Abstract
Traditionally, the energy and protein allowances are designed to produce as high as possible performance (we shall refer subsequently to the daily weight gain). Only few systems of assessing the energy and nutrient requirement offer the possibility to monitor carcass quality expressed mainly by the lipid to protein ratio.

Keywords: computer simulation, energy requirement, mathematical modeling, metabolic processes, poultry, protein requirement

1. Introduction
The method of mathematical modeling of the metabolic processes offers the possibility to assess feed allowances in their evolution, related both to the growth rate and to carcass quality. This paper presents an approach of this issue.

Because for a given weight gain the quality of this gain is included in an interval \( \min \leq \frac{L_r}{P_r} \leq \max \), where \( L_r = \) daily retained lipids and \( P_r = \) daily retained protein, it results that feed allowance will be expressed as intervals of the form \([\text{normmin}, \text{normmax}]\). We obtain thus an infinity of possible values for the feed allowance.

The choice of one possible value or of another one depends on the rearing technology, on the purpose of growing expressed in economic terms and/or in terms of a human-friendly food. In the present paper, besides the modality of calculating the intervals for energy and protein allowance we shall also present formulas which, in our opinion, characterize a physiological evolution of the weight gain and of the lipid/protein ratio of the carcass.

2. Materials and methods
Calculation of the energy and protein requirement using mathematical modeling.

The following parameters should be taken into consideration when calculating the energy and protein requirements:
- body weight \((W, \text{g})\);
- intended final body weight \((\Delta W, \text{g})\);
- ratio between the lean gain \((\text{protein+water})\) and the retained protein \((\alpha)\);
- ratio between the daily retained fat and protein \((\frac{L_r}{P_r} = \beta)\);
- ratio between the daily gain of ash and protein \((\frac{\text{Ashr}}{P_r} = \gamma)\);
- biological value of the diet \((\text{BV})\);
- environmental temperature \((T_a)\);
- digestible energy per kg DM of diet \((\text{MJ/kg DM})\).

For assessing the standard body weight we use the following formula expressing the net weight \((W_n, \text{g})\):
g) as a Gompertz time variable (t, days) (Burlacu et al.,1995):

- for males:

\[ W_n = 37.96 \times e^{0.16232 \times e^{-0.03288 \times t}} \]

(1)

- for females:

\[ W_n = 37.96 \times e^{0.15501 \times e^{-0.03223 \times t}} \]

(2)

The (gross) body weight is calculated in both situations with the formula:

\[ W = \frac{W_n}{0.973} \]

(3)

From (1) and (2) the expression of the standard daily net weight gain (\( \Delta W_n \), g/day) is obtained by derivation.

- for males:

\[ \frac{dW_n}{dt} = 0.16232 \times W_n \times e^{-0.03288 \times t} \]

(4)

- for females:

\[ \frac{dW_n}{dt} = 0.15501 \times W_n \times e^{-0.03223 \times t} \]

(5)

Body weight can, of course, be measured directly too, and used as such in the model. Weight gain is also not the unique determinant. For each body weight there is an interval \( [\Delta W_{min}, \Delta W_{max}] \) for the daily weight gain. Formulas (4) and (5) propose the maximal values for it.

The ratio between the lean gain (protein+water) and the retained protein (\( \alpha \)) was calculated function of the net body weight (\( W_n \)):

- for males:

\[ \alpha = \frac{7.51245 \times W_n}{0.07287} \]

(6)

- for females:

\[ \alpha = \frac{7.65598 \times W_n}{0.0784} \]

(7)

Unlike the parameters discussed previously, the value of \( \alpha \) is uniquely determined for a given weight.

The ratio between the daily retained fat and protein (\( \frac{Lr}{Pr} = \beta \))

This parameter has the highest variability for a given body weight and for a determined daily gain. This ratio is otherwise the key parameter in determining the daily weight gain by the feed allowance. Experimental determinations have shown that \( \beta \in [0.2; 1.2] \). The physiological value of \( \beta \), which we define as being the lowest value specific to each age, was calculated according to the body protein (\( Pt \)) and age expressed in days (t):

- for males:

\[ \beta = \frac{34.6 + 11.78 \times t_{0.06} \times e^{0.00198 \times t - 0.0017 \times t^2}}{23.6 \times 0.1765 \times Pt \times e^{-0.03425 \times t} - 1} \]

(8)

- for females:

\[ \beta = \frac{33.97 + 14.14 \times t_{0.04} \times e^{0.00536 \times t - 0.0001 \times t^2}}{23.6 \times 0.17 \times Pt \times e^{-0.03425 \times t} - 1} \]

(9)

The ratio between the daily gain of ash and protein \( \left( \frac{Ashr}{Pr} = \gamma \right) \) was calculated according to the evolution of the total body weight (\( Pt \)) with the formulas:

- for males:

\[ \gamma = 0.14518 \times Pt^{0.02523} \]

(10)

- for females:

\[ \gamma = 0.13646 \times Pt^{0.03438} \]

(11)

as in the case of \( \alpha \), the value of \( \beta \) is considered to be uniquely determined for a determined total body weight.

Calculation of the requirement of digestible crude protein and digestible amino acids

We begin this calculation with the determination of the total body protein (\( Pt \), g) (also required by formulas (8) and (9)).

\[ Pt = \frac{W}{100} \times (15.7651 + 0.00302 W) \]

(12)

In the hypothesis of a growth not restricted by the environmental factors, we propose for the calculation of the maximal body protein (at a given age) the following, Gompertz-type formula, function of time (t):

- for males:

\[ Pt_m = 5.99375 \times e^{0.17646 \times e^{-0.03425 \times t}} \]

(13)

- for females:

\[ Pt_m = 5.99375 \times e^{0.17006 \times e^{-0.03449 \times t}} \]

(14)

Based on formulas (13) and (14), by derivation, we obtain the formula for the maximal amount of daily retained protein:

- for males:

\[ \frac{dP_t}{dt} = 0.17646 \times e^{0.003425 \times t} \]

(15)

- for females:

\[ \frac{dP_t}{dt} = 0.17006 \times e^{0.003449 \times t} \]
For the other cases, the determination of the calculated value for the retained protein (Pr,c,g) is done according to the following judgment:

\[ \Delta W_n = \text{lean gain} + L_r + \text{Ashr} \]

but

\[ \text{lean gain} = \alpha \times P_{rc}, \quad L_r = \beta \times P_{rc}, \quad \text{Ashr} = \gamma \times P_{rc} \]

Thus, \( \Delta W_n = \alpha \times P_{rc} + \beta \times P_{rc} + \gamma \times P_{rc} = P_{rc} \times (\alpha + \beta + \gamma) \)

\( (\Delta W_n = 0.973 \times W) \)

It results:

\[ P_{rc} = \frac{\Delta W_n}{\alpha + \beta + \gamma} = \frac{0.973 \Delta W}{\alpha + \beta + \gamma} \]

Finally, the rate of daily retained protein (Pr, g) is determined as follows:

\[ \text{Pr} = \min(Pr^c, Pr^m) \]

Once the value of Pr is determined, we can calculate the available protein (AP, g)

\[ AP = P_{m} + \frac{Pr}{0.837} \]

where \( (P_{m}, g) \) is the protein requirement for maintenance calculated according to Pt as follows:

- for males:
  \[ P_{m} = 0.038 \times P_{t}^{0.744} \]
- for females:
  \[ P_{m} = 0.036 \times P_{t}^{0.761} \]

Based on the available protein we calculate the allowance of digestible crude protein and digestible amino acids:

\[ \text{DCP} = \frac{AP}{BV} \]

where BV ∈ [0.45; 0.85] is the biological value of the dietary protein

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- Digestible lysine = 0.066xAP
- Digestible Met.+Cys. = 0.056 x AP
- Digestible tryptophan = 0.012 x AP

For the other amino acids the calculation is similar, taking into account that the AP is multiplied with the proportion of amino acid existing in poultry meat.

Calculation of the requirement of metabolisable energy (ME, KJ)

To calculate the requirement of metabolisable energy we used the formula:

\[ \text{ME} = \text{ME}_{m} + \text{EPr} + \text{ELr} + Q' + Q'' \]

where \( \text{ME}_{m} \) is the requirement of metabolisable energy for maintenance calculated as follows:

- for males:
  \[ \text{ME}_{m} = 546 \left( \frac{W_{n}}{1000} \right)^{0.700} \]
- for females:
  \[ \text{ME}_{m} = 518 \left( \frac{W_{n}}{1000} \right)^{0.646} \]

EPr is the requirement of metabolisable energy for the synthesis and retention of protein. For both sexes the following formula was used:

\[ \text{EPr} = 50 \times Pr \]

ELr is the requirement of metabolisable energy for the synthesis and retention of lipids. For both sexes the following formula was used:

\[ \text{ELr} = 56 \times Lr, \quad \text{unde } Lr = \beta \times P_{rc} \]

The requirement of energy for thermal regulation was noted with \( Q' \) and it was given by the formula:

\[ Q' = \begin{cases} (T_{ci} - T_{a})(31.7215 - 2.042 \times 10^{-2} x W + 6.7 \times 10^{-6} x W^2 - 6.561 \times 10^{-9} x W^3) x W^{0.75}, & \text{dacă } T_{ci} > T_{a} \\ 0, & \text{în rest} \end{cases} \]

We noted \( T_{a} \) the environmental temperature and \( T_{ci} \) the lower critical temperature determined by the formula:

\[ T_{ci} = 37.5784 - 2.014 \times 10^{-2} x W + 8.242 \times 10^{-6} x W^2 - 1.231 \times 10^{-9} x W^3 \]

\( Q' \) is the energy requirement spent for the daily physical activity

\[ Q'' = \text{ME}_{m} \times \frac{140.34 - 0.4034x}{100} \]

where \( x \) is the feeding level (% of ad libitum).

Following is the calculation of the maximal amount of ingested dry matter.

- for males:
  \[ g \text{DMmax/zi} = (5.686 + 1.904xt^{1.234} x e^{-0.01159xt})x \frac{1}{\sigma} \]
- for females
  \[ g \text{DMmax/zi} = (5.686 + 2.273xt^{1.149} x e^{-0.01073xt})x \frac{1}{\sigma} \]

where \( \sigma \) is a coefficient between 0.7 and 1, whose value depends on the degree of genetic improvement (breeding) of the broilers.
Currently, the amount of the ingested dry matter is calculated according to the formula:

\[
\text{DM} = \frac{\text{ME(allowance)}}{\text{ME} / \text{kg DM}}
\]

The values thus calculated must be lower or equal to \( \text{DM}_{\text{max}} \) given in (33) and (34) which are uniquely determined, expressing variations of both the diet (the content of ME/kg DM, the biological value of the diet BV) and of the quality of gain (Lr/Pr ratio) involving the existence of allowances expressed by intervals and not by values uniquely determined as it is done traditionally.

### 3. Results and discussion

Table 1 shows the energy and protein requirement calculated according to the model proposed in broilers, for feeds and diets with variable content of metabolisable energy and with a biological value, between 13.5 and 16 MJ/kg DM, respectively 0.55 and 0.75 and with a retained fat/retained protein ratio (\( \beta \)) between 0.2 and 1.0.

<table>
<thead>
<tr>
<th>Body weight, (g)</th>
<th>DM intake, (g)</th>
<th>ME, (KJ)</th>
<th>DCP, (g)</th>
<th>Lysine, (g)</th>
<th>Met.+Cys., (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>14.5-22.2</td>
<td>232-300</td>
<td>4.7-3.1</td>
<td>0.24-0.22</td>
<td>0.15-0.13</td>
</tr>
<tr>
<td>200</td>
<td>23.3-37.4</td>
<td>373-504</td>
<td>7.5-5.3</td>
<td>0.38-0.37</td>
<td>0.23-0.22</td>
</tr>
<tr>
<td>500</td>
<td>42.0-67.4</td>
<td>673-908</td>
<td>13.2-10.9</td>
<td>0.67-0.66</td>
<td>0.41-0.40</td>
</tr>
<tr>
<td>1000</td>
<td>66.6-100.3</td>
<td>1066-1354</td>
<td>22.0-14.3</td>
<td>1.12-099</td>
<td>0.68-0.60</td>
</tr>
<tr>
<td>1500</td>
<td>83.9-125.8</td>
<td>1342-1698</td>
<td>28.0-18.2</td>
<td>1.43-1.26</td>
<td>0.87-0.77</td>
</tr>
<tr>
<td>2000</td>
<td>92.3-135.8</td>
<td>1476-1834</td>
<td>29.0-19.0</td>
<td>1.48-1.32</td>
<td>0.90-0.81</td>
</tr>
</tbody>
</table>

Based on the allowances in DM (35) and DCP (21) we can determine without any difficulty the total amount of the diet and the amount of dietary crude protein.

\[
\text{TCl} = \frac{0.001 \times \delta}{\text{DM/kg diet}}
\]

\[
\text{CP} = \frac{\text{dCP}}{} , \text{ where dCP = digestibility of the dietary crude protein}
\]

Figure 1 shows the amount of compound feed dry matter that can be given in order to attain a body weight gain from the first to the eighth week depending on the CP percentage in the diet (dCP was considered to be 0.8) taking into account the maximal rate of protein retention and the limits of the ratio between fat and protein retention (\( \beta \)).

We notice that the daily body weight can be obtained for ex. in the 28th day only by giving a compound feed in amounts ranging within wider limits, from 62 to 93g but with protein concentration between 45 to 18g/100 g DM, a \( \beta \) ratio between 0.2 to 1.0 and a biological value between 0.45 to 0.65.

### 4. Conclusions
As a conclusion, the model allows us to calculate the energy and protein requirement starting from easily determined input variables (weight gain, age in days). At a given age (body weight) and at a determined gain there is a variable requirement of feed.

References