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Research Article
Non-Linear Models to Fit Nelore Calves Growth Curves from 240 to 600 Days in the Bolivian Tropics

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Abstract

Background and Objective: The growth curves are linked to the growth characteristics and evaluation of the genetic potential of the animals. The objective of this work was to evaluate the growth curves of Nelore calves in the rearing stage (from weaning to marketing) in grazing systems raised in the Bolivian tropics. **Materials and Methods:** The adjustability of 5 growth models (Brody, Richards, Von Bertalanffy, Logistic and Gompertz) were evaluated. Retrospective data corresponding to the period between 2000 and 2014, belonging to the Agricultural Technological Center Foundation Bolivia, were used, Santa Cruz, Bolivia. Data corresponding to 109 Nelore-weaned male calves were used. For all calves from weaning (240 days), the individual live weight was obtained every 30 days until reaching 600 days in which they were sold, in all the years analyzed. The Brody and Richard models will not be taken into account since they did not converge. **Results:** The Gompertz, Logistic and Von Bertalanffy models adjusted the weight-age data. With 95% confidence, it can be stated that the asymptotic weight of the calves is between 752.5 and 1194.3 kg according to the Gompertz model, 703.1 and 996.0 kg according to the Logistic model and 796.9 and 1646.9 kg according to the Von Bertalanffy model. In this case, the Logistic model is the one that presented more precise estimates. **Conclusion:** Of the 5 models studied, only the Gompertz, Logistic and Von Bertalanffy models were adequate to describe the evolution in the weight of calves from day 240 after birth to 600 days after birth.

Key words: Nelore calves, birth weight, weaning weight, fattening, grazing system

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The Nelore breed is the most important among bovine breeds for meat production in Bolivia. Proof of this is that 8% of the Bovine population for meat corresponds to pure animals of this breed and 75% to mixed Nelore animals.

The pre-eminence of the breed is explained by its natural adaptability in the face of the challenges of the sub-tropical environment. The Nelore breed was introduced in Bolivia in 1956, being today the bovine breed with the greatest potential for impact, expansion and development within the Santa Cruz cattle herd[1].

The use of Nelore cattle in the production systems of Bolivia constituted an advance for obtaining heavier animals with high daily weight gains at a lower cost, that is, more efficient[2].

In addition to its potential in terms of animal growth, two other important characteristics cannot be omitted, which define the biological fitness of a breed, such as survival capacity and reproductive potential[2].

Selection only for higher weaning calf weight can increase adult weight due to medium to a high genetic correlation between final weight and weight at different ages[3,4].

The analysis of the growth curves of bovines for meat provides important information to be used in several aspects, one of them is for the determination of nutritional requirements, linked to the characteristics of growth and evaluation of the genetic potential of the animals, which collaborate in decision making to adopt a given technology to improve production results[5].

Cow mature weight (CMW) has increased considerably in the last 30 years[6,7]. Selection pressure for faster growth and higher slaughter weights have contributed to this increase in mature cow weight[8]. In general, heavier and larger cows require a higher daily intake than smaller and lighter-weight cows[9]. In studies carried out in different climatic areas, the conclusions differed on which were more efficient, larger cows or smaller cows[7,9,10], suggesting that efficiency is influenced by the environment. Zimmermann *et al.*[8] concluded that the use of the effects of the breed for the mature weight of the cow will depend on the objectives of the system, the management and the reproduction of the resources. Other systems that are very different should not be taken as examples without taking into account the factors mentioned above. For the study of the growth curve in cattle, non-linear models have been used mainly that relate to the weights and ages of the animals[11-13].

The Brody model provides the best fit to describe the growth curves of beef cattle[12,14,15]. However, other papers have also reported studies in which other models fit more satisfactorily to beef cattle data. de Oliveira *et al.*[16] used the Von Bertalanffy model to represent the average growth curve of Nelore cattle. de Andrade Souza *et al.*[13] reported that the Logistics equation presented the best goodness of fit for the growth curve in the Indubrasil breed. The application of the non-linear mathematical model has been carried out in investigations of the growth of beef cattle of the Nellore breed[17].

For this reason, the objective of this work was to evaluate the growth curves of Nelore calves in the rearing stage (from weaning to marketing) in grazing systems raised in the Bolivian tropics. In addition, the adjustment capacity of five growth models was evaluated: de Brody, Richards, Von Bertalanffy, Logistic and Gompertz.

MATERIALS AND METHODS

Study area: Retrospective data corresponding to the period between 01/01/2000 and 31/12/2014, belonging to the Agricultural Technological Center Foundation Bolivia (CETABOL Foundation) in Colonia Okinawa, were used.

The Japanese community is located at 286 m.a.s.l. (meters above sea level) and they present a tropical climate, with significant rainfall in most months of the year and a short dry season with little effect on the general climate.

The establishment is located 17°13'12" south latitude, 62°53'39" west longitude with a height of 286 m above sea level. The climate is tropical, with rain every month of the year, with an average rainfall annual of 1805 and 986 mm. It presents an average annual temperature of 24.3°C, with values of 26.5°C and the lowest in July with records of 20.7°C.

Animals: Data corresponding to 109 Nelore weaned male calves belonging to Agricultural Technological Center Foundation Bolivia (CETABOL Foundation) were used. For all calves from weaning 240 days, the individual live weight was obtained every 30 days until reaching 600 days in which they were sold, in all the years analyzed. The mothers weighed an average of 526.3±18 kg.

Feeding and management: The 82 hectares were used with cultivated pastures and with dry matter production of each of them: Brachiaria humidicola, Brachiaria decumbens, Brachiaria dictyoneura, Panicum maximum cv mombaza and Cynodon dactylon. The management was with a high instantaneous sload in the grazed pastures.

Body weight record: The weight of the calves used in the work was always taken at the same time (8:00 am) closing the night before weighing. The 13 individual weights of each of the calves were obtained. The manual scale brand (POCKET BALANCE, Made in Germany) was used on the day of birth. After two months of age, calves and dams were weighed with an electronic scale (ICONIX New Zealand Limited).

Ethical consideration: This work has the approval of the Ethics and Animal Welfare Committee (CICUAL) and Biosafety of the Faculty of Veterinary Sciences, of the National University of Rosario, Santa Fe, Argentina (Resol. CD 201/2019).

Variables used:

- Days elapsed since the birth of the animal
- Animal weight in kg
- To carry out the work, the following variables were used: Days elapsed since the birth of the animal in days, live weight of the animal in kg

Statistical analysis: The growth curves were as follows:

$$y_t = A\ (1\text{-}be^{-kt})+\varepsilon_t \text{ Brody}$$

$$y_t = Ae^{-be^{-kt}} + \varepsilon_t \text{ Gompertz}$$

$$y_t = \frac{A}{(1+e^{-kt})^m} + \varepsilon_t \text{ Logistic}$$

$$y_t = A\ (1\text{-}be^{-kt})+\varepsilon_t \text{ Richard}$$

$$y_t = A\ (1\text{-}be^{-kt})+\varepsilon_t \text{ Von Bertalanffy}$$

Models were fitted using the Levenberg-Marquardt algorithm[18] for nonlinear least squares. Then, to compare their adjustments, statistical indicators were calculated, such as the mean absolute error (MAE), the prediction error (PE), the Akaike Information Criterion and the mean square error (MSE) and biological indicators such as the rate of instantaneous growth rate (IGR), relative instantaneous growth rate (RIGR), absolute maturation rate (AMR) and inflection point (IP)[19].

To compare the models with a biological criterion, the instantaneous growth rate (IGR), the relative instantaneous growth rate (RIGR), the absolute maturation rate (AMR) and the inflection point (IP) were taken into account.

The instantaneous growth rate (IGR) ($\partial y^t/\partial^t$) estimated the increase in the weight of the animal for each unit of time t, in this case, days. The relative instantaneous growth rate (RIGR) indicator:

$$\left(y^{-1}\frac{\partial y_t}{\partial_t}\right)$$

calculated the increase in the weight of the animal in relation to its weight at a particular moment of time t.

The absolute maturation rate (AMR):

$$\left(A^{-1}\frac{\partial y_t}{\partial_t}\right)$$

represented the increase in the weight of the animal in relation to the asymptotic weight at time t. Finally, the inflection point corresponds to the moment where the instantaneous growth rate changes from growth to decrease, that is, the moment where the greatest increase in the animal's weight occurs how in all models the instantaneous growth rate increased until approximately day 420 and then began to decrease.

The above-mentioned analysis was performed with R 4.0.2 (2020) software.

RESULTS AND DISCUSSION

Success in beef cattle production systems is determined by strategic and efficient production control, such as animal weight development because all production processes are directly related to weight development. Usually, this description is made through growth curves in which the body weight of the animal is related to its age[1,2].

The initial values used were chosen based on the previous work. The Brody and Richard models will not be taken into account since they did not converge. The Table 1 showed that the parameter estimated with their respective 95% confidence intervals for the remaining 3 models and Fig. 1 showed the behavior of the models with respect to the observed values.

The Gompertz, Logistic and Von Bertalanffy models adjusted the weight-age data (Table 1). From the point of view of animal production, asymptotic weight (A) and maturity index (K) are considered the two most important parameters, mainly because heavier cows generally have calves that grow faster, which is desirable in the production of cattle for

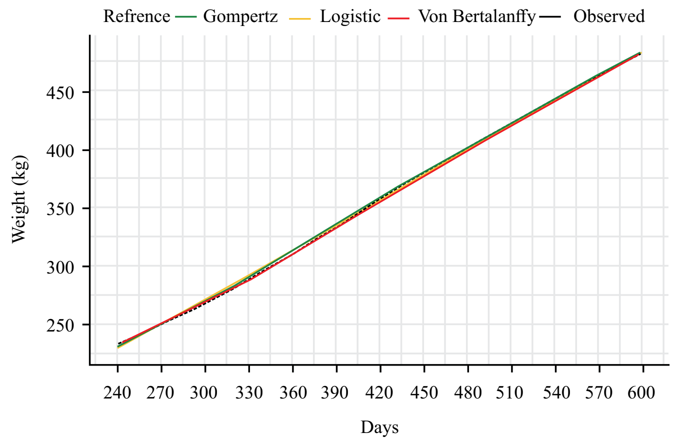

Fig. 1: Weight of calves estimated according to model (kg)

Table 1: Estimates and standard errors of the growth curve parameters: Asymptotic weight (A) in kg, integration constant (b), and maturity rate (K) in (kg/day) for the nonlinear Gompertz models, Logistic and Von Bertalanffy, for Nelore cows

Model	A (kg)	B	K (kg/day)	m
Mean and standard errors±				
Gompertz	973.4±220.9	2.351±0.098	0.002±0.0004	-
Logistic	849.6±146.4	-	0.003±0.0005	3.111±0.106
Von Bertalanffy	1221.9±425.0	0.588±0.024	0.001±0.0004	-

Parameter estimation with 95% confidence intervals±

meat[20]. Asymptotic weight (A) and maturity index (K) are considered the two most important parameters from the point of view of animal production. This is because heavier cows generally raise faster-growing and heavier calves, which is desirable in beef cattle production

On the other hand, Cartwright[21], stated that larger and heavier cows would have high daily maintenance costs, mainly in systems where food is not guaranteed, so this benefit of having a faster and heavier calf at weaning, it could not compensate for the losses due to a higher cost of maintaining the cow.

The Gompertz, Logistic and Von Bertalanffy models (Table 1) for asymptotic weight estimates were superior when compared to other studies carried out with Nelore cows with the Brody and Von Bertalanffy models.

Result can be explained by the fact that in the present study: The results obtained in this study could be explained because of the fact that animals were used animals belonging to a genetic center were used, whereas, since the end of the 1980s, the cooperative has been working with herds of cattle with the aim of providing pure reproducers of Nelore to their associates. The selection criterion in this cooperative was to obtain animals that had high average daily weights that would allow having a calf as heavy as possible at weaning[22].

da Silva Marinho *et al.*[5] used the weights from birth to 750 days of age, therefore, they were unable to estimate adult weight because these animals did not reach maturity. According to Ludwing *et al.*[23], the weights of the animals from birth to adulthood should be evaluated to obtain more precise estimates of the parameters of the nonlinear model. Within the period studied in the work of da Silva Marinho *et al.*[5] using weighing from birth to 750 days of age, the Brody mode resulted in an asymptotic weight estimate (A) that showed a better fit to zebu cattle average of 750 days compared to what was reported in the literature[24].

Somehow when using in this work the weights from weaning to 600 days of age, the same thing happened since the animals did not reach adult weight.

The models present a similar fit between them and a good fit with respect to the observed data as shown in Fig. 1.

With 95% confidence, it can be stated that the asymptotic weight of the calves is between 752.5 and 1194.3 kg according to the Gompertz model, 703.1 and 996.0 kg according to the Logistic model and 796.9 and 1646.9 kg according to the Von Bertalanffy model. In this case, the Logistic model is the one that presented more precise estimates.

To compare the fit of the three models, the prediction error (PE), the mean absolute error (MAE), the Akaike Information Criterion and the mean square error calculated using the "cross-validation" method were considered[25].

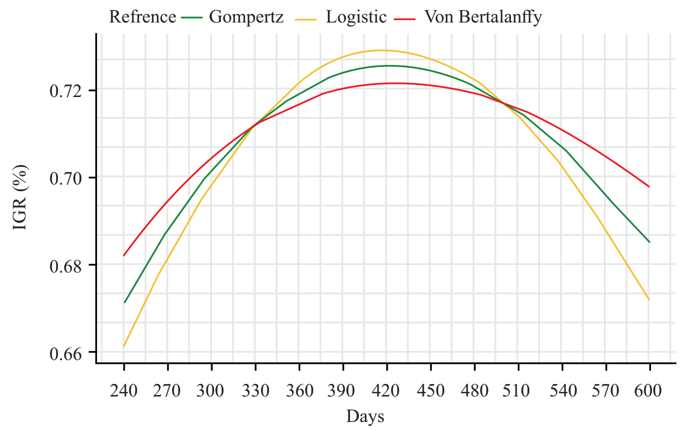

Fig. 2: Instantaneous growth rate (kg/days) according to the model

Table 2: Statistical indicators of the models

Modelo	PE	MAE	AIC	MSE
Gompertz	0.9949	26.9858	14064.55	1195.325
Logistic	0.9946	26.9758	14063.86	1194.760
Von Bertalanffy	0.9962	26.9973	14065.35	1195.988

PE: Prediction error, MAE: Mean absolute error, AIC: Akaike Information Criterion and MSE: Mean square error calculated using the cross-validation method

The prediction error is expressed as the p-value obtained with a mean difference test in paired samples comparing the observed weights with those adjusted by the corresponding model. It is observed that for the three models, the null hypothesis is not rejected, since the p-values are greater than 0.05, which means that there are no significant differences between the observed weights and those predicted by the model. The difference in the values of the mean absolute error, the Akaike information criterion and the mean square error calculated using the cross-validation method, between the 3 models are minimal and not significant, so it is considered that the 3 models show a good fit to the data (Table 2).

In the Logistic model, the instantaneous growth rate reached its maximum at approximately 0.728 kg/day as shown in Fig. 2.

In contrast, for the Gompertz model this value of the instantaneous growth rate showed 0.724 kg/day and for the Von Bertalanffy model the instantaneous growth rate was 0.720 kg/day. The three functions have a similar inflection point, occurring at 423 days for the Gompertz model, at 421 days for the Logistic model and at 428 days for the Von Bertalanffy model, when the weight of the animal reached 358.1, 357.0 and 362.1 kg, respectively.

These results do not coincide with Boligon *et al.*[4], where when using different Brody, Von Bertalanffy, Logistic and Gompertz models to describe the growth curve of Nelore cattle, it was observed that they all converged, although Brody's had the best fit. Also, Rodrigues *et al.*[26] using the Brody, Gompertz, Logistic and Von Bertalanffy function to describe the growth curve of Nelore animals, found a better fit through the model that used the von Bertalanffy function. On the other hand, de Andrade Souza *et al.*[13] fitted the growth curves for animals of the Indubrasil bovine breed and found a better fit for the logistic model, followed by the Gompertz and Von Bertalanffy models. Arango and van Vleck[14] stated that the Brody function, which despite being less sensitive to weight fluctuations, is more suitable for modeling the growth curve of cattle because the results are easier to obtain and interpret.

In the Von Bertalanffy model, the relative instantaneous growth rate (%) represented 0.292% at 240 days after birth and decreased to 0.145% at 600 days (Fig. 3).

For the Gompertz model, the relative instantaneous growth rate (%) was 0.287% on day 240 and 0.142% on day 600 after birth and if the Logistic model is observed, the value of the relative instantaneous growth rate (%) at 240 days it was 0.283% and at day 600 it was 0.139%.

It is observed that the relative instantaneous growth rate behaves in a similar way in the three models and always decreases, the absolute maturation rate is represented and it is observed that this has a similar behavior in the three models, presenting a growth until reaching its maximum on day 420 and then decreasing slightly, but they differ in the magnitudes that it takes absolute maturation rate. In the

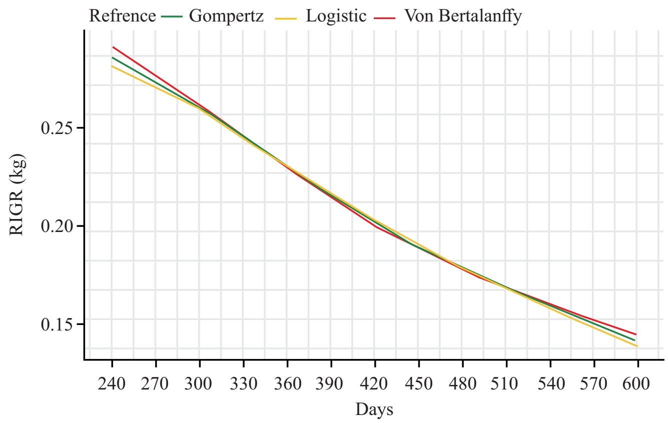

Fig. 3: Relative instantaneous growth rate (%) according to the model

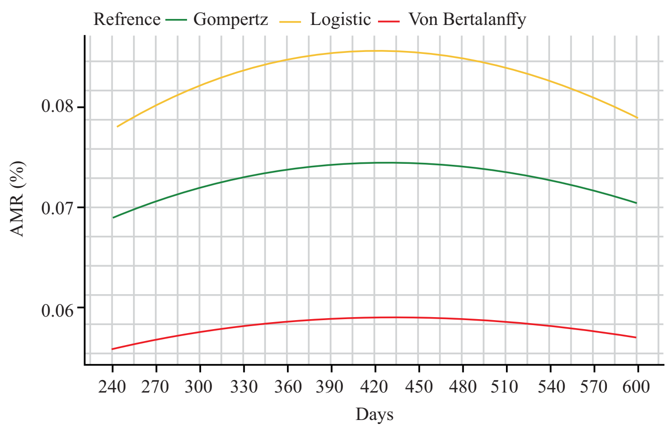

Fig. 4: Absolute maturation rate according to the model

Logistic model, the absolute maturation rate reaches its maximum value of 0.086, for the Gompertz model this value is 0.074% and in the Von Bertalanffy model its maximum occurs at 0.059% as shown in Fig. 4.

The biological analyzes provide greater clarity and precision to the criteria to use only statistics to understand and compare the different non-linear functions to describe the growth curves. The growth curve of the Nellore cows could be analyzed by the three non-linear models, from weaning to 600 days of age. In this case, the Logistic model is the one that presented more precise estimates.

CONCLUSION

Of the 5 models studied, only the Gompertz, Logistic and Von Bertalanffy models were adequate to describe the evolution in the weight of calves from day 240 after birth to 600 days after birth. These results allow real and original values to be used as a basis for determining the nutritional requirements of Nellore calves.

SIGNIFICANCE STATEMENT

There are scientific data published regarding the investigation of Nellore calves' growth curves in Bolivia. It is considered that the data will contribute to the academic study of the Nellore breed and its behavior in the Bolivian subtropics. Furthermore, the data analyzed using various models. Of the five models studied, only the Gompertz, Logistic and Von Bertalanffy models were adequate to describe the evolution in the weight of calves from day 240 after birth to 600 days after birth.

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