

Allometric coefficients of major chemical components of meat quail raised in different thermal environments

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ABSTRACT The objective of the present study was to estimate and compare allometric coefficients of the major chemical components of meat quail raised in different thermal environments, based on protein weight of feather free body (FFB) and feathers. In total, 300 meat quail, males and females, were distributed in a completely randomized design with 2 treatments (climatized environment, 26°C, and non-climatized environment, 29°C) and 6 replicates of 25 birds each. On the first day, 36 birds were selected to form the reference group and from this day on, 2 quail were weekly sampled from each cage. All selected birds were fasted for 24 h, weighed, slaughtered, plucked, and reweighed. The FFB and feathers were ground separately to obtain homogeneous samples, which were freeze-dried to determine the water content, and thereafter, ground again in a micromill before analyzing for protein, lipid, and ash using AOAC procedures. The adjustment of the allometric equations was made using crude protein (CP)

weight as the independent variable and water, lipid, and ash weight as the dependent variables. The data of each dependent variable were transformed into natural logarithm (ln), regressed according to lnCP, and subjected to a parallelism test. In the FFB, water showed early development and lipid and ash showed late development in relation to the CP weight. In feathers, water and ash weight showed early development in relation to the feathers protein weight, whereas lipids showed late development. The environments of 26°C and 29°C did not affect the allometric coefficients that described the growth between the chemical components in the body and in the feathers, except for lipids in male FFB, that showed higher allometric coefficient at 29°C than 26°C. Describing the allometric relationships between the major chemical components of meat quail body is an important step in supporting future research comprised modeling of body growth and nutrition for meat quail.

Key words: allometric growth, chemical component, meat quail, thermal environment

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INTRODUCTION

Modeling has been invaluable for the broiler industry through the years. Studies have described the growth parameters of poultry, such as body weight, physical components, or chemical composition (Goliomytis et al., 2003; Sakomura et al., 2011; Gous, 2014; Caldas et al., 2019), which are extremely useful for research in genetic and nutrition of the current poultry.

Poultry growth is generally described using the Gompertz equation (1825). Wilson (1977) reported that differences between broiler genotypes could be more distinguishable by means of growth curve evaluations than by weight measurements at a single time point. However, growth functions have certain drawbacks such as

requirements of suitable conditions for measuring the potential growth (Emmans, 1995, 1997), which may be affected by factors such as genetics, nutrition, and environment.

In addition to using growth curves to describe the potential growth, allometric relationships that exist between important body parts has been a significant tool for poultry industry. An allometric relationship means that the weight of one body part can be explained as a simple function of weight of another body part. The consumer preference for select portions such as thighs, drumsticks, wings, and mainly breast has led to studies about relationships between carcass parts and body weight in broilers as the independent variable (Goliomytis et al., 2003; Danisman and Gous, 2008; Fisher and Gous, 2008; Marcato et al., 2008; Schmidt et al., 2009). However, it is preferable to estimate the protein content of the whole carcass and use it as the independent variable for describing allometric relationships between body components (Danisman and Gous, 2008, 2011; Sakomura et al., 2011).

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The reason for using protein weight rather than body weight is that body lipid content, lipids being the excess energy reserves, varies with different feeds and in different environments (Sakomura et al., 2011). Allometric models using body protein weight can be used to predict the growth of any scaled components of the body, as any components parts that share the same rate of maturing (Danisman and Gous, 2008, 2011).

Although this method has been used in broilers, little data are available on quail. Quail meat has gained considerable popularity among consumers and farmers owing to benefits of quail meat and great performance of these birds (Aminzade et al., 2012; Tavaniello et al., 2014; Abou-Kassem et al., 2019).

There is a relationship between husbandry practices, carcass chemical composition, and meat quality. Body chemical composition can be modified by factors intrinsic and extrinsic to the animal, which makes the description of major chemical components of the body in different conditions challenging. The use of allometric regressions simplifies the prediction of the effects of feed and environment on the weights of chemical and physical components of the body, in that only protein growth in body and feather need to be simulated and not each component individually (Emmans and Fisher, 1986).

In view of the lack of information about the relationship between the chemical components and body protein weight in quail and the importance of allometry for factors such as feeding program and choice of suitable slaughter age, the objective of this study was to estimate and compare the allometric coefficients of the body major chemical components against body protein weight in male and female meat quail raised in different thermal environments.

MATERIALS AND METHODS

The experiment was conducted at the Center of Agrarian and Environmental Sciences of the Federal University of Maranhão, located in the municipality of Chapadinha, Maranhão (03°44'30"S and 43°21'33"W), Brazil, with an average altitude of 105 m. According to the climatic classification of Köppen, the climate of the region falls into the type Aw, a tropical zone with dry winters (Alvares et al., 2013). The ethics committee of the Federal University of Maranhão has approved all procedures on animal use (record 23115.002714/2014–74).

Birds, Housing, Experimental Design, and Husbandry

In total, 300 one-day-old meat quail (*Coturnix coturnix*) (not sexed) with initial body weight of 9.26 ± 1.25 g were used in the trial.

The birds were housed in cages (0.85 m × 0.85 m) located in 2 masonry rooms (5.0 m × 7.7 m) with

Table 1. Ingredients and nutrient composition of the 2 feeds used in the experiment.

Ingredient (g/kg)	1 to 21 D	22 to 42 D
Corn	520.05	605.77
Soybean meal	434.66	360.19
Soybean oil	0.00	9.20
Dicalcium phosphate	11.85	9.52
Limestone	10.09	8.26
Salt	3.79	3.25
DL-Methionine (98%)	3.44	1.61
L-Threonine (98%)	1.93	0.10
L-Lysine HCl (78,5%)	0.25	0.00
Vitamin supplementation ¹	1.00	1.00
Mineral supplementation ²	0.50	0.50
Choline chloride (60%)	0.60	0.60
Inert (washed sand)	11.87	0.00
Nutritional composition		
ME (kcal/kg)	2,950	3,100
CP (g/kg)	250	220
Calcium (g/kg)	8.5	7.0
Available phosphorous (g/kg)	3.2	2.7
Sodium (g/kg)	1.7	1.5
Digestible methionine + cystine (g/kg)	10.4	8.0
Digestible methionine (g/kg)	6.7	4.8
Digestible lysine (g/kg)	13.7	11.8
Digestible threonine (g/kg)	10.4	7.8

¹Vitamin supplementation (composition/kg of feed): vitamin A, 12,000,000 IU; vitamin D3, 3,600,000 IU; vitamin E, 3,500 IU; vitamin B1, 2,500 mg; vitamin B2, 8,000 mg; vitamin B6, 5,000 mg; pantothenic acid, 12,000 mg; Biotin, 200 mg; vitamin K, 3,000 mg; folic acid, 1,500 mg; nicotinic acid, 40,000 mg; vitamin B12, 20,000 mg; Se, 150 mg; vehicle q.s.p.

²Mineral supplementation (composition/kg of feed): Mn, 160 g; Fe, 100 g; Zn, 100 g; Cu, 20 g; Co, 2 g; I, 2 g; vehicle q.s.p.

side windows, 6 cages per room. One of the rooms had air conditioning (Electrolux Ecoturbo 24000 BTU/h, Curitiba, PR, Brazil) used for climate control of the environment and the other one had no air conditioning for maintaining the actual temperature of the environment. The birds were subjected to 24 h of light per day (continuous light).

On the first day, the birds were randomly distributed and until 14 days old, were reared under the same management and suitable environmental conditions (between 32°C and 35°C), using incandescent lamps of 60 W for artificial heating of quail. At day 14, the quail were subjected to the 2 treatments (climate control environment with 26°C and no climate control environment with 29°C). A completely randomized design was used with 2 treatments (climatized and no climatized environment) and 6 replicates of 25 quail each, in a total of 12 experimental units.

Environmental temperature and relative humidity in the rooms where the birds were housed were measured daily (at 7 am, 12 pm, and 6 pm) throughout the whole trial using a thermohygrometer (MT-241, Minipa Brazil Ltd., Joinville, SC, Brazil) located at the geometric center of the rooms.

The birds were fed with 2 corn-soya diets during the trial: feed 1 (from 1 to 21 D of age) and feed 2 (from 22 to 42 D of age), formulated according to the recommendations of the Tables for Japanese and European Quail (Silva and Costa, 2009) (Table 1). During the

experimental period, birds had free access to water and feed.

Data Collection

On the first day, 36 birds were selected to form the reference group. From this day on, 2 birds from each cage were randomly sampled weekly; they were fasted for 24 h to allow complete emptying of the gastrointestinal tract, weighed to determine the fasted body weight (**FBW**), and slaughtered by cervical dislocation. Subsequently, the quail were plucked and weighed once again to estimate the feather weight by calculating the difference between body weight before and after plucking. The same procedure was followed for the reference group birds. Seven slaughters were carried out with a total of 180 birds slaughtered (95 males and 85 females).

Up to 21 d of age, when sexual dimorphism was not yet evident, the birds were eviscerated for sex identification on the basis of the presence or absence of testicles. The plucked birds and their feathers were placed in a plastic bag, identified, and frozen at -20°C . The plucked body of each bird was ground in an industrial meat grinder (98 STI model—C.A.F., Sao Paulo, SP, Brazil) to obtain homogeneous samples, which were freeze-dried (L108, Liotop, Sao Carlos, SP, Brazil) at -50°C for 72 h to determine the water content, and thereafter, ground again in the micromill (IKa A11 Basic, Ika Works Brazil Ltd., Taquara, RJ, Brazil). Feather samples were cut into small pieces manually with scissors until homogeneous samples were obtained.

Dried samples of carcass and feather were analyzed for crude protein (**CP**) by the Kjeldahl method (954.01), lipids (method 920.39), and ash (method 942.05), according to the AOAC (1995) procedures.

The weekly weights of water, protein, lipid, and ash of the plucked body and feathers were obtained by multiplying the concentration of the each chemical component in the sample with their respective weights.

Statistical Analysis

The equation used to describe the protein weight of feather free body (**FFB**) and feathers weight was that of Gompertz (1825) which has the following form:

$$W_t = W_m \cdot \exp \{ -\exp [-B(t - t^*)] \}$$

where W_t (g) the protein weight of FFB or feather weight at time t ; W_m (g) the mature protein weight of FFB or feather weight; B (d^{-1}) the rate of maturing parameter; and t^* (d) the time at which the growth rate is at its maximum.

To verify the effect of the environment on the growth of protein weights of FFB and feather weight, the estimated growth curves were compared for each sex

using the F statistical test according to Motulsky and Ransnas (1987):

$$F = (SS_{\text{pool}} - SS_{\text{sep}}) / (df_{\text{pool}} - df_{\text{sep}}) / (SS_{\text{sep}} / df_{\text{sep}}),$$

where SS_{pool} and df_{pool} correspond, respectively, to the sum of squares and degrees of freedom of the error of Gompertz equation adjusted for the data set ignoring the environment effect. SS_{sep} and df_{sep} correspond, respectively, to the sum of squares and degrees of freedom of the equations adjusted for each environment $SS_{\text{sep}} = SS_{\text{climatized}} + SS_{\text{no climatized}}$; $df_{\text{sep}} = df_{\text{climatized}} + df_{\text{no climatized}}$.

The F statistic was used to test the following hypothesis:

$$H_0 : P_{m_{\text{clim.}}} = P_{m_{\text{no clim.}}} = P_m, B_{\text{clim.}} =$$

$$B_{\text{no clim.}} = B, t^{*\text{clim.}} = t^{*\text{no clim.}} = t^*$$

H_a : At least one of the equality is a difference.

A large F-value (corresponding low P -value) indicated that the separate fit explained variation in the data more appropriately than the pooled fit. Thus, where $P < 0.05$ the hypothesis that the curves for the 2 environments were equal was rejected, and growth curves were reported as different, or having shifted.

For the adjustment of allometric equations, the data of each dependent variable (water, lipid, and ash) in each environment were transformed into natural logarithm ($\log_e = \ln$) and regressed as a function of $\ln\text{CP}$.

Then, linear equations $\ln Y = a + b \cdot \ln X$ were adjusted. The allometric coefficients of chemical components of the birds raised in different environments were compared by performing parallelism tests using environment as a categorical variable and $\ln\text{CP}$ as a covariate, according to the following model described by Kaps and Lamberson (2004): $Y_{ij} = \beta_0 + A_i + \beta_1 \cdot \ln\text{CP}_{ij} + \sum_i \beta_{2i} (A \cdot \ln\text{CP})_{ij} + \epsilon_{ij}$, where Y_{ij} is the natural logarithm (\ln) of the chemical component (water, lipid, or ash) corresponding to observation j of environment i ; A_i is the effect of the environment; β_0 , β_1 , and β_{2i} are the parameters of regression; $(A \cdot \ln\text{CP})_{ij}$ is the effect of the interaction between the categorical variable and covariate; and ϵ_{ij} is the random error associated with observation j of environment i .

In this case, the hypotheses tested were:

a) H_0 : $A_i = 0$ for all i , there is no effect of the environment.

H_1 : $A_i \neq 0$ for at least one i ; there is an environmental effect.

b) H_0 : $\beta_1 = 0$; the general slope is equal to zero; there is no regression.

H_1 : $\beta_1 \neq 0$; the general slope differs from zero; there is a regression.

Table 2. Body composition of male meat quail from 1 to 42 D of age under climate control environment (26°C) and no climate control environment (29°C).

Treatments	Age (d)													
	1		7		14		21		28		35		42	
	26°C	29°C	26°C	29°C	26°C	29°C	26°C	29°C	26°C	29°C	26°C	29°C	26°C	29°C
FBW ¹ (g/bird)	9.12	9.12	26.8	26.8	62.7	62.7	133.1	130.8	140.9	160.4	172.5	197.1	201.5	229.7
FBW (g/kg)														
Carcass	957	957	940	940	917	917	894	908	910	921	939	943	949	952
Feathers	43	43	60	60	83	83	106	92	90	79	61	57	51	48
FFB ² (g/kg)														
Water	788	788	769	769	733	733	711	717	704	678	685	654	685	619
Ash	22	22	25	25	31	31	35	36	37	33	33	32	34	34
Protein	149	149	173	173	183	183	191	189	200	196	205	188	194	185
Lipid	42	42	34	34	54	54	63	58	59	94	77	127	86	162
Feathers (g/kg)														
Water	101	101	109	109	98	98	88	86	91	98	81	80	82	83
Ash	25	25	24	24	18	18	13	12	12	15	12	14	16	14
Protein	873	873	839	839	805	805	828	813	811	832	852	855	818	819
Lipid	1	1	29	29	78	78	71	88	86	55	56	51	83	84

¹FBW = fasted body weight.

²FFB = feather free body.

c) $H_0: \beta_{2i} = 0$; the slope of environment i does not differ from the average slope.

$H_1: \beta_{2i} \neq 0$; the slope of environment i differs from the mean slope.

According to the test, the linear equations ($\ln Y = a + b \cdot \ln X$) were subjected to potentiation in order to obtain the allometric equation of power function of Huxley (1932), defined as $Y = a \cdot x^b$,

where Y = response variable (water, lipid, or ash), a = intercept of logarithmic linear regression on Y , x = independent variable (protein), and b = allometric coefficient representing the relative growth velocity of Y in relation to x .

The 95% confidence interval of the allometric coefficient (b) was used as a tool to verify whether “ b ” is statistically different ($P < 0.05$) from unit (1). If the confidence interval contains the value of parameter (1), we accept H_0 . Otherwise, we reject H_0 at the level of significance adopted.

The Gompertz function was fitted using NLIN and the allometric equation using GLM procedures of Statistical Analysis System (SAS institute, 2001), with 5% significance.

Growth was considered isometric when $b = 1$, suggesting that the growth rates of X and Y were proportional. Growth was considered positive allometry and negative allometry when $b > 1$ and $b < 1$, respectively, indicating late and early growth, respectively, of the independent variable (Furusho-Garcia et al., 2006; Souza Júnior et al., 2009).

RESULTS

The mean, minimum, and maximum temperatures and average relative humidity inside the climate control room during the experimental period were $26.03 \pm 1.32^\circ\text{C}$, 25.98°C , 28.65°C , and $67.59 \pm 9.06\%$, re-

spectively. In the no climate control room, these temperatures and average relative humidity were $29.27 \pm 0.77^\circ\text{C}$, 26.95°C , 33.70°C , and $77.83 \pm 3.03\%$, respectively.

The mean weekly FBWs (g/bird) and the proportions of carcass and feathers in the FBW, as well as the water, ash, protein, and lipid contents in both these components of males and females raised under climate control (26.0°C) and no climate control (29.0°C) environments are given in Tables 2 and 3, respectively. The data from 1 to 14 days old did not differ between the 2 treatments, because the quail were subjected to the 2 different treatments only from day 14.

No environment effect ($P > 0.05$) on protein growth of FFB (g) or feather growth (g) was observed indicating that only one curve for males and another one for females was sufficient to describe the growth of these components.

Despite the absence of environmental effect, it was observed that the rate of maturing (B) of feathers (0.2312 for male and 0.1985 for female) differs from the rate of maturing of FFB protein (0.0801 for male and 0.0703 for female) (Table 4).

For the males and females data set, an allometry between feather weight and body protein weight was observed (Figure 1), with no differences between the climatized environment and non-climatized environment. It was showed an isometric growth ($b = 1$), indicating that the feather weight and body protein weight were directly proportional to one another (Table 5 and 6).

In both environments, the water content (g/kg) in the FFB declined with increasing age, showing the highest values on day 1, as expected for newborn animals. Unlike water content, the trends for ash, protein, and lipid content in FFB increased with quail age; from 28 D of age, a small decrease was observed for ash and protein

Table 3. Body composition of female meat quail from 1 to 42 D of age under climate control environment (26 °C) and no climate control environment (29°C).

Treatments	Age (D)													
	1		7		14		21		28		35		42	
	26°C	29°C	26°C	29°C	26°C	29°C	26°C	29°C	26°C	29°C	26°C	29°C	26°C	29°C
FBW ¹ (g/bird)	9.4	9.4	26.6	26.6	66.6	66.6	130.4	131.9	161.3	157.0	225.0	210.3	248.9	252.2
FBW (g/kg)														
Carcass	950	950	944	944	905	905	899	905	910	926	946	941	951	953
Feathers	50	50	54	54	95	95	101	95	90	74	54	59	49	47
FFB ² (g/kg)														
Water	791	791	773	773	750	750	722	717	671	695	646	648	637	636
Ash	21	21	26	26	25	25	39	36	35	34	35	34	31	34
Protein	151	151	173	173	185	185	191	194	200	198	193	186	184	187
Lipid	37	37	27	27	39	39	48	52	94	73	126	131	148	142
Feathers(g/kg)														
Water	101	101	112	112	91	91	89	86	91	86	81	78	86	90
Ash	25	25	23	23	20	20	12	11	11	13	12	13	10	15
Protein	873	873	827	827	816	816	828	824	834	825	844	852	840	799
Lipid	1	1	37	37	73	73	71	81	64	75	62	57	63	97

¹FBW = fasted body weight.²FFB = feather free body.**Table 4.** Estimates of the values of the 3 parameters (\pm se) of the Gompertz equation for protein weight of FFB and feathers, for males and females in each environment.

Parameter	Males	Females
	Protein weight of FFB ¹	
W _m ² , g	43.84 \pm 1.64	54.89 \pm 2.03
B ³ , d ⁻¹	0.0801 \pm 0.005	0.0703 \pm 0.004
t* ⁴ , d	17.31 \pm 0.712	20.32 \pm 0.722
	Feather weight	
W _m ⁵ , g	11.79 \pm 0.23	12.97 \pm 0.26
B ⁶ , d ⁻¹	0.2312 \pm 0.026	0.1985 \pm 0.015
t* ⁷ , d	11.38 \pm 0.44	11.79 \pm 0.26

¹FFB = feather free body.²W_m = mature protein weight of FFB.³B = rate of maturing parameter for protein weight of FFB.⁴t* = time at which growth rate is maximized for protein weight of FFB.⁵W_m = mature feather weight.⁶B = rate of maturing parameter for feather weight.⁷t* = time at which growth rate is maximized for feather weight.

content in FFB. Water and ash content in the feather samples decreased from 1 to 21 D of age, maintaining a practically constant proportion thereafter. Protein content (g/kg) in the feather samples showed variable values, with the highest protein proportion observed at 7 d. Lipid content (g/kg) in the feather samples significantly increased from 1 to 14 D and from 14 to 21 D of age.

The allometric regressions fitted to the major chemical components of meat quail kept in different environments, using the ln FFB protein weight and ln feather protein weight as the independent variable are given in Tables 7 and 9, respectively.

The allometric coefficients for water (b) in FFB were lower than those for ash and lipid. It was observed that water content showed negative allometric growth ($b < 1$), indicating early development in relation to the carcass protein. In contrast, ash and lipid content showed

positive allometric growth ($b > 1$), indicating late development in relation to carcass CP. In the feather samples, the ratio of water and ash weight to feather protein weight decreased as feather protein weight increased ($b < 1$), whereas the ratio of lipid weight to feather protein weight increased as feather protein weight increased ($b > 1$).

Parallelism tests showed no effect of temperature on the allometric coefficients of the chemical components of either FFB (Table 8) or feathers (Table 10), with the exception of FFB lipid in males ($P < 0.05$).

In general, the absence of differences between the allometric coefficients ($P > 0.05$) of the individual equations for the different environments indicated that only one equation was sufficient to describe the allometric growth of each chemical component, except for FFB lipid in males, in which the allometric coefficients at 29°C were higher than those at 26°C.

DISCUSSION

The chemical and physical composition of the body completely changes during growth (Gous et al., 1999). Some initial physiological features might justify highest carcass proportions in the FBW at 1 and 7 D as compared to 14 D of age; the yolk sac represents approximately 20% of body weight after hatching, but it is completely absorbed by day 7 (Ding and Lilburn, 1996; Khan et al., 2004).

Unlike in broiler chicken, in which body growth rate and live weight were higher in males than in females at older ages (Marcato et al., 2008), the female meat quail showed a higher body growth and live weight than males at 21 days old (Grieser et al., 2018). In addition, the development of female reproductive system contributes to a greater live weight in females than males in older age, suggesting greater lipid accumulation in

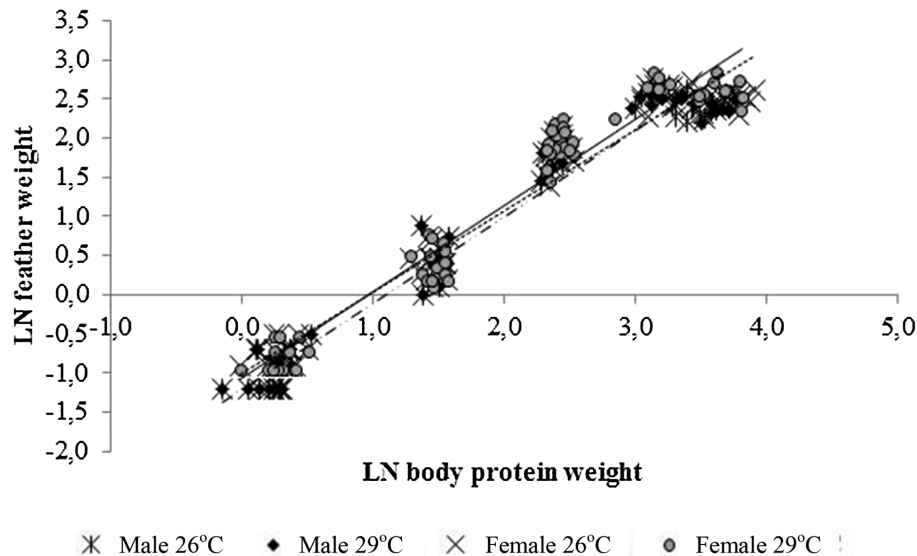


Figure 1. Allometric plot of feather weight against body protein.

Table 5. Allometric coefficients relating feather weight (ln, g) to FFB protein weight (ln, g) in male (M) and female (F) meat quail under climate control environment (26°C) and no climate control environment (29°C).

Sex	26°C Equations					29°C Equations				
	Constant term		Regression coefficient		r ²	Constant term		Regression coefficient		r ²
	Mean	SE ¹	Mean	SE ¹		Mean	SE ¹	Mean	SE ¹	
M	-1.197	0.094	1.095	0.041	0.97	-1.170	0.067	1.061	0.029	0.97
F	-0.994	0.105	1.036	0.044	0.94	-1.013	0.075	1.047	0.032	0.94

¹Standard error.

Table 6. Allometric equations of feather weight, as a function of the FFB protein weight in male (M) and female (F) meat quail.

Sex	Equations	r ²	P > t ¹	SE ²	CI (95%) ³
M	Feather weight = 0.306*CP1.078	0.97	0.417	0.041	0.998 ≤ μ ≤ 1.158
F	Feather weight = 0.377*CP1.042	0.94	0.811	0.044	0.956 ≤ μ ≤ 1.128

¹Probability of t-test for difference in allometric coefficients between different environments.

²Standard error.

³CI = confidence interval for allometric coefficient (95%).

females owing to estrogen secretion from the ovaries (Marks, 1993). In this sense, the difference in temperature of 3°C did not affect the females in the same way as the males, which showed considerably higher lipid proportions in FFB at 29°C than at 26°C after 28 D of age.

The estimates of the parameters of Gompertz equation for FFB protein and feathers indicated that these components have no similar growth trend. The rate of maturing of feathers was higher than the rate of maturing of FFB protein, and according to most bird studies involving growth description, these both components would not allometrically related and the feather weight could not be predicted from body protein weight

(Martin et al., 1994; Hancock et al., 1995; Hubry et al., 1995; Gous et al., 1999; Sakomura et al., 2011).

One reason for not relating allometrically feather weight to body protein is that for 2 components to be allometrically related it is necessary that the maturity rates of these components are similar (Emmans, 1989; Hruby et al., 1995; Danisman and Gous, 2008; 2011; Sakomura et al. 2011). Conversely, in recent study, Gous et al. (2019) showed that, in turkeys, the allometric relationship between feathers and body protein can be established, as observed in our study with meat quail.

Feathers comprise a considerable proportion of the total protein in the body, and a correct description of

Table 7. Allometric coefficients relating water, lipid, and ash weights (ln, g) to protein weight (ln, g) in the feather free body (FFB) in male (M) and female (F) meat quail under climate control environment (26°C) and no climate control environment (29°C).

Sex	Items	26°C Equations				r ²	29°C Equations				r ²
		Constant term		Regression coefficient			Constant term		Regression coefficient		
		Mean	SE ¹	Mean	SE ¹		Mean	SE ¹	Mean	SE ¹	
M	Water	+1.699	0.010	0.867	0.004	0.99	+1.696	0.007	0.872	0.003	0.99
	Lipid	-1.401	0.084	1.080	0.038	0.96	-1.500	0.083	1.223	0.036	0.95
	Ash	-1.943	0.027	1.051	0.012	0.99	-1.950	0.019	1.062	0.008	0.99
F	Water	+1.690	0.009	0.875	0.004	0.99	+1.688	0.006	0.877	0.003	0.99
	Lipid	-1.951	0.011	1.286	0.047	0.91	-1.907	0.081	1.254	0.034	0.90
	Ash	-2.019	0.034	1.064	0.014	0.98	-2.030	0.024	1.070	0.010	0.99

¹Standard error.

Table 8. Allometric equations of the water, lipid, and ash weights, as a function of the protein weight in the feather free body (FFB) in male (M) and female (F) meat quail under climate control environment (26°C) and no climate control environment (29°C).

Sex	Items	FFB Equations	r ²	P > t ¹	SE ²	CI (95%) ³
M	Water (W)	W = 5.459* CP ^{0.870}	0.99	0.363	0.003	0.864 ≤ μ ≤ 0.876
	26 Lipid (L)	L = 0.246* CP ^{1.080}	0.96	0.007	0.037	1.005 ≤ μ ≤ 1.155
	29 Lipid (L)	L = 0.223* CP ^{1.223}	0.95		0.034	1.151 ≤ μ ≤ 1.295
	Ash (A)	A = 0.143* CP ^{1.057}	0.99	0.516	0.008	1.041 ≤ μ ≤ 1.073
F	Water (W)	W = 5.415* CP ^{0.876}	0.99	0.736	0.003	0.871 ≤ μ ≤ 0.881
	Lipid (L)	L = 0.145* CP ^{1.271}	0.91	0.643	0.034	1.205 ≤ μ ≤ 1.338
	Ash (A)	A = 0.132* CP ^{1.067}	0.99	0.763	0.010	1.047 ≤ μ ≤ 1.086

¹Probability of t-test for difference in allometric coefficients between different environments.

²Standard error.

³CI = confidence interval for allometric coefficient (95%).

Table 9. Allometric coefficients relating water, lipid, and ash weights (ln, g) to protein weight (ln, g) in the feathers in male (M) and female (F) meat quail under climate control environment (26°C) and no climate control environment (29°C).

Sex	Items	26°C Equations				r ²	29°C Equations				r ²
		Constant term		Regression coefficient			Constant term		Regression coefficient		
		Mean	SE ¹	Mean	SE ¹		Mean	SE ¹	Mean	SE ¹	
M	Water	-1.920	0.066	0.966	0.009	0.99	-1.936	0.093	0.968	0.012	0.99
	Lipid	-6.006	0.639	1.388	0.074	0.95	-6.169	0.904	1.408	0.105	0.95
	Ash	-2.370	0.127	0.807	0.017	0.97	-2.514	0.179	0.829	0.023	0.99
F	Water	-1.737	0.069	0.946	0.009	0.99	-1.751	0.100	0.948	0.013	0.99
	Lipid	-4.729	0.352	1.243	0.042	0.87	-5.331	0.510	1.323	0.061	0.88
	Ash	-2.103	0.152	0.782	0.019	0.95	-2.454	0.219	0.834	0.027	0.97

¹Standard error.

feather growth is necessary for calculating the nutritional requirements, especially of the amino acids. Estimate feather growth is a difficult area of research; the increase in feather weight during growth is the net result of a continuous process of growth, loss, and regrowth in successive feathering stages (Gous et al., 2019).

Among the difficulties in estimating feather growth is the amount of feathers lost at the place where the birds are raised. According to Emmans and Fisher (1986), feathers grown and shed during development are obviously not present at slaughter; therefore, the weight of

feathers at slaughter may underestimate total feather growth.

The change in chemical composition of FFB during growth observed in the present study is in agreement with the data in literature for broilers. It is well documented that the tissues get drier with age and the lipid, protein, and ash content of FFB increased as the birds developed (Hakansson et al., 1978a, b; Hurwitz et al., 1991; Gous et al., 1999; Marcato et al., 2008). However, the chemical composition of feathers during growth in our study showed certain differences in comparison with others studies. Rivera-Torres et al. (2011) reported that

Table 10. Allometric equations of the water, lipid, and ash weights, as a function of the protein weight in the feathers in male (M) and female (F) meat quail under climate control environment (26°C) and no climate control environment (29°C).

Sex	Items	Feathers Equations	r ²	P > t ¹	SE ²	CI (95%) ³
M	Water (W)	W = 0.145* CP ^{0.967}	0.99	0.837	0.006	0.955 ≤ μ ≤ 0.979
	Lipid (L)	L = 0.002* CP ^{1.398}	0.93	0.852	0.052	1.295 ≤ μ ≤ 1.501
	Ash (A)	A = 0.087* CP ^{0.818}	0.98	0.329	0.012	0.795 ≤ μ ≤ 0.841
F	Water (W)	A = 0.177* CP ^{0.945}	0.99	0.871	0.006	0.933 ≤ μ ≤ 0.957
	Lipid (L)	W = 0.007* CP ^{1.283}	0.94	0.187	0.030	1.219 ≤ μ ≤ 1.338
	Ash (A)	L = 0.104* CP ^{0.808}	0.96	0.061	0.014	0.779 ≤ μ ≤ 0.833

¹Probability of t-test for difference in allometric coefficients between different environments.

²Standard error.

³CI = confidence interval for allometric coefficient (95%).

the feather protein content did not change, and water content increased with increasing feather mass in male turkeys.

The allometry in the present study indicated an early development of water with respect to FFB protein, indicating a higher water content in the early stages of growth. Grieser et al. (2018) showed that in meat quail the maximal growth for body water was reached at 15.6 D, whereas for body protein, maximal growth was reached at 22.2 D. Water participates in several metabolic processes and it significantly affects meat quality. Studies on meat quail have shown that meat from younger quail was juicier than meat from older ones, owing to the higher water content in younger birds. Marcato et al. (2008) also reported an early development of water than that of body protein in different broiler strains (negative allometric growth) and a higher growth rate for body water than body protein in all strains.

Similar to water, lipids have many important metabolic functions in the body. In our study, temperature affected the allometric coefficients of FFB lipid content in males, where lipid accumulation per unit protein at 29°C was higher than at 26°C, being similar to the allometric coefficients of lipid content in females, which have not been affected by temperature. In females, high lipid accumulation is expected; higher lipid content was observed in female meat quail and carcasses with skin than in male meat quail (Genchev et al., 2008; Abou-Kassem et al., 2019), and according Choi et al. (2012), estrogen secreted from the ovaries could increase the lipid accumulation in female quail preparing them for future egg laying.

In comparison with broilers, meat quail have higher thermal comfort temperatures and may be more tolerant to heat stress because of a greater surface-to-volume ratio (Sousa et al., 2014). Studies with quail have reported negatives effects on productive performance occurring normally at temperatures over 30°C (Sahin and Kucuk, 2003; Onderic et al., 2005; Sahin et al., 2005); therefore, the temperature of 29°C in our study was not enough to cause heat stress in quail. Females naturally have higher lipid content; thus, the different environments in this study may not have affected feed intake or metabolic changes that lead to different levels of lipid

accumulation per unit protein. In contrast, the temperature of 29°C likely led to an increased feed intake in males, and the excess of nutrients ingested promoted the lipogenesis.

It should be emphasized that the lipid content in the body may be influenced by factors such as the composition of the feed and the environmental conditions, making it difficult to define the allometric relationship between lipid and protein genetically determined. The weights of major physical components of broilers can only be accurately estimated if the amount of lipid deposited in tissues above the genetically determined, or the normal, was taken into account as noted by Danisman and Gous, 2011. Thus, studies establishing allometric relationships between body lipid weight and body protein weight should be viewed with caution.

In the present study, the allometric regressions fitted to the ash weight in FFB against protein weight in FFB showed a later development of ash in relation to that of protein, different from the findings reported by Marcato et al. (2008), in which body ash in broilers exhibited an earlier development than body protein. These authors reported that in broilers, the maximum development of ash was reached at a lower age than the maximum growth of protein, whereas Grieser et al. (2018) reported that in meat quail, the maximum development of ash and protein in the body were reached at 31 and 22.2 D of age, respectively. The mineral component of the body, analyzed as ash, is strongly related to bone tissue. Features such as increased body mass have been associated with skeletal deformities (Lilburn, 1994; Gonzales et al., 1998; Julian, 1998; Bessi, 2006), and to avoid them, the bone structure should increase in the same proportion as the musculature. The largest amount of ash is in the bones, in the same way as most of body protein is in the muscles, and according to Emmans (1981), a close functional relationship exists between both tissues. In the present study, in spite of the late growth of FFB ash in relation to that of FFB protein, the allometric coefficients (b) for ash against protein weight were virtually equal to 1, suggesting that bone and muscle tissue growth in quail do not contribute to bone problems as evidenced in broilers. This is widely accepted according

to Schmidt Nielsen (1984), Emmans (1987), and Gous et al. (2019).

Regarding feathers, previous studies have shown differences between feather and FFB growth, as well as between their components (Hakansson et al., 1978a, b; Nitsan et al., 1981; Hurwitz et al., 1983). Emmans (1989) and Stilborn et al. (1997) have assumed that it is useful to distinguish between the growth of feathers and that of the rest of the body when determining amino acid requirements of growing broilers, because the amino acid composition of these 2 tissues is markedly different. The present study showed an earlier development of water weight than feather protein weight, corroborating the findings reported by Marcato et al. (2009), who presented allometric coefficient (b) values for female broilers equal to those in our study. However, in the study by Marcato et al. (2009), the allometric relationships between feather ash weight and feather protein weight were different than those observed in the present study, which showed an earlier development of feather ash weight than feather protein weight. There is a lack of data on growth characteristics of feathers and their components in quail, and differences in feather characteristics between broilers and quail may be justified in part by the fact that quail are flying birds, whereas broilers are not.

In broilers, the allometric relationships of the major chemical components and body protein weight as well as the effect of factors such as sexes, strains, and feed programs on their allometric components are well documented; however, not enough research on these relationships has been done in meat quail. As discussed in the present study, body chemical components play important roles for both birds' performance and meat quality. According to Armsby and Moulton (1925), body weight of an animal is the sum of the weight of proteins, ash, water, and lipids; therefore, describing the growth of these chemical components and their allometric relationships becomes necessary to elaborating models to predict the growth and nutritional requirement of meat quail.

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