Characterization of growth in French Saddle horses using non-linear models in the Colombian high tropics

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Abstract

This research was conducted with the aim of characterizing the average growth curve of French saddle horses in the geographical conditions of Eastern Antioquia (Colombia), using non-linear models. To achieve this objective, weight and height measurements were taken monthly, resulting in 1305 measurements from 49 females and 1379 measurements from 53 males of the French Saddle breed raised at the San Isidro farm located in La Ceja, Antioquia. When comparing different models, it was found that the Brody model best fit the weight growth data (AIC=26279.44, BIC=26303.02) and height growth data (AIC=15346.65, BIC=15370.22) of horses. Modelling growth curves for males and females revealed a negative correlation between adult weight and growth rate, and it was also observed that animals stabilized their weight growth at around 36 months, while maximum height growth was reached at 24 months. The main conclusion of this study is that the Brody model best characterizes the growth curve in French Saddle horses raised in the conditions of the Colombian high tropics. In this sense, it is important to understand the growth dynamics in horses raised under Colombian high tropic conditions in order to make informed decisions regarding the initiation of training for these populations of show jumping horses.

Key words: *Showjumping horses; Precocity; Adult weight; Height; AIC; BIC*

Introduction

The French Saddle Horse is everything a sport horse should be: kind, athletic, strong, intelligent, and with a good temperament. Known primarily for its performance in showjumping, it also excels in dressage and eventing (Lincoln, 2022). Studying growth in sport horses is key to the future performance of these ani-

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mals; regular measurements can optimize the athletic potential of horses by reducing the risks associated with abnormal growth. The growth rates of the French Saddle Horse are not as well described as those of other breeds, and accurate data to evaluate their musculoskeletal development are scarce (Valette et al., 2008). In the field of animal growth and development, different linear and non-linear mathematical models have been used (Gompertz, Logistic, Von Bertalanffy, Brody, Richards), chosen for their goodness of fit and the ease of biological interpretation of their parameters. However, new models with random inputs are being created based on these, simulating the behaviour of environmental factors that affect animal growth, apart from the genetic and management conditions of the studied populations (Pearl and Reed, 1923; Winsor, 1932; Brody, 1945; Richards, 1959; Hossein-Zadeh and Ghorbani, 2018; Huntington et al., 2020). Various studies have modelled the growth curve in sport horses, noting that they use the coefficient of determination, the percentage of significant and atypical curves found for each function, Akaike Information Criterion (AIC), and Bayesian Information Criterion (BIC) to validate the fit of these models and their relationship with environmental conditions of feeding, agroclimatic conditions, and behaviour (Agudelo-Gómez et al., 2007; Onoda et al., 2014; Hossein-Zadeh and Ghorbani, 2018). The aim of this study was to apply non-linear models to characterize the average growth curve of French Saddle Horses in the geographical conditions of the Colombian high tropics.

Materials and methods

Ethics statement

This study was approved by the Animal Bioethics Committee at the Universidad Católica de Oriente.

Location: The study was conducted at the Haras San Isidro breeding farm, located in the municipality of La Ceja (Antioquia, Colombia), where the average temperature ranges from 15 to 18°C and the relative humidity is 60% (Spark, 2021).

Animals: In this study, French Saddle horses were evaluated. Animals were raised under confinement conditions and began their training at 36 months of age. The diet for these horses consists of pangola grass hay (*Digitaria ciliaris*) *ad libitum*, supplemented with balanced feed and commercial mineralized salt.

Data analysis: For the modelling of growth curves, weight measurements in kilograms and height in centimetres were

Table 1. Models used to characterize the growth curve of French Saddle horses

Model	Equation	Autor
Brody	$y = a\,(1 - be^{-ct})$	Brody
Logistic	$y = a\,(1 + e^{-ct})^{-1}$	-
Gompertz	$y = ae^{be^{-ct}}$	Gompertz
Von Bertalanffy	$y = a\,(1 - be^{-ct})^{3}$	Von Bertalanffy
Negative exp	$y = a - (ae^{-kt})$	-

y is the variable weight or height, t is the age of the animal at each measurement and, a, b, c are specific parameter of each model.

used. Weight and height were monitored monthly, resulting in 1305 measurements from 49 females and 1379 measurements from 53 males of the French Saddle Horse breed. To characterize the growth curves of weight and height, five non-linear models were compared, which are presented and explained in Table 1.

For selecting the model that best fits the growth of the horses, the lowest value for the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) were used; these criteria are described below:

$$AIC = -2 \ln L + 2K \text{ (Akaike, 1974)}$$

$$BIC = -2 \ln L + K \, Ln \, N \text{ (Schwarz, 1978).}$$

K is the number of estimated parameters, -2 lnL is the maximum likelihood function value, and n is the sample size. The analyses were conducted using the nls2 and nlstools libraries of the R-Project statistical program version 4.4.1 (Baty et al., 2013; Grothendieck and Grothendieck, 2013; R Development Core Team, 2024).

After identifying the equation that best described the growth curve of the horses included in the study, the parameters and the average curve were then estimated for sex effect (male or female) along with their respective 95% confidence intervals, to observe similarities or differences in the trajectory for this factor. Additionally, based on the estimated curve parameters, the age at which the animals reached 60% and 95% maturity percentage was calculated, as this could be indicative of the age at which the animals could start the training phase.

Results and Discussion

Considering the lower values of AIC and BIC, the model that best fit the description of the growth curve in French Saddle horses in Eastern Antioquia was the Brody model (AIC=26279.44, BIC=26303.02). The models that least fitted the weight and height measurements of the equines were: the logistic model (AIC=26717.48, BIC=26741.05) for weight and the negative exponential function (AIC=20813.76, BIC=20831.44) for height. These results are consistent with those obtained by Hossein-Zadeh and Ghorbani (2018), where they compared growth models in weight and morphometric traits of horses from the Caspian Sea region and found that the lowest values of AIC, BIC, and -log likelihood (-Log L) were observed for the Brody function in all growth characteristics. The Brody model was also the best fit for weight, height, and other morphological measurements of equines from the Caspian region (Hossein-Zadeh and Ghorbani, 2018). The models that enabled an estimation of the parameters for weight in kg and height in cm are presented in Table 2.

Using the Brody model, the parameters *a* (weight and height at adult age), *b*, and *c* (growth acceleration) were calculated for the entire population, and separately for males and females (Table 3). The results presented in Table 3 show that females (a=591.2 kg) reach a higher adult weight than males (a=579 kg), though during the growth period, mares (c=0.0795) grew more slowly than stallions (c=0.0808). For the height characteristic in males and females, the pattern was different, with a greater adult height for males of 168 cm, while for females it was lower at 165.8 cm. Similarly, for height considering the growth acceleration parameter *c*, females grew faster than males with values for this parameter of 0.118 and 0.117, respectively. Hossein-Zadeh and Ghorbani (2018) found similar growth dynamics as presented here, where females had a higher adult

Table 2. Parameters (a, b, and c) and model selection criteria for the functions used in the description of the growth curve and height of French Saddle horses

Body weight (kg)					
Model	a ± S.E.	b ± S.E.	c ± S.E.	AIC	BIC
Brody	584.7 ± 2.517	0.941 ± 0.0043	0.0802 ± 0.0011	26279.44	26303.02
Logistic	540.607 ± 1.513	4.041 ± 0.0657	-0.181 ± 0.0021	26717.48	26741.05
Gompertz	553.5 ± 1.74	0.6378 ± 0.0097	0.131 ± 0.0016	26426.46	26450.04
Von Bertalanffy	560.6 ± 1.891	0.4961 ± 0.0039	0.114 ± 0.0014	26346.29	26369.86
Negative exp	568.9 ± 1.862		0.092 ± 0.00079	26447.56	26465.25
Withers height (cm)					
Model	a ± S.E.	b ± S.E.	c ± S.E.	AIC	BIC
Brody	166.9 ± 0.199	0.388 ± 0.0021	0.118 ± 0.0016	15346.65	15370.22
Logistic	165.827 ± 0.179	0.573 ± 0.0047	-0.149 ± 0.0018	15500.19	15523.77
Gompertz	166.292 ± 0.187	-0.755 ± 0.0068	0.133 ± 0.0017	15419.84	15443.41
Von Bertalanffy	166.5 ± 0.191	0.1468 ± 0.0009	0.1282 ± 0.0016	15394.41	15417.98
Negative exp	155.8 ± 0.251		0.647 ± 0.0088	20813.76	20831.44

S.E.= Standard Error, AIC = Akaike Information Criterion, BIC = Bayesian Information Criterion

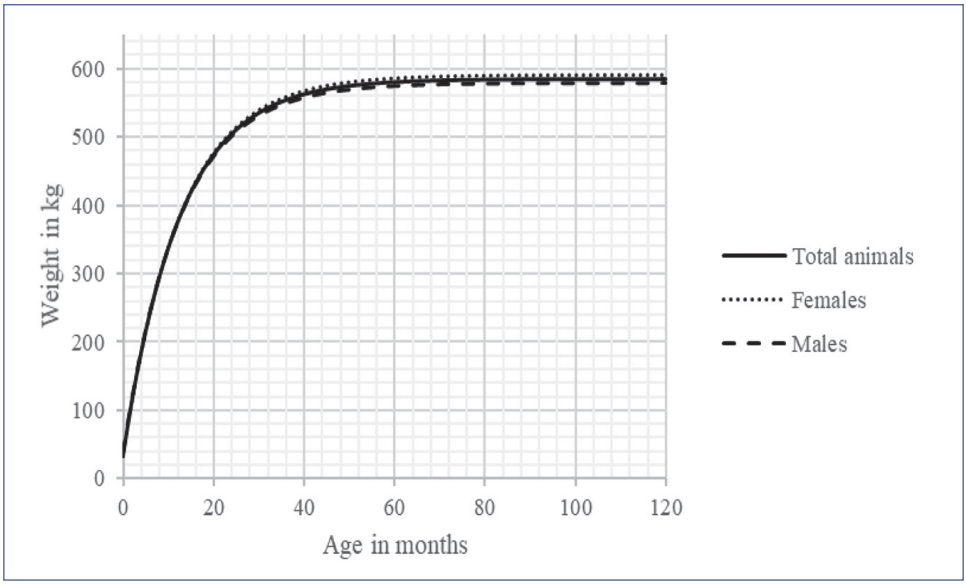


Figure 1. Growth curves in male and female French Saddle horses

weight (a=162.66) than males (a=84.37), while growth acceleration was higher in males (c=0.07) than in females (c=0.021) for the main variable analysed, which was weight. These consistent results may indicate that this growth behaviour, differentiated by sex, is more species-dependent than associated with management, nutrition, or the region where the horses are raised. In another study conducted on Brazilian horses, the best model used the Weibull function, which differs from the present research. However, in that study, the growth curves for males and females were very similar to those in this study, as it is difficult to find a difference between the growth curve trajectories differentiated by sex (Santos et al., 1999).

The results presented here demonstrate a negative correlation between adult weight and growth rate in the Brody model, which is consistent with the results of studies and reviews conducted on horses and other species of productive interest (Agudelo et al., 2007; Onoda et al., 2014; Hossein-Zadeh and Ghorbani, 2018). This could indicate that animals that grow faster generally stop growing more quickly and, consequently, stabilize at a lower adult weight compared to animals that grow more slowly. The parameters estimated using the Brody model for males and females are presented in Table 3.

The growth dynamics observed in Figure 1 demonstrate that there was no difference in growth between the sexes; the inflection point of the curves for weight in kg was reached at 36 months, while for height in cm it was reached at 24 months. Accordingly, weight gain after 24 months is represented by muscle mass gain and fat deposition, not by animal growth. This may be important when training specimens as it indicates that training should begin after two years of age when growth stabilizes in equines. These results can be validated with the findings reported by Agudelo et al. (2007), where they describe the most

Table 3. Growth parameters for male and female French Saddle horses, estimated using the Brody model

Body weight (kg)	Parameters (confidence interval)		
	a (Lower–Upper limit)	*b* (Lower–Upper limit)	*c* (Lower–Upper limit)
Total animals	584.7 (579.811–589.683)	0.941 (0.932–0.949)	0.0802 (0.078–0.082)
Females	591.2 (583.895–598.414)	0.946 (0.934–0.958)	0.0795 (0.0763–0.0827)
Males	579 (572.249–585.668)	0.935 (0.923–0.947)	0.0808 (0.0776–0.0839)
Withers height (cm)	**Parameters (confidence interval)**		
	a (Lower–Upper limit)	*b* (Lower–Upper limit)	*c* (Lower–Upper limit)
Total animals	166.9 (166.484–167.267)	0.388 (0.384–0.392)	0.118 (0.115–0.121)
Females	165.827 (165.149–166.22)	0.384 (0.378–0.389)	0.118 (0.114–0.123)
Males	168 (167.466–168.563)	0.391 (0.386–0.397)	0.117 (0.113–0.121)

important points in the trajectory of the growth curve in animals of zootechnical interest such as the inflection point, precocity, and adult weight.

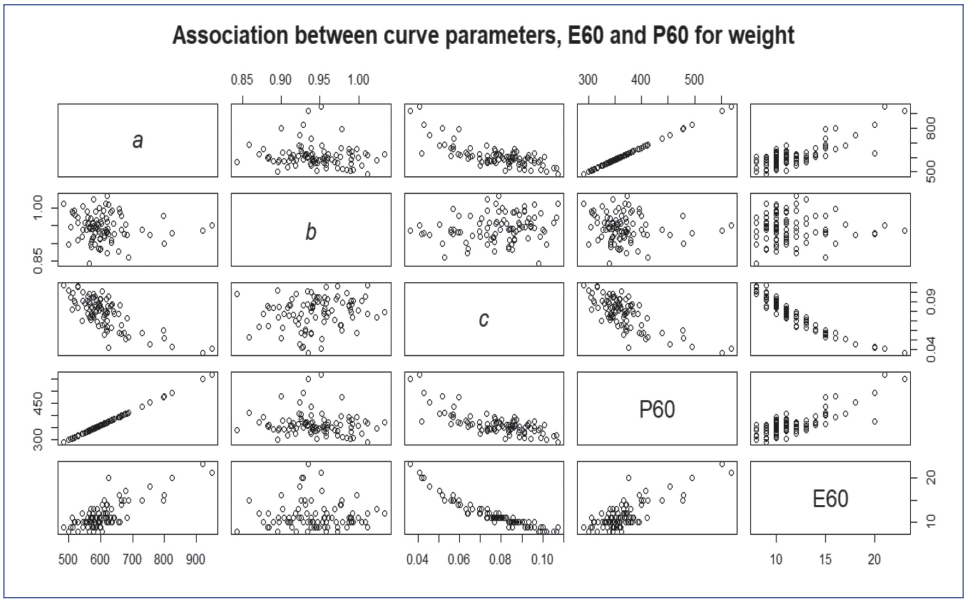
Figure 2 indicates that there is a significant positive correlation between parameter *a* and the weight achieved at 60% maturity of the animal; this suggests that a higher value of this parameter in an animal results in a correspondingly higher adult weight at 60%. The same trend is observed for the height characteristic. Additionally, a negative correlation was found between parameter *c* and the age at which 60% maturity of growth in weight and height is reached, indicating that a higher value of parameter *c* (growth acceleration) results in reaching 60% maturity of animals at a faster rate or at a younger age (Figures 2A and 2C). In this figure, a regression between the age at 60% weight and height vs parameter *c* is also observed differentiated for males and females. Thus, we can infer that there is no difference between the sexes regarding the dynamics of growth acceleration, but there is a difference in growth regarding height, with males having a higher value of parameter c and thereby achieving 60% maturity faster.

Conclusions

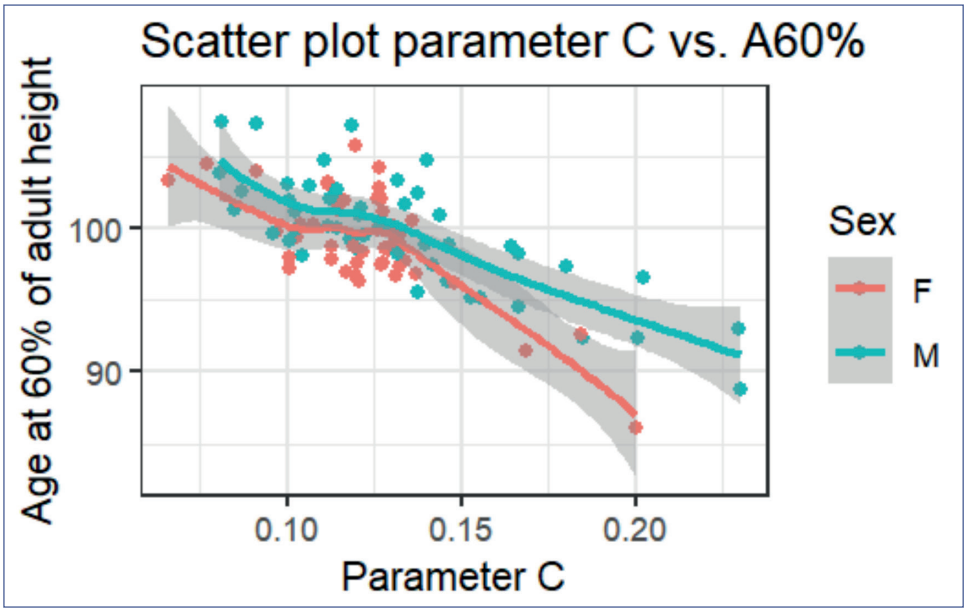
The Brody model is the model that best characterizes the growth curve in French Saddle horses raised in the conditions of the Colombian high tropics.

There was a marked negative correlation between parameter *c* and the maturity of animals with respect to weight and height, and a negative correlation between parameters *a* and *c*, demonstrating that animals with faster growth acceleration achieved lower adult weights, and vice versa.

It can be concluded that there is a significant difference between the sexes regarding height, with males reaching maturity first for this trait under the feeding conditions in place at the production centre. It can be concluded that animals grow in height until 24 months but take an additional year to reach their adult weight. It is important to understand the growth



Figures 2.A



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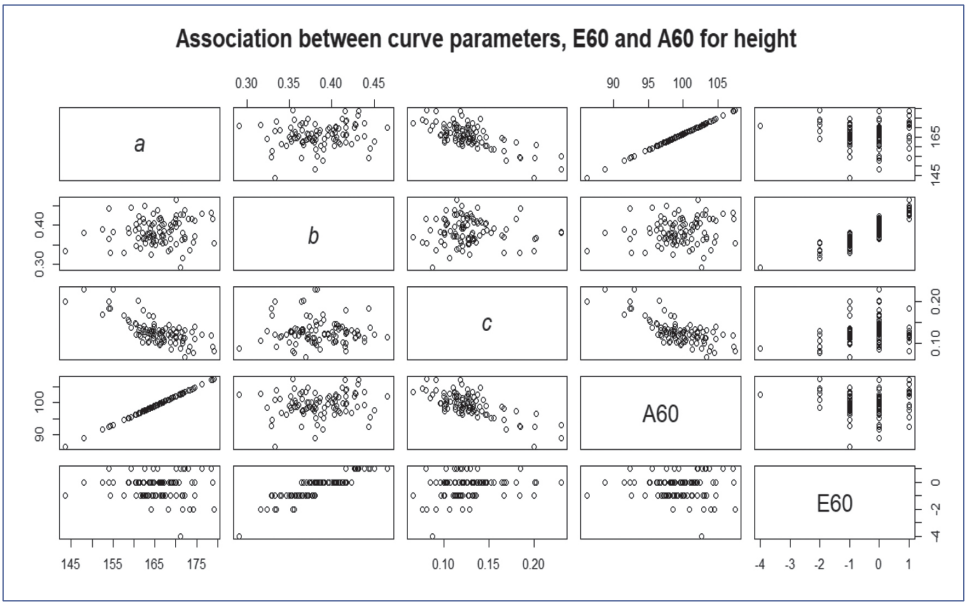

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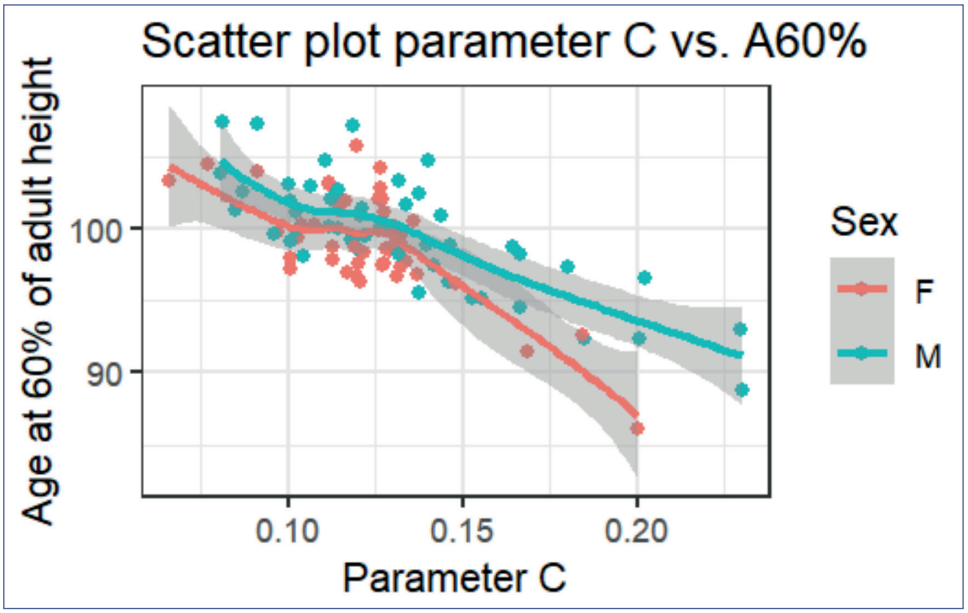

Figures 2.D

Figure 2. Correlation plot between curve parameters, age, and weight at 60% maturity (A), regression plot between age at 60% weight and parameter *c* (B), correlation plot between curve parameters, age, and height at 60% maturity (C), regression plot between age at 60% height and parameter *c* (D); from the growth curves modelled for French Saddle horses

dynamics in horses raised under the conditions of the Colombian high tropics, in order to make the best decisions regarding the start of training for these populations of showjumping horses.

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Karakterizacija rasta francuskih jahaćih konja uporabom nelinearnih modela u tropskom području velike nadmorske visine Kolumbije

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Ovo je istraživanje provedeno s ciljem karakterizacije prosječne krivulje rasta francuskih jahaćih konja u geografskim uvjetima istočne Antioquiae (Kolumbija), uporabom nelinearnih modela. Za postizanje ovog cilja, mjesečno su obavljana mjerenja mase i visine, čime su se dobila 1305 mjerenja koja

su pripadala 49 ženki i 1379 mjerenja koja su pripadala 53 mužjaka francuske jahaće pasmine uzgojenih na farmi za uzgoj konja San Isidro koja se nalazi u La Ceja, Antioquia. Kada se usporede različiti modeli, otkriveno je da Brodyjev model najbolje odgovara podatcima o povećanju mase (AIC=26279,44, BIC=26303,02) i podatcima o povećanju visine (AIC=15346,65, BIC=15370,22) konja uzgojenih na ovoj farmi. Krivulje modeliranja rasta za mužjake i ženke otkrivaju negativan odnos između mase odrasle životinje i stope rasta, a zamijećeno je i da životinje stabiliziraju povećanje svoje mase s oko 36 mjeseci starosti, dok se najveće povećanje visine dostiže u dobi od 24 mjeseca. Glavni zaključak ove studije jest da Brodyjev model najbolje karakterizira krivulju rasta francuskih jahačkih konja uzgojenih u tropskim uvjetima na velikoj nadmorskoj visini u Kolumbiji. U tom smislu, važno je razumjeti dinamiku rasta u konja uzgojenih u tropskim uvjetima na velikoj nadmorskoj visini u Kolumbiji da bi se donijele informirane odluke u svezi početka treniranja za ove populacije konja za preponsko jahanje.

Ključne riječi: *konji za preponsko jahanje, prijevremeni razvoj, masa odrasle životinje, visina, AIC, BIC*