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ANGONE BOVINE GROWTH PATTERN ASSESSED BY NONLINEAR MODELS

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ABSTRAK

Studi tentang perkembangan dan pertumbuhan sapi dari lahir sampai pemotongan memungkinkan identifikasi individu mudanya. Penelitian ini bertujuan untuk mengidentifikasi model non-linier yang paling sesuai untuk menggambarkan kurva pertumbuhan sapi Angone. Data pengukuran bobot hidup dalam rentang dari lahir sampai usia 720 hari dari 47 hewan digunakan. Model non-linier yang dievaluasi adalah Gompertz, Von Bertalanffy, Logistic dan Brody. Kecocokan model dibandingkan dengan menggunakan: koefisien determinasi, koefisien determinasi yang disesuaikan, kriteria informasi Akaike dan Bayesian dan mean square error *sebagai kriteria statistik, dan kriteria biologis laju pertumbuhan sesaat dan titik belok. Berat asimtotik yang lebih tinggi (A) diamati untuk model Brody (157,5 kg) dan perilaku terbalik diamati untuk tingkat pematangan (K) dengan nilai mulai dari 0,002 kg/hari hingga 0,005 kg/hari. Hal ini menunjukkan prekositas yang lebih rendah dari kelompok yang dievaluasi. Perilaku yang didukung oleh tingkat pertumbuhan seketika di mana kenaikan 0,030 kg/hari diamati untuk model Gompertz, 0,100 kg/hari untuk model Logistik, 0,127 kg/hari untuk model Brody dan 0,168 kg/hari untuk model Von Bertalanffy. Model Brody memberikan kesesuaian yang lebih baik.*

Keeywords: Berat badan dewasa, Pertumbuhan sesaat, Prekoksitas, Regresi nonlinier, Ternak Sapi

ABSTRACT

The study of the development and growth of cattle from birth to slaughter allows the identification of early individuals. The objective of this study was to identify the non-linear model with the best fit to describe the growth curve of Angone cattle. Data of live weight measurements in the range from birth to 720 days of age of 47 animals were used. The evaluated non-linear models were Gompertz, Von Bertalanffy, Logistic and Brody. The model fitness was compared using the: coefficient of determination, adjusted coefficient of determination, Akaike and Bayesian information criteria and mean square error as statistical criteria, and biological criteria the instantaneous growth rate and inflection point. Higher asymptotic weight (A) was observed for the Brody model (157.5 kg) and inverse behavior was observed for the maturing rate (K) with values ranging from 0.002 kg/day to 0.005 kg/day, demonstrating lower precocity of the evaluated group. Behavior supported by the instantaneous growth rate where gains of 0.030 kg/day were observed for the Gompertz model, 0.100 kg/day for the Logistic model, 0.127 kg/day for the Brody model and 0.168 kg/day for the Von Bertalanffy model. The Brody model provides better goodness of fit.

Keywords: Adult weight, Instantaneous growth, Precocity, Nonlinear regression, Beef cattle

INTRODUCTION

In Mozambique, the production of beef cattle is carried out mostly in a traditional extensive system, based on native breeds such as Angone cattle that has high adaptability to extreme conditions and survival at low feeding levels (Capaina, 2020). This adaptation is due to the fact that these breeds are reared from their origin under natural conditions and with a low level of artificial selection (Mwai *et al*., 2015).

Adverse environmental conditions, food and nutrition, matrix age, race, gender, time of birth, location and geography of the region are growth conditioners; among these factors, nutrition plays an important role in all stages of the animal's life (Pimentel *et al*., 2017).

The study of the development of animals from birth to weaning to slaughter is essential to identify individuals with high precocity (Oliveira *et al*., 2013). Several studies show that the body growth of most animal species can be represented by a sigmoid curve (Carneiro *et al*., 2014; Teleken *et al*., 2017; Rodrigues *et al*., 2018).

However, for the determination of adequate management and breeding programs, it is indispensable to study the growth of animals, this makes it possible to identify early animals in the herd (Santana, 2013). In breeding programs, the evaluation of growth curves can lead to improvements in productive efficiency (Da Paz *et al*., 2018).

Nonlinear models make it easy to deal with a set of data such as weight at various ages (Saghi *et al*., 2012; Crispim *et al*., 2015). These models provide parsimonious adjustments, thus making it simpler to study the weight of animals, the speed of growth and critical points of changes in speed and growth rate (Souza *et al*., 2010; Silva *et al*., 2011).

However, intrinsic factors such as animal genetics and extrinsic factors related to the environment in which they are inserted influence the variation in animal growth; therefore, it is important to emphasize that each population or breed has its specific growth characteristics, and it is essential to test the nonlinear regression models in the breed concerned to find the best fit (Dominguez-Viveros *et al*., 2020).

In the literature there are several studies that addressed the growth curves of cattle (Souza *et al*., 2010; Silva *et al.,* 2011; Marinho *et al*., 2013; De Oliveira *et al*., 2013; Carneiro *et al*., 2014; Pereira *et al*., 2016; Widyas *et al*., 2018). However, there are groups of animal populations that have not been characterized in detail, following the example of local Angone beef cattle. With this, one cannot adjust the growth curves of the Angone Bovine based on a study done in another breed and region, because each breed has a specific growth behavior.

Thus, the aim of this study was to evaluate the growth of Angone Beef Cattle through nonlinear regression models and identify the model that best describes the growth pattern.

MATERIAL AND METHOD

Description of the Study Area and Data Collection

The District of Angonia is located in the north-northeast end of Tete Province, being limited to the north, northeast and east by Malawi, to the south by the district of Tsangano and to the Northwest by the district of Macanga. Angonia is characterized by the predominance of a humid tropical climate, the average annual temperature to be around 18ºC to 22ºC and relative humidity of 70 % (MAE, 2014).

A total of 47 animals born between 2007 and 2010 reared in a semi-intensive system were analyzed. Age-weight data were used from birth to 720 days of age of Angone cattle supplied by the Zootechnical Station of Angonia - Tete. The animals were weighed at approximately 1-month intervals, totaling twenty-five weight records per animal.

Adjusted Models

The properties associated with the non-linear models used in the present study (Table 1) and the parameters of the models were estimated by the iterative Gauss-Newton procedures, adopting the criterion of 10^{-8} convergence (Hartley, 1961).

In the mathematical expressions y_t represents the weight of animal at a given age (*t*); parameter *A* is asymptotic weight if $t \to \infty$; when the adult weight of the animal is not reached, this reflects in an estimate of the weight of the last weighings; *B*, is a constant without biological interpretation, but it is important to model the sigmoidal format of the growth curve from birth (t = 0) until the adult age of the animal ($t \to \infty$).

K is interpreted as maturity index, which expresses the ratio of the maximum growth rate in relation to the adult size, where lower *k* values indicate delayed maturities and higher *k* values indicate accelerated maturity, *e is* the natural base logarithm; the *L* parameter has no biological meaning, but together with K constitutes *b*, which has the function of modeling the sigmoidal curve; and ε represents the random error associated with each weighing.

Table 1: Nonlinear function used for modeling the growth curves

Model	Function
Brody	$Y=A(1-\beta e^{-kt})+\varepsilon$
Von Bertalanffy	$Y=A(1-\beta e^{-kt})^3+\varepsilon$
[a] Logistic	$Y=A/(1+\beta e^{-kt})+\varepsilon$
Gompertz	$Y=Ae^{-\beta e^{-kt}}+\varepsilon$

Source: Adapted from Gotuzzo (2018) and [a]Santana (2013).

To compare the non-linear models for goodness of fit, the statistical or mathematical criteria and biological interpretation of the parameters were used (Ribeiro, 2014; Ferreira *et al*., 2019). The statistical criteria were: coefficient of determination (R^2), mean square error (MSE), Akaike information criterion (AIC), Bayesian information criterion (BIC), and adjusted coefficient of determination (R^2_{aj}).

The following were assessed for the biological interpretation of the parameters: instantaneous growth rate and inflection point presented respectively in tables 2 and 3. All procedures were performed in the statistical environment R Core Team (2020).

Table 2: Function used for the instantaneous growth rate evaluation

Models	Instant growth rate
Brody	$abke^{-kt}$
Von Bertalanffy	$3abke^{-kt}(1-be^{-kt})^2$
Logistic	$2kye^{-kt}/(1+e^{-kt})$
Gompertz	$bkye^{-kt}$

Source: Pereira *et al*. (2016)

RESULT AND DISCUSSION

Parameters Estimated by Models

The estimates of the parameters of the nonlinear models evaluated used in the prediction of growth curves considering the mean of the data, for each model are presented in table 4. From the zoo technical point, asymptotic weight (A) and growth rate (K) are considered the two most important parameters, because they have biological interpretation and help in the identification of earlier animals for production characteristics and economic importance (Coutinho, 2014; Lopes *et al*., 2011).

Parameter A represents the estimation of the asymptotic weight (weight to maturity), which can be interpreted as adult weight of the Bovine or average weight at the maturity of the animal. The results presented in table 4 indicate that the Brody model presented the highest values for parameter A and the

Table 3: Biological interpretation parameters used for modeling the growth curves

Models	**Age at inflection point (days)**	**Weight at inflection point (Kg)**
Brody	*--	*--
Von Bertalanffy	ln(3b)/k	8A/27
Logistic	ln(b)/k	A/e
Gompertz	-ln(1/b)/k	A/2

*The tipping point for Brody's model is the birth weight itself.
Source: Gotuzzo (2018)

Table 4: Estimates and standard error of the parameters (A, B, K) of the models evaluated in the description of the growth curves of the Angone Bovine

Models	**Parameters**		
	A (kg)	**B**	**K (kg/day)**
Brody	157.50 ± 9.18	0.83 ± 0.01	0.001983 ± 0.0002631
Von Bertalanffy	142.50 ± 6.73	0.41 ± 0.01	0.003142 ± 0.0003587
Logistic	131.70 ± 5.27	1.04 ± 0.08	0.005324 ± 0.0005641
Gompertz	138.50 ± 6.17	0.40 ± 0.04	0.003701 ± 0.0004089

*Asymptotic weight (A), efficient insertion c (B) and maturation rate (K)
Source: The authors (2021)

animal. The results presented in table 4 indicate that the Brody model presented the highest values for parameter A and the Logistic model presented the lowest value, thus representing higher adult predicted values of Angone Cattle for Brody model in relation to the Logistic model.

The same was observed in studies involving Caracu females, were the values estimated for the parameter A was 514.6

kg, 488.3 kg, 480.4 kg and 473.9 kg for the Brody, Von Bertalanffy, Gompertz and Logistic models respectively (Moreira *et al*., 2014); in Angus cattle, Brody model (1242 kg), Von Bertalanffy (660.0717 kg), Gompertz (597.8022 kg) and Logistic (521.9071 kg) (De Oliveira *et al*., 2018); in crossbred dairy females, the highest value was verified in Brody model (1982 kg), followed by Von Bertalanffy (550.5 kg), Gompertz (497.7 kg) and Logistic (405.2 kg) (Pereira *et al*., 2016), although these present higher values than those observed in the present study.

These differences between several studies existing in the literature may be associated with the different growth patterns of the animals involved, type of food management, production system and computational ease of each model.

The weight to maturity observed (720 days of age) in the animals evaluated was 147.53 kg and, comparisons made with estimates of the asymptotic weight presented in table 4, indicate that the Brody model overestimated the weight of the observed maturity, while the other models underestimated, and the Von Bertalanffy model with closer values.

The growth rate represented by the Parameter K (maturity rate) is an indicator of the speed with which the animal approaches its adult size (Drumond *et al*., 2013; Giese, 2015; De Jesus *et al*., 2019). It is of great importance in breeding programs for example of cattle, because the faster the bovine grows, the shorter the time interval for it to reach adulthood and, with this, it is possible to reduce feeding costs, reduce the generation intervals, and consequently increase the genetic gain with each generation (Drumond *et al*., 2013).

The estimate of the K parameter presented in table 4 indicates that the highest growth rate was verified in the Logistic and Gompertz models, and the lowest growth was observed in the Von Bertalanffy and Brody models, respectively; this in practical terms may mean that in the Logistic and Gompertz models the Angone Bovine reaches the adult weight faster and does not mean that they have higher adult weights.

For the Brody and Von Bertalanffy models, it is observed that the animals will take longer to reach adult weight compared to the previous models (table 4). This phenomenon indicates longer permanence of these animals in the herd and higher adult weights achieved, generating higher expenses. It was observed that for the evaluated group, k estimates were low, thus generally indicating lower growth rate of animals and that this genetic group can be considered with non-early growth pattern.

However, it is important to note the influence of feeding on animal growth and development, which may probably have been a factor of greater impact for observed results, since the evaluated animals were mostly reared in low-quality native pastures. It is important that this factor be considered in future studies, for better evaluation, as well as in other populations in the same breed and in different breeding system.

The present result corroborates those verified by Pereira *et al*. (2016) in crossbred dairy females, and by Santana (2013) when studying growth curves for beef cattle. Controversies were pointed out by Espigolan *et al*. (2013), of which the lowest estimate of parameter K was observed for the von Bertalanffy model (0.00180 kg/day), followed by Brody (0.00212 kg/day), Gompertz (0.00255 kg/day) and Logistic (0.00478 kg/day).

According to Souza *et al*. (2010); Santana (2013) and Falcão *et al*. (2015) the higher the K value, the higher the growth rate of the animal, presenting early maturity in relation to animals with lower K value and similar initial weight, because they develop faster in relation to animals with lower K values and similar initial weight, which reduces the production cycle and economic return.

It was found that all models overestimated birth weights and underestimated weight at 720 days of age. In the results presented in Table 4, it is possible to note that, as the asymptotic weight increases, there is a decrease in the maturity rate, thus indicating a relationship between the 2 parameters of the greatest zoo technical interest in the study of growth curves in animal production.

This behavior indicates that heavier animals in adulthood have lower growth rate. Although animals with higher K value have higher growth rate, it is not indicative of having higher weights at maturity, and that, rather, animals with lower estimates of K have higher possibilities of presenting higher values of A, and due to the longer they remain in the herd to reach adult weight compared to animals with higher growth rate.

Choosing the Best Model

Statistical Criteria

The results of the statistical criteria used to select the function or functions that best described the adjusted growth data are show in table 5. The results obtained for the coefficient of determination indicate that it was higher in the Brody model (0.99), followed by von Bertalanffy (0.98), Gompertz (0.98) and Logistic (0.97). For the adjusted coefficient of determination (R^2_{aj}), they indicated similarity between the models, and the Brody model (0.99) presented the highest value and the best fit and would be the most recommended to describe the growth of Angone Cattle, if this parameter was taken into account in isolation.

However, considering the other parameters (AIC and BIC), it was observed that the Brody model presented lower estimates for both criteria. Moreover, it was the model that presented the lowest estimate of the MSE (Table 5).

Considering only the statistical or mathematical criteria above, the Brody model presented the best fit, followed by von Bertalanffy and Gompertz models, different from logistic, which was less adjusted to the data.

Similar results to the present study were observed by Alves (2016), when studying the growth of Guzerá cattle through mixed nonlinear models where the Brody model had the best fit, using the criteria R^2, AIC and BIC. The same was verified by De Oliveira *et al*. (2018) in Angus, Lopes *et al*. (2016) in Nelore and Coutinho (2014) in growth curves of carcass characteristics in Nellore cattle.

Table 5: Results of the fit quality evaluators for the models evaluated in the description of the growth curves of Angone Bovine

Models	Fit Quality Evaluators				
	R^2	R^2_{aj}	AIC	BIC	QMR
Brody	0.99	0.99	139.38	144.25	12.74
Von Bertalanffy	0.98	0.98	148.97	153.85	18.71
Logistic	0.97	0.97	161.19	166.06	30.49
Gompertz	0.98	0.98	152.74	157.62	21.75

*Coefficient of determination (R^2), adjusted coefficient of determination (R^2_{aj}), Akaike information criterion (AIC), Bayesian information criterion (BIC), and mean square error (MSE).
Source: Prepared by the authors (2021)

Biological Criteria

Instant growth rate

The estimates of instantaneous growth rates (IGR) is shows in figure 1. According to the results, it is possible to verify that the Logistic and Gompertz models presented the maximum point of weight gains at the same age (150 days), thus indicating that these two models presented similar behavior.

Moreover, it was found that the longest growth period of the evaluated group occurred in the first year of life, with gains greater than 0.168 kg/day for the Von Bertalanffy model; 0.127 kg/day for the Brody model; 0.100 kg/day for the Logistic model and 0.030 kg/day for the Gompertz model, and the lowest growth was verified from 500 days of age in all models evaluated. These results confirm the fact that younger animals tend to have higher growth rates compared to more mature animals (Echeverri, 2011).

The results of the instantaneous growth rate (IGR) observed in Figure 1 indicate that weight gains started in the order of 0.02789 kg/day for the Gompertz model and grew until reaching average gains of 0.05379 kg/day at 150 days of age, and subsequently there was a decrease up to 720 days with average gains of 0.01319 kg/day.

Weight gains for the Logistic model started with a rate of 0.10025 kg/day until reaching a maximum of around 0.20909 kg/day in the average time of 150 days of age and subsequently there was a decreasing behavior up to 720 days of age with average gains of 0.02884 kg/day.

For the Von Bertalanffy model, gains in initial weights of 0.32 kg/day were observed increasingly until reaching a maximum of 0.32973 at approximately 30 days of age and later a decrease until reaching 0.05664 kg/day at 720 days of age (Figure 1). The Brody model presented initial average gains of 0.25995 kg/day and was automatically decreasing until reaching a minimum of 0.06235 kg/day in the meantime of 720 days of age.

With these results it is possible to estimate the initial weight gains per month in the following order: Gompertz (0.83669 kg/month), Logistics (3.00749 kg/month), Brody (7.79838 kg/month) and Von Bertalanffy (9.72402 kg/month).

It is observed that the Logistic, Brody and Von Bertalanffy models were able to describe the increase in body weight and, however, the Gompertz model was inadequate for this purpose, underestimating the increase in body weight for Angone cattle. This indicates that three (03) of the four (04) models analyzed in the present study can be satisfactorily used to describe the growth pattern of this evaluated group.

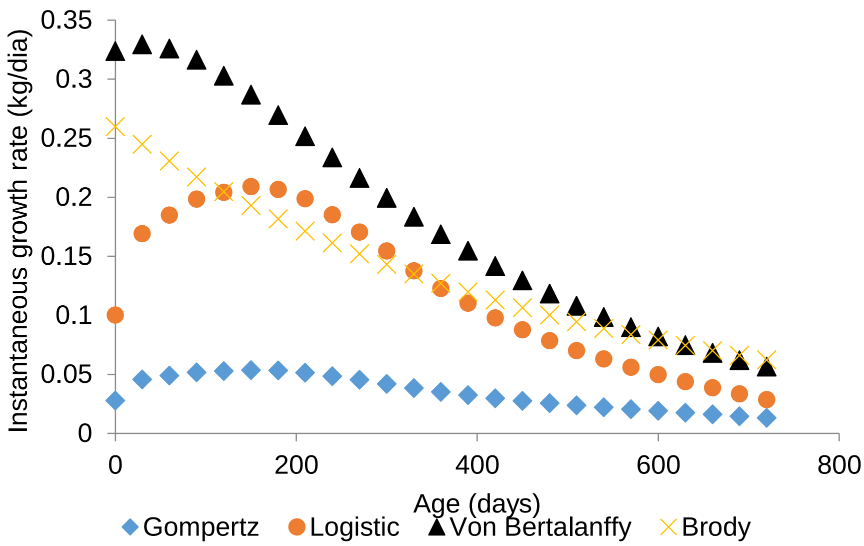

Figure 1: Instantaneous growth rate (CIT) estimated by the evaluated models
Source: The author (2021)

Knowing the moment (weight or age) when there is a reduction in the muscle growth of the animal, which usually coincides with puberty, is extremely important. When there is a reduction in this growth, there is an increase in adipose tissue in the body, since the nutrients ingested are directed to fat formation. This phenomenon causes increased production costs, and when in excess, causes the devaluation of the product (Silva, 2011). The IGR is used to emphasize of accelerated and retarded growth, and thus can help the animal's nutritional management (Souza Junior, 2013).

Inflection Point

The results referring to this criterion are presented in table 6 and the estimates of age at the inflection point (IP) indicate that the Gompertz model was not able to determine this age. This probably occurred, because in the Gompertz model the equations have fixed IP (Souza Júnior, 2013).

The Von Bertalanffy and Logistic models were able to determine age at the tipping point, but only the Von Bertalanffy model was suitable for this purpose. Because, by the Logistic model it would be inappropriate to conclude that the weight of 48.45 kg was reached at 6 days of age and taking into account the IGRs presented for this model, they demonstrated that the maximum rates of average gains were reached at the mean age of 150 days, contrary to the results of the IP calculations.

The Brody model showed regrowth after birth. This is because, according to Giese (2015), in Brody's function the IP coincides with the birth, that is, it is a derivation of the Richards function, in which the parameter that forms the curve (m) in the Brody m model is equal to 1, resulting in a non-sigmoid curve. Thus, the same author had similar results to the present study, which, in both sexes, verified a phase of self-deceleration of growth that occurs after birth, which represents the inflection point.

In view of these results, it can be said that only the Brody, Gompertz and Von Bertalanffy models were adequate to describe the IP of Angone Cattle, and the Logistic model was inadequate, and its use was discarded for this purpose in this evaluated population.

The inflection point of nonlinear models is important information for the researcher, because they increase the inference about production over time, thus determining when growth is faster (Eloy, 2018). From this point that there is a decrease in the growth rate due to a series of physiological factors that progressively instill growth, although the animal does not cease to grow until it reaches maturity (SOUZA *et al*., 2010).

Table 6. Estimation of weight and age at the inflection point (PI) for the models evaluated in the description of the growth curves of Angone Cattle

Model	Age at inflection point (days)	Weight at inflection point (Kg)
Brody	--	--
Von Bertalanffy	63,39	42,22
Logistic	6,46	48,45
Gompertz	-247,44	69,25

This parameter is also important because it helps in choosing the best slaughter age at the best cost and benefit and in specific food programs; nutritional strategies for the post-weaning phase can minimize the meal change effects in this phase and minimize the sharp decrease in ICT in post-weaning.

Based on statistical and biological criteria, the best models that described the growth pattern of this racial group were the Brody, Von Bertalanffy and Gompertz models; and having Brody model presented better fit. Similar results to those of the present study were pointed to different rearing conditions (Dominguez-Viveros *et al*., 2013; Marinho *et al*., 2013) and racial proportions (De Lima *et al*., 2011; Dominguez-Viveros *et al*., 2020).

However, other studies have pointed out different results from the present study, such as for Nellore cattle from northern Brazil (Lopes *et al.,* 2011; Lopes *et al*., 2012), in Siboney cows (Dominguez-Viveros *et al*., 2019) and crossed dairy cows in different proportions (Velez *et al.*, 2019) the Von Bertalanffy model was the best fit to describe the growth of the populations analyzed.

In Zebu de Cuba cattle (Dominguez-Viveros et al., 2017), in Indubrasil cattle reared in the State of Sergipe (Souza *et al*., 2010) and Indubrasil cattle from northeastern Brazil (from Andrade *et al*., 2010), the growth curves were sigmoid, but described by the Logistic model.

It is possible to notice contradictory results in the literature, of course this may be due to various factors such as race and population structure, especially with regard to the maturation rate; sex of animals; food handling; environmental conditions; sampling and statistical methods. All these factors can affect the shape of the growth curve and its parameters (Freetly et al., 2011; Selvaggi *et al*., 2015).

Therefore, it is necessary to carry out studies considering the peculiarity of each breed created under different environmental conditions, application of different methods and models to compare with the results of this work, such as the application of Bayesian inference considering a hierarchical model in several stages in order to contemplate the simultaneous estimation of the parameters and genetic and environmental factors that act on them.

CONCLUSION

The Brody, Von Bertalanffy and Gompertz models were adequate to describe the growth of Angone Cattle; however, the Brody model presented the best fit for growth data in the evaluated population group.

Lower values were found for the asymptotic index, proving that Angone cattle are late animals. Higher growth rates were observed in the first year of life, with logistic, Brody and Von Bertalanffy models best described as body weight increase. In addition, the Brody, Gompertz and Von Bertalanffy models were adequate to describe the point of maximum growth rate of Angone Bovine.

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