Journal of Agriculture and Rural Development in the Tropics and Subtropics
Vol. 124 No. 1 (2023) 77–82

https://doi.org/10.17170/kobra-202306128204 ISSN: 2363-6033 (online); 1612-9830 (print) – website: www.jarts.info

Estimation of growth parameters in Brahman cattle from Mexico

Joel Dominguez-Viveros

Facultad de Zootecnia y Ecología, Universidad Autónoma de Chihuahua, Mexico

Abstract

The objectives were to evaluate non-linear models (NLM) to define the growth curve of Brahman cattle in Mexico. The database was derived from weight development control, with live weight measurements (150,932 in females and 286,804 in males) taken in the interval from birth to 1095 days of age. Four NLM were evaluated: Brody, Bertalanffy, Gompertz and Logistic. The selection of the NLM with the best adjustment was made based on the Akaike and Bayesian information criteria. Growth parameters were generated: adult weight (AW), growth rate (GR), correlation (Υ) between AW and GR, age and weight at the inflection point, evolution of live weight (as a percentage of adult weight), maturity level, daily growth rate (DGR; kg day^{-1}). The model with the best fit was Brody, followed by Bertalanffy. For AW, the average value was 787.2 kg for males and 592.1 kg for females; for GR, the average values (%) were 0.28 for males and 0.25 for females. All Υ were less than −0.90. The DGR, for males presented values in the range of 0.347 to 0.786 and a mean of 0.537; for females, the mean was 0.424 with values in the range of 0.274 to 0.620. Heifers at 15 months of age reach an average weight of 287 kg, representing 57.7 % of the adult weight. The growth analysis shows the response and/or adaptation to tropical livestock, based on a growth curve with a constant growth rate and no inflection point.

Keywords: tropical livestock, *Bos indicus*, nonlinear models, weight gain, Zebu cattle

1 Introduction

The Brahman breed, in the context of Zebu cattle, developed in the United States from the crossbreeding of the Gyr, Guzerat, and Nelore breeds (Sanders, 1980). Brahman cattle arrived in Mexico in the 1920s and distributed within tropical regions under grazing-based production systems. The genealogical and productive record dates from 1962 (AMCC, 2019); the productive record is derived from the weight development control (AMCC, 2000), where the affiliated breeders weigh periodically and record the live weight data at different ages, generating a distribution of points over time that allows growth to be analyzed. Animal growth, the product of live weight variation over time, has been approached with nonlinear regression analysis and nonlinear models (NLM). The regression coefficients that make up the NLM, their combinations, as well as the mathematical derivatives, generate a series of growth parameters with biological interpretation that are used in the design of feeding, management, and genetic improvement schemes (France *et al.*, 1996; Agudelo *et al.* 2008; Teleken *et al.*, 2017). The evolution of growth, the product of genetic and environmental effects, causes diversity in the growth curves and their components (Arango and Van Vleck, 2002; Alemneh and Getabalew, 2019), generating for each population a growth pattern with its own characteristics; therefore, in various populations of Zebu cattle, studies have been carried out to define the growth curve and its components (Nunes *et al.*, 2000; Regis *et al.*, 2005; de Andrade *et al.*, 2010; da Silva *et al.*, 2013; Souza *et al.*, 2014; Karim *et al.*, 2019; Lopes *et al.*, 2016; Domínguez-Viveros *et al.*, 2017; Domínguez-Viveros *et al.*, 2020).

The analysis of growth curves makes it possible to identify areas in the production system or life cycle that could be the object of strategic changes aimed at improving production efficiency (López *et al.*, 1992; Menchaca *et al.*, 1996). For the Brahman cattle, the growth analysis shows the response and/or adaptation of tropical livestock. The objectives of this study were to evaluate NLM to define the growth curve, as well as its growth parameters, which define the growth pattern of Brahman cattle in Mexico.

* Corresponding author: jodominguez@uach.mx

Published online: 4 July 2023 – Received: 12 January 2023 – Accepted: 26 June 2023

Table 1: *Nonlinear models and growth parameters evaluated in Brahman cattle.*

Model	*Equation*	*DM*	*DGR*
Logistic	$\hat{y}_i = \beta_1 / (1 + \beta_2$*(exp($-\beta_3$*t))) + ϵ_i	$1/(1+\beta_2 * \epsilon^{\beta_3 (t)})$	$\beta_3 * \hat{y}_i * (1 - (\hat{y}_i/\beta_1))$
Bertalanffy	$\hat{y}_i = \beta_1$ * ((1 − β_2*(exp($-\beta_3$*t))**3) + ϵ_i	$(1-\beta_2 * \epsilon^{-\beta_3 (t)})^3$	$3\beta_3 * \hat{y}_i * (((\hat{y}_i/\beta_1)^{-1/3})-1)$
Gompertz	$\hat{y}_i = \beta_1$ * (exp(− β_2*(exp($-\beta_3$*t)))) + ϵ_i	$\epsilon^{-\beta_2}(\epsilon^{(-\beta_3 * t)})$	$\beta_3 * \hat{y}_i * (\ln(\hat{y}_i/\beta_1)^{-1})$
Brody	$\hat{y}_i = \beta_1$ * (1 − β_2*(exp($-\beta_3$*t))) + ϵ_i	$(1-\beta_2 * \epsilon^{-\beta_3 (t)})$	$\beta_3 * \beta_1 * (1 - (\hat{y}_i/\beta_1))$

Note: $\hat{y}_i$ = live weight in kg, measured at time t. Regression coefficients: $\beta_1, \beta_2, \beta_3$. DM, degree of maturity. DGR, rate of growth.

2 Materials and methods

The database was derived from the weight development control (AMCC, 2000), with live weight measurements (150,932 in females and 286,804 in males) taken in the interval from birth weight to 1095 days of age. Four NLM were evaluated (Agudelo *et al.*, 2008; Agudelo-Gómez *et al.*, 2009; Lopes *et al.*, 2016): Brody, Bertalanffy, Gompertz, and Logistic; all made up of three regression coefficients (β_1, β_2, β_3), which are described in Table 1.

The analyses were carried out by sex with the NLIN procedure of the SAS statistical analysis program (SAS, 2001). The selection of the NLM with the best fit was made based on (Teleken *et al.*, 2017; Domínguez-Viveros *et al.*, 2020):

Akaike information criterion [AIC = n*ln(sce/n) + 2k];

Bayesian information criterion [BIC = n*ln(sce/n) + k*ln(n)];

Coefficient of determination [R^2 = (1 – (sce/sct))];

model standard error (EEG = $\sqrt{\frac{sce}{(n-k-1)}}$).

Where: n, total number of data; sce, sum of squares of the error; sct, total sum of squares; k, number of parameters in the model; ln, = natural logarithm.

Growth parameters were generated (Domínguez-Viveros *et al.*, 2019; Martínez-Rocha *et al.*, 2021): adult weight (AW), the mature weight or asymptotic value, which corresponds to the interpretation of β_1; growth rate (GR), expressing the weight gain as a proportion of the total weight, which corresponds to the interpretation of β_3; the correlation ϒ) between AW and GR; age (API) and weight (WPI) at the inflection point.

The calculation of the live weight as a percentage of the adult weight was analysed (ELW = (PLW / LWE)*100), based on the relationship of the predicted live weight through the age of the animal (PLW) and the live weight at the end (LWE) of the growth curve (at 1095 days). The degree of maturity (DM) and the daily growth rate (DGR; kg day^{-1}) were estimated with the components of each NLM (Table 1; Fitzhugh, 1976; Brown *et al.*, 1976).

Table 2: *Statistics for the selection of the best fit model.*

Statistic	*Brody*	*Gompertz*	*Logistic*	*Bertalanffy*
		Males		
R^2	96.3	96.2	96.2	96.3
EEG	57.4	57.7	58.1	57.6
AIC	2323146.7	2326262.0	2330452.5	2324977.1
BIC	2323178.4	2326293.7	2330484.2	2325008.8
		Females		
R^2	95.1	95.0	94.9	95.0
EEG	53.4	54.1	54.7	53.8
AIC	1201120.6	1204726.0	1208177.2	1203498.2
BIC	1201150.4	1204755.8	1208207.0	1203527.9

AIC: Akaike information criterion; BIC: Bayesian information criterion; R^2: coefficient of determination; EEG: model standard error.

Table 3: *Regression coefficients and growth parameters derived from the non-linear models evaluated.*

Model	β_1	β_2	β_3	*r*	*API*	*WPI*
			Females			
Brody	849.8	0.9395	0.000778	-0.99	–	–
Gompertz	512.8	1.9755	0.002750	-0.96	8.3	188.7
Logistic	447.0	4.4302	0.004660	-0.90	10.6	223.5
Bertalanffy	558.6	0.5098	0.002100	-0.97	6.7	165.5
			Males			
Brody	1295.8	0.9673	0.000628	-0.99	–	–
Gompertz	625.4	2.2104	0.003010	-0.96	8.8	230.0
Logistic	530.4	5.4571	0.005350	-0.90	10.6	265.2
Bertalanffy	697.2	0.5539	0.002230	-0.97	7.6	206.6

Regression coefficients: β_1: asymptotic value or adult weight; β_2: adjustment parameter; β_3: growth rate, expressing weight gain as a proportion of the total weight. Age (API, months) and weight (WPI, kg) at the inflection point. r: correlation between β_1 and β_3.

3 Results

The model with the best fit was Brody, followed by Bertalanffy (Table 2), although the differences between all models in degree of fit were small but there were big differences in actual parameters. The Brody model is characterized by a growth curve with constant GR without inflection point, Fig. 1 shows the growth curve for each sex with the Brody model. All NLM presented R2 greater than 94 %. Table 3 presents the results for the regression coefficients and the growth parameters API, WPI and ϒ. For AW, the average value was 787.2 kg for males and 592.1 kg for females; for GR, the average values (in terms of percentage) were 0.28 for males and 0.25 for females. All ϒ were negative, with estimates below -0.90. The ELW through the age of the animal is presented in Fig. 2; likewise, the DM with respect to the age of the animal is presented in Fig. 3. The DGR, as daily weight gain, for males presented values in the range of 0.347 to 0.786 kg and an average of 0.537 kg; for females, the mean was 0.424 kg with values in the range of 0.274 kg to 0.620 kg. The evolution of the DGR through the age of the animal is presented in Fig. 4.

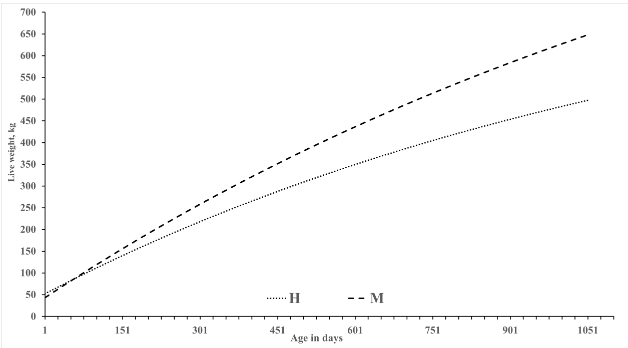

Fig. 1: *Growth curves for Brahman cattle (H, females; M, males) based on the Brody model.*

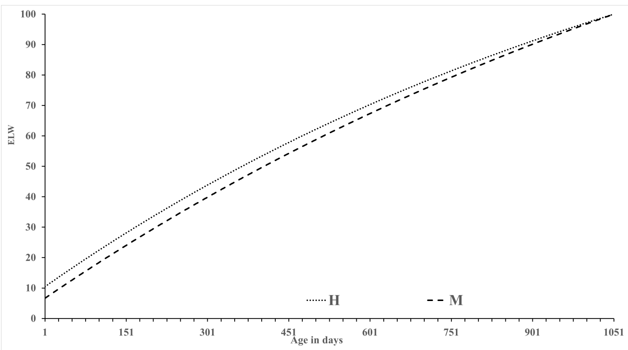

Fig. 2: *Evolution of live weight (ELW (%) = (PLW / LWE)*100)) in Brahman cattle (H, females; M, males), based on the relationship of the predicted live weight through the age of the animal (PLW) and the live weight at the end (LWE) of the growth curve (at 1095 days), with the Brody model.*

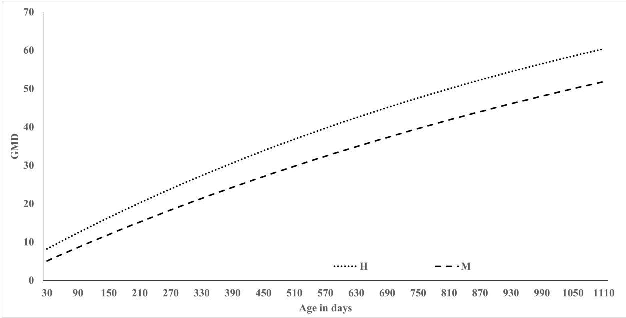

Fig. 3: *Development of the degree of maturity (DM), based on the Brody model, in Brahman cattle (H, females; M, males).*

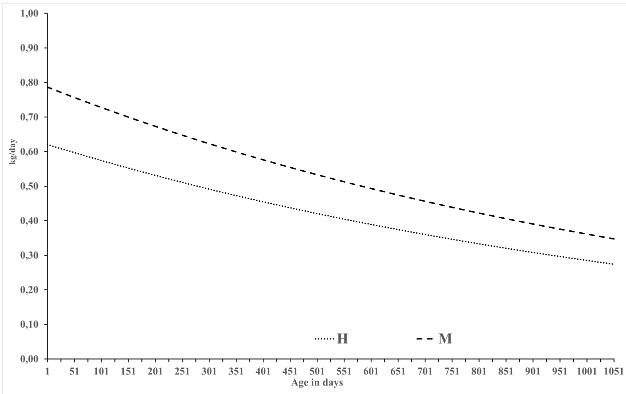

Fig. 4: *Growth rate development (DGR, kg/day) based on the Brody model in Brahman cattle (H, females; M, males).*

4 Discussion

Points have been made to the Brody model in the analysis of animal growth: ease of implementation in computational algorithms, good fit based on statistical criteria, interpretation of regression coefficients, allows missing data points, less sensitive to fluctuations in weight (Arango & Van Vleck, 2002). In the results obtained with Brody, overestimations of live weight are observed at the extremes of the growth curve. At the beginning, the prediction of live weight was higher in females, up to 53 days of age, with a maximum difference of 8 kg in birth weight (Fig. 1); for AW, Brody presented differences greater than 250 kg in females and 500 kg in males (Table 3). In the NLM contrast, the growth curve with constant GR and no inflection point vs sigmoid curves shows higher AW estimates (Domínguez-Viveros *et al*., 2013; Karim *et al*., 2019; Domínguez-Viveros *et al*., 2020; Colares *et al*., 2023). The analysis of growth in bovines has been proposed based on a sigmoid curve, where the inflection point has significance in the productive and reproductive phase (Lawrence & Fowler, 2002; France & Kebread, 2008). For tropical production systems, with grazing feeding, several studies have been published where the NLM of best adjustment presents a growth curve without inflection point. In the tropical regions of Mexico, where the Brahman population of the present study develops, Martínez-Rocha *et al*. (2021) in Romosinuano cattle and Domínguez-Viveros *et al*. (2013) in Tropicarne cattle, reported that the NLM with the best fit was Brody;

likewise, Domínguez-Viveros *et al.* (2020) in five Bos indicus breeds published that the NLM were Brody, Mitscherlich and Meloun III. Similar studies, in Zebu breeds and crosses with Zebu, where the Brody model was selected: de Lima *et al.* (2011) in Nelore and its crosses with Canchim, Angus and Simental; da Silva *et al.* (2013) and Colares *et al.* (2023) in Nelore; Souza *et al.* (2014) in Tabapua; Ramirez *et al.* (2009) and Herrera *et al.* (2008) in crosses of Zebu with Angus, Holstein, Blanco orejinegro, Senepol, and Romosinuano; Karim *et al.* (2019) in Brahman.

For DGR (kg/day) in Nelore cattle, Colares *et al* (2023) reported results in the range of 0.26 to 0.92 for males and 0.19 to 0.92 for females; Lopes *et al.* (2016) published estimates in the interval 0.70 to 0.259. Colares *et al* (2023) point out that females with a higher estimate of the maturation rate will have lighter carcasses at the time of slaughter (lower DGR). Biologically, β is of great relevance, negative values indicate that animals with higher maturation rates are not associated with higher adult weights, or animals with a lower maturation rate tend to be heavier at maturity and take longer to reach their mature weight (Hafiz *et al.*, 2016). The growth curve is extremely important in the efficiency of the production system, it transcends the reproductive phase of the females and the production costs per commercialized animal (López *et al.*, 1992; Arango & Van Vleck, 2002). The age at first calving is an indicator of the time it takes an animal to reach sexual maturity and reproduce for the first time, mating around 15 months with 60 % of adult weight and age at first calving around 24 months, has positive effects on the longevity and productivity of the cow (Núñez-Domínguez *et al.*, 1991; Patterson *et al.*, 1992; Cushman *et al.*, 2013). However, within breeds, differences in optimal size depend on the production system, especially the environment and management practices (Andersen, 1978; Alemneh & Getabalew, 2019). Fig. 1 and 2 show that Brahman heifers at 15 months of age achieve an average weight of 287 kg, representing 57.7 % of adult weight. The low levels of DM and its evolution through age, which are observed in Fig. 3, can be attributed to overestimations of the AW since it is part of the estimation process (Table 1). For DM at 540 days, Domínguez-Viveros *et al* (2013) in Tropicarne cattle and Martínez-Rocha *et al* (2021) in Romosinuano cattle, reported estimates of 65.2 % and 45.4 %, respectively; likewise, Herrera *et al* (2008) in five genotypes, product of the cross with Zebu, published values in the range of 50.3 to 62.0 %.

5 Conclusion

For Brahman cattle from Mexico, the Brody model defined the growth curve, with a constant growth rate and no inflection point. The females presented a higher maturity rate and greater evolution of live weight, with a lower growth rate development. The contrast in the behavior of the degree of maturity vs. growth rate development is associated with the results of the negative correlation between growth rate and adult weight.

Conflict of interest

The author declares that they have no conflict of interest.

Acknowledgements

To the Mexican Association of Zebu Breeders for providing the database analysed.

References

Agudelo, G. D. A, Cerón, M. M. F., & Restrepo, B. L. F. (2008). Modeling of growth functions applied to animal production. *Revista Colombiana de Ciencias Pecuarias*, 21(1), 39–58.

Agudelo-Gómez D, Hurtado-Lugo, N., & Cerón-Muñoz, M. F. (2009). Growth curves and genetic parameters in Colombian buffaloes (Bubalus bubalis Artiodactyla, Bovidae). *Revista Colombiana de Ciencias Pecuarias*, 22(2), 178–188.

Alemneh, T. A., & Getabalew, M. (2019). Factors influencing the growth and development of meat animals. *International Journal of Animal Science*, 3(3), 1048–1053.

AMCC. (2000). *Reglamento de control de desarrollo ponderal.* Asociación Mexicana de Criadores de Cebú. Tampico, Tamaulipas, México.

AMCC. (2019). *Reglamento técnico 2019.* Asociación Mexicana de Criadores de Cebú. Tampico, Tamaulipas, México.

Andersen, B. B. (1978). Animal size and efficiency, with special reference to growth and feed conversion in cattle. *Animal Production*, 27(3), 381–391. https://doi.org/10.1017/S000335610003628X.

Arango, J. A., & Van Vleck, L. D. (2002). Size of beef cows: early ideas, news developments. *Genetics and Molecular Research*, 1(1), 51–63.

Brown, J. E., Fitzhugh Jr, H. A., & Cartwright. T. C. (1976). A comparison of nonlinear models for describing weight-age relationships in cattle. *Journal of Animal Science*, 42(4), 810–818. https://doi.org/10.2527/jas1976.424810x.

Colares, C. R. N., Vieira, A. C, da Silva, W. C., de Araújo, S. I., Barbosa, L. R., Matimoto, N. L. R., Mendes, C. L., Luiz M. F., Maciel, S. A. G., Ximenes, S. L. K., Rodrigues, S. J. A., Correa, B. A. V., Felipe, M. J. R., & de Brito, L. J. (2023). Mixed Models in Nonlinear Regression for Description of the Growth of Nelore Cattle. *Animals*, 13(1), 101. https://doi.org/10.3390/ani13010101.

Cushman, R. A., Kill, L. K., Funston, R. N., Mousel, E. M. & Perry, G. A. (2013). Heifer calving date positively influences calf weaning weight through six parturitions. *Journal of Animal Science*, 91(9), 4486–4491. https://doi.org/10.2527/jas.2013-6465.

da Silva, M. K. N., Ribeiro, F. A., da Silva, F. A. J., & Ferreira, D. F. E. 2013. Nonlinear models for fitting growth curves of Nellore cows in the Amazon Biome. *Revista Brasileira de Zootecnia*, 42(9), 645–650. https://doi.org/10.1590/S1516-35982013000900006.

de Andrade, S. L., Novais, C. D., Souza, C. P. L., Mendes, M. C. H., & Martins, F. R. (2010). Curvas de crescimento em bovinos de raça Indubrasil criados no Estado do Sergipe. *Revista Ciência Agronômica*, 41(4), 671–676. https://doi.org/10.1590/S1806-66902010000400022.

de Lima, S. F., Mello, A. M., Ribeiro, F. A., Packer, I. U., & Barreto, M. G. (2011). Curvas de crescimento em vacas de corte de diferentes tipos biológicos. *Pesquisa Agropecuária Brasileira*, 46(3), 262–271. https://doi.org/10.1590/S0100-204X2011000300006.

Domínguez-Viveros, J., Urbina-Valenzuela, A. R., Palacios-Espinoza, A., Callejas-Juárez, N., Ortega-Gutiérrez, J. A., Espinoza-Villavicencio, J. L., Padrón-Quintero, Y., & Rodríguez-Castro, M. (2017). Characterization of growth of Cebu cattle in testing performance on grazing. *Ecosistemas y Recursos Agropecuarios*, 4(11), 341–348. https://doi.org/10.19136/era.a4n11.1149.

Domínguez-Viveros, J., Rodríguez-Almeida, F. A., Aguilar-Palma, N. G., Castillo-Rangel, F., Saiz-Pineda, J. F., & Villegas-Gutiérrez, C. (2020). Fitting of non-linear models to characterize the growth of five zebu cattle breeds. *Livestock Science*, 242, 104303. https://doi.org/10.1016/j.livsci.2020.104303.

Domínguez-Viveros, J., Rodríguez-Almeida, F. A., Núñez-Domínguez, R., Ramírez-Valverde, R., Ortega-Gutiérrez, J. A., & Ruiz-Flores, A. (2013). Ajuste de modelos no lineales y estimación de parámetros de crecimiento en bovinos Tropicarne. *Agrociencia*, 47(1), 25–34.

Domínguez-Viveros, J., González-Prieto, S., Palacios-Espinosa, A., Suárez-Tronco, M. A., Rodríguez-Almeida, F. A., Espinoza-Villavicencio, J. L., & Rodríguez-Castro, M. (2019). Parámetros de crecimiento y sus efectos en la edad al primer empadre de vacas Siboney. E*cosistemas y Recursos Agropecuarios*, 6(17), 383–389. https://doi.org/10.19136/era.a6n17.1786.

Fitzhugh, H. A. (1976). Analysis of growth curves and strategies for altering their shape. *Journal of Animal Science*, 42(4), 1036–1051. https://doi.org/10.2527/jas1976.4241036x.

France, J., & Kebreab, E. (2008). *Mathematical modelling in animal nutrition-introduction.* Cabi, Wallingford UK.

France, J., Dijkstra, J., & Dhanoa, M. S. (1996). Growth functions and their application in animal science. *Annales de Zootechnie*, 45(1), 165–174.

Hafiz, M. A W, Bahtiar, A. J. I., Hifzan, R. M., Ariff, O. M., & Ashraff, A. L. F. (2016). Describing growth pattern of Bali cows using non-linear regression models. *Malaysian Journal of Animal Science*, 19(2), 1–7.

Herrera, R. A. C., Vergara, G. O. D., Cerón, M. M. F., Agudelo-Gómez, D., & Arboleda, Z. E. M. (2008). Growth curves in crossbreed cattle using Brody model. *Livestock Research for Rural Development*, 20(9), 20140.

Karim, A. A. H., Maharani, D., & Widayati, D. T. (2019). Determination of the best nonlinear function to estimate Brahman female cattle growth. *Annual Scientific Conference Life Science*, 2019, 122–129. https://doi.org/10.18502/kls.v4i11.3858.

Lawrence, T., & Fowler, V. (2002). *Growth of farm animal.* 2a ed. CAB International. London UK. 478 p.

Lopes, F. B., Magnabosco, C. U., de Souza, F. M., de Assis, A. S., & Brunes, L. C. (2016). Análises de dados longitudinais em bovinos Nelore mocho por meio de modelos não lineares. *Archivos de Zootecnia*, 65(250), 123–129. https://doi.org/10.21071/az.v65i250.478.

López, T. G., Candotti, J. J., Reverter, A., Bellido, M. M., Vasco, P., García, L. J., & Brinks, J. S. (1992). Effects of growth curve parameters on cow efficiency. *Journal of Animal Science*, 70(9), 2668–2672. https://doi.org/10.2527/1992.7092668x.

Martínez-Rocha, R., Ramírez-Valverde, R., Núñez-Domínguez, R., García-Muñiz, J. G., & Parra-Bracamonte, G. M. (2021). Comportamiento de crecimiento y reproductivo en hembras bovinas Romosinuano. *Revista MVZ Córdoba*, 26(1), e2033. https://doi.org/10.21897/rmvz.2033.

Menchaca, M. A., Chase, C. C., Olson, T. A., & Hammond, A. C. (1996). Evaluation of growth curves of Brahman cattle of various frame sizes. *Journal of Animal Science*, 74(9), 2140–2151. https://doi.org/10.2527/1996.7492140x.

Nunes, O. H., Barbosa, L. R., & Silva, P. C. (2000). Comparação de modelos não-lineares para descrever o crescimento de fêmeas da raça Guzera. *Pesquisa Agropecuária Brasileira*, 35(9), 1843–1851. https://doi.org/10.1590/S0100-204X2000000900017.

Núñez-Domínguez, R., Cundiff, L. V., Dickerson, G. E., Gregory, K. E., & Koch, R. M. (1991). Lifetime production of beef heifers calving firts at two vs three years of age. *Journal of Animal Science*, 69(9), 3467–3479. https://doi.org/10.2527/1991.6993467x.

Patterson, D. J., Perry, R. C., Kiracofe, G. H., Bellows, R. A., Staigmiller, R. B., & Corah, L. R. (1992). Management considerations in heifer development and puberty. *Journal of Animal Science*, 70(12), 4018–4035. https://doi.org/10.2527/1992.70124018x.

Ramírez, E. J., Cerón, M. M. F., Herrera, A. C., Vergara, O. D., Arboleda, E. M., & Restrepo, B. L. F. (2009). Growth of crossbred females in the Colombian tropic. *Revista Colombiana de Ciencias Pecuarias*, 22(4), 642–647.

Regis, S. K., Paes, B. S. B., Albuquerque, B. L. H., & Souza, S. E. (2005). Estimativas de parâmetros de curvas de crescimento de bovinos Zebu, criados no estado de Pernambuco. *Revista Brasileira de Zootecnia*, 34(6), 2262–2279.

Sanders, J. O. (1980). History and development of zebu cattle in the United States. J*ournal of Animal Science*, 50(6), 1188–1200. https://doi.org/10.2527/jas1980.5061188x.

SAS. 2001. *Statistical Analysis System Institute*. User´s Guide: Statistics (version 9.0). Cary NC, USA.

Souza, C., Policarpio, A., Muniz, J. A., Souza, C. P. L., Mendes, M. C. H., Martins, F. R., & Fonseca, S. F. (2014). Identidade de modelos não lineares para comparar curvas de crescimento de bovinos da raça Tabapuã. *Pesquisa Agropecuária Brasileira*, 49(1), 57–62. https://doi.org/10.1590/S0100-204X2014000100008.

Teleken, J. T., Cazonatto, G. A. & Silva, R. W. (2017). Comparing non-linear mathematical models to describe growth of different animals. *Acta Scientiarum*, 39(1), 73–81. https://doi.org/10.4025/actascianimsci.v39i1.31366.