + 3.22WG\ (T >LCT)$ |
| | $ME=W^{0.75}\ 92.40+6.73(LCT-T) + 4.94WG\ (T<LCT)$ |
| | $ME=W^{0.75}\ 92.40+0.88(T-LCT) + 4.94WG\ (T\geq LCT)$ |
| | $ME=W^{0.75}\ 92.40+6.73(LCT-T) + 6.32WG\ (T<LCT)$ |
| | $ME=W^{0.75}\ 92.40+0.88(T-LCT) + 6.32WG\ (T\geq LCT)$ |
| | **Laying hen[4]** |
| | $ME = W^{0.75}(165.74 - 2.37.T) + 6.68.WG + 2.40.EM$ |
| | **Female broiler[5]** |
| 1 to 3 | $ME = W^{0.75}(307.87 - 15.63.T + 0.31.T^2) + 3.98.WG$ |
| 4 to 6 | $ME = W^{0.75}(307.87 - 15.63.T + 0.31.T^2) + 3.93.WG$ |
| 7 to 8 | $ME = W^{0.75}(307.87 - 15.63.T + 0.31.T^2) + 7.04.WG$ |
| | **Male broiler[5]** |
| 1 to 3 | $ME = W^{0.75}(307.87 - 15.63.T + 0.31.T^2) + 3.72.WG$ |
| 4 to 6 | $ME = W^{0.75}(307.87 - 15.63.T + 0.31.T^2) + 4.21.WG$ |
| 7 to 8 | $ME = W^{0.75}(307.87 - 15.63.T + 0.31.T^2) + 4.51.WG$ |
| | **Broiler[6]** |
| 1 to 8 | $ME = W^{0.75}(307.87 - 15.63.T + 0.3105.T^2) + 13.52.FG + 12.59.PG$ |

ME = metabolizable energy requirement (kcal/bird/day), $W^{0.75}$ = metabolic body weight (kg), T = ambient temperature (C), WG = daily weight gain (g), EM = daily egg mass (g), FG = fat weight gain (g) and PG = protein weight gain (g), LCT = 24.54 – 5.65F, F is feathering score (0 to 1). 1 - Sakomura *et al.*, 2003. 2 - Rabelo, 2001. 3 - Neme, 2004. 4 - Sakomura *et al.* (in press,a).5 - Longo *et al.* (in press). 6 - Sakomura *et al.* (in press,b).

## Evaluation of ME requirement models

The models to predict nutritional requirements before making recommendations in feeding programs should be submitted to validation. According to Black (1995), the models can be evaluated in three ways: (1) simulation of experiments reported in the literature, and comparison of simulated to measured requirements; (2) subjective evaluation of the response of model predictions to changes input values (behavioral analysis); (3) tests of sensibility of model predictions to changes in selected model parameters. In doing so, feeding trials were conducted with broiler breeder pullets (Sakomura *et al.*, 2003), broiler breeder hens (Rabelo, 2001), and laying hens (Sakomura *et al.*, in press, b) in order to evaluate the models determined at UNESP. In those trials, the energy requirements were determined applying the performance data (body weight, weight gain, egg production, and body composition) and ambient temperature in the models, which were compared to energy intake, according to the genetic line recommendations.

The results for broiler breeder pullets, shown in Table 6, indicated that models (2) were better in predicting the energy requirements than models (1). Likewise, it is necessary to reevaluate the energy requirement recommendation by Hubbard because this provided body weight above lineage recommendation.

**Table 6** - Broiler breeder pullet performance from 5 to 20 weeks of age feed according to energy models and Hubbard recommendation[1].

| Treatments | ME intake (kcal/bird) 5 to 20 wk | Body weight (kg) At 20 wk |
|---|---|---|
| Hubbard recommendation | 20566 a | 2100 a |
| ME Models[2] | 20324 ab | 2059 ab |
| ME Models[3] | 20068 b | 2022 b |
| CV (%) | 1.36 | 1.54 |

1 - Sakomura *et al.* (2003). 2 - 1 to 8 wks - ME = $W^{0.75}$ (186.52 – 1.94.T) + 2.47.WG; 9 to 14 wks - ME = $W^{0.75}$ (186.52 – 1.94.T) + 2.69.WG; 15 to 20 wks - ME = $W^{0.75}$ (186.52 – 1.94.T) + 2.47.WG. 3 - 1 to 8 wks - ME = $W^{0.75}$ (174 – 1.88.T) + 2.83.WG; 9 to 14 wks - ME = $W^{0.75}$ (174 – 1.88.T) + 2.50.WG; 15 to 20 wks - ME = $W^{0.75}$ (174 – 1.88.T) + 3.24.WG. Means followed by different letter in the same column are different ($p<0.05$).

For broiler breeder hens, the results in Table 7 show that ME model exhibit good adjustment because the birds had similar performance to Hubbard recommendation.

Both ME models for laying hens promoted accurate energy requirement predictions and good performance. However, the *ad libitum* feeding promoted higher ME intake than ME models but showed similar performance to Lohmann's recommendation and model treatments (Table 8).

In order to evaluate the broiler's model, a trial with broiler chicks was conducted to collect data of ME intake, body weight, weight gain, fat and protein body composition, and ambient temperature. These data were applied in UNESP model, Emmans (1989) and Chwalibog (1991) models and compared to ME intake observed. UNESP model predicted ME intake close to that observed in the trial compared to Emmans and Chwalibog models (Table 9).

In conclusion, the ME requirement models determined at UNESP provided good performance in the feeding trials; thus, they are adjusted to determine the ME requirement, and can be used to elaborate broiler breeder, laying hen, and broiler nutritional programs.

## Models applied to feeding programs

Mathematical models have been proposed as a tool for more accurate estimations of energy requirements for poultry when compared to results from empirical experimentation. This modeling approach presents the advantage to determine more flexible nutrient requirement estimation for specific growth rates, egg production, and environmental temperature.

The application of ME requirement models can help to establish accurate dietary energy levels and to

**Table 7** - Broiler breeder hen performance from 31 to 46 weeks of age feed according to energy model and Hubbard recommendation[1]

| Treatments | Energy Intake (kcal/bird/day) | Egg Production (%bird/day) | Egg Mass (g/bird/day) | Body Weight g | Hatchability (%) | Chicks Weight g g |
|---|---|---|---|---|---|---|
| Hubbard | 455.37 a | 83.30 | 52.71 | 3942 | 93.86 | 46.29 |
| ME model[2] | 444.38 b | 84.15 | 53.14 | 3906 | 94.18 | 46.31 |
| CV(%)[1] | 0.51 | 1.81 | 1.96 | 2.17 | 3.09 | 1.10 |

1 - Rabelo (2001). 2 - ME = $W^{0.75}$ (192.76 – 6.32.T + 0.12.$T^2$) + 7.62.WG + 2.40.EM. Means followed by different letter in the same column are different ($p<0.05$).

**Table 8** - Laying hens performance from 30 to 45 weeks age feed according to energy models, Lohmann's reccomendation and ad libitum feeding[1].

| Treatments | ME intake (kcal/bird/day) | Body weight 45 wk (g) | Egg mass (g/bird/day) | Feed conversion (kg/kg egg) | Energy conversion (kcal/kg egg) |
|---|---|---|---|---|---|
| *Ad libitum* | 321 a | 1656 | 59.9 | 1.88 a | 5361 |
| Lohmann | 308 b | 1653 | 59.5 | 1.82 a | 5186 |
| ME Models[2] | 307 b | 1665 | 59.1 | 1.74 b | 5197 |
| ME Models[3] | 312 b | 1663 | 60.0 | 1.74 b | 5198 |
| CV (%) | 1.39 | 1.57 | 2.09 | 2.25 | 2.26 |

1 - Sakomura *et al.* (in press). 2 - ME = $W^{0.75}$ (165.74 – 2.37.T) + 6.68.WG + 2.40.EM. 3 - ME = $W^{0.75}$ (163.67 – 2.09.T) + 6.68.WG + 2.40.EM. Means followed by different letter in the same column are different ($p<0.05$).

**Table 9** - ME requirements predicted by UNESP (2002) model, Emmans (1989) e Chwalibog (1991) models compared to ME intake of male broiler Ross.

| Age (week) | UNESP (2002)[1] | Emmans (1989)[2] | Chwalibog (1991)[3] | ME intake observed[4] |
|---|---|---|---|---|
| 7 to 14 | 154 | 121 | 127 | 148 |
| 15 to 21 | 272 | 217 | 222 | 255 |
| 22 to 28 | 405 | 331 | 342 | 401 |
| 29 to 35 | 536 | 445 | 448 | 516 |
| 36 to 42 | 567 | 465 | 501 | 586 |
| 43 to 49 | 713 | 602 | 619 | 660 |
| 50 to 56 | 619 | 513 | 520 | 721 |
| Total (kcal) | 22.868 | 18.848 | 19.445 | 23.016 |

1 - $ME=(307.87-15.63T+0.311T^2)\ W^{.75} + 13.52.FG + 12.59.PG$. 2 - Emmans (1989) - ME = 0.275 WP + 11.95. PG + 13.38 FG (WP =protein body weight, g ). 3 - Chwalibog (1991) - $ME = 111.1\ W^{0.75} + 8.03\ PG + 13.38\ FG$. 4 - ME = ME intake observed in the trial. Sakomura *et al.* (in press, b).

elaborate more profitable feeding programs for broiler breeders, laying hens, and broilers.

Tables 10, 11, 12, and 13 show simulations by applying the models determined at UNESP in order to elaborate feeding programs. The ME requirements were determined by applying in the models the ambient temperature, body weight, weight gain, body composition, and egg production for different genetic, Hubbard Hy-Yield and Hy-Line.

For broiler breeders (Tables 10 and 11), we could determine the ME requirements (kcal/bird/day) and predict the feed intake according to the diet energy levels. It is very important to determine accurate ME requirements for broiler breeders because they are controlled fed; the excess or deficiency of energy can be prejudicial to performance.

The prediction of ME requirements for laying hens could be used to establish diet energy levels, according to daily energy requirement and daily feed intake. Since there are significant variations in feed intake, according to genetic and environmental temperature, it is important to consider both energy requirement and feed intake to establish diet energy level (Table 12).

For laying-type pullets, the models take into account feathering, besides temperature and metabolic body weight for MEm, and the differences between Brown-egg and White-egg laying pullets for growing requirements (Table 13). Thus, we can determine more accurate energy requirements considering the differences between strains.

**Table 10** - Simulations of broiler breeder pullet ME requirements by applying the Hubbard Hy-Yield performance in the models[1]

| Age (weeks) | Body weight mean (g) | Weight gain (g/day) | ME intake (kcal/b/d) | Feed intake[2] (g/b/d) |
|---|---|---|---|---|
| 1 | 78 | 10.71 | 50 | 17 |
| 2 | 170 | 15.71 | 79 | 28 |
| 3 | 273 | 13.57 | 88 | 31 |
| 4 | 365 | 12.86 | 99 | 35 |
| 5 | 455 | 12.86 | 110 | 38 |
| 6 | 545 | 12.86 | 120 | 42 |
| 7 | 635 | 12.86 | 131 | 46 |
| 8 | 725 | 12.86 | 141 | 49 |
| 9 | 815 | 12.86 | 146 | 51 |
| 10 | 905 | 12.86 | 155 | 54 |
| 11 | 995 | 12.86 | 164 | 58 |
| 12 | 1085 | 12.86 | 173 | 61 |
| 13 | 1180 | 14.29 | 186 | 65 |
| 14 | 1280 | 14.29 | 195 | 68 |
| 15 | 1380 | 14.29 | 215 | 75 |
| 16 | 1488 | 16.43 | 232 | 81 |
| 17 | 1603 | 16.43 | 242 | 85 |
| 18 | 1718 | 16.43 | 252 | 88 |
| 19 | 1833 | 16.43 | 262 | 92 |
| 20 | 1948 | 16.43 | 272 | 95 |
| 21 | 2070 | 18.57 | 289 | 101 |
| 22 | 2203 | 19.29 | 302 | 106 |
| 23 | 2340 | 20.00 | 316 | 111 |
| 24 | 2551 | 40.36 | 398 | 140 |

1. 1 to 8 weeks $ME = W^{0.75}\ (174 – 1.88T) + 2.83G$; 9 to 14 weeks $ME = W^{0.75}(174 – 1.88T) + 2.50G$; 15 to 20 weeks $ME = W^{0.75}\ (174 – 1.88T) + 3.24G$; ambient temperature at 22 °C. 2. Feed intake determined considering the dietary energy of 2,850 kcal ME/kg.

**Table 11** - Simulations of broiler breeder hens ME requirements by applying the Hubbard Hy-Yield performance in the model[1].

| Age (weeks) | Body weight mean (g) | Weight gain (g/b/d) | ME intake[1] (g/b/d) | Egg mass (kcal/b/d) | Feedintake[2] (g/b/d) |
|---|---|---|---|---|---|
| 26 | 2875 | 15.71 | 15.95 | 405 | 142 |
| 28 | 3065 | 12.86 | 38.62 | 449 | 158 |
| 30 | 3205 | 7.14 | 46.87 | 435 | 153 |
| 32 | 3290 | 5.71 | 50.72 | 438 | 154 |
| 34 | 3378 | 6.43 | 50.82 | 449 | 158 |
| 36 | 3430 | 2.86 | 50.87 | 426 | 149 |
| 38 | 3448 | 0.71 | 50.14 | 409 | 143 |
| 40 | 3458 | 0.71 | 49.01 | 406 | 143 |
| 42 | 3483 | 2.14 | 48.59 | 418 | 147 |
| 44 | 3513 | 2.14 | 47.48 | 417 | 146 |
| 46 | 3528 | 0.71 | 46.82 | 405 | 142 |
| 48 | 3538 | 0.71 | 45.85 | 404 | 142 |
| 50 | 3548 | 0.71 | 44.71 | 402 | 141 |
| 52 | 3558 | 0.71 | 43.70 | 400 | 140 |
| 54 | 3568 | 0.71 | 42.33 | 397 | 139 |
| 56 | 3578 | 0.71 | 41.18 | 395 | 139 |
| 58 | 3588 | 0.71 | 40.49 | 394 | 138 |
| 60 | 3598 | 0.71 | 39.71 | 393 | 138 |
| 62 | 3608 | 0.71 | 38.69 | 391 | 137 |
| 64 | 3618 | 0.71 | 37.43 | 388 | 136 |

1 - $ME = W^{0.75}(192.76 – 6.32.T + 0.12.T^2) + 7.62.WG + 2.40.EM$. Ambient temperature at 22 °C. 2 - Feed intake determined considering the dietary energy of 2,850 kcal ME/kg.

**Table 12** -Simulations of laying hens ME requirements by applying the Hy-line performance in the model[1].

| Age (weeks) | Body weight (g) | Weight gain (g/b/d) | Egg mass (g/b/d) | ME intake[1] (kcal/b/d) | Feed intake (g/b/d) | ME diet[2] (kcal/kg) |
|---|---|---|---|---|---|---|
| 20 | 1405 | 12.86 | 23.87 | 290 | 105 | 2760 |
| 24 | 1575 | 1.43 | 50.23 | 290 | 105 | 2760 |
| 28 | 1605 | 1.43 | 55.58 | 305 | 104 | 2932 |
| 32 | 1630 | 0.00 | 56.03 | 298 | 104 | 2869 |
| 36 | 1645 | 1.43 | 56.43 | 310 | 103 | 3010 |
| 40 | 1665 | 1.43 | 56.16 | 311 | 102 | 3048 |
| 44 | 1685 | 1.43 | 55.33 | 310 | 102 | 3043 |
| 48 | 1690 | 0.00 | 54.32 | 299 | 101 | 2958 |
| 52 | 1700 | 0.00 | 53.45 | 297 | 101 | 2945 |
| 56 | 1700 | 0.00 | 52.65 | 295 | 101 | 2926 |
| 60 | 1710 | 0.00 | 51.09 | 292 | 101 | 2896 |
| 64 | 1710 | 0.00 | 49.20 | 288 | 101 | 2851 |
| 68 | 1720 | 0.00 | 48.54 | 287 | 101 | 2843 |
| 72 | 1720 | 0.00 | 47.30 | 284 | 101 | 2814 |
| 76 | 1725 | 1.43 | 45.40 | 290 | 101 | 2866 |
| 80 | 1730 | 0.00 | 44.22 | 277 | 101 | 2748 |

1 - ME = $W^{0.75}$ (165.74 – 2.37.T) + 6.68.WG + 2.40.EM. 2 - Diet ME level according to ME intake and feed intake.

**Table 13** - Simulations of laying-type pullets ME requirements by applying the Hy-Line Brown and Hy-Line W36 performances in the models[1].

| Age (weeks) | Hy Line Brown[1] | | | | Hy Line W36[2] | | | |
|---|---|---|---|---|---|---|---|---|
| | Body weight (g) | Weight gain(g/day) | ME intake[1] (kcal/b/d) | Feed intake (g/b/d)[1] | Body weight (g) | Weight gain (g/day) | ME intake[2] (kcal/b/d) | Feed intake (g/b/d)[1] |
| 1 | 60 | 2.9 | 26 | 9.0 | 68 | 3.9 | 24 | 8.3 |
| 2 | 109 | 7.0 | 36 | 12.3 | 116 | 6.7 | 37 | 12.6 |
| 3 | 178 | 9.8 | 56 | 19.5 | 180 | 9.1 | 55 | 19.1 |
| 4 | 228 | 7.1 | 77 | 26.6 | 263 | 11.9 | 62 | 21.3 |
| 5 | 370 | 20.3 | 81 | 27.9 | 353 | 12.9 | 68 | 23.6 |
| 6 | 485 | 16.4 | 95 | 32.7 | 443 | 12.9 | 81 | 27.8 |
| 7 | 605 | 17.1 | 136 | 47.0 | 539 | 13.7 | 125 | 43.0 |
| 8 | 717 | 16.0 | 138 | 47.8 | 655 | 16.6 | 126 | 43.3 |
| 9 | 822 | 15.0 | 148 | 50.9 | 711 | 8.0 | 134 | 46.2 |
| 10 | 938 | 16.6 | 157 | 54.1 | 785 | 10.6 | 142 | 49.1 |
| 11 | 1042 | 14.9 | 166 | 57.3 | 849 | 9.1 | 159 | 54.8 |
| 12 | 1168 | 18.0 | 152 | 52.2 | 963 | 16.3 | 151 | 52.2 |
| 13 | 1291 | 17.6 | 202 | 69.6 | 1033 | 10.0 | 208 | 71.7 |
| 14 | 1394 | 14.7 | 202 | 69.4 | 1099 | 9.4 | 201 | 69.3 |
| 15 | 1481 | 12.4 | 209 | 72.2 | 1152 | 7.6 | 193 | 66.5 |
| 16 | 1501 | 2.9 | 198 | 68.2 | 1168 | 2.3 | 184 | 63.4 |
| 17 | 1595 | 13.4 | 204 | 70.5 | 1250 | 11.7 | 174 | 60.0 |
| 18 | 1679 | 12.0 | 211 | 72.7 | 1321 | 10.1 | 163 | 56.3 |

1 - 1 to 6 weeks ME = $W^{0.75}$ (92.40 + 6.73).(LCT – T) + 3.22 G, (T< LCT) and ME = $W^{0.75}$ (92.40 + .88).(T - LCT) + 3.22 G, (T > LCT); 7 to 12 weeks ME = $W^{0.75}$ (92.40 + 6.73).(LCT – T) + 4.94 G, (T< LCT) and ME = $W^{0.75}$ (92.40 + .88).(T - LCT) + 4.94 G, (T > LCT) ;13 to 18 weeks ME = $W^{0.75}$ (92.40 + 6.73).(LCT – T) + 6.32 G, (T< LCT) and ME = $W^{0.75}$ (92.40 + .88).(T - LCT) + 6.32 G, (T > LCT). 2-1 to 6 weeks ME = $W^{0.75}$ (92.40 + 6.73).(LCT – T) + 3.44 G, (T< LCT) and ME = $W^{0.75}$ (92.40 + .88).(T - LCT) + 3.44 G, (T > LCT); 7 to 12 weeks ME = $W^{0.75}$ (92.40 + 6.73).(LCT – T) + 5.19 G, (T< LCT) and ME = $W^{0.75}$ (92.40 + .88).(T - LCT) + 5.19 G, (T > LCT),13 to 18 weeks ME = $W^{0.75}$ (92.40 + 6.73).(LCT – T) + 9.49 G, (T< LCT) and ME = $W^{0.75}$ (92.40 + .88).(T - LCT) + 9.49 G, (T > LCT). Ambient temperature at 24 °C. Feed intake determined considering the diet energy level of 2,900 kcal ME/kg.

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