Revista Ciência Agronômica, v. 47, n. 3, p. 572-581, jul-set, 2016
Centro de Ciências Agrárias - Universidade Federal do Ceará, Fortaleza, CE
www.ccarevista.ufc.br

Artigo Científico
ISSN 1806-6690

Adjustment of growth parameters for the major body components of pullets[1]

Ajuste dos parâmetros de crescimento para os principais componentes corporais de frangas de postura

Edney Pereira da Silva[2]*, Nilva Kazue Sakomura[3], Juliano Cesar de Paula Dorigam[3], Euclides Braga Malheiros[4] and Nelson José Peruzzi[4]

ABSTRACT - The purpose of this research was analyze the fit of Gompertz function with or without fixing some of the parameters to describe body growth and major bodily chemical constituents of growing pullets. Weekly, data of body weight and chemical components of body free of feathers and feathers were collected from 1,200 chicks of four laying strains (Hisex Brown, Hisex White, Hy Line Brown and Hy Line White W36) until 18 weeks of age. The variables were subjected to two adjustments fixing, or not, some parameters of Gompertz function. The allometric model parameters were calculated for the chemical components. The lipid and protein composition of the body free of feathers were the components with the biggest change in the last weeks. Moreover, the chemical composition of the feather showed small variation. The parameters of the Gompertz function assumed values according to the employed adjustment, especially for protein and fat of the body free of feathers carcass. The adjustment of the Gompertz function by fixing the two parameters allowed coherence and biological significance. The allometric coefficients indicate that as the protein weight increased, the proportion of fat increased and the proportion of water and ashes in the body decreased. The fit of the model allows setting the parameters with consistency and biological significance without losing accuracy in the estimates.

Key words: Carcass. Growth curve. Weight protein. Feather.

RESUMO - O intuito desta pesquisa foi analisar o ajuste da função Gompertz fixando, ou não alguns parâmetros para descrever o crescimento corporal e dos principais constituintes químicos corporais de frangas de postura em crescimento. Foram coletados semanalmente os dados de peso corporal e os componentes químicos da carcaça depenada e penas de 1.200 pintainhas de quatro linhagens de postura: Hisex marrom, Hisex branca, Hy Line marrom e Hy Line branca W36, até a 18ª semana de idade. As variáveis foram submetidas a dois ajustes, fixando-se ou não alguns parâmetros da função Gompertz. Foram calculados os parâmetros de um modelo alométrico para os componentes químicos. Lipídeo e proteína foram os componentes da carcaça depenada com maior variação nas últimas semanas. Por outro lado, a composição química da pena apresentou pouca variação. Os parâmetros da função Gompertz assumiram valores de acordo com o ajuste empregado, sobretudo para proteína e gordura da carcaça depenada. O ajuste da função Gompertz, fixando os dois parâmetros, permitiu coerência e significado biológico. Os coeficientes alométricos indicaram que à medida que aumentou o peso proteico, aumentou a proporção de gordura e reduziu a proporção de água e cinzas no corpo. O ajuste do modelo, fixando os parâmetros, possibilita coerência com significado biológico, sem perder a precisão nas estimativas.

Palavras-chave: Carcaça. Curva de Crescimento. Peso proteico. Penas.

* Autor para correspondência
[1]Recebido para publicação em 09/02/2014; aprovado em 02/09/2015
Pesquisa financiada pela FAPESP
[2]Programa de Pós-Graduação em Modelagem na Nutrição e Produção de Aves, Departamento de Zootecnia, Unesp/Jaboticabal, Brasil, edney@fcav.unesp.br
[3]Departamento de Zootecnia, Unesp/Jaboticabal, Brasil, sakomura@fcavunesp.br, dorigam@ig.com.br
[4]Departamento de Ciências Exatas, Unesp/Jaboticabal, euclides@fcav.unesp.br, peruzzi@fcav.unesp.br

INTRODUCTION

The integration of factorial models with the growth curves enables to estimate the nutritional requirements of birds dynamically (SAKOMURA *et al.*, 2005; SILVA *et al.*, 2014). Thus, the description of the growth of the animals has become an essential step in the use of these models (SAKOMURA *et al.*, 2005; SILVA *et al.*, 2014). Currently, the relation of weight in function of time can be described by various mathematical functions (Brody, Gompertz, Logistic, Richards, von Bertalanffy), which is difficult to discriminate them using statistical tools, because they have good adjustments (AMANCIO *et al.*, 2014; SOUZA *et al.*, 2010). Among these functions, the most widely used for poultry is the Gompertz function. This function has parameters with biological significance allowing interpretations and practical applications in poultry (SAKOMURA *et al.*, 2005; SILVA *et al.*, 2014).

To take advantage in the applications of the Gompertz function, it is necessary that the parameters faithfully represent the biological events occurring during the growth of the bird. This is because the statistical adjustment can result in coefficients that are not consistent from a biological point of view for the body components such as the weight of protein, lipid, water, and mineral matter. To check the consistency of the parameters, the simple ratio of the weight of the component at maturity (**C*m***) by the body weight at maturity (**W*m***), shows the chemical composition at this age. In some studies, it is observed that the converged parameters accurately describe the data set. However, the C*m*/W*m* ratio of the chemical composition at maturity estimate values that are not consistent with the observed values, especially for lipid content (NEME *et al.*, 2006) and protein content in the body (BUTERI *et al.*, 2009), which are the main body components that determine the energy and nutrient requirements for amino acids. Despite its importance, this hypothesis has not been demonstrated or discussed in the literature and the reasons relating such inconsistencies were not presented. Therefore, the objective of this research was to analyze the adjustment of the Gompertz function, fixing or not some parameters to describe the growth of the body and the main body chemical constituents of growing pullets.

MATERIAL AND METHODS

The database used consists of information of the body weight and chemical composition of feathers and body free of feathers from 1,200 pullets of four laying strains: Hisex Brown (**HB**), Hy Line Brown (**HLB**), Hisex White (**HW**) e Hy Line W-36 White (**HLW**). The data used in this study were obtained from experiments carried out in 2002 in the current Poultry Science Laboratory of the Department of Animal Science of the Faculty of Agricultural and Veterinary Sciences, FCAV-UNESP, Jaboticabal-SP.

The one-day-old chicks of four strains were housed in brooding (1^{st} to 6^{th} week) and rearing cages (7^{th} to 18^{th} week) and distributed into four groups consisting of four evaluated strains (HB, HLB, HW and HLW), with four replications of 75 birds per replication, totaling 300 birds for each strain. The diets were formulated based on corn, soybean meal and wheat bran to meet the minimum requirements of metabolizable energy, crude protein, lysine, methionine+cystine, calcium, phosphorus and sodium, obtained from Rostagno et al. (2000). The birds received the same feeds and were raised in *ad libitum* regimen.

Birds and feed leftovers were weighed weekly to quantify the body weight and feed intake. At this time, two birds per replicate were selected based on average weight for slaughter by cervical dislocation after 24 hours of solid fasting. The feathers were removed from the body (8 per strain) to quantify the weight of feathers and the body without feathers in each age. Samples of the feathers and the body free of feathers were processed and analyzed separately. The moisture analysis, crude protein (**CP**), ether extract (**EE**) and mineral matter (**MM**) were made according to the procedures of AOAC (1990) with replicates.

The variables analyzed were: body weight, weight of body free of feathers, weight of feathers and their chemical components: protein, lipids, water and mineral matter of the body free of feathers and feathers collected weekly. To model the relation of the weight of the variables in function of time, it was used the Gompertz function: the first adjustment (**A1**) was performed without fixing the function parameters, using the equation described by Gous *et al.* (1999):

$$Wt = Wm\, e^{-e^{-B\,(t-t^*)}} \qquad \text{Eq. (1)}$$

Where, W*t* is the weight at age t (kg); W*m* is the weight at maturity (kg); *B* is the parameter of growth rate (day^{-1}); *t** is the inflection point (day); *e* is the Euler number; *t* is the bird age (day).

The second adjustment (**A2**) was carried out by fixing up two parameters of the Gompertz function: Initial weight (**W*i***) and weight at maturity (W*m*) to estimate the parameter *B*. The parameter W*i* was used to describe the growth in the replacement of the parameter *t**, adding the expression $ln(-ln(Wi/Wm))/B$ in the equation 1, according to the description made by Gous *et al.* (1999):

$$Wt=Wm\ e^{-e\ ln\ -ln\ Wi/Wm\ -\ Bt} \quad \text{Eq. (2)}$$

Where *ln* is the natural logarithm; W*i* is the weight in kg at time zero (t = 0) or at birth. The expression –*ln*(W*i*/W*m*) can be replaced by the expression $-ln(u_0)$, where *u* is the maturity rate, expressed by the division of the weight in time t in relation to the weight at maturity (*u* = W*t*/W*m*).

The parameter W*i* was considered the mean body weight of the bird, body free of feathers and feathers obtained at birth. To obtain W*i* of the chemical components, the initial weight, or at birth, of the body free of feathers and feathers were multiplied by their respective content of CP, EE, humidity and MM (g/kg). For example: W*i*×CP; W*i*×EE; W*i*×humidity; W*i*×MM.

The egg production of these strains begins around the 18^{th} week of age. Based on this, the W*m* of the strains considered the mean body weight of the bird, the body free of feathers and feathers obtained at 18 weeks of age. For the W*m* of the chemical components, it was applied an analogous procedure as presented for W*i*. Thus, two reference points were defined in the curve trajectory only to estimate the growth rate.

The adjustments were evaluated by the studentized residuals (R_s), according to the formula described by Lemonte (2008).

$$R_s=t(n\text{-}p\text{-}1/n\text{-}p\text{-}t^2)^{½} \quad \text{Eq. (3)}$$

Where Rs is the studentized residual; *n* is the number of observations and *p* is the number of the parameters in the model. Thus, the residuals satisfy the t-Student distribution with *n*-*p*-1 degrees of freedom. The value of R_s was used to detect the outliers in the estimates, indicating that the model does not describe satisfactorily such observation. Following the recommendation of Lemonte (2008), it was considered an observation marginally aberrant with modular value of $|R_s|>2$.

The growth of the body free of feathers is obtained by adding the growth of four chemical components predicted from linear coefficients using the protein weight of the body free of feathers as reference, according to the procedure described by Martin, Bradford and Gous (1994). The ratios were estimated to satisfy the following equation:

$$dC/dBP = Z\times b\times u^c \quad \text{Eq. (4)}$$

Where, *d*C/*d*BP is the deposition of the component (*d*C) in function of body protein weight (*d*BP); *Z* is the index obtained by the relation between the component at maturity *Cm* and body protein at maturity BP*m* (*Z*=C*m*/BP*m*); C*m* is the weight of the chemical component lipid (**l**), water (**w**) and mineral matter (**mm**) at maturity; *u* is the maturity rate of protein, defined as *u*=BP*t*/BP*m*; *c* is the allometric coefficients in relation to *u*, obtained by considering *b*-1; *b* is the linear coefficient of the allometric relation of the chemical component (C*q*) and body protein weight (BP) obtained by *ln* of C*q* (*ln*C*q*) of water, lipid and mineral matter in function of *ln* of BP (*ln*BP), according to equation 5:

$$lnCq = a + b\ lnBP \quad \text{Eq. (5)}$$

The growth rate of the body free of feathers can be obtained by the sum of the growth rates of the four components, according to Martin, Bradford and Gous (1994).

$$dC/dt = [BPt\times B\times ln(1/u)]\times[1+(Z_w\times b_w\times u^c{}_w) + (Z_l\times b_l\times u^c{}_l)+(Z_{mm}\times b_{mm}\times u^c{}_{mm})] \quad \text{Eq. (6)}$$

Where, *d*C/*dt* is the growth rate of the body free of feathers (kg/day), BP*t* is the body protein at age *t*; *B* is the growth rate; *u* is the degree of maturity, Z_w, Z_l *e* Z_{mm} are the indexes that represents the relation between C*m*/BP*m* for water, lipid and mineral matter, respectively; c_w, c_l and c_{mm} are the allometric coefficients of the relation of *ln* C*q* in function of *ln u*. Thus, the prediction of growth potential and the chemical composition become dependent on the degree of maturity, the relation between the components at maturity, allometric constants, *B* and BP*m*.

The *b* coefficients estimated by Eq. [5] for the four strains were compared using the description of Kaps and Lamberson (2004). The following null hypothesis were tested: the b coefficients are similar for all strains and the alternative hypothesis: the *b* coefficients for one strain differ in relation to other strains. The statistical analysis were performed using the PROC NLIN procedure in the SAS software (SAS - User's guide, 2008).

RESULTS AND DISCUSSION

The results show that the chemical composition of the body free of feathers varied with age. The composition of feathers presented a small variation with age (Table 1). A greater increase in chemical constituents in relation to birth was observed, and after this period, the composition tends to stabilize, according to the chemical constituent (Figure 1A). Other researchers also found that the largest increase occurs in this period and tends to decrease at later ages (MARTIN; BRADFORD; GOUS, 1994).

The smallest increases were observed for concentration of mineral matter and crude protein with an increase of 14.3 and 50.8 g kg, respectively, from birth to 18 weeks of age (Figure 1A). The concentrations of dry matter and water conversely changed during growth, approximately 221.8 g kg in relation to the birth. The concentration of lipid in the body free of feathers increased from 56 g kg at birth to 196 g kg at 18 weeks of age, showing an increase of 140 g kg in this period (Figure 1A). Analyzing the increase of the chemical composition in function of age, it is possible to observe a reduction in the concentration, followed closely by an increase thereof (Figure 1A). For a bird kept in non-limiting conditions, fluctuations observed do not

Figure 1 - Increase on the chemical constituents during the growth phase in relation to the chemical composition at birth. 1A: body free of feathers. 1B: feathers. DM = dry matter, CP = crude protein, EE = ether extract and MM = mineral matter

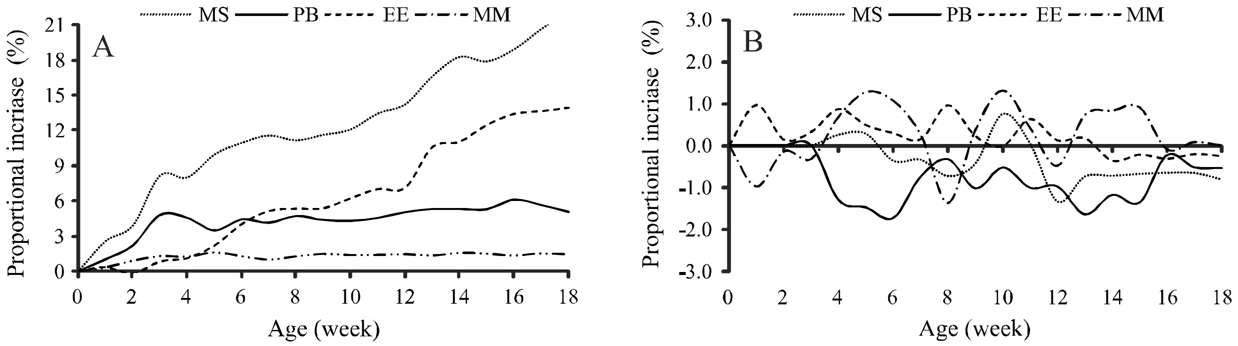


Table 1 - Average values of dry matter (DM), crude protein (CP), ether extract (EE) and mineral matter (MM) of the body free of feathers and feathers at different ages (g/kg)#

Age days	Body free of feathers				Feathers			
	DM	CP	EE	MM	DM	CP	EE	MM
0	241.9	150.0	56.5	25.2	923.1	892.8	9.5	20.9
1	267.5	160.3	59.6	28.5	923.1	892.8	19.2	11.1
2	280.7	172.2	54.2	34.1	923.1	892.8	10.8	19.5
3	323.3	198.2	64.5	38.1	923.1	892.8	12.7	17.6
4	321.6	195.6	67.3	37.5	925.7	879.8	18.2	27.7
5	341.2	185.0	78.0	41.1	926.0	878.1	14.3	33.6
6	351.1	194.4	96.4	37.9	919.5	875.6	12.4	31.5
7	357.3	191.5	107.7	35.1	919.7	885.4	10.9	23.5
8	353.1	197.4	109.5	37.9	915.8	889.5	19.2	17.2
9	357.9	193.9	110.0	39.9	918.8	882.6	11.6	24.6
10	362.4	193.2	118.6	38.9	930.8	887.5	9.2	34.0
11	376.1	195.6	126.4	39.1	923.6	882.7	15.8	25.1
12	383.8	200.7	127.5	39.6	909.7	883.1	10.6	16.0
13	407.6	203.2	162.2	38.5	915.7	876.4	11.2	28.2
14	424.1	203.2	166.8	40.8	915.9	881.1	5.7	29.2
15	420.2	203.1	181.2	40.1	916.4	879.2	7.2	30.0
16	430.5	211.3	190.7	38.5	916.6	890.5	6.2	19.9
17	447.9	206.7	193.0	40.3	916.6	887.6	7.3	21.7
18	463.7	200.8	195.8	39.5	915.0	887.4	6.8	20.8

#Data obtained from Neme (2004); Average values from four laying strains Hy-Line White, Hy-Line Brown, Hisex White, Hisex Brown represent an expected result. Therefore, the fluctuations may be related to the methodology used in the sampling of the chemical composition of birds and can negatively influence the estimation of the equation parameters.

From birth up to 12 weeks, the lipid content of the body free of feathers increased by 70 g/kg and during the last four weeks, there was an increase of 63 g/kg. Thus, the greater deposition of lipid in this phase may be related to the preparation of the bird for reproduction; similar results were found in other studies (KWAKKEL; VERSTEGEN; DUCRO, 1997; SILVA *et al.*, 2013). The chemical composition of feathers shows a slight variation (Figure 1B). It was observed that the increase is less than the variation.

A descriptive analysis of the Gompertz function parameters shown in Table 2 suggest that body weight at maturity (W*m*) within the brown and white birds categories were similar to Hisex and Hy-line strains, as well as the W*i*, *B* and *t** values.

The growth parameters estimated by A1 and A2 adjustments converged to different coefficients; however, they describe the growth of the chemical components of the body free of feathers with similar trajectories. The difference between the parameters estimated by A1 and A2 adjustments can be attributed to the variability of body chemistry. For mineral matter, there were greater similarities between the adjustments (A1 and A2), on the other hand, the largest differences were observed for body lipid.

In general, the value converged for lipid weight at maturity (**L*m***) of the adjustment A1 was 2.7 and 2.4 times greater than the value converged by the adjustment A2 of the Hisex brown and white, respectively. The relation between L*m* and body free of feathers (**BFF**) at maturity (**W*m***) showed that the lipid concentration in the bird's body were 603, 435, 348 and 212 g/kg for HB, HW, HLB and HLW, respectively. Based on the relation between the parameters, converged coefficients for A1 are not consistent from a physiological point of view.

The residual analysis applied to protein weight of the BFF showed that the adjustments were similar (Figure 2). As mentioned, the protein weight suffers less influence of environmental factors and this feature helps to explain the similarity between the A1 and A2 adjustments for most of the evaluated strains (HB, HW and HLB). Analyzing the residuals for W*i* e W*m*, it is observed that the variation around the W*i* is minimal when compared to the variation of W*m*, however, the residuals found for W*m* are within the acceptable range |2|. Therefore, this study shows that fixing both W*i* and W*m* parameters is an sustainable procedure.

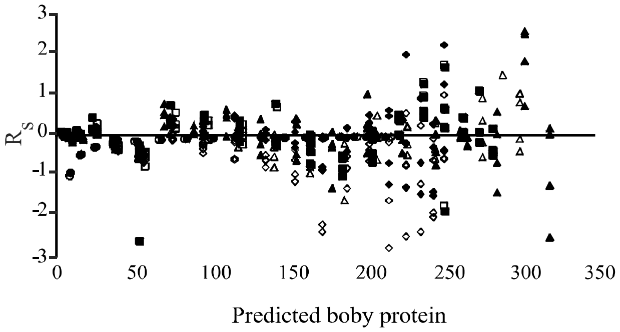
The definition of W*i* and W*m* in the adjustment A2 provided an increase of 24% in the value of the parameter B for HLW in comparison to the adjustment A1. In the first ten weeks of age, the estimates were consistent (R_s<=|2|), and from the 13th week, high residual values (R_s>=|2|) were observed, mainly for adjustment A2. Although the Rs values for HLW were lower for A1, the composition of the protein at maturity calculated (240 g/kg CP) was not consistent with the analyzed values (Table 2). This result clearly demonstrates that the traditional procedure (A1) tends to fit better when there is variability in the sampling, on the other hand, the biological interpretation of the Gompertz function parameters become limited or inadequate.

Table 2 - Estimate of the parameters that describe the growth of the body free of feathers of four genotypes of pullets

Parameters	Hisex Brown		Hy-Line Brown		Hisex White		Hy-Line White	
Wi	27.4		26.7		29.6		26.9	
Wm	1765.2		1770.0		1346.2		1261.0	
B	0.0238		0.0238		0.0241		0.0263	
t*	59.9		60.3		55.5		51.2	
Confidence interval, considering α = 95%								
	Limits		Limits		Limits		Limits	
	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
Wi	19.8	35.0	18.7	34.7	21.6	37.5	18.3	35.5
Wm	1681.2	1849.2	1680.0	1860.0	1282.2	1410.2	1203.0	1319.0
B	0.0220	0.0256	0.0220	0.0256	0.0223	0.0259	0.0239	0.0287
t*	57.4	62.4	57.5	63.1	52.9	58.0	48.8	53.6

W*i*, initial weight; W*m*, weight at maturity; *B*, maturity rate, *t**, inflection point

Figure 2 - Studentized residuals (R_s) predicted by two adjustments (A1 and A2) for protein weight during the growth phase of laying pullets

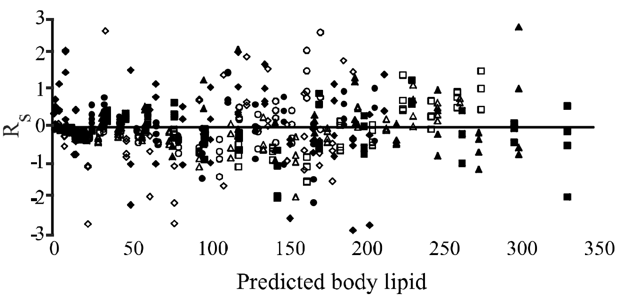


A1 Hisex white ●; A2 Hisex white o; A1 Hisex brown ■; A2 Hisex brown □; A1 Hy-Line white; ▲A1 Hy-Line brown; ΔA2 Hy-Line brown; ♦ A1 Hy-Line white; ◊A2 Hy-Line white

Unlike the protein, the body lipid not only reflects the genetic potential, but also the environmental conditions, especially dietary factors. Due to these factors, it was expected a greater deviation from the prediction in relation to the observed data (Figure 3). In general, the predictions by A1 and A2 adjustments were similar in the 14^{th} week of age; after that age, the Rs values increased for most of the evaluated strains, especially for the A2 adjustment at 18 weeks. However, the converged coefficients for A1 suggests that the lipid content of the body free of feathers may reach 600 g/kg and therefore does not reflect the body composition, being inappropriate for interpretation.

The differences between the A1 and A2 adjustments were due to variability in the observations that can be attributed to the methodology employed in the sampling by the comparative slaughter technique. The birds sampled for the growth and body composition studies in each week are not the same and represent the body condition of the group at the time of slaughter, being a punctual growth response. Sampling of body composition was taken in different individuals and the inherent variation in each sample group may have contributed to the emergence of influential points in the adjusted models. These results confirm the hypothesis that the parameters converged by the traditional adjustment do not estimate consistent values of the compositions at maturity, despite of the good description of the data analyzed. Based on the A2 adjustment, a possible way to avoid this problem would be to use of two samplings. A specific sample for the study of the body growth from birth to maturity and other sampling for obtaining the body composition, from birth to maturity. Thus, the body growth and its constituents tend to be more homogeneous with advancing age. However, an alternative solution is the analysis of the same individual in time, using non-destructive methods to collect body composition information from the same individual over time. Thus, it would be possible to obtain statistical precision and biological interpretation. On the other hand, it is known that non-destructive methods have high cost and their use is prioritized for humans.

Figure 3 - Studentized residuals (R_s) predicted by two adjustments (A1 and A2) for lipid weight during the growth phase of laying pullets



A1 Hisex white ●; A2 Hisex white o; A1 Hisex brown ■; A2 Hisex brown □; A1 Hy-Line white; ▲A1 Hy-Line brown; ΔA2 Hy-Line brown; ♦ A1 Hy-Line white; ◊A2 Hy-Line white

In Table 4, the estimates of the parameters that describe the growth of four strains feathers are presented. Protein and water are the main constituents of the feather. A small variation was observed in the composition of feathers, as already mentioned. The parameters estimated for maturity rate of the feathers suggest that feather growth is faster in brown strains in relation to the growth of body free of feathers, justifying the separation between BFF and feathers. The adjustments A1 and A2 were similar in the estimates of the parameters that describe the growth of protein and water in the body. Only one difference was recorded for the maturity rate of feather protein (B), estimated by the adjustment A1 for Hisex brown, possibly by the low Wi converged.

The other constituents, lipid and mineral matter, have low concentration in feathers and estimates of Wi, B and Wm differed considerably between the adjustments within each genotype and between genotypes, especially for mineral matter in the feathers. Concentrations found for mineral matter content at maturity were lower than those determined by Martin, Bradford e Gous (1994) of 70.3 and 91.6 g/kg for Wi and Wm, respectively. The difficulty in the parameter adjustment can be attributed to the variability displayed (Figure 1).

The percentage of feathers at maturity was 8 and 10% for white and brown birds, regardless of strain; 9 and

10% for Hisex and Hy line strains, regardless of whether white or brown. Overall, at the maturity of these birds, the protein of the feathers corresponds to approximately 31% of total protein (protein in feathers/protein in BFF+feathers × 100). Based on values of the adjusted *B* parameter for body weight (Table 2) and protein weight of BFF (Table 3), it was observed that the feather weight and protein in feathers grow at a faster rate than the body and protein of the BFF in approximately 1.22 and 1.13 times, respectively. Similar results were found in other researches (GOUS *et al*., 1999; SAKOMURA *et al*., 2005).

The use of allometric equations allows some generalizations that simplify the calculations and, when integrated with the Gompertz function enables to calculate the weight gain (MARTIN; BRADFORD; GOUS, 1994). Generalizations must be sustained by theoretical concepts already described (EMMANS, 1981; EMMANS;

Table 3 - Estimate of the parameters that describe the growth of the body free of feathers of four genotypes of pullets

Parameters	Unit	Hisex Brown		Hisex White		Hy-Line Brown		Hy-Line White	
		A1	A2	A1	A2	A1	A2	A1	A2
Crude Protein, CP									
CciCP	g kg	109.5	150.0	158.8	150.0	228.5	150.0	226.8	150.0
CcmCP	g kg	184.7	186.6	179.3	184.5	255.4	206	243.9	225.2
Wi	g	3.0	4.1	4.7	4.4	6.1	4.0	6.1	4.0
Wm	g	326.0	329.4	241.4	248.4	452.0	364.6	307.6	284.0
B	day^{-1}	0.0273	0.0262	0.0269	0.0264	0.0198	0.0246	0.0222	0.0276
t*	day	57	57	51	63	74	77	62	58
Lipid, L									
CciL	g kg	113.1	56.5	84.5	56.5	56.2	56.5	26.0	56.5
CcmL	g kg	603.7	220.6	435.3	175.8	348.0	207.9	212.7	179
Wi	g	3.1	1.5	2.5	1.7	1.5	1.5	0.7	1.5
Wm	g	1065.6	389.4	586	236.7	616	368.0	268.2	225.7
B	day^{-1}	0.0128	0.0221	0.0132	0.0219	0.0169	0.0222	0.0261	0.0278
t*	day	138	79	129	75	106	79	68	60
Water, W									
CciW	g kg	554.7	758.1	500.0	758.1	430.7	758.1	382.9	758.1
CcmW	g kg	513.3	556.6	532.1	572.9	470.1	526	475.0	480.3
Wi	g	15.2	20.8	14.8	22.4	11.5	20.2	10.3	20.4
Wm	g	906	982.5	716.3	771.2	832	931.0	599	605.7
B	day^{-1}	0.0277	0.0245	0.0289	0.0252	0.031	0.0257	0.0351	0.316
t*	day	51	55	47	50	47	52	40	40
Mineral matter, MM									
CciMM	g kg	25.2	27.4	33.1	29.5	30.7	28	37.5	16
CcmMM	g kg	36.3	38.4	36.7	38.9	42.8	41.2	44.3	39.3
Wi	g	0.7	0.8	0.98	0.9	0.82	0.7	1.0	0.4
Wm	g	64	67.8	49.4	52.4	75.7	72.9	55.8	49.6
B	day^{-1}	0.0273	0.0256	0.0263	0.0245	0.0232	0.0244	0.0231	0.0284
t*	day	55	58	52	56	65	63	60	55

A1, adjustment 1; A2, adjustment 2; Cci, concentration at birth or initial; Ccm, concentration at maturity; i, initial or at birth; m, maturity. Cci and CCm of the adjustment A1 were obtained by calculation, Cci = weight estimated by the initial constituent/initial weight of BFF (Table 2), Ccm = weight estimated of the constituent at maturity/weight of BFF at maturity (Table 2). Cci and CCm of the adjustment A2 represent the chemical composition analyzed; Wi, initial weight; Wm, maturity weight; B, maturity rate, t*, inflection point

KYRIAZAKIS, 1995; MARTIN; BRADFORD; GOUS, 1994) and, therefore, the parameters of the Gompertz function should meet this assumption.

In Table 5, the values of *b* and *Z* for water, lipid and mineral matter of the strains evaluated are presented. The coefficient *b*, or *c* (*b*-1), informs the

Table 4 - Estimate of the parameters that describe the growth of feathers of four genotypes of pullets

Parameters	Unit	Hisex Brown		Hisex White		Hy-Line Brown		Hy-Line White	
		A1	A2	A1	A2	A1	A2	A1	A2
Feathers									
Wi	g	1.2		1.2		1.8		1.6	
Wm	g	160.3		141.6		176.5		151.7	
B	day^{-1}	0.0294		0.0282		0.0269		0.0227	
t*	day	55		55		57		54	
Crude protein, CP									
CciCP	g kg	25.0	902.7	833.3	894.8	888.9	898.6	875.0	874.9
CcmCP	g kg	885.8	895.1	889.8	875	866.9	880.5	952.5	899
Wi	g	0.03	1.1	1.0	1.1	1.6	1.6	1.4	1.4
Wm	g	142.0	143.5	126.0	123.9	153.0	155.4	144.5	136.4
B	day^{-1}	0.0325	0.0290	0.0285	0.0290	0.0271	0.0271	0.0277	0.0277
t*	day	56	56	55	52	56	56	54	54
Lipid, L									
CciL	g kg	8.3	7.2	0.0	9.4	1.1	8.4	0.0	12.7
CcmL	g kg	0.6	6.7	6.4	6.8	6.8	7	8.6	6.7
Wi	g	0.01	0.01	0.00	0.01	0.00	0.02	0.00	0.02
Wm	g	0.1	1.1	0.9	1.0	1.2	1.2	1.3	1.0
B	day^{-1}	0.0747	0.0747	0.0924	0.0483	0.0676	0.0676	0.0676	0.0419
t*	day	35	35	31	30	38	38	39	36
Water, A									
CciW	g kg	0.0	74.6	141.7	74.5	27.8	78.1	75.0	80.2
CcmW	g kg	81.1	88.0	101.0	86.4	82.2	84.1	101.5	81.5
Wi	g	0.0	0.1	0.2	0.1	0.1	0.1	0.1	0.1
Wm	g	13.0	14.1	14.3	12.2	14.5	14.8	15.4	12.4
B	day^{-1}	0.0405	0.0405	0.0219	0.0262	0.0295	0.0253	0.0257	0.032
t*	day	54	54	68	59	59	62	58	51
Mineral matter, MM									
CciMM	g kg	16.7	15.4	0.0	21.2	16.7	15.0	0.0	32.1
CcmMM	g kg	29.3	10.2	14.8	31.9	31.2	28.0	30.3	12.8
Wi	g	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Wm	g	4.7	1.6	2.1	4.5	5.5	4.9	4.6	1.9
B	day^{-1}	0.0254	0.0608	0.0590	0.0191	0.0621	0.0621	0.0432	0.0569
t*	day	66	33	41	79	64	64	56	29

A1, adjustment 1; A2, adjustment 2; Cci, concentration at birth or initial; Ccm, concentration at maturity; i, initial or at birth; m, maturity. Cci and CCm of the adjustment A1 were obtained by calculation, Cci = weight estimated by the initial constituent/initial weight of BFF (Table 2), Ccm = weight estimated of the constituent at maturity/weight of BFF at maturity (Table 2). Cci and CCm of the adjustment A2 represent the chemical composition analyzed; W*i*, initial weight; W*m*, maturity weight; *B*, maturity rate, *t**, inflection point

Table 5 - Allometric parameters adjusted for growth of the body free of feathers of four strains of laying pullets

Parameters	Hisex Brown	Hisex White	Hy-Line Brown	Hy-Line White
		Lipid		
Z1	1.182	0.953	1.011	0.795
B2	1.282	1.277	1.275	1.277
C3	0.282	0.277	0.275	0.277
		Water		
Z	2.983	3.105	2.553	2.133
B	0.862	0.885	0.849	0.835
C	-0.138	-0.115	-0.151	-0.1646
		Mineral matter		
Z	0.206	0.211	0.200	0.175
B	1.010	1.017	1.001	1.066
C	0.010	0.017	0.001	0.066

[1]*Z* = index obtained by the relation between component at maturity *Cm* and body protein at maturity BP*m* (*Z*=C*m*/BP*m*); [2]*B* = parameter of rate (day^{-1}); [3]*C* = Allometric coefficients for water, lipid and mineral matter

growth rate of the chemical components depending on body protein (*b*) of the *ln* of *u* (*c*). For *c* values close to zero, it means that growth was proportional to body protein; *c* (+) represents a later growth and when *c* (-) is an early growth. Therefore, the mineral matter and body protein increased at similar rates. The water increased at higher rate than the protein, whereas the body lipid grown later.

The parallelism analysis performed among strains revealed similarity between the values of *b*, so a single linear equation explains the relation between the *ln* of lipid and *ln* of protein (*ln*Lipid = *-1.7777 ± 0.1007 + 1.2817 ± 0.0218* × lnProtein, $R^2 = 0.977$). Thus, a single *b* or *c* is sufficient to describe the growth rate of the components of the strains evaluated. The overall value of *c* was estimated at 0.2817. It was expected a variation between genotypes considering the values obtained for *b* and *c*, but the variation observed was similar to other components. These results are supported by other findings in the literature (MARTIN; BRADFORD; GOUS, 1994).

There are few studies published in the literature with this methodology. For water, the reduction with increasing protein weight can be attributed to the increased lipid ratio in the body (GOUS *et al.*, 1999). Two equation were necessary to describe the relation between *ln* of water and *ln* of protein, being one specific for the Hy-Line strain (*ln*Water = *1.8744 ± 0.0434 + 0.83554 ± 0.0094* × *ln*Protein, $R^2 = 0.987$) and another for Hisex (*ln*Water = *1.8218 ± 0.0398 + 0.8623 ± 0.0086* × *ln*Protein, $R^2 = 0.991$).

For mineral matter, two equation also were needed to explain the logarithmic relation (*ln*) between mineral matter and protein, one for Hy-Line (*ln*Mineral matter = *-2.004 ± 0.0652 + 1.0662 ± 0.0145* × *ln*Protein, $R^2 = 0.987$) and another for Hisex (*ln*Mineral matter = *-1.6486 ± 0.05187 + 1.0083 ± 0.01125* × *ln*Protein, $R^2 = 0.990$). These results indicate that the Hy-Line strain has a different growth pattern in comparison to other strains. For mineral matter, there seems to be controversy values for *c* (*b*-1). The coefficients determined were positives, as well as those from Kwakkel, Verstegen and Ducro (1997) and Zelenka *et al.* (2011). However, the coefficients presented by Marcato *et al.* (2008) and Rivera-Torres, Noblet and Van Milgen (2011) were negatives and, thus, presenting an inverse behavior to that observed in this study. At the moment, there is still no clear explanation in the literature for this divergence.

For the Z index of the lipid, a difference in the values between genotypes was expected. The values found by Martin, Bradford and Gous (1994) for different strains of pullets also have a similar degree of body lipid. The B values of Gompertz function for water and mineral matter showed that water and mineral matter are the chemical components of highest growth rate, and thus, reach maturity earlier than the other components (Table 3). Despite the differences in the *Wm* of these components for the evaluated strains (Table 3), the values obtained for Z_w (2.9) and Z_{mm} (0.2) shown in Table 5, were similar to those coefficients suggested for all species and because of this similarity, they may be considered almost constant (EMMANS; KYRIAZAKIS, 1995) and can be generalized.

CONCLUSION

The adjustment of the model, fixing the parameters, enables consistency with biological significance without losing precision in the estimates.

REFERENCES

AMANCIO, A. L. L. *et al.* Use of mathematical models in the study of bodily growth in GIFT strain Nile tilapia. **Revista Ciência Agronômica**, v. 45, n. 2, p. 257-266, 2014. Disponivel em: <http://www.ccarevista.ufc.br/seer/index.php/ccarevista/article/view/2925/958>. Acesso em: 12 fev. 2014.

ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS. **Official methods of analysis**. Washington, D.C: AOAC, 1990. 1141 p.

BUTERI, C. *et al*. Effects of different nutritional plans on broiler performance. **Revista Brasileira de Ciência Avícola**, v. 11, n. 4, p. 225-234, 2009. Disponivel em: <http://dx.doi.org/10.1590/S1516-635X2009000400003>. Acesso em: 22 mar. 2011.

EMMANS, G. C. A model of the growth and feed intake of ad libitum fed animals, particularly poultry. *In*: HILLYER, G. M.; WHITTEMORE, C. T.; GUNN, R. G. (Ed.). COMPUTERS IN ANIMAL PRODUCTION, 1981, Edinburgh. **Proceedings...** Edinburgh: British Society of Animal Production, 1981. p.106-110.

EMMANS, G. C.; KYRIAZAKIS, I. A general method for predicting the weight of water in the empty bodies of pigs. **Animal Science**, v. 61, n. 1, p. 103-108, 1995. Disponivel em: <http://dx.doi.org/doi:10.1017/S1357729800013576>. Acesso em: 13 mar. 2013.

GOUS, R. M. *et al.* Evaluation of the parameters needed to describe the overall growth, the chemical growth, and the growth of feathers and breast muscles of broilers. **Poultry Science**, v. 78, n. 6, p. 812-821, 1999. Disponivel em: <http://dx.doi.org/10.1093/ps/78.6.812>. Acesso em: 5 mar. 2011.

KAPS, A. M.; LAMBERSON, W. R. **Biostatistics for Animal Science**. London: CABI Publishing, 2004. 445 p.

KWAKKEL, R.; VERSTEGEN, M.; DUCRO, B. Diphasic allometric growth of body components in white Leghorn pullets fed ad libitum and restricted diets. **Poultry Science**, v. 76, n. 7, p. 1020-1028, 1997. Disponivel em: <http://dx.doi.org/10.1093/ps/76.7.1020>. Acesso em: 10 mar. 2011.

LEMONTE, A. J. Diagnóstico em regressão normal linear: princípios e aplicação. **Revista Brasileira de Biometria**, v. 26, n. 2, p. 7-26, 2008. Disponivel em: <http://jaguar.fcav.unesp.br/RME/fasciculos/v26/v26_n2/A1_Artur.pdf>. Acesso em: 8 mar. 2011.

MARCATO, S. *et al.* Growth and body nutrient deposition of two broiler commercial genetic lines. **Revista Brasileira de Ciência Avícola**, v. 10, p. 117-123, 2008. Disponivel em: <http://dx.doi.org/10.1590/S1516-635X2008000200007>. Acesso em: 8 mar. 2011.

MARTIN, P. A.; BRADFORD, G. D.; GOUS, R. M. A formal method of determining the dietary amino acid requirements of laying-type pullets during their growing period. **British Poultry Science**, v. 35, n. 5, p. 709-724, 1994. Disponivel em: <http://dx.doi.org/10.1080/00071669408417737>. Acesso em: 8 mar. 2010.

NEME, R. **Estimativa das exigências energéticas e curvas de desenvolvimento e composição corporal de linhagens de postura na fase de crescimento**. 2004. 104 f. Tese (Doutorado em Zootecnica) - Faculdade de Ciências Agrárias e Veterinárias, Universidade Estadual Paulista, Jaboticabal, 2004.

NEME, R. *et al.* Curvas de crescimento e de deposição dos componentes corporais em aves de postura de diferentes linhagens. **Revista Brasileira de Zootecnia**, v. 35, p. 1091-1100, 2006. Disponivel em: <http://dx.doi.org/10.1590/S1516-35982006000400021>. Acesso em: 12 mar. 2010.

RIVERA-TORRES, V.; NOBLET, J.; VAN MILGEN, J. Changes in chemical composition in male turkeys during growth. **Poultry Science**, v. 90, n. 1, p. 68-74, 2011. Disponivel em: <http://dx.doi.org/10.3382/ps.2010-00633>. Acesso em: 4 abril 2011.

ROSTAGNO, H. S. *et al.* **Tabelas brasileiras para aves e suínos**: composição de alimentos e exigências nutricionais. Viçosa, MG: UFV, 2000. 141 p.

SAKOMURA, N. K. *et al.* Modeling energy utilization and growth parameter description for broiler chickens. **Poultry Science**, v. 84, n. 9, p. 1363–1369, 2005. Disponivel em <http://dx.doi.org/10.1093/ps/84.9.1363>. Acesso em: 12 mar. 2011.

SILVA E. P. *et al.* A model to estimate the amino acid requirements for growth and sexual development in laying pullets. *In*: INTERNATIONAL SYMPOSIUM: MODELLING IN PIG AND POULTRY PRODUCTION, 2013, Jaboticabal. **Proceedings...** Jaboticabal: Funep, 2013. p.1-14.

SILVA E. P. *et al.* A procedure to evaluate the efficiency of utilization of dietary amino acid for poultry. **Acta Scientiarum. Animal Sciences**, v. 36, n. 2, p. 163-169, 2014.

SOUZA, L. A. *et al.* Curvas de crescimento em bovinos da raça Indubrasil criados no Estado do Sergipe. **Revista Ciência Agronômica**, v. 41, n. 4, p. 671-676, 2010. Disponivel em: <http://www.ccarevista.ufc.br/seer/index.php/ccarevista/article/view/457/494>. Acesso em: 6 fev. 2014.

ZELENKA, J. *et al.* Allometric growth of protein, amino acids, fat and minerals in slow- and fast-growing young chickens. **Czech Journal of Animal Science,** v. 56, n. 3, p. 127-135, 2011. Disponivel em: <http://www.agriculturejournals.cz/publicFiles/36762.pdf>. Acesso em: 20 set. 2011.