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RESEARCH ARTICLE

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Body growth and phenotypic variation of the carcasses of native duck lineages (*Cairina moschata*)

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Abstract

Natives ducks are birds that require little handling and are resistant to many diseases that affect chickens. Thus, they adapt to low-input farming conditions, which contributes to the food security of small farmers. Although they exhibit potential for growth, their production characteristics are relatively unknown, so they are underexploited. The objective of this study was to compare how nonlinear models fit the growth curve of two genetic groups of duck and to evaluate variation based on carcass characteristics. Two hundred and twenty four animals were weighed weekly, from birth to 90 days of age. We used nonlinear models (Brody, Richards, Gompertz, Von Bertalanff and Logistic) to describe growth curve. For the evaluation of phenotypic variation, we measured seven carcass traits from 81 ducks carried out by principal component analysis. The logistic model best fit the growth curve, and the absolute growth rates (AGR) for the Catolé duck showed that females reached their maximum AGR at approximately 30 days but did not reach their ideal commercial weight. The drumstick, thigh and liver yields accounted for 41.17% of the differences between the Catolé and Paysandu ducks. The slaughter of male Catolé ducks is recommended between 70 and 90 days because a drastic decrease in growth occurs after this time. For the slaughter of females, feeding management modifications and improvement in growth indices are recommended to increase the final weight and AGR. The carcass yields indicate potential for native duck meat production.

Additional keywords: body weight; slaughter age; multivariate; nonlinear models; family poultry.

Abbreviations used: AGR (absolute growth rate); BY (breast yield); CY (carcass yield); DY (drumstick yield); GY (gizzard yield); HY (heart yield); LY (liver yield); MAD (mean absolute deviation); RMS (residual mean square); TY (thigh yield).

Authors' contributions: Conceived and designed the experiments: ECJA, TCBSCB and PLSC. Performed the experiments: ECJA and RVFF. Analyzed the data: ECJA, LAN and CHMM. Wrote the paper: ECJA. Contributed experimental animals: RVFF. Revision of the manuscript: PLSC, CHMM, LAN and TCBSCB. All authors read and approved the final manuscript.

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Introduction

The native duck species *Cairina moschata* is original to South America and was domesticated by indigenous tribes. Currently this species is widely distributed throughout Brazil (Gois *et al.*, 2012). In southern and southwestern Bahia state, this duck is known as "pato Catolé" (Catolé duck) and is raised by small farmers without any type of known breeding programs. The Paysandu lineage was developed in the 1990s by crossing selected bloodlines with regional duck varieties from Para state, resulting in a lineage with genetic composition 3/8 and 5/8 of the ancestors used. These birds have peculiar meat characteristics and a slaughter weight of ≃ 4 kg at 90 days of age, and are used commercially, especially in the north of the Brazil (Lima & Lima Neto, 2006).

Although natives ducks are less productive than commercial varieties, which have been developed for greater productivity, they are important for maintaining agrobiodiversity because they exhibit large genetic variability and valuable production characteristics (Seo *et al.*, 2016), which can be used in genetic improvement.

Among the species of domestic birds, the duck is likely to be better adapted to extensive farming systems due to its capacity to utilize foods that are not used by humans or other animal production systems (Banga-Mboko *et al.*, 2007). Additionally, they are less demanding nutritionally and less susceptible to diseases that affect chickens and show production potential due to their rapid growth rate and high live weight (Yakubo & Ugbo, 2011).

Although native ducks are well adapted to low-input systems, its production potential is unknown and commercially underexplored in the region. Thus, it is necessary to evaluate the growth potential of these birds in order to develop management strategies suitable for production systems. Additionally, knowledge of the carcass characteristics is essential for genetic improvement of the species. Therefore, the objectives of this study were (i) comparing the growth curves of the native duck (Catolé duck) and a commercial variety (Paysandu duck) using different nonlinear models; (ii) to identify slaughter periods for the Catolé duck; and (iii) to evaluate the variation in carcass yield characteristics via multivariate analysis.

Material and methods

Local and experimental animals

The experiment was conducted in the Aviculture Sector of the State University of Southwestern Bahia (Universidade Estadual do Sudoeste da Bahia, UESB) located in the city of Itapetinga, Bahia state, Brazil, from November 2014 to January 2015. Catolé ducks belong to the UESB and Paysandu ducks were purchased with one day of age from a specialized farm in the Pará state, Brazil.

Growth curves

Experimental animals

The study of growth curves used a total of 224 birds from two genetic groups as follows: 130 Catolé ducks (64 males and 66 females) and 94 Paysandu (35 males and 59 females). The ducklings were identified with individual numeration on the right wing, and weighed weekly up to 90 days in an electronic scale (0.005 kg precision).

The birds were raised in a semi-closed shed until 30 days of life, after which time they were released into poultry paddocks, with access to Tifton 85 grass (*Cynodon* spp), water and a feed supply provided *ad libitum* where they remained until the end of the experiment. The diets used were formulated to contain 2960 kcal/kg of metabolizable energy and 22% of protein, in the initial phase (1 – 15 days) and 2800 kcal/kg of metabolizable energy and 18% protein, in the growth phase (16 – 90 days). The foods were corn- and soybean meal-based, according to the following ingredient composition: Initial diet (corn, 61%; soybean meal, 35%; dicalcium phosphate, 2%; calcitic limestone, 1.1%; vitamin and mineral mix, 0.3; NaCl, 0.6%); Growth diet (corn, 67%; soybean meal, 35%; dicalcium phosphate, 2%; calcitic limestone, 1.1%; vitamin and mineral mix, 0.6; NaCl, 0.3%).

Statistical analysis

The Brody ($y=A(1-Be^{-kt})+\varepsilon$), Richards ($y=A(1-Be^{-kt})^m+\varepsilon$), Gompertz ($y=Ae^{-Be^{-kt}}+\varepsilon$), von Bertalanffy ($y=A(1-Be^{-kt})^3+\varepsilon$) and Logistics ($y=A(1+e^{-kt})^{-m}+\varepsilon$) nonlinear functions described by Veloso *et al.* (2015) were used to adjust the weight by age using the ordinary least squares method with the Gauss-Newton algorithm in PROC NLIN of SAS Inst (2004), where y is the predicted weight in grams, t is the age in days, A is the asymptotic weight in grams, k is the growth rate, m is the parameter that gives shape to the curve, B is a constant and ε is the error.

The criteria adopted to select the function that best described the growth curve were convergence percentage (C%), coefficient of determination (R^2), mean square (RMS) and mean absolute deviation (MAD) of residuals calculated as:

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

where Y_i is the observed value, $\hat{Y}_i$ is the estimated value and n is the sample size.

After choosing the best model, analysis of variance (ANOVA) was performed to verify the effect of gender and genetic group on the parameters estimated by the models. For significant effects ($p < 0.05$), a curve was obtained for each gender and genetic group.

The absolute growth rate (AGR) for the chosen model was obtained based on the first derivative of the time-adjusted model ($\partial Y / \partial t$).

Phenotypic variation of carcass traits

Experimental animals

For the evaluation of phenotypic variation in carcass traits, a total of 81 ducks (20 Payssandu females, 19 Payssandu males, 19 Catolé females and 23 Catolé males) were slaughtered at 90 days of age. For slaughter, the ducks were fasted for 6 h and later slaughtered by desensitization and bleeding, followed by scalding, plucking and evisceration. After removal of abdominal fat, the carcasses without feet, head, neck and edible viscera were weighed to obtain yields.

Measured traits and statistical analyzes

For the multivariate analysis, carcass yield (CY) was calculated based on the relationship between the hot carcass weight and live weight after fasting. The breast (BY), drumstick (DY), thigh (TY), liver (LY), gizzard (GY) and heart (HY) yields were calculated based on the relationship between the weight of these organs and the weight of the carcass. The data were subjected to a multivariate analysis of variance (MANOVA). The matrix model was described by:

$$y=X\beta+\varepsilon$$

where: y = vector of observations for traits; β = fixed effects vector for treatment; X = incidence matrix of fixed effects and ε = vector of random errors associated with each observation.

The contribution of variables towards the total variation between groups was evaluated using the Jollife criteria. Then, a principal component analysis was performed to generate the biplots. SAS Inst (2004) was used for the ANOVA and MANOVA, and Past 2.03 (Hammer *et al.*, 2001) was used for the principal component analysis.

Results

The Gompertz, von Bertalanffy and logistic models converged for all animals, whereas the Brody and Richards models exhibited convergence difficulties for ≃ 64% of the animals and greater residual variance (Table 1). The Gompertz, logistic and von Bertalanffy models exhibited high coefficients of determination (>98.9%) (Table 1). Because little variation was detected in the R^2 values between the models, the RMS and MAD were important to discriminate between them. The von Bertalanffy model exhibited a lower quality of fit (larger RMS and MAD), especially in the growth curve of the commercial ducks. The logistic model was slightly superior to the Gompertz model, with less MAD in both groups (Table 1), and was chosen as the model that best fit the growth curve.

There was a significant effect of gender, genetic and gender *vs* genetic group interaction on the parameters estimated by the logistic model ($p<0.05$) (Table 2). Therefore, the models were adjusted for gender and genetic group. The unfolding of the interaction showed that for all the estimated parameters, males and females differed for both the Catolé and Paysandu genetic groups. The male ducks showing a greater estimated adult weight (A) and lower growth rate (k) than the females. Likewise, the ducks of Catolé genetic group exhibited a lower estimate for A and k compared with the ducks of Paysandu commercial genetic group (Table 2).

The maximum AGR was reached at 37 days for female (22.26 g/day) and 48 days for male (33.46 g/day) Catolé

Table 1. Growth models fit statistics for ducks.

Models	R^2	RMS	MAD
	Catolé duck		
Gompertz	99.07	6381.85	4.68
Von Bertalanffy	98.97	7162.74	8.93
Logistic	99.09	6216.87	2.59
Brody	90.96	37551.00	129.91
Richards	90.87	37831.00	130.32
	Paysandu duck		
Gompertz	99.44	6959.55	6.16
Von Bertalanffy	99.33	8519.84	12.16
Logistic	99.47	6580.08	3.18
Brody	91.23	75847.00	126.35
Richards	91.18	76206.00	126.93

R^2 = coefficient of determination (%). RMS = residual mean square. MAD = mean absolute deviation.

Table 2. Logistic growth models parameter estimates by gender and genetic group (Catolé or Paysandu) in ducks.

Gender	Catolé	Paysandu	Means
		A (g)	
Males	3356.34^{Ab}	4285.79^{Aa}	3692.17**
Females	1819.32^{Bb}	2473.49^{Ba}	2132.43**
Means	257.213**	3148.21**	---
		m	
Males	6.701^{Ab}	7.057^{Aa}	6.828**
Females	5.997^{Bb}	6.510^{Bb}	6.241**
Means	6.344**	6.708**	---
		k (g/day)	
Males	0.040^{Bb}	0.044^{Ba}	0.042**
Females	0.049^{Ab}	0.052^{Aa}	0.051**
Means	0.045**	0.049**	---
		MAD	
Males	2.40	2.44	---
Females	2.78	3.62	---

Means followed by equal letters, uppercase in the columns and lowercase in the rows, do not differ from each other, by Tukey test at 5% probability. *$p<0.05$. **$p<0.01$. A = asymptotic weight (g); m = inflection parameter; k = growth rate (g/day); MAD = mean absolute deviation.

ducks. For the Paysandu genetic group the maximum AGR occurred at ≃ 36 and 44 days for the females (32.16 g/day) and males (47.13 g/day), respectively (Fig. 1). The females (Catolé and Paysandu) reached their maximum AGRs earlier than the males. The males reached their maximum AGRs with weights of 1231.58 g and 1588.24 g for the Catolé ducks and commercial genetic group, respectively. At 90 days of age, there was a considerable reduction in the growth of the birds (Fig. 1).

The MANOVA detected differences ($p<0.001$) between the mean vectors of the carcass yields using the Wilks Pillai, Hotelling-Lawley and Roy tests. The BY and GY characteristics showed larger coefficients in the last eigenvectors (≤ 0.7) based on the Jollife criteria and consequently made a smaller contribution to the total variation; therefore, these characteristics were dropped from the analysis.

The first two principal components (PC1 and PC2) explained 66.11% of the total variation between groups and were described as:

$$PC1 = -0.42*CY + 0.52*DY + 0.53*TY + 0.52*LY - 0.10*HY$$
$$PC2 = 0.54*CY + 0.29*DY + 0.06*TY - 0.07*LY - 0.79*HY$$

In PC1, the variables drumstick yield (DY), thigh yield (TY) and liver yield (LY) showed high and positive scores. This component can be characterized as an index of the duck legs and liver yield, which represented 41.17% of the variation between treatments. For PC2, the most important variable was heart yield (HY), but there was a contrast between the variables CY and TY on one side and HY on the other. Thus, PC2 represented the difference between the carcass yield and the heart of the ducks, with 24.94% of the variation between birds resulting from this difference.

The greater dispersion within and less variation between the groups of ducks (Fig. 2) resulted in the Paysandu genetic group being mostly positioned in the same direction as the CY vector, which indicated superior performance of these groups compared to the Catolé ducks for this variable. The male Catolé genetic group were positioned in the same direction as the DY, TY and LY characteristics (Fig. 2), highlighting the better performance of this group in relation to the other groups. The individuals who were positioned in the center of the chart exhibited carcass yields and cuts close to the mean. The Catolé ducks showed higher average yields for DY (11.06%), TY (12.63%) and LY (2.70%) in relation to the commercial ducks (DY = 10.15%; TY = 11.97% and LY = 2.30%).

Discussion

The Brody and Richards models are not suitable for the growth curves of ducks due to convergence problems and high residual variation. Convergence difficulties of these models were also observed in studies with birds (Tholon & Queiroz, 2007; Drumond *et al.*, 2013). The logistic model provided the best fit for the native duck weight data and was chosen to describe the growth curves of the Catolé and Paysandu genetic groups. In studies with chickens, geese and ducks, the logistic model also had a good fit for the growth curves (Tang *et al.*, 2010; Zhang *et al.*, 2013; Eleroglu *et al.*, 2014).

The differences between the male and female ducks in the estimates for parameters A and k by the logistic model characterize the variation in the growth of males and females of this species, which exhibit marked sexual dimorphism, with males being larger and heavier than females. However, the females have greater precocity of growth (*i.e.*, they reach their adult weights in a shorter amount of time).

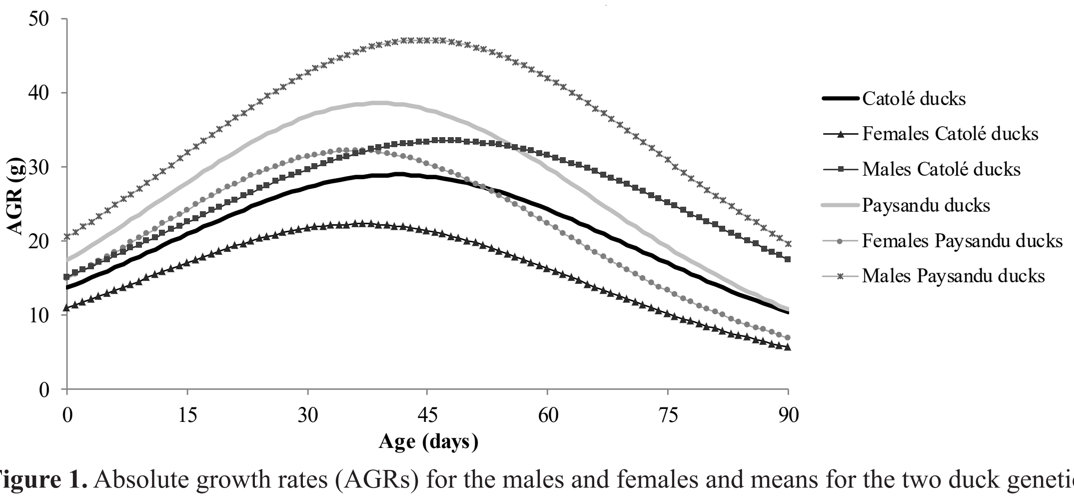

Figure 1. Absolute growth rates (AGRs) for the males and females and means for the two duck genetic groups estimated by the Logistic model.

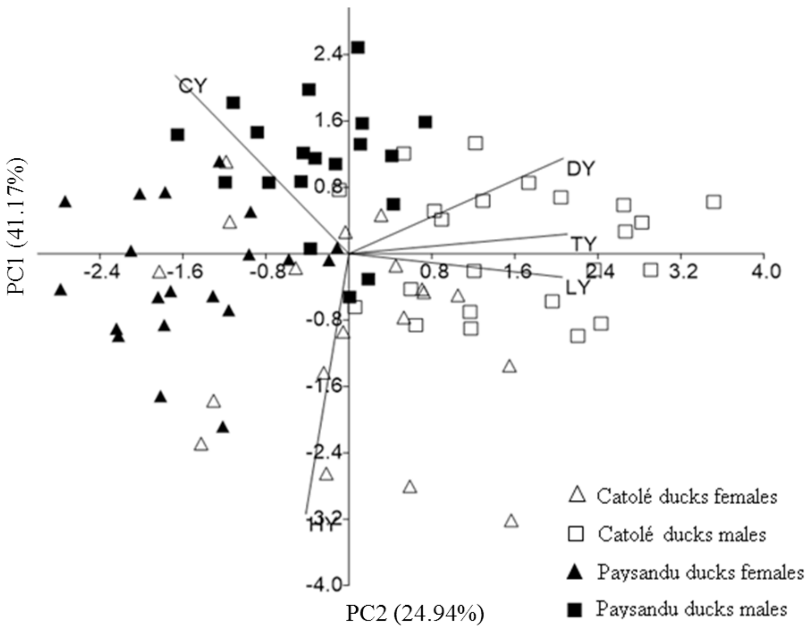

Figure 2. Biplot based on the first two principal components (PC1 and PC2) obtained from measurements of the native and commercial genetic groups carcass yields. CY = carcass yield. DY = drumstick yield. TY = thigh yield. LY = liver yield. HY = heart yield.

The Paysandu commercial ducks have higher adult weights and greater growth rates than the native ducks, indicating greater precocity of growth of commercial ducks as a result of the artificial selection performed during the development of this genetic group. The growth curves can be modified according to the selection criteria used; therefore, the selection of animals to increase the growth rate consequently leads to improvements in productive efficiency and decreased production costs (Drumond *et al.*, 2013).

Although the ducks of Catolé genetic group have slower development and weigh less than the selected genetic group, there are factors involved in Catolé duck production related to sustainability and the sociocultural identity of the locations where they are raised that must be considered. Traditional Catolé duck production systems are based on utilizing natural resources, positive fact and that should be evaluated in other studies considering low-input.

The AGRs found for the commercial ducks were similar to those reported by Dourado *et al.* (2009) in a study with broiler lines, which noted the potential for duck growth in comparison to chickens. The growth rate depends on the species, with small animals growing faster than large animals. In the case of ducks, which are aquatic birds, the rapid growth is also related to the accumulation of fat, which is needed for the isolation of feathers in contact with water (Mignon-Grasteau & Beaumont, 2000).

Knowledge of the age and weight at which the animal reaches the inflection point in the growth curve is important because it assists producers in monitoring feeding and reproductive programs and in defining the slaughter age for a better cost benefit (Carneiro *et al.*, 2009).

The females reached their maximum AGRs earlier than the males. Females are more precocious than males; however, the maximum rate of growth in females occurred very early at an age at which the commercial weight was not yet reached (668.79 g for Catolé ducks females and 909.95 g for the Paysandu ducks females). Based on the comparison of the AGRs of males and females and considering that both were fed the same diet, males are more indicated for meat production. At 90 days, the Catolé ducks females weighed approximately 1632 g, which is low for commercial weight. The use of selection targeted for greater weight and nutritional management modifications to increase the absolute growth rates of females is recommended. Alternatively, females could be preferentially used as breeding females and/or as egg layers, which commonly occurs in Cotolé ducks home production.

In the duck growth curve, weight gains are reduced after 90 days of age; therefore, the permanence of the birds in the production system ceases to be economically viable, and slaughter is recommended at an age of less than three months. Therefore, similar to the recommended to Paysandu genetic group, for Cotolé ducks, the best slaughter period is between 70 and 90 days. This finding is evidenced by the average weights obtained at 70 days (2165.960 g), 75 days (2445.630 g), 85 days (2588.190 g) and 90 days (2751.510 g). The final product must meet consumer demands, and Catolé duck can meet market niches interested in smaller carcasses. Moreover, given the growing market for local products, the aggregate value of Catolé duck may increase relative to commercial varieties ducks.

The variation among the groups based on their carcass yields showed little separation between the groups. The male and female Paysandu selected genetic group had superior performances compared to Catolé ducks for the carcass yield variable. Although the Catolé genetic group had lower carcass yields than the commercial ducks (average CY of 72.67% and 78.31% for the Catolé and Paysandu ducks, respectively), they showed a good yield, and the values were higher than those reported by Madeira *et al.* (2010) in commercial "caipira" (rustic) broiler lines slaughtered at 84 days.

The potential of the Catolé duck for carcass yield can be considered equivalent to the commercial genetic group. Therefore, Catolé ducks have potential to be better utilized in production south and southwest of the Bahia state. The selection of the best individuals within this population could result in significant improvements in the performance of these birds because that they show promising results in terms of the growth rate and carcass yield, allowing for a new perspective for the production of natives ducks in the region.

The promising results obtained for naive duck indicate a clear possibility of their use in traditional production systems. In Catolé ducks production, males must be slaughtered between 70 and 90 days of age; slaughter after 90 days is not recommended given the slow growth during this period. Females can also be slaughtered before 90 days; however, the use of selection targeted for greater weight aided by modifications in nutritional management to increase the absolute growth rate is recommended. Moreover, the Catolé ducks have potential for meat production, with carcass yields close to those observed for the selected commercial genetic group. However, practices that add value to the final product are necessary, including the identification and development of niche markets, the assessment of meat quality and the development of processed products. These practices will expand the possibilities for the use and conservation of these birds.

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