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Original Article

# The Growth Pattern of Brazilian Canela-Preta Chickens with Different Plumages Reared in Two Rearing Systems

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## ABSTRACT

Growth pattern is essential for economically efficient poultry production. In this study, we aimed to describe the growth curve of chickens of the Canela-Preta breed reared in two different rearing systems, considering their different plumage colors. Initially, 204 one-day-old male and female chicks were randomly distributed in confinement and semi-confinement (102 animals in each system) without separation by gender. The animals were individually identified by wing and foot plastic brands and were weighted every seven days. The body weight and age records were used to estimate the growth curves of the following factors using the Richards model: plumage color, gender, and rearing system. The likelihood ratio test was used to verify the equality of parameters and identify nonlinear models to compare the growth patterns of the evaluated groups. The growth pattern of Canela-Preta chickens changed as a function of gender, plumage color, and rearing system. Females with black plumage, black and gold hens, and males with black and white plumage showed greater sensitivity to changes in rearing systems. Within-breed selection strategies for specific colors can improve the use of growth pattern differences, improving production efficiency. Semi-confinement is suitable for rearing Canela-Preta chickens with any plumage color, as these animals meet the free-range poultry niche market requirements.

## INTRODUCTION

Several studies have reported that the *Gallus gallus* species was brought to Brazil by Europeans and Africans during colonization (Mesquita,1970; Fonteque *et al.*, 2014). Then, those animals started randomly mating among themselves under natural selection pressure and originated Brazilian native chicken breeds. These breeds are more adapted to local edaphoclimatic conditions than exotic breeds (Rocha *et al.*, 2020).

In Brazil, the production of free-range chickens is carried out predominantly by smallholders, which is why this activity is essential for generating income in rural areas and minimizing rural exodus. Differently from the industrial production system, the free-range system allows for management and structural adaptations according to the specific particularities of each rural property, due to the rusticity and resistance of Creole chickens (Sousa Júnior *et al.*, 2020). In this regard, the free-range production system provides a greater competitive advantage in the market. Similarly to the organic production system, free-range production also offers better conditions for animal welfare to meet the demands of this niche market (Oliveira *et al.*, 2019).

With the increasing market demand for free-range chickens, it is necessary to study specific traits of economic interest within each breed.

In this context, we could reference the phenotypic patterns of plumage color and gender in Canela-Preta chickens, with females having black, black and gold, and black and white feathers; and males having black and white, black and silver, and black and red feathers (Carvalho *et al.*, 2017, 2020). One of the key traits that can directly affect the nutritional management and selection of animals is the growth curve, which can increase the productivity and profitability of poultry production.

Canela-Preta chickens are native to the semiarid region of the Piauí state. This breed has a dual purpose, the production of eggs and meat. The phenotypic pattern that gives the breed its name is their black legs. They can be found in family production systems in this region and some municipalities of the neighboring state of Maranhão (Carvalho, 2016). Raising free-range chickens represents the main economic activity and source of income for many families in those states. Therefore, it is essential to provide information that can positively improve these animals' raising and increase their productivity. This information would boost the local economy, improve the quality of life of producers, decrease rural exodus, strengthen the socio-cultural role of native animals, and safeguard Brazilian genetic resources.

In the current study, we aimed to describe the growth curve of males and females of the Canela-Preta chicken breed, considering the different plumage colors of confined and semi-confined birds applying the likelihood ratio test to verify the equality of parameters and identity of nonlinear regression models for these factors (Regazzi, 2003).

## MATERIAL AND METHODS

This study uses information from the Group of Studies in Genetics and Animal Breeding (GEMA) database of the Federal University of Piauí (UFPI), Campus Ministro Petrônio Portella. The data collection occurred at the Poultry Sector of the Department of Animal Science (latitude 5°02'31.3"S, longitude 42°47'00.3"W) and the Technical College of Teresina (latitude 5°02'54.3"S, longitude 42°46'53.0"W), both located at the Campus of UFPI in the municipality of Teresina, Piauí-Brazil. The Ethics Committee on the Use of Animals (CEUA/UFPI) approved this research under protocol number 623/19.

Initially, 204 one-day-old male and female chicks of the Canela-Preta breed were randomly distributed in two different systems (confined and semi-confined) without separation by gender. Birds in the confined system were housed in a108 $m^2$ experimental masonry shed surrounded with galvanized wire mesh and covered with ceramic tiles, with a 2.80 m ceiling height. The semi-confined animals were housed in a shed with access to a grassed paddock of Tifton-85 (*Cynodon* spp.) surrounded by a galvanized chicken wire mesh fence (1.70 m × high× 30.0 m length× 4.50 m width) as shown in Figure 1.


**Figure 1** – Experimental masonry shed where birds in the confined system were housed (A). Shed with access to a grassed paddock where semi-confine animals were housed (B).

In both systems, all chicks were initially housed in protective circles made of wood fiber sheets and lined with rice straw, being supplied with water, feed, and a heating system with incandescent lamps. The animals were individually identified by wing and foot plastic bands and were weighed using a digital scale with a 5 kg capacity. The birds were vaccinated on the seventh day of life against Newcastle disease and infectious Bronchitis, and at 21d of age, they were vaccinated against Fowl pox. The injection of each vaccine followed the manufacturer's instructions.

The protection circles were removed when the chickens reached 29 days of age. During this period, the semi-confined birds started to access theTifton-85 pasture during the morning and afternoon shifts with *ad libitum* feed and water, and were locked in the shed at night. The daily management included washing drinking fountains, providing water and food, and checking mortality. According to the National Institute of Meteorology (INMET), the average temperatures (°C) in Teresina during the months of the experiment were

27.01°C in June, 26.59°C in July, 27.90°C in August, 29.22°C in September, 30.29°C in October, 29.76 °C in November, and 28.99°C in December.

Until the seventh day of age, 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 formulated to meet their requirements, according to the nutritional program recommended by the company that provided the ration. The feeding program was divided into three phases: pre-initial, initial, and growth.

The birds were individually weighed every seven days until 182 days of age. The body weight and age records were used to estimate the growth curves related to the following factors: plumage color, gender, and rearing system arranged in a completely randomized design (Table 1).

**Table 1 –** Number of individuals per grouping factors (rearing system, gender, and plumage color).

| Rearing system | Male | B/W | B/S | B/R | Female | B | B/G | B/W |
|---|---|---|---|---|---|---|---|---|
| Confined | 65 | 3 | 28 | 34 | 37 | 13 | 18 | 6 |
| Semi-confined | 62 | 8 | 29 | 25 | 40 | 19 | 17 | 4 |
| Total | 127 | 11 | 57 | 59 | 77 | 32 | 35 | 10 |

B/W – Black and White. B/S – Black and silver. B/R – black and red. B – Black. B/G – Black and gold.

The SAS®University Edition was used for statistical analysis. The Richards nonlinear model was adopted because it was reported by Machado (2018) to be the model that best describes the growth curve of Canela-Preta chickens. Richards' model is represented as:

$$Y = A(1 - Be^{-kt})^{-m} + \varepsilon$$

Where Y is the body weight at age t; A is the asymptotic weight when t tends to infinity, which is interpreted as adult body weight; Be, also known as B, is an integration constant associated with the initial weights of the animal, which has not a well-defined biological interpretation and is established by the initial values of Y and t; the parameter k means the maturity rate, i.e., the weight change in relation to the weight at maturity; m means an inflection parameter, i.e., the point where the growth switches from an accelerated to a slower phase, indicating the point from which the efficiency of the growth rate starts to decrease and shape the curve; $\varepsilon$ is the error associated with each observation (McManus *et al.*, 2003; Drumond *et al.*, 2013).

Parameters A, B, k, and m were estimated for each animal separately with an interval grid of initial guesses so that the method could find the best combination of initial values to start the estimation of parameters. The modified Gauss-Newton interactive method available in the PROC NLIN of the SAS®Institute software (2020) was used for all parameter estimations. After estimating the individual parameters, the means for each gender were calculated and used as initial guesses for subsequent comparisons.

In the next step, the equality of parameters and identity of nonlinear models were verified to determine if a single curve would be appropriate to describe the growth of Canela-Preta chickens, as well as to compare the growth curves of males and females with different plumage colors within the breed and between rearing systems. All factors were compared in pairs (e.g., confined males × semi-confined males), where each group was named as either1 or 2, that is, 1 for the first group (e.g., confined males) and 2 for the second group (e.g., semi-confined males). The likelihood ratio test was applied to test the comparison hypotheses between groups 1 and 2 based on all pairwise comparisons performed (Regazzi, 2003). The Richards model with additive error and parameterization was adapted from Regazzi (2003) as follows:

$$Y_{ij} = A_i\left\{1 - B_i\left[\exp\left(-K_i x_{ij}\right)\right]^{m_i}\right\} + \varepsilon_{ij},$$

with j=1, ..., $n_i$, i=1,..., g.$A_i$, $B_i$, $K_i$, $m_i$> 0

where $Y_{ij}$ = value observed in the j$^{th}$ animal of the i$^{th}$ comparison group; $x_{ij}$ = age associated with $Y_{ij}$; $A_i$ = asymptotic weight for each group i; $B_i$ = related to the value of E($Y_{ij}$) when $x_{ij}$ = 0; $K_i$ = mean growth rate of group i (maturation rate); $m_i$ = inflection parameter (an increase offlexibilityinthefit of data); $\varepsilon_{ij}$ = random error associated with each observation $Y_{ij}$, $\varepsilon_{ij}$ ~ NID(0, $\sigma^2$). $\sum_{i=1}^{g} n_i$ = n represents the total number of observations per group.

The hypotheses tested were:

1. $H_0^{(1)}: A_1 = A_2(= A), B_1 = B_2(= B), K_1 = K_2(= K),$ $and\ m_1 = m_2\ (= m)\ vs. H_a^{(1)}$
at least an equality is an inequality;

2. $H_0^{(2)}: A_1 = A_2(= A)\ vs. H_a^{(2)}$
not all $A_i$ are the same;

3. $H_0^{(3)}: B_1 = B_2(= B)\ vs. H_a^{(3)}$
not all $B_i$ are the same;

4. $H_0^{(4)}: K_1 = K_2 (= K)\ vs.\ H_a^{(4)}$
not all $K_i$ are the same;

5. $H_0^{(5)}: m_1 = m_2 (= m)\ vs.\ H_a^{(5)}$
not all $m_i$ are the same;

6. $H_0^{(6)}: A_1 = A_2 (= A)\ and\ B_1 = B_2 (= B)\ vs.\ H_a^{(6)}$
at least an equality is an inequality;

7. $H_0^{(7)}: A_1 = A_2 (= A)\ and\ K_1 = K_2 (= K)\ vs.\ H_a^{(7)}$
at least an equality is an inequality;

8. $H_0^{(8)}: A_1 = A_2 (= A)\ and\ m_1 = m_2 (= m)\ vs.\ H_a^{(8)}$
at least an equality is an inequality;

9. $H_0^{(9)}: B_1 = B_2 (= B)\ and\ K_1 = K_2 (= K)\ vs.\ H_a^{(9)}$
at least an equality is an inequality;

10. $H_0^{(10)}: B_1 = B_2 (= B)\ and\ m_1 = m_2 (= m)\ vs.\ H_a^{(10)}$
at least an equality is an inequality;

11. $H_0^{(11)}: K_1 = K_2 (= K)\ and\ m_1 = m_2 (= m)\ vs.\ H_a^{(11)}$
at least an equality is an inequality;

12. $H_0^{(12)}: A_1 = A_2 (= A)\ and\ B_1 = B_2 (= B)\ and\ K_1 = K_2 (= K)\ vs.\ H_a^{(12)}$
at least an equality is an inequality;

13. $H_0^{(13)}: A_1 = A_2 (= A)\ and\ B_1 = B_2 (= B)\ and\ m_1 = m_2 (= m)\ vs.\ H_a^{(13)}$
at least an equality is an inequality;

14. $H_0^{(14)}: A_1 = A_2 (= A)\ and\ K_1 = K_2 (= K)\ and\ m_1 = m_2 (= m)\ vs.\ H_a^{(14)}$
at least an equality is an inequality;

15. $H_0^{(15)}: B_1 = B_2 (= B)\ and\ K_1 = K_2 (= K)\ and\ m_1 = m_2 (= m)\ vs.\ H_a^{(15)}$
at least an equality is an inequality;

The following dummy variables were used in the model for those comparisons:

$$D^1 = \begin{cases} 1\ if\ the\ observation\ Y_{ij}\ belongs\ to\ group\ 1 \\ 0\ if\ the\ observation\ Y_{ij}\ belongs\ to\ group\ 2 \end{cases}$$

i =1, 2.

After applying the dummy variables, the model can be represented as follows:

$$Y_{ij} = \sum_{u=1}^{g} D_u \left\langle A_u \left\{ 1 - B_u \left[ exp\left( -K_u x_{ij} \right) \right]^{m_u} \right\} \right\rangle + \varepsilon_{ij}$$

with j=1, ..., ni, i=1,..., g.

For the application of the likelihood ratio test used to hypotheses testing using the dummy variables, it is necessary to follow the steps described by Regazzi (2003):

Fit the complete general model ($\Omega$) as the average estimation of the parameters for both genders with all parameters. With the complete model, we calculated $\sigma_\Omega^2 = \frac{SQR_\Omega}{n}$, where $SQR_\Omega$ is the residual sum of squares for $\Omega$ and $p_\Omega$ (= 4) is the number of parameters estimated using the complete model;

1. Fit the reduced model ($w$) with the restrictions imposed by the tested hypotheses. With the reduced model, we calculated $\sigma_w^2 = \frac{SQR_w}{n}$, where $SQR_w$ equals the residual sum of squares for $w$ and $p_w$ is the number of parameters estimated in each reduced model. Note: a total of 15 hypotheses were tested, of which the first ($H_0^{(1)}$) was comparing the complete model with itself for different groups (1 and 2).

2. Calculate the test statistics:

$$X^2_{Calculated} = n\,ln\left( \frac{\sigma_\Omega^2}{\sigma_w^2} \right)$$

or,

$$X^2_{Calculated} = -n\,ln\left( \frac{\frac{SQR_\Omega}{n}}{\frac{SQR_w}{n}} \right)$$

3. Decision rule

If $X^2_{Calculated} \geq X^2_{Table} \rightarrow H_0$ is rejected. The table value is a function of the 5% significance and the number of degrees of freedom $v = p_\Omega - p_w$.

The *p*-value associated with each $X^2_{Calculated}$ was calculated for each pairwise comparison with the appropriate restrictions imposed by the tested hypotheses. The groups compared were: male × female; confined × semi-confined; confined males × semi-confined males; confined females × semi-confined females; black/silver male × black/white male; black/silver male × black/red male; black/red male × black/white male; black female × black/white female; black female × black/gold hen; black/gold female × black/white female; confined black female × confined black/

white female; confined black female × confined black/gold female; confined black/gold female × confined black/white female; semi-confined black female × semi-confined black/white female; semi-confined black female × semi-confined black/gold female; semi-confined black/white female × semi-confined black/gold female; confined black female × semi-confined black female; confined black/white female × semi-confined black/white female; confined black/gold female × semi-confined black/gold female; confined black/white male × semi-confined black/white male; confined black/red male × semi-confined black/red male; and confined black/silver male × semi-confined black/silver male.

Finally, the growth curves and the absolute growth rate were estimated. The absolute growth rate was obtained right after the first derivative of the model by using the R software v. 4.1.0.

## RESULTS AND DISCUSSION

The estimation of parameters for each animal using the nonlinear Richards model resulted in 80%of convergence. Similarly, Machado (2018) reported 84.19% of convergence in a study using the Canela-Preta chicken breed and the same rearing systems shown here. The slight difference observed between our results is probably due to the author using more animals (n = 400), as mentioned above

The combinations of the following parameters of the nonlinear Richards model generated 15 possible comparison hypotheses: A – asymptotic weight, that is, adult body weight; B – integration constant associated with the initial weights; K – maturation rate in inflection parameter that establishes the degree of maturity (McManus *et al.*, 2003; Drumond *et al.*, 2013). The hypothesis $H_0^{(1)}$ is not valid if at least one of the model parameters differs from the others ($p$<0.05). In this regard, it is pointed out if there is any difference between the experimental groups. Comparisons with the other hypotheses are carried out only if there is a significant difference from the above mentioned hypothesis (Regazzi, 2003).

When each parameter (A, B, K, and m) was compared separately (i.e., hypotheses $H_0^{(2)}$, $H_0^{(3)}$, $H_0^{(4)}$, and $H_0^{(5)}$), significant differences ($p$<0.05) were observed only in the comparisons between the following growth curves: males and females; females of the two rearing systems; confined and semi-confined females with black plumage (Table 2).

The combination between A and B, that is, hypothesis $H_0^{(6)}$, showed a significant difference ($p$<0.05) for the comparison of male × female (Table 2). In the combination between A and K ($H_0^{(7)}$), there was a difference ($p$<0.05) for the following comparison groups: male × female; confined female × semi-confined female; black female × black and gold female; confined black female × semi-confined black female; confined black and gold female× semi-confined black and gold female; confined black and white male ×semi-confined black and white male.

In the combination of parameters A and m ($H_0^{(8)}$), a significant difference ($p$<0.05) was also observed when comparing males × females (Table 2). The combinations of B and K ($H_0^{(9)}$), B and m ($H_0^{(10)}$), and K and m ($H_0^{(11)}$) showed significant differences ($p$<0.05) between confined black females and semi-confined black females.

The comparison of A, B, and K ($H_0^{(12)}$) showed significant difference ($p$<0.05) for the following comparison groups (Table 2): male × female; confined female × semi-confined female; black female × black and gold female; confined black female ×semi-confined black and gold female; confined black female ×semi-confined black female; confined black and gold female ×semi-confined black and gold female; confined black and white male ×semi-confined black and white male.

When comparing the parameters A, B, and m ($H_0^{(13)}$), the comparisons of male× females and black female × black and gold females showed significant difference ($p$<0.05). Similarly, the comparison of A, K, and m ($H_0^{(14)}$) showed significant difference ($p$<0.05) for the following comparison groups: male × female; confined female × semi-confined female; black female × black and gold female; confined black female × confined black and white female; confined black female × confined black and gold female; confined black female ×semi-confined black female; confined black and gold female ×semi-confined black and gold female; confined black and white male ×semi-confined black and white male.

The combinations of B, K, and m ($H_0^{(15)}$)also showed a significant difference ($p$<0.05) for the following comparisons (Table 2): confined male× semi-confined male; semi-confined black female × semi-confined black and white female; confined black female × semi-confined black female.

The combinations of the tested parameters that form hypotheses $H_0^{(1)}$, $H_0^{(2)}$, $H_0^{(6)}$, $H_0^{(7)}$, $H_0^{(8)}$, $H_0^{(12)}$, $H_0^{(13)}$, and $H_0^{(14)}$ showed a significant difference ($p$<0.05) (Table 2).Therefore, those parameters differed for

**Table 2 –** Hypotheses tested and *p*-values for curves between Canela-Preta chickens of the same or different genders, kept in the same or different rearing systems, with the same or different plumages.

| Hypothesis | Groups | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | M × F | C × SC | MC × MSC | FC × FSC | FB× FB/G | FB× FB/W | FCB× FCB/W | FCB × FCB/G | FSCB× FSC B/W | FCB× FSCB | FCB/G× FSCB/G | MCB/W× MSCB/W |
| 1[1] | 0.00001 | 0.0024 | 0.0328 | 0.0279 | 0.00001 | 0.000001 | 0.0001 | 0.000001 | 0.0001 | 0.000001 | 0.0036 | 0.000001 |
| 2[2] | 0.0001 | 0.1142 | 0.3167 | 0.0296 | 0.4463 | 0.6707 | 0.4648 | 0.9727 | 0.6197 | 0.0284 | 0.1286 | 0.686 |
| 3[3] | 0.6493 | 0.0869 | 0.0862 | 0.1982 | 0.8524 | 0.8579 | 0.5144 | 0.765 | 0.7606 | 0.0693 | 0.4821 | 0.6373 |
| 4[4] | 0.7307 | 0.1098 | 0.1313 | 0.1073 | 0.927 | 0.5398 | 0.2948 | 0.5961 | 0.797 | 0.0107 | 0.3826 | 0.8286 |
| 5[5] | 0.8623 | 0.076 | 0.0715 | 0.1957 | 0.8318 | 0.8389 | 0.4312 | 0.6676 | 0.7606 | 0.0483 | 0.4884 | 0.74 |
| 6[6] | 0.0001 | 0.2165 | 0.2021 | 0.0622 | 0.2775 | 0.8833 | 0.7607 | 0.8575 | 0.4223 | 0.0907 | 0.2048 | 0.892 |
| 7[7] | 0.00001 | 0.2734 | 0.1047 | 0.0196 | 0.0058 | 0.6968 | 0.2629 | 0.0567 | 0.6918 | 0.0234 | 0.0268 | 0.0202 |
| 8[8] | 0.00001 | 0.2034 | 0.1362 | 0.0534 | 0.1908 | 0.8833 | 0.7306 | 0.6489 | 0.3834 | 0.089 | 0.1599 | 0.9215 |
| 9[9] | 0.1854 | 0.2304 | 0.2282 | 0.2273 | 0.969 | 0.52 | 0.4677 | 0.8018 | 0.3171 | 0.0129 | 0.6555 | 0.3284 |
| 10[10] | 0.1302 | 0.1796 | 0.1634 | 0.406 | 0.9365 | 0.9383 | 0.5488 | 0.658 | 0.9565 | 0.0266 | 0.7772 | 0.48 |
| 11[11] | 0.2311 | 0.2003 | 0.1702 | 0.2045 | 0.9316 | 0.4219 | 0.4562 | 0.8431 | 0.2258 | 0.0119 | 0.6183 | 0.2986 |
| 12[12] | 0.00001 | 0.3246 | 0.2085 | 0.022 | 0.0005 | 0.2642 | 0.0781 | 0.0026 | 0.5036 | 0.0006 | 0.0093 | 0.0008 |
| 13[13] | 0.00001 | 0.3206 | 0.0742 | 0.0525 | 0.0497 | 0.9693 | 0.6716 | 0.2036 | 0.3725 | 0.0619 | 0.0709 | 0.2956 |
| 14[14] | 0.00001 | 0.2269 | 0.212 | 0.0193 | 0.0001 | 0.1032 | 0.0138 | 0.0001 | 0.3523 | 0.0001 | 0.0062 | 0.0001 |
| 15[15] | 0.2547 | 0.1354 | 0.0271 | 0.1735 | 0.7224 | 0.2372 | 0.664 | 0.7685 | 0.0116 | 0.0311 | 0.3802 | 0.4571 |

[1]A1B1K1m1=A2B2K2m2=ABKm.[2]A1=A2=A.[3]B1=B2=B.[4]K1=K2=K.[5]m1=m2=m. [6]A1B1=A2B2=AB. [7]A1K1=A2K2=AK.[8]A1m1=A2m2=Am. [9]B1K1=B2K2=BK.[10]B1m1=B2m2=Bm .[11]K1m1=K2m2=Km.[12]A1B1K1=A2B2K2=ABK.[13]A1B1m1=A2B2m2=ABm.[14]A1K1m1=A2K2m2=AKm.[15]B1K1m1=B2K2m2=BKm. Reject $H_0$ if $p<0.05$. M – male. F – female. C – confinement system. SC – semi-confinement system. B – black. B/G – Black and gold. B/W – Black and White.

both genders, indicating that males and females have different growth patterns. The difference between the growth curves of males and females corroborates the findings reported by Machado (2018) for Canela-Preta chickens. The other hypotheses tested in the current study were not rejected, indicating that they do not show substantial differences in the growth pattern of these animals.

The differences observed between the growth curves of males and females can be due to the sexual dimorphism in the Canela-Preta breed (Carvalho *et al.*, 2017). This phenomenon resulted in different adult body weights and growth rates for males and females (Figure 2). It is essential to highlight that only the hypotheses that considered the asymptotic weight (A), that is, the adult body weight, H0, were rejected (Tedeschi *et al.,* 2000).

At early ages, the predicted weights were similar for males and females (Figure 2). Females had higher predicted weights than males until the 16th day; however, males showed a higher growth rate in this period and started to have higher predicted weights from the 17th day. Faraji Arough *et al.* (2019) reported similar findings in Iranian Khazak chickens. On the other hand, Machado (2018) observed differences between males and females after 35 days of age in Canela-Preta chickens. The differences between our results and those of Machado (2018) are probably due to the statistics used. In the study mentioned above, the parameters were compared using only analysis of variance (ANOVA)and a test of means, whereas in the current study, parameters were combined in all possible ways formulating hypotheses using the method proposed by Regazzi (2003).

According to Sarmento *et al.* (2006), the inflection point of the growth curve is observed when the growth rate switches from an accelerated to an inhibitory phase. In the current study, the age of males and females at the inflection point were 106 (1944.53 g) and 115 (1527.89 g) days, respectively. These findings differ from those of Narinç *et al.* (2010), reported for semi-confined medium-growing chickens (males and females).

In a comparison between the growth curves of confined and semi-confined birds (Figure 2), it is possible to observe that only hypothesis $H_0^{(1)}$ was significant ($p$<0.05) (Table 2). When comparing only males reared in both systems, curves differed in the parameters of the hypotheses $H_0^{(1)}$and $H_0^{(15)}$. In the case of females reared in the two evaluated systems, the differences were observed in hypotheses $H_0^{(1)}$, $H_0^{(2)}$, $H_0^{(7)}$, $H_0^{(12)}$, and $H_0^{(14)}$ ($p$<0.05). In this regard, it is necessary to plot an individual curve for each analyzed group.

The curves of weights predicted for males and females reared in the confined, and semi-confined systems were apparently similar, but significantly different ($p$<0.001), as shown in Table 2. The predicted weights of semi-confined birds were the highest until 22 days; confined chickens were the heaviest from 23 days onwards (Figure 2). Until the fourth day, the absolute growth rate in the semi-confinement system (5.17 g/day) was greater than that of the confinement (5.07g/day). Nevertheless, from the fifth day onwards, the growth rate in confinement was superior to that of the semi-confinement system.

The age of birds reared in the confinement and semi-confinement systems at the inflection point were 98 (1643.93 g) and 133 days of age (2130.66 g), respectively. Despite the expressive differences at the inflection point between birds reared in different systems, the significance obtained using the likelihood ratio test was observed only in hypothesis $H_0^{(1)}$ ($p$<0.001), which could explain the low visual differentiation in Figure 2. This low visual differentiation could also be due to the values of A and m estimated for each group (A confined = 3106, A semi-confined = 2859, m confined 2.3284, and m semi-confined 8.1245). These parameters are the basis for calculating the inflection points obtained after the first derivative of the model. The inverse proportion of parameters between groups generated this difference that is not seen in Figure 2 (Narinç *et al.*, 2017).

The predicted weights of semi-confined males until 22 days of age were higher than those obtained for confined males. However, the predicted weights of males reared in the confinement system were higher from 22 days onwards (Figure 2). In the first seven days of life, the semi-confined males showed higher growth rates than those reared in the confinement system. After 59 days, the semi-confined males had superior performance until 146 days. From this period on, the confined males showed a superior growth rate until the end of the experiment. The age of confined and semi-confined males at the inflection point was 93 (1730.95 g) and 136 days (2417.62 g), respectively.

The predicted weights of semi-confined females were higher than those observed for confined females until 28 days. However, from this date onwards, the predicted weights of confined hens were superior (Figure 2). In the first four days of life, females reared in semi-confinement showed higher growth rates than those reared in the confinement system. After this period, the growth rate of confined hens was superior until 49 days of life, when semi-confined females showed higher performance again. Finally, the confined hens showed a superior growth rate from 96 days of life until the end of the experimental period. The ages of confined and semi-confined females at the inflection point were 110 days (1466.90 g) and 125 days (1641.38 g), respectively.

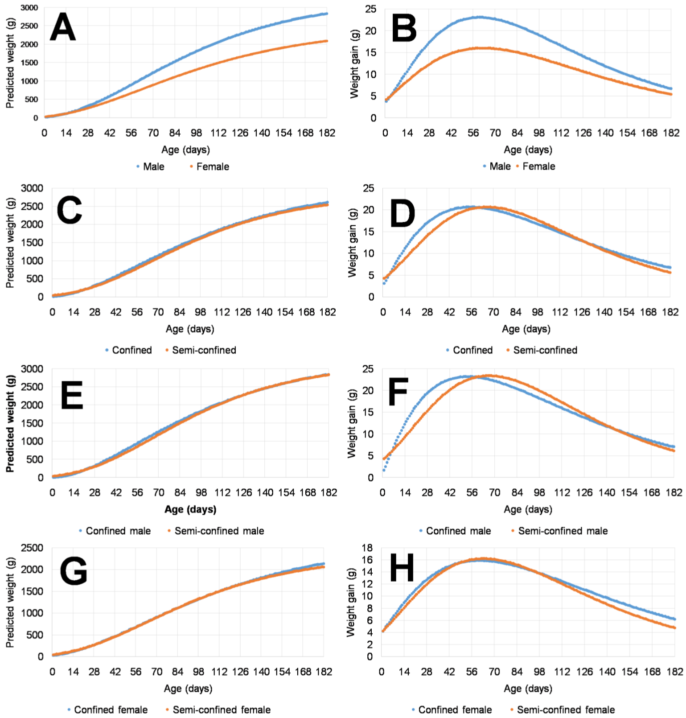


**Figure 2** – Growth curve (left) and absolute growth rate (right) predicted using the Richards model according to combinations of the parameters A, B, K, and m for males and females (A and B), confinement and semi-confinement systems (C and D), semi-confined and confined males (E and F), and females from both rearing systems (G and H).

These results showed that the initial growth rate of confined chickens was probably slightly higher than that observed in semi-confined animals. Subsequently, the semi-confinement growth rate was higher, demonstrating that animals reared in this system have slower growth than those reared in confinement. This difference is probably associated with parameter K (Table 3) (Tarôco, 2016). Animals with higher initial growth rates are less likely to reach higher weights at maturity than those that grow more slowly in early life (Mikulski *et al.*, 2011). It is important to mention that semi-confined free-range chickens have specific behaviors that demand extra energy, such as hunting for insects, scratching, and grazing. These activities may justify the lower initial weight gain of the semi-confined birds. Nevertheless, these specific characteristics contribute to free-range chicken products' differentiated taste and quality (Dias *et al.*, 2016).

The genotype-environment interaction is widely studied, both in regards to evolution and in terms of animal production. According to Bowman (1981), a change in the relative performance of a character of at least two genotypes measured in two or more environments can define this interaction. Environmental sensitivity can denote a measure of the ability mentioned above. Therefore, genotypes with more remarkable plasticity show more significant phenotypic variation in different environments (Ambrosini *et al.*, 2012).

**Table 3 –** Mean estimates of the parameters A, B, K, and m for curves between Canela-Preta chickens of the same or different genders, kept in the same or different rearing systems, with the same or different plumages.

| Groups | Parameters | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | A | | B | | K | | m | |
| M× F [1] | 3267.6 | 2471.0 | 0.8038 | 0.6890 | 0.0162 | 0.0152 | 3.3007 | 3.7488 |
| C × SC[2] | 3106.0 | 2859.0 | 0.9357 | 0.4140 | 0.0140 | 0.0184 | 2.3284 | 8.1245 |
| MC × MSC[3] | 3358.3 | 3170.5 | 0.9846 | 0.3935 | 0.0142 | 0.0189 | 2.1665 | 8.9710 |
| FC× FSC[4] | 2636.0 | 2352.3 | 0.8334 | 04967 | 0.0132 | 0.0171 | 2.6854 | 5.9611 |
| MB/S× MB/W[5] | 3334.4 | 3202.8 | 0.8896 | 0.7937 | 0.015 | 0.0165 | 2.6963 | 3.4266 |
| MB/S × MB/R[6] | 3334.4 | 3224.7 | 0.8896 | 0.6968 | 0.015 | 0.0173 | 2.6963 | 4.197 |
| MB/R ×MB/W[7] | 3224.7 | 3202.9 | 0.6969 | 0.7938 | 0.0173 | 0.0165 | 4.1894 | 3.4260 |
| FB× FB/W[8] | 2429.6 | 2379.3 | 0.7216 | 0.6691 | 0.0149 | 0.0165 | 3.4558 | 3.9428 |
| FB× FB/G[9] | 2429.6 | 2539.1 | 0.7216 | 0.6676 | 0.0149 | 0.0152 | 3.4558 | 4.3293 |
| FB/G × FB/W[10] | 2459.2 | | 0.66835 | | 0.01585 | | 3.9517 | |
| FCB× FCB/W[11] | 2743.0 | 2502.6 | 0.9232 | 0.6985 | 0.0104 | 0.0150 | 1.9786 | 3.6376 |
| FCB × FCB/G[12] | 2743.0 | 2759.4 | 0.9232 | 0.8222 | 0.0104 | 0.0132 | 1.9786 | 2.8154 |
| FCB/G× FCB/W[13] | 2631.0 | | 0.76035 | | 0.0141 | | 3.2265 | |
| FSCB× FSCB/W[14] | 2355.0 | 2297.3 | 0.5022 | 0.0178 | 0.0170 | 0.0178 | 5.9192 | 4.3585 |
| FSCB× FSCB/G[15] | 2358.5 | | 0.4728 | | 0.0171 | | 6.3713 | |
| FSCB/W× FSCB/G[16] | 2329.65 | | 0.53715 | | 0.0175 | | 7.7704 | |
| FCB× FSCB[17] | 2743.0 | 2355.0 | 0.9232 | 0.5022 | 0.0104 | 0.0170 | 1.9786 | 5.9188 |
| FCB/W× FSCB/W[18] | 2401.45 | | 0.6647 | | 0.0164 | | 3.99815 | |
| FCB/G× FSCB/G[19] | 2759.4 | 2362.0 | 0.8222 | 0.4434 | 0.0172 0.0132 | | 2.8154 | 6.8236 |
| MCB/W× MSCB/W[20] | 3253.7 | 3168.8 | 0.8932 | 0.7206 | 0.0170 | 0.0162 | 2.9823 | 3.8291 |
| MCB/R× MSCB/R[21] | 3224.7 | | 0.6968 | | 0.0173 | | 4.1897 | |
| MCB/S× MSCB/S[22] | 3334.4 | | 0.8896 | | 0.0173 | | 4.1897 | |

[1]Male × female. [2]confined ×semi-confined. [3]male confined× male semi-confined. [4]female confined× female semi-confined. [5]black/silver male×black/white male. [6]black/silver male×black/red male. [7]black/red male×black/white male. [8]black female×black/white female. [9]black female ×black/gold female. [10]black and gold female×black/white female. [11]black females confined ×black and white female confined. [12]black female confined ×Black and gold female confined. [13]black and gold female confined×black and white female confined. [14]black female semi-confined×black and white female semi-confined. [15]black female semi-confined×black and gold female semi-confined. [16]black and white female semi-confined×black and gold female semi-confined. [17]black female confined×black female semi-confined. [18]black and white females confined×black and white female semi-confined. [19]black and gold female confined×black and gold female semi-confined. [20]black and white male confined×black and white male semi-confined. [21]black and red male confined×black and red male semi-confined. [22]black and silver male confined×black and silver male semi-confined. A = asymptotic weight. B = constantof adjustmentfor the initial weight. K = growth rate.m = inflection point.

The difference in the growth curves of animals reared in different breeding systems is probably related to the specific environment and nutritional management of each system (Silva *et al.*, 2004), as these aspects directly influence the weight gain and growth of the individuals. In this context, the traditional semi-confined system provides conditions that are more similar to the ones birds are adapted to, which reflects in their performance.

Comparing the growth curve based on the plumage color showed that black females differed from black and gold hens in rejected hypotheses $H_0^{(1)}$, $H_0^{(7)}$, $H_0^{(12)}$, $H_0^{(13)}$, and $H_0^{(14)}$. When comparing black females to black and white females, hypothesis $H_0^{(1)}$ was rejected ($p<0.05$) (Table 2). These findings suggest that females with different plumages showed different growth patterns, as shown in Figure 3.

During the experimental period, the predicted weights of black females were lower than those observed in black and gold hens. Black females showed higher growth rates until 26 days; however, after the 27th day, the black and gold females had superior growth rates until the end of the experiment (Figure 3). The inflection point for black females was estimated at 112 days of age (1466.35 g), whereas the age of black and gold females at the inflection point was 118 days (1595.05 g).

When comparing black hens with black and white females, the former had lower predicted weights throughout the analyzed period. Black and white females showed higher growth rates until 106 days, after which the black hens showed a higher growth rate (Figure 3). The age of black female chickens at the inflection point was 112 days (1466.35 g), whereas for black and white females the inflection point was 109 days (1492.75 g).

Plumage color in chickens is a factor that can influence growth rate; therefore, chickens with different plumage colors within the same breed can differ in terms of livability and growth performance (Rizzi, 2017).

The difference between black hens and females with black and gold plumage occurred in the hypotheses that included combinations with parameter K, which represents the maturity rate. Therefore, animals with higher K values (Table 3) display higher precocity than those with lower K (Mikulski *et al.*, 2011; Tarôco, 2016).

Our findings corroborate those reported by Jaap & Grimes (1956), Collins & Wentworth (1958), and Rizzi (2017). In studies on the growth of chickens based on their plumage colors, the authors above observed that chickens with only black feather shad lower growth than those with white plumage.

These results indicate that it is possible to use more efficient selection management considering the slaughter weight of animals. Black and gold hens, as well as black and white females, showed higher weight gain in comparison to black female chickens. Therefore, a selection directed to meat production can be applied to provide consumers with a product of the same quality and higher weight. Considering their favorable adult body weight and relatively small size, Canela-Preta hens can meet all the free-range chicken market requirements and supply the niche market that prefers smaller birds.

Several factors, such as genetics, can influence plumage color (Silva *et al.*, 2004; Makarova *et al.*, 2019). These factors may explain the growth differences in the hypotheses whose combinations included the parameter K. According to Sarmento *et al.* (2006), such K effect can be attributed to genetic factors, which could justify our findings. Given these results, studies that associate plumage color with Canela-Preta chicken growth genes are necessary.

When the growth curves of black and gold hens were compared to those of black and white females, no significant differences were observed ($p$<0.05) for any of the hypotheses (Table 2). Therefore, a single curve can describe the growth of these females (Figure 3). Similarly, a single curve is needed to represent the growth of Canela-Preta male chickens with different plumage colors.

There were no differences between the curves of black and gold hens when compared to black and white females. We estimated average parameters (Table 3) and only an average curve of predicted weights, growth rate, and a mean inflection point at 113 days of life (1543.87 g).

The fact that a single curve is needed for both Canela-Preta female chickens with some plumage colors and for all plumage colors of roosters of this breed may be due to the different actions of growth-related genes. Another plausible explanation is that genes determining the plumage color could be in higher linkage to genes responsible for the growth pattern. This hypothesis may indicate genetic differences, as the animals were subjected to the same management and environmental conditions. These assumptions reinforce the need for research on the association between growth genes and plumage color in chickens (Rizzi, 2019).

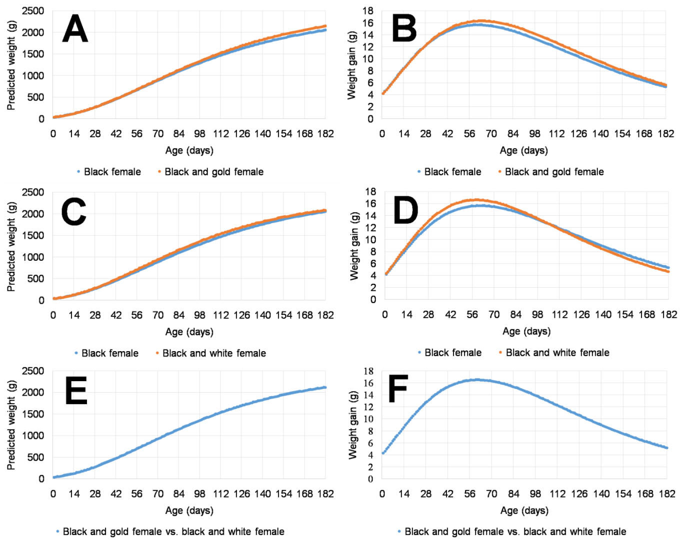


**Figure 3 –** Growth curve (left) and absolute growth rate (right) predicted using the Richards model based on combinations of the parameters A, B, K, and m for black Canela-Preta female chickens vs. black and gold females (A and B), black hens vs. black and white females (C and D), black and white females vs. black and gold females (E and F).

Another important aspect to be verified was whether females with different plumage colors kept under the same rearing system have different growth curves. In this regard, the following results were obtained: black females compared with black and white hens reared in confinement differ in hypotheses $H_0^{(1)}$and $H_0^{(14)}$ ($p$<0.05) (Table 2); for black hens compared to black and gold female chickens kept under the confinement system, H0 was rejected for the hypotheses $H_0^{(1)}$, $H_0^{(12)}$, and $H_0^{(14)}$ ($p$<0.05); in the semi-confinement, black females differ from black and white hens in hypotheses $H_0^{(1)}$, and $H_0^{(15)}$ ($p$<0.05). Therefore, two curves are necessary for each group of birds analyzed in this case. The same performance in the following comparisons was found:black and white females vs. black and gold hens in the confinement system; black and gold vs. black females in the semi-confinement system; black and white vs. black and gold hens. Based on these results, a single curve for each group can describe the analyzed growth (Figures 4 and 5).

The predicted weights of confined black females were lower than those observed in black and gold hens reared in the confinement system throughout the experimental period. Confined black females showed higher growth rates until 27 days of age; however, between days 28 and173, the black and gold females showed superior growth, and after this period, black hens had a higher growth rate until the end of the experiment (Figure 4). The age of black female chickens at the inflection point was 109 days (1365.80 g), whereas for the black and gold females, the inflection point was 114 days of age (1560.23 g).

During the experiment, confined females with black plumage had lower predicted weights than black and white hens reared in the confinement system. The growth rate of confined black females was superior until 29 days; however, after the 30th day of age, females with black and white plumage had the highest growth rate until day 132, after which the black females showed a superior growth rate (Figure 4).

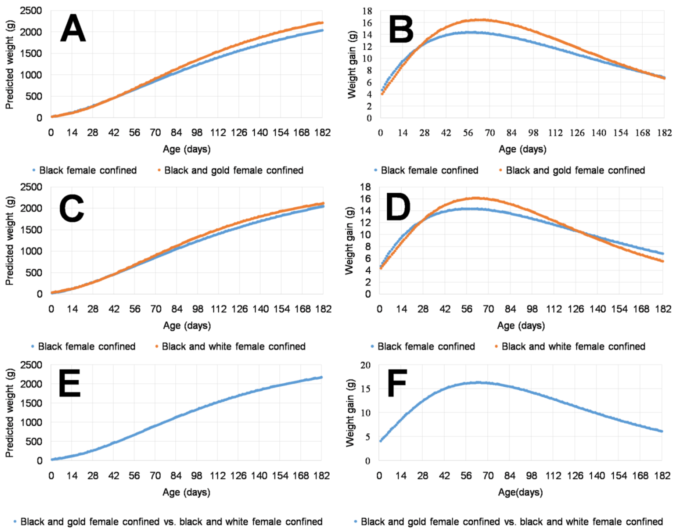


**Figure 4** – Growth curve (left) and absolute growth rate (right) predicted using the Richards model based on combinations of parameters A, B, K, and m for confined black Canela-Preta female chickens vs. confined black and gold females (A and B), confined black females vs. confined black and white females (C and D), confined black and white females vs. confined black and gold females (E and F).

The inflection point for black females was at 109 days of age (1365.80 g), whereas the age of black and white hens at the inflection point was 114 days (1533.80 g). The curves of confined black and gold hens and confined black and white females showed no difference. In this sense, we estimated average parameters (Table 3) and only an average curve of predicted weights, growth rate, and a mean inflection point at 114 days of age (1554.64 g).

Black hens and female chickens with black and gold plumage, both reared in semi-confinement, showed no difference in their curves. Therefore, average parameters (Table 3) and a single average curve of

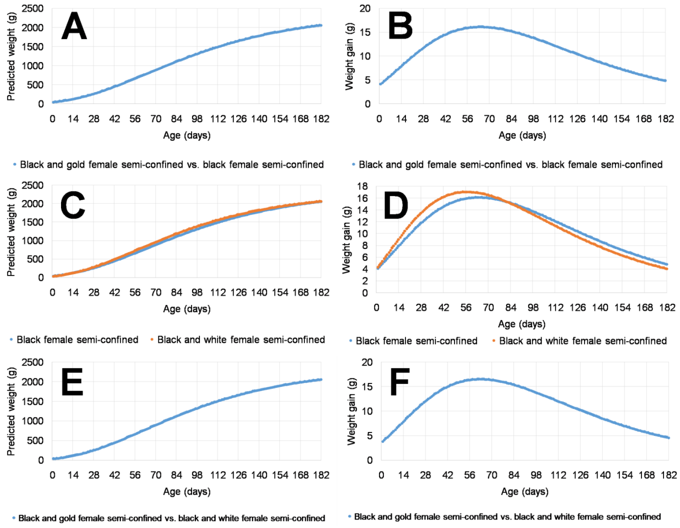


**Figure 5** – Growth curve (left) and absolute growth rate (right) predicted using the Richards model based on combinations of the parameters A, B, K, and m in semi-confined black Canela-Preta female chickens vs. semi-confined black and gold hens (A and B), semi-confined black females vs. semi-confined black and white females (C and D), semi-confined black and white hens vs. semi-confined black and gold females (E and F).

predicted weights, growth rate, as well as a mean point of inflection at 128 days (1670.74 g), were estimated (Figure 5).

In the semi-confinement system, the predicted weights of black females were higher than those observed in black and white hens until the ninth day. However, after the 10th day of age, the predicted weights of black and white females were superior. These birds also showed higher growth rates until 82 days of life. After this period, females with black plumage had a superior growth rate (Figure 4). The inflection point for black females was 126 days of age, when their weight was 1640.60 g, whereas the age of black and white females at the inflection point was 106 days (1484.02 g).

There was no difference between the curves of females with black and gold plumage and black and white hens reared in semi-confinement. Therefore, average parameters (Table 3), a single average curve of predicted weights, absolute growth rate, and a mean inflection point at 121 days (1601.31 g) were estimated.

Due to the differences between the curves of females with different plumage colors and the differences between hens kept under different rearing systems, one could wonder if females with the same plumage color reared in different systems grow at different rates. In this sense, when black females confined were compared to black hens reared in semi-confinement, hypotheses $H_0^{(1)}$, $H_0^{(2)}$, $H_0^{(4)}$, $H_0^{(5)}$, $H_0^{(7)}$, $H_0^{(9)}$, $H_0^{(10)}$, $H_0^{(11)}$, $H_0^{(12)}$, $H_0^{(14)}$, and $H_0^{(15)}$ were rejected ($p$<0.05); when black and gold females reared in the two rearing systems were compared, hypotheses $H_0^{(1)}$, $H_0^{(7)}$, $H_0^{(12)}$, and $H_0^{(14)}$($p$<0.05) (Table 2) were rejected. The same growth pattern was verified when black and white females were analyzed.

When black females reared in different systems (confinement and semi-confinement) were compared, the results showed that the semi-confined hens had higher predicted weights until the 16th day. After the 17th day, the predicted weights of confined female chickens were superior until day 53. Subsequently, the semi-confined hens showed higher predicted weights until the end of the experiment. The growth rates of confined black females were superior until 34 days of life. After this period, the semi-confined black females showed a higher growth rate until 120 days of age, and subsequently, the confined hens showed a superior growth rate (Figure 6). The age of confined black females at the inflection point was 109 days (1365.80 g), whereas the semi-confined hens with black feathers reached the inflection point at 126 days of age (1640.57 g).

When black and gold females reared in the two different systems were compared, the semi-confined hens had higher predicted weights until day 41. After the 42nd day, the predicted weights of confined hens were superior until the end of the experiment. The semi-confined females with black and gold plumage showed higher growth rates until the third day, after which the confined hens were superior (Figure 6). The inflection point for the confined black and gold females was 114 days old (1560.23 g), whereas the age of semi-confined females at the inflection point was 130 days (1698.50 g).

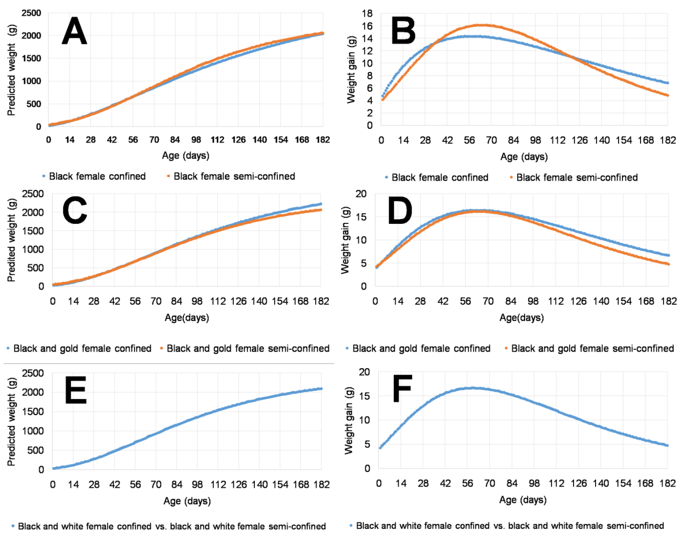


**Figure 6 –** Growth curve (left) and absolute growth rate (right) predicted using the Richards model based on combinations of the parameters A, B, K, and m in semi-confined black Canela-Preta female chickens vs. confined black Canela-Preta hens (A and B), semi-confined black and gold females vs. confined black and gold hens (C and D), semi-confined black and white females vs. confined black and white females (E and F).

No differences between the curves of black and white females reared in different systems were observed. The average parameters (Table 3), a single average curve of predicted weights, absolute growth rate, and an average inflection point at 115 days, with an average weight of 1511.67 g (Figure 6), were estimated.

Given the findings above, a possible hypothesis is that black, white, and gold females show plasticity according to their environment (feeding and rearing systems), as demonstrated by the phenotypic variation in adult body weight (Ambrosini *et al.*, 2012). On the other hand, black and white females showed phenotypic stability in the different environments evaluated here. These results reinforce that the genotype × environment interaction may differ in Canela-Preta chickens according to their plumage colors. The fact that Canela-Preta is a native breed of chickens with greater genetic variability can explain this interaction (Carvalho *et al.*, 2016).

Black and red males, both confined and semi-confined, did not show different growth patterns, which means that a single curve can describe them. The abovementioned findings are valid for black and silver males reared in confinement and semi-confinement. On the other hand, the black and white roosters differed in hypotheses $H_0^{(1)}$, $H_0^{(7)}$, $H_0^{(12)}$, and $H_0^{(14)}$, which made two curves necessary (Figure 7).

The semi-confined black and white males showed higher predicted weights than those reared in the confinement system until 32 days of life. After the 33rd day, the confined black and white males showed superior predicted weights (Figure 7). The semi-confined black and white males showed higher growth rates until 12 days of age, after which the confined males were superior until day 125, when the semi-confined black and white roosters were superior again. Confined black and white males were 98 days old (1874.92 g) at the inflection point, whereas semi-confined males reached the inflection point at 112 days of age (1971.46 g).

No differences between the curves of semi-confined black and red males and roosters with the same plumage color reared in the confinement system were observed. The same occurred with the black and silver males kept in the two systems (Figure 7). Thus, the average parameters were estimated (Table 3) with a single average curve of predicted weights, one average curve of absolute growth rate, and an average inflection point for each plumage group as compared between the systems. The ages of black and

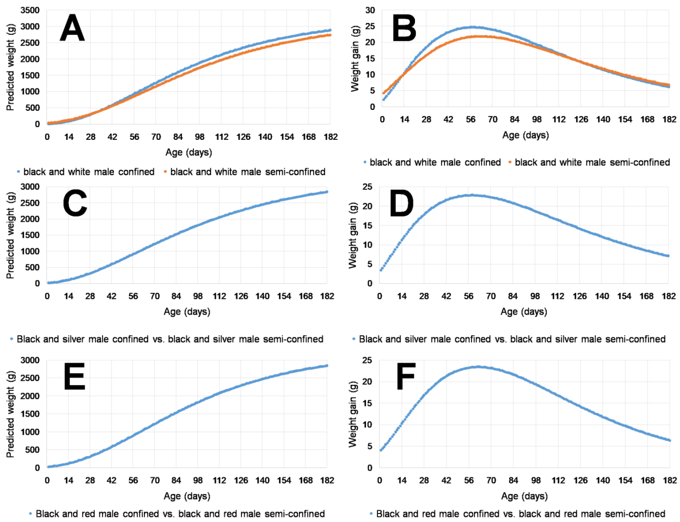


**Figure 7** – Growth curve (left) and absolute growth rate (right) predicted using the Richards model according to combinations of parameters A, B, K, and m for semi-confined black and white Canela-Preta male chickens vs. confined black and white males (A and B), semi-confined black and silver males vs. Confined black and silver males (C and D), semi-confined black and red males vs. confined black and red males (E and F).

red males and black and silver roosters at the inflection point were 111 days, with 2057.92 g and 1858.12 g, respectively.

The comparison between males with the same plumage color kept in different rearing systems demonstrated the genetic variability within the Canela-Preta chicken breed (Carvalho *et al.*, 20016). Therefore, only black and white males have plasticity according to their environment.

The comparisons between females and males with the same plumage color reared in different breeding systems showed that Canela-Preta chickens have an excellent response to the characteristics of free-range production (e.g., slaughter age above 85 days, greater grazing activity, movement, intake of forage, insects, and earthworms). Such characteristics corroborate the native condition of Canela-Preta chickens, that is, the adaptation to the edaphoclimatic conditions of northeastern Brazil (Dias *et al.*, 2016; Carvalho *et al.*, 2017). Therefore, if producers provide good welfare conditions for those birds, with proper feeding management, birds will respond well to the semi-confinement system (Santos, 2005). Some confined chickens have a higher maturity rate; however, this does not represent financial losses for free-range chicken producers. In this regard, there is the possibility of selection within the breed according to the production objective, so as to meet the demands of all niche markets for free-range products and make good profits for producers.

Our findings can be used as a guide to help producers in terms of nutritional management and selection of birds destined for meat production based on weight gain and growth rate, since Canela-Preta chickens produce both meat and eggs. With proper management, the productivity of meat chickens will increase, making more profits for producers and providing the market with better products.

## CONCLUSIONS

Canela-Preta chickens have different growth patterns that vary according to gender, plumage color, and rearing system. The estimated growth rates suggested that selection, and nutritional and environmental management strategies can be applied to improve Canela-Preta chickens' productive efficiency. Females with black plumage, black and gold hens, and males with black and white plumage showed greater sensitivity to changes in rearing systems. Black and white females, males with black and red plumage, and roosters with black and silver feathers did not show plasticity regarding changes in the rearing system. In general, Canela-Preta chickens showed superior growth in the semi-confinement system, regardless of gender and plumage color.

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## REFERENCES

Ambrosini DP, Carneiro PLS, Braccini Neto J, Malhado CHM, Martins Filho R, Cardoso FF. Interação genótipo × ambiente para peso ao ano em bovinos Nelore Mocho no Nordeste do Brasil. Pesquisa Agropecuária Brasileira 2012;47(10):1489-95.

Carvalho DA, Bonafé CM, Rodriguez-Rodriguez MP, Almeida MJO, Sarmento JLR, Britto FB, *et al.* Caracterização genética e estrutura populacional de galinhas crioulas Canela-Preta. Pesquisa Agropecuária Brasileira 2016a;51(11):1899-906.

Carvalho DA. Caracterização fenotípica e genotípica de galinhas nativas canelas-preta. [dissertation]. Diamantina (MG): Universidade Federal dos Vales do Jequitinhonha e Mucuri; 2016b.

Carvalho DA, Bonafé CM, Almeida MJO, Rodriguez-Rodriguez MP, Sarmento JLR, Silva MA, *et al.* Padrão racial fenotípico de galinhas brasileiras da raça Canela-Preta. Archivos de Zootecnia 2017;66(254):195-202.

Carvalho DA, Martínez AM, Carolino I, Barros MC,Vallejo MEC, Silva FS, *et al.* Diversity and genetic relationship of free-range chickens from the northeast region of Brazil. Animals 2020;10:1857.

Collins WM, Wentworth H. Influence of plumage color on hatching ratio and growth rate in chickens. Poultry Science 1958;37(1):69-77.

Dias AN, Maciel MP, Aiura ALO, Arouca CLC, Silva DB, Moura VHS. Linhagens de frangos caipiras criadas em sistema semi-intensivo em região de clima quente. Pesquisa Agropecuária Brasileira 2016;51(12):2010-17.

Drumond ESC, Gonçalves FM, Carvalho VR, Amaral JM, Balotin LV, Pires AV, *et al.* Curvas de crescimento para codornas de corte. Ciência Rural 2013;43(10):1872-7.

Faraji- Arough H, Rokouei M, Maghsoudi A, Mehri M. Evaluation of nonlinear growth curves models for native slow-growing Khazak chickens. Poultry Science Journal 2019;7(1):25-32.

Fonteque GV, Battilana J, Paludo E, Lima-Rosa CAV. Genetic polymorphism of fifteen microsatellite loci in Brazilian (Blueegg Caipira) chickens. Pesquisa Veterinária Brasileira 2014;34:98-102.

INMET – National Institute of Meteorology. Annual historical data 2020 [cited 2022 Aug 15]. Available from: https://portal.inmet.gov.br/dadoshistoricos.

Jaap RG, Grimes JF. Growth rate andplumage color in chickens. PoultryScience 1956;35:1264-69.

Machado LPM. Curva de crescimento e características de carcaças de galinhas Canela-Preta em diferentes sistemas de criação [dissertation]. Bom Jesus (PI): Universidade Federal do Piauí; 2018.

Makarova AV, Mitrofanova OV, Va Khrameev AB, Dementieva NV. Molecular-genetic bases ofplumagecoloring in chicken. Journal of Genetics and Breeding 2019;23(3):343-54.

McManus CHM, Carneiro PLS, Fernandes LAC, Miranda RM, Bernal FEM, Santos NR. Curvas de crescimento de ovinos Bergamácia criados no Distrito Federal. Revista Brasileira de Zootecnia 2003;32:1207-212.

Mesquita MB. Subsídios para a história da avicultura no Brasil. Avicultura Industrial. Chácaras e Quintais 1970;61:726-9.

Mikulski D, Celej J, Jankowski J, Majewska T, Mikulska M. Growth performance, carcass traits and meat quality of slower-growing and fast-growing chickens raised with and without outdoor access. Asian-Australasian Journal of Animal Sciences 2011;24(10):1407–16.

Narinç D, Aksoy T, Karaman E, Curek D.I. Analysis of fitting Growth Models in medium growing chicken raised indoor system. Trends in Animal and Veterinary Sciences 2010;1:12-18.

Narinç D, ÖksüzNarinç N, Aygün A. Growth curve analyses in poultry science. World's Poultry Science Journal 2017;73(2):1-13.

Oliveira R, Silva HL, Mira LB, Silva LV, Jesus SFP. Bem-Estar das galinhas poedeiras. Anais do 11th Simpósio Nacional de Tecnologia em Agronegócio; 2019. Ourinhos (SP): Fatec; 2019.

Regazzi AJ. Teste para verificar igualdade de parâmetros e a identidade de modelos de regressão não-linear. Revista Ceres 2003;50:9-26.

Rizzi C. Growth and slaughtering performance, carcass fleshiness, and meat quality according to the plumage color in Padovana male chickens slaughtered at 18 weeks of age. Italian Journal of Animal Science 2019;18(1):450-9.

Rizzi C. Plumage color in Padovana chicken breed: growth performance and carcass quality. Italian Journal of Animal Science 2017;17(3):797-803.

Rocha AO, Carvalho DA, Sarmento JLR, Carvalho AA, Barbosa BL. Polimorfismo no gene do receptor da leptina em raças brasileiras de galinhas caipiras (*Gallusgallus*). Revista Científica de Produção Animal 2020;21(2):45-8.

Santos AL, Sakomura NK, Freitas ER, Fortes CMS, Carrilho ENVM. Comparison of free-range broiler chicken strains raised in confined or semi-confined systems. Brazilian Journal of Poultry Science 2005;7(2):85–92.

Sarmento JLR, Regazzi AJ, Sousa WH, Torres AS, Breda FC, Menezes GRO. Estudo da curva de crescimento de ovinos Santa Inês. Revista Brasileira de Zootecnia 2006;35(2):435-42.

Silva NAM, Aquino LH, Silva FF, Oliveira AIG. Curvas de crescimento e influência de fatores não-genéticos sobre as taxas de crescimento de bovinos da raça Nelore. Ciência e Agrotecnologia 2004;28(3):647-54.

Sousa Júnior JC, Rocha FRT, Coelho KO. Análise bibliométrica sobre galinha e frango caipira / colonial. Research, Society and Development 2020;9(8):e.773986354.

Tarôco G. Normas de reação para parâmetros da curva de crescimento em codornas de corte alimentadas com dietas contendo diferentes relações treonina: lisina [dissertation]. Diamantina (MG): Universidade Federal dos Vales do Jequitinhonha e Mucuri; 2016.

Tedeschi LO, Boin C, Nardon RF, Leme PR. Estudo da curva de crescimento de animais da raça Guzerá e seus cruzamentos alimentados a pasto, com e sem suplementação. 1. análise e seleção das funções não-lineares. Revista Brasileira de Zootecnia 2000;29(2):630-7.