MODELLING THE SCROTAL GROWTH OF BRAKMAS CATTLE USING NON-LINEAR REGRESSIONS MODELS

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ABSTRACT. Finding the most appropriate non-linear regression model to explain the growth trend for scrotal circumference in Brakmas cattle is the goal of this study. The mature weight, maturing rate, and integration constant were determined by the use of Brody, von Bertalanffy, Gompertz, and Logistic models. These models were tested to scrotal circumference measured from 31 Brakmas cattle from birth to the age of 72 months old. The optimal model to explain the growth pattern of scrotal circumference was identified using the coefficient of determination (R^2) and mean square of error (MSE). The Von Bertalanffy model exhibited the best goodness-of-fit, as evidenced by its highest R^2 and lowest MSE (0.990 and 9.508, respectively). It was followed by the Gompertz (0.989 and 10.193, respectively), Logistic (0.989 and 10.919, respectively), and Brody (0.827, 9.954, respectively) models. Negative correlation was found between rate of maturing and matured scrotal circumference ranged from -0.757 to -0.615; therefore, slow growing animals will have higher mature size measured and attain their maturity at a later age. In conclusion, a non-linear model could summarise the relationship between scrotal growth and age into several biologically interpreted parameters compared to the entire lifespan size-age data points that are difficult to interpret.

Keywords: growth, non-linear regression, scrotal circumference, Brakmas cattle, beef cattle

INTRODUCTION

The development of Brakmas cattle began with the crossbreeding of Brahman and Kedah-Kelantan beef breeds. Kedah-Kelantan cattle are highly fertile and adaptable to the local environment. However, the growth rate is relatively low and uneconomical for beef cattle operators (Johari & Jasmi, 2009). This program developed Brakmas, a cattle breed that produce progenies which are superior than the Kedah-Kelantan. Dahlan (1985) reported the superiority of Brakmas compared to Kedah-Kelantan cattle in birth-, weaning- and post-weaning-weight. Strict breeding and selection program has resulted in Brakmas breed with 50 % - 50 % of Brahman and KK bloodline, respectively. This breed demonstrated significant capability to be produced commercially especially under the oil palm plantations due to their high adaptability towards local climate, heat tolerance, resistance to ticks and parasites, and easy to maintain (Mohd. Hafiz *et al.,* 2015; Johari & Jasmi, 2009).

The growth of scrotal circumference in cattle has been a subject of interest in various studies. A study on Nellore cattle by Nascimento *et al.* (2020) focused on estimating adjustment factors of scrotal circumference for its growth, while Boligon *et al.* (2010) highlighted the importance of including scrotal circumference in selection indexes for beef cattle, as it is associated with growth traits and mature cow body weight. Furthermore, Chacur *et al.* (2018) identified a strong correlation between scrotal circumference and testicular volume in Zebu cattle, indicating the role of various factors such as breed, body condition score, and age at puberty on scrotal development. These findings emphasise the multifactorial nature of scrotal growth in cattle.

Moreover, genetic studies have shed light on the significance of scrotal circumference in cattle breeding programs. Camargo *et al.* (2015) identified a significant genetic effect of a specific gene on scrotal circumference measurements in cattle, further underlining the genetic basis of scrotal development. Scrotal circumference can serve as a selection criterion in breeding programs considering its moderate to high heritability estimates and its association with growth traits and female sexual precocity (Sant'Anna *et al.*,2012). Additionally, Carrara *et al.* (2022) demonstrated genetic correlations between scrotal perimeter traits, body weights, and milk production traits in cattle, highlighting the interconnectedness of these traits.

While the references provide valuable insights into the factors influencing scrotal growth in cattle, it is essential to consider the non-linear aspects of this growth. Boligon *et al.* (2011) discussed the estimation of Nellore cattle genetic attributes and relationships between growth characteristics and scrotal circumference measured at various ages in, indicating the potential non-linear associations between these traits. This suggests the need to explore non-linear models to accurately describe the growth of scrotal circumference in cattle, as highlighted by Bilgin *et al.* (2004) in their study on non-linear growth functions to determine the growth of Awassi lamb scrotal circumference. Based on the provided references, several studies have utilised non-linear regression models to estimate growth curves and analyse various traits in animal-related research. For instance, Waheed *et al.* (2011) employed non-linear regression models to estimate the Beetal goats' growth curve parameters, demonstrating the application of Gompertz and Brody mathematical functions in analysing growth data. Similarly, Hifzan *et al.* (2015) reported that Gompertz function is the best model to describe the Kalahari Red goats' growth pattern due to the sigmoid curve form of animal growth.

In the context of cattle, Yin and König (2018) suggested the use of random regression models with cubic Legendre polynomials and cubic regressions for describing growth curves in Nellore and dairy cattle, emphasising the application of non-linear modelling in cattle research. Additionally, the availability of longitudinal body weight records has enabled the application of non-linear models to predict phenotypic and genomic growth curves in dairy cattle (Yin & König, 2020).

Furthermore, non-linear regression models have been utilised in diverse animal-related studies beyond growth curve estimation. For example, Rhyu *et al.* (2021) applied non-linear and log-linear regression models to evaluate non-stochastic and stochastic increases in cancer incidence, demonstrating the versatility of non-linear regression in medical research. Moreover, the use of random regression models has been explored to estimate genetic parameters for sequential growth of beef cattle, showcasing the application of non-linear modelling in animal genetics and breeding (Nobre *et al.,* 2003).

This study aims to identify the most suitable non-linear regression models for characterizing scrotal growth in Brakmas cattle.

MATERIALS AND METHODS

Data Collection

Data on scrotal circumference were gathered from 31 male Brakmas cattle, spanning from birth to 72 months of age in MARDI Kluang, Johor (1.9494° N, 103.3656° E). The animals grazing extensively on *Brachiaria decumbens* pasture. The measurement was conducted by evaluating the scrotal circumference at the point of maximum diameter of the testes, ensuring both testes were aligned symmetrically side by side, as depicted in Figure 1, using a standard measuring tape. This approach, as recommended by Loaiza-Echeverri *et al.* (2013), resulted in the distension of the scrotum skin.

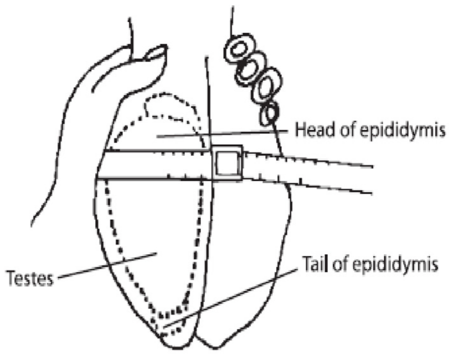

Figure 1. Measuring the scrotal circumference

Statistical Analysis

The dataset for Brakmas scrotal circumference was subjected to fitting with four nonlinear growth functions - specifically, Brody, Gompertz, von Bertalanffy, and Logistic by using SAS v9.4. The aim was to determine the growth curve parameters. These models, each comprising three parameters denoted as A, B, and k, encompass the asymptote (A), the constant of integration (B), and the rate of maturing (k). The choice of these models was guided by considerations of ease of calculation and biological interpretation (Brown *et al*., 1976). Domínguez-Viveros *et al*. (2023) detailed the models used in this study in Table 1, where Yt represents the observed size measurement at age t in months, where A signifies the asymptote for the size measurement, B denotes the constant of integration, and k represents the rate of maturing per day, interpreted as the daily rate of growth relative to the asymptotic size. The highest value of R^2 and the lowest value of residual mean square (MSE) will indicate the best model to describe the growth pattern for scrotal circumference in Brakmas cattle. Domínguez-Viveros *et al.* (2023) suggested that a model exhibiting higher coefficient of determination and lower residual mean square is deemed superior, as it can elucidate a greater percentage of the variations in sizes compared to a model with lower R^2 and higher MSE.

Table 1. Non-linear model equations and points of inflection used characterize the scrotal circumference growth of Brakmas cattle

Model	Equation	Point of inflection
Brody	$Yt=A(1-Be^{-kt})$	-
Gompertz	$Yt=Ae^{-Be^{-kt}}$	0.368*A
von Bertalanffy	$Yt=A(1-Be^{-kt})^3$	0.296*A
Logistic	$Yt=A/(1+Be^{-kt})$	A/2

RESULTS AND DISCUSSION

Goodness of Fit of Non-linear Models

The model that yielded the highest R^2 with lowest mean square error is considered the best model (Singh *et al.,* 2015), in this case to describe the scrotal growth of Brakmas cattle. Table 2 displays the estimated growth curve parameters for the scrotal circumference in Brakmas cattle using the Logistic, von Bertalanffy, Gompertz, and Brody models. Parameter A varied between 33.29±1.06 cm and 33.79±1.14 cm, with the Brody model exhibiting the greatest scrotal circumference estimate in Brakmas cattle and the Logistic model displaying the lowest. The maturation rate (k) varied in magnitude, ranging from 0.07±0.01 to 0.11±0.02. Von Bertalanffy had the greatest R^2 value among all the models, which all displayed excellent R^2 values. Four non-linear equations used in this can describe the scrotal growth of Brakmas cattle appropriately, with von Bertalanffy showing the best goodness of fit, followed by Gompertz, Logistic and Brody. The von Bertalanffy model's lowest mean square error value supports it. These results are in line with earlier growth curve modelling research. For instance, Sloat and Reeves (2014) discussed the use of the Gompertz growth equation to describe individual mass trajectories in steelhead and rainbow trout, highlighting the applicability of this model in characterising growth patterns in fish. Moreover, Lugert *et al.* (2014) emphasised the importance of R^2 as a measure of goodness-of-fit in fish growth modelling, aligning with the high R^2 values observed in the current study. A lot of work has been done using non-linear models to show how scrotal circumference and growth traits relate to one another in cattle. The importance of scrotal circumference as a marker of reproductive potential in beef cattle was highlighted by Bourdon and Brinks (1986). This was further supported by Boligon *et al.* (2011), who examined the genetic parameters and connections between growth traits and scrotal circumference in Nellore cattle, highlighting the significance of non-linear models. Omoniwa *et al*. (2021) compared various nonlinear models to describe live weight from birth to maturity in female Jersey cattle, showcasing the practicality of non-linear approaches in modelling cattle growth. Yin and König (2020) employed non-linear models with diverse kernel functions to forecast phenotypic and genomic growth curves in Holstein dairy cattle, further accentuating the significance of non-linear modelling in understanding cattle growth patterns. Collectively, these studies underscore the widespread use and importance of non-linear models in comprehending the relationship between scrotal circumference and growth traits in diverse cattle breeds, offering valuable insights into genetic parameters, reproductive potential, and growth patterns.

Table 2. Growth model parameters derived from Gompertz, Brody, von Bertalanffy and Logistic models, R^2 and MSE for scrotal circumference of Brakmas cattle

Model	**Growth curve parameter1**			**R^2**	**MSE**
	A (cm)	B	k		
Gompertz	33.46±1.07	1.09±0.17	0.09±0.02	0.989	10.193
Brody	33.79±1.14	0.72±0.07	0.07±0.01	0.827	9.954
by Bertalanffy	33.55±1.09	0.32±0.04	0.08±0.02	0.990	9.508
Logistic	33.29±1.06	Select size 1.69±0.39	0.11±0.02	0.989	10.919

While Fernandes *et al*. (2019) and Santana *et al*. (2016) concluded that the von Bertalanffy model, together with the Brody model, adequately explained cattle growth curves. On the other hand, Noor *et al.* (2012) found that the von Bertalanffy model presented the greatest difficulty in meeting the convergence conditions, with the Logistic and Gompertz models following closely behind. In Ongole cattle, Maharani *et al*. (2017) observed variations in parameter A between Brody's model and that of von Bertalanffy, Gompertz, and the Logistic model.

Lopes *et al*. (2016) compared the performance of Brody, von Bertalanffy, Logistic, and Gompertz models in predicting cattle growth, showcasing their utility in analysing the growth of Nellore cattle and Hanwoo steer, respectively. Manjula *et al.* (2018) highlighted the frequent use of Logistic, Gompertz, von Bertalanffy, and Richards models in fitting the growth curve of poultry breeds. Collectively, these findings suggest that the Brody and von Bertalanffy models are commonly used and favoured for describing cattle growth curves, while the Logistic and Gompertz models also play significant roles in growth curve modelling.

Numerous studies have been conducted on the importance of growth models such as Brody, von Bertalanffy, Gompertz, and Logistic in relation to the scrotal growth of cattle. Males selected for larger scrotal circumference should have higher body weights, testicular volumes, and yearling weights, according to Boligon *et al*. (2010). The significance of scrotal circumference in cattle reproduction and growth was highlighted by Schmidt *et al.* (2019) genetic analysis of growth characteristics, scrotal circumference, and female reproductive efficiency in Nellore cattle.

Nasri *et al*. (2008) discussed the application of the Gompertz function in modelling the lactation curve of dairy cows, showcasing the versatility of mathematical functions in studying growth and reproductive traits in cattle. Zimmermann *et al*. (2019) compared various mathematical models to define the growth from weaning to maturity in crossbred beef cattle, underscoring the relevance of growth models such as the Brody function in understanding cattle growth patterns. Novotná *et al.* (2022) conducted a genetic evaluation of scrotal circumference in beef bulls, revealing the heritability coefficient of scrotal circumference, which is crucial for understanding the genetic basis of scrotal growth in cattle.

Mature Size and Rate of Maturing Correlation

The correlation of mature size and rate of maturing is biologically important in growth curve study (Da Silva *et al*., 2012). In Table 3, the genetic association between parameter A and k is displayed. Negative association of matured scrotal size and rate of maturing ranging from -0.757 to -0.615 was observed in all models. According to the negative association between these factors, animals with higher k values will reach adulthood sooner than those with lower k values. The strongest inverse association between parameter a and k was displayed by the Brody model. All models showed negative relationships when the mature scrotal circumference and the pace of maturing as calculated by Gompertz, Brody, von Bertalanffy, and Logistic models were correlated. A continuous negative link between mature weight and maturing rate was indicated by the correlations, which varied from -0.757 to -0.615. According to this, animals with higher k values will reach their mature size; in this study, the scrotal circumference, earlier than those with a lower k value. Notably, the Brody model exhibited the highest negative relationship between parameter A and k.

Table 3. Correlation (r) between mature scrotal circumference and rate of maturing estimated by Gompert, Brody, von Bertalanffy and Logistic models

Models	r
Gompertz	-0.678
Brody	-0.757
By Bertalanffy	-0.702
Logistic	-0.615

CONCLUSION

In conclusion, the growth of scrotal circumference in cattle is influenced by genetic, environmental, and physiological factors, and its association with growth traits underscores its importance in cattle breeding programs. The potential nonlinear nature of this growth necessitates further exploration using appropriate models to enhance the understanding of scrotal development in cattle. Furthermore, a study on scrotal growth in cattle has practical implications for improving reproductive management, health monitoring, genetic selection, and economic outcomes in cattle farming operations. Studying scrotal growth has practical implications for reproductive management, health monitoring, genetic selection, and economic outcomes in cattle farming. Future studies promise advancements in livestock management through longitudinal studies across breeds and environments, genetic investigations, and exploration of nutrition, health, and technological factors. Integration of these efforts can enhance management practices, genetic selection programs, and economic outcomes for cattle producers worldwide.

REFERENCES

1. Bilgin, Ö., Emsen, E., & Davis, M. (2004). Comparison of nonlinear models for describing the growth of scrotal circumference in Awassi male lambs. *Small Rumin. Res, 52*(1-2), 155-160.
2. Boligon, A., Baldi, F., & Albuquerque, L. (2011). Genetic parameters and relationships between growth traits and scrotal circumference measured at different ages in Nellore cattle. *Genet Mol Biol, 34*(2), 225-230.
3. Boligon, A., Silva, J., Sesana, R., Sesana, J., Junqueira, J., & Albuquerque, L. (2010). Estimation of genetic parameters for body weights, scrotal circumference, and testicular volume measured at different ages in Nellore cattle1. *J Anim Sci, 88*(4), 1215-1219.
4. Bourdon, R. M. and J. S. Brinks. 1986. Scrotal circumference in yearling Hereford bulls: Adjustment factors, heritabilities and genetic, environmental and phenotypic relationships with growth traits. *J. Anim. Sci. 62*:958-969.\
5. Brown, J. E., Fitzhugh, H. A., & Cartwright, T. C. (1976). A Comparison of Nonlinear Models for Describing Weight-Age Relationships in Cattle1. *Journal of Animal Science, 42*(4), 810–818.
6. Camargo, G., Porto-Neto, L., Kelly, M., Bunch, R., McWilliam, S., Tonhati, H., … & Moore, S. (2015). Non-synonymous mutations mapped to chromosome X associated with andrological and growth traits in beef cattle. *BMC Genomics, 16*(1).
7. Carrara, E., Peixoto, M., Veroneze, R., Silva, F., Ramos, P., Bruneli, F., … & Lopes, P. (2022). Genetic study of quantitative traits supports the use of Guzerá as dual-purpose cattle. *Animal Bioscience, 35*(7), 955-963.
8. Chacur, M., Arikawa, A., Oba, E., Souza, C., & Gabriel Filho, L. R. (2018). Influence of testosterone on body and testicular development in Zebu cattle in the tropical climate. Advances in Testosterone Action. *IntechOpen*.
9. da Silva, L. S. A., Fraga, A. B., da Silva, F. D. L., Beelen, P. M. G., de Oliveira Silva, R. M., Tonhati, H., & da Costa Barros, C. (2012). Growth curve in Santa Inês sheep. Small Rumin. *Res, 105*(1-3), 182-185.
10. Dahlan, I. (1985). Growth performance, body conformation, carcass characteristics, and palatability of KK cattle and its crossbreds. *MSc. Thesis, UPM*.
11. Fernandes, F.A., Fernandes, T.J., Pereira, A.A., Meirelles, S.L., & Costa, A.C. (2019). Growth curves of meat-producing mammals by von Bertalanffy's model. Pesquisa Agropecuária Brasileira.
12. Hifzan, R., Idris, I., & Yaakub, H. (2015). Growth pattern for body weight, height at withers, and body length of Kalahari Red goats. *Pak J Biol Sci, 18*(4), 200-203.
13. Johari, J.A., & Jasmi, Y. (2009). Breeds and breeding program for beef production in Malaysia. *In Proc. 8th Malaysia Congress on Genetics 2009* (pp. 22- 28).

14. Loaiza-Echeverri, A. M., Garcia, A., Luiz, F., Osorio, J. P., Santana, A., Luís Mendonça, V.S. Moustacas, & Henry, M. O. (2013). Use of nonlinear models for describing scrotal circumference growth in Guzerat bulls raised under grazing conditions. *Theriogenology, 79*(5), 751–759.
15. Lopes, F., Magnabosco, C., Souza, F., Assis, A., & Brunes, L. (2016). Analysis of longitudinal data in owl Nellore cattle using nonlinear models. *Arch Zootec, 65*(250), 123-129.
16. Lugert, V., Thaller, G., Tetens, J., Schulz, C., & Krieter, J. (2014). A review on fish growth calculation: multiple functions in fish production and their specific application. *Rev Aquacult, 8*(1), 30-42.
17. Maharani, D., Amrullah, A. H. K., Widayati, D. T., Sumadi, S., Fathoni, A., & Khusnudin, M. (2017). Predicting the age and weight at puberty of Ongole Grade cattle using non-linear mathematical model in Kebumen Farmer Association. *Journal of the Indonesian Tropical Animal Agriculture, 42*(4), 233-239.
18. Manjula P, Park H, Seo D, et al. Estimation of heritability and genetic correlation of body weight gain and growth curve parameters in Korean native chicken. *Anim Biosci 2018;31*(1): 26-31.
19. Mohd. Hafiz, A.W., Mohamad Hifzan, R., Izuan Bahtiar, A.J., & Ariff, O.M. (2015). Describing growth pattern of Brakmas cows using non-linear regression models. *Malaysian J. Anim. Sci. 18*(2): 37-45.
20. Nascimento, B., Silva, G., Carvalheiro, R., Teixeira, R., & Dias, L. (2020). Alternative adjustment of scrotal circumference for growth traits in Nellore cattle. *Rev Bras Zootec, 49*.
21. Nasri, M. H. F., France, J., Odongo, N. E., Lopez, S., Bannink, A., & Kebreab, E. (2008). Modelling the lactation curve of dairy cows using the differentials of growth functions. *The Journal of Agricultural Science, 146*(6), 633–641.
22. Nobre, P., Misztal, I., Tsuruta, S., Bertrand, J., Silva, L., & Lopes, P. (2003). Analyses of growth curves of Nellore cattle by multiple-trait and random regression models. *J Anim Sci, 81*(4), 918-926.
23. Noor, R., Saefuddin, A., & Talib, C. (2012). Comparison on accuracy of Logistic, Gompertz, and von Bertalanffy models in predicting growth of newborn calf until first mating of Holstein Friesian heifers. *J Indonesian Trop Anim Agric, 37*(3).
24. Novotná, A., Brzáková, M., Birovaš, A., & Veselá, Z. (2022). Genetic evaluation of the scrotal circumference of beef bulls in the Czech Republic. *Czech Journal of Animal Science, 67*(9), 349–355.
25. Omoniwa, D.O., Akinsola, J.E., Okeke, R.O., Madu, J.M., & Umar, D.S. (2021). Comparison of Non Linear Models and Artificial Neural Network to Describe the Liveweight from Birth to Maturity in Female Jersey Cattle. Journal of Experimental Agriculture International.
26. Rhyu, M.-G., Oh, J.-H., Kim, T.-H., Kim, J.-S., Rhyu, Y. A., & Hong, S.-J. (2021). Periodic Fluctuations in the Incidence of Gastrointestinal Cancer. *Frontiers in Oncology, 11*.
27. Sant'Anna, A. C., Da Costa, M. J. R. P., Baldi, F., Rueda, P. M., & Albuquerque, L. G. (2012). Genetic associations between flight speed and growth traits in Nellore cattle1. *Journal of Animal Science, 90*(10), 3427–3432. https://doi.org/10.2527/jas.2011-5044
28. Santana, T.J., Scalon, J.D., Bittencourt, T.C., & Santana, A.R. (2016). A VON BERTALANFFY MODEL WITH RESPONSE PLATEAU TO DESCRIBE GROWTH CURVES OF BEEF CATTLE. *Revista Brasileira de Biometria, 34*, 646-655.
29. Schmidt, P., Campos, G., Roso, V., Souza, F., & Boligon, A. (2019). Genetic analysis of female reproductive efficiency, scrotal circumference and growth traits in Nelore cattle.*Theriogenology, 128,* 47-53.
30. Singh, S., Paul, A. K., Paul, R. K., Bhar, L. M., Kumar, A., & Alam, W. (2015). Study of growth pattern of cattle under different error structures. *Model Assisted Statistics Appl, 10*(2), 109-115.
31. Sloat, M., & Reeves, G. (2014). Individual condition, standard metabolic rate, and rearing temperature influence steelhead and rainbow trout (Oncorhynchus mykiss) life histories. *Can J Fish Aquat Sci, 71*(4), 491-501.
32. Waheed, A., Khan, M., Ali, S., & Sarwar, M. (2011). Estimation of growth curve parameters in Beetal goats. *Arch Anim Breed, 54*(3), 287-296.
33. Yin T, König S. Genetic parameters for body weight from birth to calving and associations between

weights with test-day, health, and female fertility traits. *J Dairy Sci. 2018 Mar;101*(3):2158-2170. doi: 10.3168/jds.2017-13835. Epub 2017 Dec 21. PMID: 29274962.
34. Yin T, König S. Genomic predictions of growth curves in Holstein dairy cattle based on parameter estimates from nonlinear models combined with different kernel functions. *J Dairy Sci. 2020 Aug;103*(8):7222-7237
35. Zimmermann, M. J., Kuehn, L. A., Spangler, M. L., Thallman, R. M., Snelling, W. M., & Lewis, R. M. (2019). Comparison of different functions to describe growth from weaning to maturity in crossbred beef cattle1. *Journal of animal science, 97*(4), 1523–1533.

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