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Original Article

Growth Curve of Brazilian Creole Chickens (Canela-Preta Breed) Raised in Two Different Rearing Systems under Tropical Climate

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ABSTRACT

The objective of this study was to describe the growth curve of Brazilian Creole chickens of the Canela-Preta breed raised in two different rearing systems using non-linear growth models. A total of 400 birds were divided into two groups of 200 animals (of both genders), which were kept in confined or semi-confined systems. The confined birds were housed in an experimental masonry shed and the semi-confined animals were housed in another shed with access to pasture from 29 days of age. Birds were individually weighed every seven days during six months for determination of the growth curves of body weight using 10 non-linear models. The parameters of the models were estimated using the Gauss Newton method. The performance of the models was assessed using mean squared error (MSE), coefficient of determination (R^2), percentage of convergence, and residual mean absolute deviation (MAD). With the exception of the Inverse Polynomial, all the other models had R^2 values close to one. Therefore, the best models were chosen based on the lowest MSE and MAD values, with the Richards model ranking first followed by the Von Bertalanffy model. Gender and rearing system effects significantly influenced (p<0.05) some parameters of the Richards model. In conclusion, the Richards model was the most adequate to describe the growth of Canela-Preta chickens. Gender and rearing system significantly influenced the growth of the birds. The growth rates observed indicated that management strategies can be performed to increase the production efficiency of Canela-Preta chickens

INTRODUCTION

In recent years, there has been an increase in demand for meat of chickens raised in alternative systems due to attributes such as texture, taste, and the characteristic coloring of this type of meat (Santos *et al.,* 2005; Li *et al.,* 2017). Consumers have also been demanding healthier products that are less aggressive to the environment and take animal welfare into account (Castellini *et al.,* 2002; Fanatico *et al.,* 2006; Wang *et al.,* 2009). Given the factors mentioned above, several studies have been carried out to assess the performance of chickens raised in alternative rearing systems (Silva *et al.,* 2002; Mikulski *et al.,* 2011; Morais *et al.,* 2015; Yang *et al.,* 2015; Li *et al.,* 2017). In this sense, body weight and weight gain records are crucial to determine the pattern and growth potential of the animals.

Body weight data recorded at different ages are commonly used as selection criteria in animal breeding programs of meat-type animals (Silva *et al.,* 2011). The weight gain during a certain period of time, also known as growth curve, has been explained by non-linear models in chickens and other species (Aggrey, 2002; Freitas, 2005; Sarmento *et al.,* 2006; Kaplan & Gurcan, 2018; Ibiapina Neto *et al.*, 2020).

Non-linear models allow the biological interpretation of different parameters that represent essential criteria in the evaluation of growth curve models. These parameters provide important information for breeders and the poultry sector because they allow a greater understanding of the growth process of animals (Silva *et al.,* 2010) and the definition of strategies to increase their weight gain and food efficiency. Through estimates of the growth of birds, it is also possible to determine the nutritional requirements of each phase (starter, grower, and finisher) and predict the best age for slaughter, as well as production efficiency indexes (Marcato *et al.,* 2010).

There are few reports on the body development of free-range chickens in Brazil, especially in the Northeastern region of the country, where the Canela-Preta breed represents one of the main native chickens. Animals of this breed are mainly found in some regions of the Piauí state and are mostly raised in extensive systems, with little to none technological or zootechnical control (Carvalho *et al.,* 2020). Canela-Preta chickens are greatly appreciated by consumers due to their dark meat (Carvalho *et al.,* 2017); however, there are no studies reporting the body development of animals of this breed.

Considering the aspects mentioned above, the objective of this study was to describe the growth curve of male and female chickens of the Canela-Preta breed raised in different rearing systems using non-linear models.

MATERIALS AND METHODS

This study was approved by the Ethics Committee on the Use of Animals (CEUA) of the Federal University of Piauí (protocol number 352/17).

Local of the experiment

The experiment was conducted in the city of Teresina, PI, Brazil, from June to December, 2017. The birds were raised at the Poultry Sector of the Department of Animal Science (latitude 5°02'31.3"S, longitude 42°47'00.3"W) of the Federal University of Piauí, and at the Technical College of Teresina (latitude 5°02'54.3"S, longitude 42°46'53.0"W). Teresina is located at an average altitude of 72 m A.S.L. (Menezes *et al.,* 2016).

According to INMET (2020), the average air temperature (ºC), average relative humidity of the air (%), and total precipitation (mm) in Teresina during the months of this experiment were respectively: 27.01ºC, 70.75%, and 9 mm in June; 26.59ºC, 59.02%, and 26.6 mm in July; 27.90ºC, 59.64%, and 42.8 mm in August; 29.22ºC, 48.52%, and 0.00 mm in September; 30.29ºC, 49.68%, and 0.6 mm in October; 29.76ºC, 54.64%, and 15.4 mm in November; and 28.99ºC, 60.71%, and 93.4 mm in December. During these months of 2017, the minimum and maximum temperatures were recorded in July (16.9ºC) and October (38.9ºC), respectively; whereas the relative humidity ranged from 14% (September) to 91% (June and July); and the total precipitation was 187.8 mm (June 1 to December 31).

Animals and raising systems

Initially, 400 one day-old chicks (males and females) of the Canela-Preta breed were randomly distributed in two different raising systems (confined and semi-confined), with 200 animals of both genders in each system. Birds in the confined system were housed in a 108 m^2 experimental masonry shed surrounded by galvanized wire mesh, covered with ceramic tiles, with 2.80 m ceiling height. The semi-confined animals were housed in a shed with access to a grassed paddock of irrigated Tifton-85 (*Cynodon* spp.) surrounded by a galvanized chicken wire mesh fence (30.0 m length × 4.50 m width × 1.70 m high).

In both systems, all chicks were individually identified by wing and foot plastic bands. In the first 28 days, birds were housed in protective circles made of wood fiber sheets. They were lined with rice straw, equipped with a heating system with incandescent lamps and supplied with water and feed. Birds were vaccinated on the seventh day of life against Newcastle disease and infectious Bronchitis, and at 21 days of age against Fowl pox. Each vaccine was administered according to the recommendations of the manufacturer.

The protection circles were removed when the animals reached 29 d of age. In this same period, birds raised in the semi-confined system started having access to the pasture during the morning and afternoon shifts (weather permitting), being locked in the shed at night. In both systems, daily management included washing drinking fountains, providing water and food, and checking mortality.

All animals had access to feed and water *ad libitum* throughout the experimental period. Until the seventh day, screw pressure drinkers and infant tubular feeders were used. From the eighth day onwards, the birds received water in automatic bell drinkers and commercial feed in tubular feeders for adult birds. The animals were fed diets composed mainly of corn and soybean meal, and formulated to meet their requirements, according to the nutritional program recommended by the company that provided the feed.

Data collection and statistics

From the beginning until the end of the experiment, all animals were individually weighed every seven days using a digital scale, with 5 kg capacity. The weight and age records were used to estimate the growth curves using 10 non-linear models (Table 1), namely: Brody III, Inverse Polynomial, Logarithmic Quadratic, Papajcsik and Bodero, Logistic, Richards, Von Bertalanffy, Gompertz, Incomplete Gamma Function, and Linear Hyperbolic.

Table 1 – Non-linear models used to describe the growth curve of Canela-Preta chickens raised in confined and semi-confined systems.

Models	General equation	Authors
Brody III	$Y = A(1 - Be^{-kt}) + \varepsilon$	Brody (1945)
Inverse Polynomial	$Y = t(\beta_0 + \beta_1 t + \beta_2 c^2)^{-1}$	Nelder (1966)
Logarithmic Quadratic	$Y = \beta_0 + \beta_1 t + \beta_2 t^2 + \beta_2 \ln(t) + \varepsilon$	Bianchini Sobrinho (1984)
Papajcsik and Bodero	$Yt = at^*e^{-kt} + \varepsilon$	Papajcsik & Bodero (1988)
Logistic	$Y = A/(1 - e^{-kt})^{-m} + \varepsilon$	Nelder (1961)
Richards	$Y = A(1 - Be^{-kt})^{-m} + \varepsilon$	Richards (1959)
Von Bertalanffy	$Y = A(1 - Be^{-kt})^3 + \varepsilon$	Von Bertalanffy (1957)
Gompertz	$Y = Ae^{Be(-kt)} + \varepsilon$	Maruyama *et al.* (1999)
Imcomplete Gama Function	$Y = At^{\beta}e^{-kt} + \varepsilon$	Wood (1967)
Linear Hiperbolic	$Y = \beta_0 + \beta_1 t + \beta_2 1/t + \varepsilon$	Bianchini Sobrinho (1984)

The terms of these non-linear models can be defined as follows: is the body weight at age ; , which can also be called or , is the asymptotic weight when tends to infinite (this parameter is interpreted as the adult body weight); , which is also named as , is an integration constant related to the initial weights of the animal, without a well-defined biological interpretation, and established by the initial values of and ; , also known as ,is interpreted as the maturation rate, which must be understood as the weight change in relation to the weight at maturity; is the inflection parameter, which is not common in all models and refers to the point in which the animal moves from an accelerated to an inhibitory growth phase, indicating the point from which the efficiency of the growth rate starts to decrease and shape the curve; is the error associated with each observation (McManus *et al.* 2003; Drumond *et al.* 2013).

A preliminary analysis of the data was carried out to remove from the dataset the chickens that had less than five weight records, with 386 animals remaining for further analyses.

The model parameters were estimated using the modified Gauss-Newton method described by Hartley (1961), which is based on an approximation by a first-order Taylor series to produce a linearization of the non-linear function (Regazzi & Silva, 2003). The NLIN procedure of the SAS software (SAS University Edition, Cary, NC, EUA, 2017) was used to obtain parameter estimates for each proposed model.

The convergence criterion for each estimate was:

$$\frac{(RSSj^{-1} - RSSj)}{(RSSj + 10^{-6})} \leq 10^{-8}$$

where: $RSSj$ is the residual sum of squares in the iteration.

The statistical criteria used to select the model that best described the growth curve were: mean squared error (MSE), which was calculated using the quotient resulting from the division of the residual sum of squares (obtained by SAS) by the number of observations, which is the maximum likelihood estimator of the residual variance; coefficient of determination (R^2), calculated as the square of the correlation between observed and estimated weights; convergence percentage (CP%) of each model; and mean absolute deviation (MAD).

MSE is defined by the following equation:

$$MSE = \frac{\sum_{i=1}^{n}(y - \hat{y})^2}{n}$$

where: y and $\hat{y}$ are the observed and estimated values, respectively, which represent a maximum likelihood estimator; and is the number of observations.

MAD is calculated as follows:

$$MAD = \frac{\sum_{i=1}^{n}|Y_i - \hat{Y}_i|}{n}$$

where: Y_i is the observed value; $\hat{Y}_i$ is the estimated value; and MAD is the sample size. Lower MSE and MAD values indicate better fitting of the model.

After adjusting and determining the best model, the absolute growth rate (AGR) and inflection point (IP) were calculated. AGR was obtained by the first derivative of the adjusted model in relation to time. The biological interpretation for AGR is the weight gain per time. In this case, AGR represents the average daily weight gain estimated over the growth trajectory, that is, the average growth rate of animals of the studied population. IP indicates the point in which the body growth switches from a fast to a slower phase.

The parameters , B, k, and m estimated for each animal and adjusted model were analyzed using the PROC GLM of SAS. The same procedure was used for comparisons between fixed effects with Tukey test. The model that best fit the data was used to estimate the curve of average daily weight gain by identifying the weight and inflection point.

RESULTS

All the equations proposed to study the growth curve of Canela-Preta chickens have converged (Table 2). Except for the Inverse Polynomial model, very similar values (close to one) were obtained for R^2, indicating that any other model could be used to describe the average growth curve of the birds of the studied population considering their R^2 values.

The lowest values of MSE and MAD were obtained using the Richards model (Table 2). Concerning CP%, the Hyperbolic Linear, Papajcsik and Bodero, and Logarithmic Quadratic models presented the highest values (99.740%), whereas the lowest value was obtained using the Incomplete Gamma Function (4.404%). Note that higher percentages of convergence indicate better results. The von Bertalanffy and Richards models presented CP% values (95.854 and 84.196%, respectively) within the range observed for this criterion in the other models. Therefore, considering the CP% along with the lowest values of MSE and MAD for the Richards model, this model was chosen as the best to describe the growth curve of the population of Canela-Preta chickens used in this study. The von Bertalanffy model had the second better fit, based on MSE and MAD values.

Table 2 – Comparison of goodness-of-fit for different non-linear models used to describe the growth of Canela-Preta chickens.

Convergence criterion	Models									
	Von Bertalanffy	Brody III	Gompertz	Logistic	Richards	Incomplete Gamma Function	Hyperbolic Linear	Papajcsik and Bodero	Logarithmic Quadratic	Inverse Polynomial
MSE[1]	1312.02	7769.022	1697.333	5554.933	944.398	11333.9	12656.6	11022.6	2725.83	1983473
MAD[2]	23.966	69.913	28.66	60.157	19.724	78.557	88.805	83.294	38.151	1029.54
R2[3]	0.998	0.99	0.997	0.993	0.998	0.989	0.982	0.988	0.996	0.219
CP%[4]	95.854	73.575	90.155	97.927	84.196	4.404	99.740	99.740	99.740	98.445

[1]Mean squared error; [2]Mean absolute deviation; [3]Coefficient of determination; [4]Convergence percentage.

Only the Incomplete Gamma Function (0.116), Papajcsik and Bodero (0.749), and Inverse Polynomial (0.982) models did not show a negative correlation between and (Table 3). The highest estimates for the parameters and were obtained using the Inverse Polynomial model. On the other hand, the highest estimates for the parameter k were obtained using the Incomplete Gamma Function, followed by the Inverse Polynomial, and Logarithmic Quadratic models.

Table 3 – Means of the parameters A, B, k, and m obtained from non-linear models used to describe the growth of Canela-Preta chickens.

Parameters	Models									
	Von Bertalanffy	Brody III	Gompertz	Logistic	Richards	Incomplete Gamma Function	Hyperbolic Linear	Papajcsik and Bodero	Logarithmic Quadratic	Inverse Polynomial
A[1]	3839.101	9295.586	2840.601	2538.155	3146.340	14.065	56.301	16.270	26.944	9650440
B[2]	0.840	1.028514	4.033	18.247	0.801	-0.64	16.130	-	-0.04	11496119
k[3]	0.0156	0.003375	0.021	0.037	0.015	263492065.3	60.783	0.0003	140.75	1969782
m[4]	-	-	-	-	0.801	-	-	-	-	-
r_{Ak}[5]	-0.27	-0.40	-0.46	-0.57	-0.20	0.116	-0.995	0.749	-0.762	0.982

[1]asymptotic weight; [2]adjustment constant for the starting weight; [3]growth rate;[4]inflection point; [5]correlation between the parameters A and k.

The effects of gender and rearing system significantly influenced ($p<0.05$) some parameters of the Richards model (Table 4). The higher growth rate of males allowed them to have higher estimates of adult weight; however, the inflection point has not shown significant difference between males and females. Note that the integration constant for the initial weight (parameter B) was lower for males. Regarding the raising system, significant effects (p<0.05) were observed only for the growth rate and inflection point.

Table 4 – Effects of sex and rearing system on estimates of parameters of the Richards model used to describe the growth of Canela-Preta chickens.

Parameters	Sex		Raising System	
	Male	Female	Confined	Semi-Confined
A[1]	3304.550[a]	2940.820[b]	3244.640[a]	3117.890[a]
B[2]	0.829[b]	1.067[a]	0.958[a]	0.884[a]
k[3]	0.016[a]	0.014[b]	0.014[b]	0.016[a]
m[4]	4.193[a]	4.276[a]	3.440[b]	4.816[a]

[1]asymptotic weight; [2]adjustment constant for the starter weight; [3]growth rate; [4]inflection point; [a,b] Means with different superscripts within a row of the same parameter regarding the same effect are significantly different by Tukey test (p<0.05).

The inflection point of the Richards model was 2109.3 g at 142 days of age for male chickens and 1887.3 g at 166 days of age for females (Figure 1). Similar predicted weights were observed for both genders from 1 until approximately 17 days of age. After that, males were heavier than females until the end of the trial period. In fact, differences in weight gain between genders were evident since the first week, when male chicks started to gain more weight than females (Figure 2).

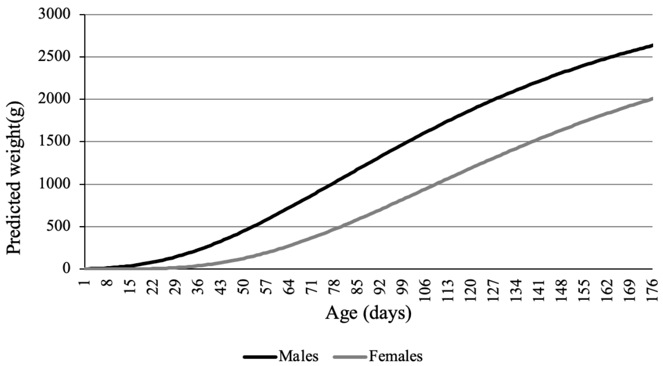

Figure 1 – Growth curve adjusted using the Richards model for the predicted weight in males and females of the Canela-Preta chicken breed.

Figure 2 – Absolute growth rate predicted using the Richards model for males and females of the Canela-Preta chicken breed.

DISCUSSION

As in the present study, other authors have reported similar R^2 values for different models used to describe the growth or production curves of animals of different species (Sarmento *et al.,* 2006; Mohammed, 2015; Adenaike *et al.,* 2017; Kuhi & France, 2019). When similar R^2 values are obtained for different models, other adjustment criteria should be used (Sarmento *et al.,* 2006; Adenaike *et al.,* 2017), so lower MSE and MAD values indicate the better fit of the Richards model to describe the growth curve of Canela-Preta chickens. Several other models are frequently presented as being capable to describe the growth of both free-range and industrial chickens (Eleroğlu *et al.,* 2014; Mohammed, 2015; Morais *et al.,* 2015; Veloso *et al.,* 2015). Therefore, it is necessary to determine the model that provides the best fit to the growth curve of Canela-Preta chickens, since there are no reports of this type for these birds.

The Von Bertalanffy, Brody III, and Gompertz models are special cases of the Richards model and can be obtained by assigning specific values at the inflection point of the model (Mohammed, 2015). In studies on the growth curve of various free-range chicken breeds, Veloso *et al.* (2015) and Morais *et al.* (2015) noted that the Richards model was not suitable to describe the growth of animals, as the model failed to converge.

The Richards model has excellent properties due to its possibility of adjusting the shape of the curve with the inflection point; however, this model has the disadvantage of being highly parameterized, which can hinder its convergence (Mohammed, 2015). Nevertheless, the Richards growth model is more flexible and has better adjustments when it reaches convergence, as compared to models such as Von Bertalanffy, Brody III, and Gompertz, which have fixed inflection points (Kaplan & Gurcan, 2018). This is probably the reason why Richards was one of the models that best fit the growth data of Canela-Preta in our study.

The most important relationship for a single curve is between parameters and . The negative correlation between these parameters indicates that animals that mature earlier have a lower probability of reaching higher adult weights than those whose maturation is slower (McManus *et al.,* 2003). Parameter presents an estimate of the asymptotic weight, which is interpreted as the adult weight. Parameter , in turn, represents the maturity rate and indicates the growth rate to reach the asymptotic weight. Animals with high values show earlier maturity in comparison to those with low values (Garnero *et al.,* 2005).

Lower initial weights and higher asymptotic weights of males in comparison to females in our study highlighted the growth speed of males of the Canela-Preta breed. The effect of sex on the growth curve of these chickens was already expected due to the expressive effect of sexual dimorphism for adult weight and growth rate in the *Gallus gallus* species (Johnson, 1988). Our findings corroborate those of Eleroğlu *et al.* (2014), who also observed higher asymptotic weights () and growth rates () for roosters compared to hens, using different models than the ones tested here.

Our results indicated that the semi-confined system was more advantageous than the confined one, increasing the growth rate and delaying the decrease in the growth of chickens. In this sense, adjustments in food management would be necessary to manipulate the growth curve in the short term, which would be more efficient if combined with the genetic improvement of the birds, as noted by Mohammed (2015). It would be interesting to carry out these adjustments in Canela-Preta chickens, as they take a long time (over 150 days) to reach the slaughter weight recommended by the Brazilian Ministry of Agriculture, Livestock and Supply (Brasil, 2012), that is, 2300 g. The growth rate of males and females evaluated in our study started to decrease (i.e., reached the inflection point) at 142 and 166 d of age, respectively, when the animals weighed less than 2300 g. Therefore, growth rate is a good selection criterion that has to be genetically improved in the Canela-Preta breed.

The growth rates of male and female broiler chickens are usually similar until 21 days of age, and males start to have more accelerated growth from the 28th day onwards (Santos *et al.,* 2005). However, our results showed that the AGR for males of the Canela-Preta breed was higher than for females since their first days of life until around 120 days of age, when both sexes have converged in the AGR growth curve obtained using the Richards model.

To the best of our knowledge, there are no previous reports on growth modeling and AGR for Canela-Preta chickens, either considering the effect of sex or not. The AGR study indicates where the growth of the animal is accentuated in terms of their life time. Thus, management can be adjusted to benefit from this response and increase the profitability and attractiveness Canela-Preta chicken rearing for producers.

CONCLUSIONS

Despite all models evaluated in this study having converged, the goodness-of-fit indicated that the Richards model was the most recommended to represent the growth curve of Canela-Preta chickens, which was significantly influenced by the effects of sex and rearing system. Chickens of the studied breed take long to reach ideal slaughter weight. Moreover, the observed growth rates indicated that management strategies can be implemented to increase the productive efficiency of Canela-Preta chickens, such as adjustments in food management and implementation of a bird genetic improvement program.

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