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Estimation of Growth Patterns of Boschveld Indigenous Chicken using Non-linear Growth Curve Models

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ABSTRACT

Growth curves are a common mathematical tool for describing growth, allowing growth parameters to be understood within a biological context. The study was conducted to estimate the growth pattern of indigenous Boschveld chicken using non-linear growth curve models and to compare the performance of the functions. The study used 63 indigenous Boschveld chicken from 0 to 19 weeks. The chickens' growth curves were defined using four different non-linear models: Gompertz, Logistic, Von Bertalanffy and Richards. The growth curve models were fitted using the Bayesian information criterion (BIC), Akaike's information criterion (AIC), adjusted coefficient of determination (Adj.R2), and coefficient of determination (R2). The values of R^2 were 0.92, 0.91, 0.89, 0.89 while the values of Adj.R^2 were 0.91, 0.91, 0.88, 0.88 for Logistic, Gompertz, Von Bertalanffy and Richards, respectively. The AIC were 1087.93, 1088.62, 1088.66, 1089.93 and BIC were 1084.63, 1085.31, 1085.36 and 1085.03 for Von Bertalanffy, Gompertz, Logistic, and Richards, respectively. In conclusion, the von Bertalanffy model is the best fit model to describe the native chicken growth patterns of the Boschveld. The findings will help Boschveld chicken farmers to effectively choose a well-suited model for their breed to take informed decisions on their production systems.

Key words: Boschveld indigenous chicken, Growth curve modelling, Non-linear models, Body weight estimation, Growth pattern analysis.

INTRODUCTION

Poultry production helps address protein deficiencies and supports local economies in developing countries (Sufe and Alewi 2022; Taye et al. 2023). The Boschveld chicken is the only synthetic African indigenous breed that is grown in free-range household production of meat and eggs in rural areas (Okoro et al. 2017; Petrus et al. 2019). Body weight is one of the most significant traits in poultry production because it is associated with growth rate, feed conversion efficiency and occurrence of diseases in a flock (Kiani, 2022). Growth curves illustrate the progression of animal development, enabling dynamic understanding and prediction of growth patterns (Wang et al. 2014). Analyzing these curves can inform breeding decisions, particularly when estimating early growth trends and genetic factors, having significant implications for optimizing breeding strategies (Zhao et al. 2015). However, traditional breeding approaches focus on the final body weight of the chickens, neglecting growth rate progression (Mancinelli et al. 2023). To optimize production, mathematical models can be used to analyse growth curves, enabling predictions of body weight at specific ages and informing more effective breeding decisions (Mancinelli et al. 2023). Growth analysis is an essential component of many biological studies (Moharrery and Mirzaei 2014). Precise growth models can assist to develop strategies to ensure efficiency and cost-effectiveness in animal production (Afrouziyeh et al. 2021). According to Faraji- Arough et al. (2019), it is possible to predict the growth patterns of poultry species with non-linear structures, sigmoid forms, and biologically justifiable justification factors by using growth curves based on mathematical models. N'dri et al. (2018) indicated that animals in the same physiological stages, where growth speed is at its maximum, can be predicted; however, this cannot be done with a traditional body weight study. Therefore, the models that predict weight and growth data are suitable (Brunner and Kühleitner 2021). Mathematical models, particularly non-linear growth

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curves, can effectively predict growth patterns in poultry, enabling informed decision making such as estimating the daily nutritional requirements for various genetic groups and ages, improving livestock production efficiency and assessing the impact of selection progress on a growth curve's parameters (Faraji- Arough et al. 2019; Afrouziyeh et al. 2021; Akinsola et al 2021). Moreover, it will enable the breeders to expect the weight of animals at a specific age and to detect the phase that associated with the reduction in growth rate (Şengül et al. 2024). Modelling growth helps optimize management decisions and assess how selection influences growth traits (Arando et al. 2021). Few studies have been conducted to analyse the dynamics of the parental line's growth rate, and it was concluded that the Gompertz model can accurately analyse growth rate of the parental lines (N'dri et al. 2018; Afrouziyeh et al. 2021; Mancinelli et al. 2023; Şengül et al. 2024). Studies on Japanese quail growth have used Gompertz, Logistic, or von Bertalanffy models, all of which share the feature of a fixed inflection point (Júnior et al. 2023; Haqani et al. 2021; Güler et al. 2022). The study addresses a key gap by evaluating which non-linear growth model best fits Boschveld chickens, a breed gaining importance in Southern Africa. By comparing four models—Gompertz, Logistic, Von Bertalanffy, and Richards—it aims to improve growth prediction accuracy and support better breeding and management decisions in indigenous poultry systems.

Thus, the objectives of the study were to estimate the growth pattern of indigenous Boschveld chicken using non-linear models and compare the performance of different non-linear models in estimating the growth pattern of the Boschveld chicken.

MATERIALS AND METHODS

Study area and animal management

This investigation was done at the University of Limpopo Experimental Farm (Syferkuil), which is 1324 meters above sea level and situated in the Limpopo Province of South Africa at 23°50′36.86″ S 29°40′54.99″ E. (Phefadu and Kutu 2016). The study used a total of 63 Boschveld chickens of zero week of age. The chickens were reared intensively in pens, where they were fed with starter for the first three weeks and grower from ten weeks to the end of 19 weeks. The chicks were divided into five groups based on sex, and they were vaccinated against Newcastle disease. Each pen was equipped with one feeder and one drinker for manual feed distribution and a lighting was provided for the first four weeks to regulate the chick's body temperature. Feed and water were provided *ad libitum*. The floor of the pens was concrete and covered with litter made of wood shavings.

Study design and Sampling procedure

The study used a longitudinal study design, where data was collected at different stages of growth. Simple random sampling (SRS) was used to select the chickens. They were divided into 5 groups of 20 chickens per pen, the ratio of female to male was determined by the number of each gender procured from the incubator.

Data collection

An automated weighing scale was used to weigh each chick once a week till week 19. Dead chick data were removed from the data set. Five non-linear functions that describe the growth curve on body weight data were fitted in order to estimate body weight (BW) at a specific age. The growth functions that were used in this study are:

Gompertz: $W = A * Exp(-Exp(b - ct))$

Logistic: $W = A/(1 + b * Exp(-ct))$

Richards: $W = A(1 - b * Exp(-kt))^M$

Von Bertalanffy: $W = A * (1 - B * EXP(-kt) ** 3$

Where W is the corresponding weight at time t. A is the adult value or asymptote, b, c, k, M are model parameters.

Statistical Analysis

The Statistical Package for Social Sciences version 29.0 (IBM SPSS 2022) was used to fit the growth functions nonlinearly to the live weight measurements related to age. The quality of fit was assessed by comparing the estimated functions' performances using the Bayesian information criterion (BIC), Akaike's information criterion (AIC), the coefficient of determination (R2), and adjusted coefficient of determination (Adj.R2). The body weight data for the various age groups were examined for normality using the Shapiro test, and when the data was not normally distributed, the Kruskal-Walli test was employed.

RESULTS

Descriptive statistics

Table 1 shows the body weight of the Boschveld chicken from week 0 to week 19. The results showed that the body weight gain in week 8 and week 10 was higher compared to other weeks. It also indicates that the growth rate was very slow in weeks 13, 14 and 15.

Table 1: The average body weight of Boschveld indigenous chickens per week

Age (week)	Unsexed (N=63) (Mean ± SE)
0	30.2±30.52
1	46.90±0.77
2	76.67±1.72
3	137.38±2.95
4	207.02±4.10
5	242.70±5.98
6	350.49±6.11
7	500.84±11.32
8	711.11±15.32
9	906.19±20.46
10	1123.10±30.97
11	1207.27±27.92
12	1545.87±40.17
13	1678.84±39.14
14	1680.24±32.17
15	1696.91±55.10
16	1834.21±33.43
17	1859.06±40.99
18	1937.32±35.72
19	2002.10±32.24

N: Total number of birds, SE = Standard Error.

Growth curve parameters

Table 2 shows the estimated growth curve parameters for Boschveld chicken using Gompertz, Logistic, Von Bertalanffy and Richards. The asymptotic value (A) of Von Bertalanffy model was higher (146117.95) compared to other models. The values for B parameter were in the same range of >10 for Gompertz, Von Bertalanffy and Richard's models. The values of k for Gompertz, Logistic and Von Bertalanffy were higher than 0 whereas for Richard's it was 0. The B parameter values for Von Bertalanffy and Richard's were the same. The shape parameter for Richard's model were 1.2.

Table 2: The growth curve parameters for body weight in Boschveld indigenous chickens

Model	A	B	k
Gompertz	2144.24	7.34	0.24
Logistic	1968.23	53.07	0.42
Von Bertalanffy	146117.11	1.00	0.01
Richards	-34341.35	1.00	0.00

A = asymptotic weight (g) when time goes to infinity; B = scaling parameters (constant of integration); k = maturing rate (g/week).

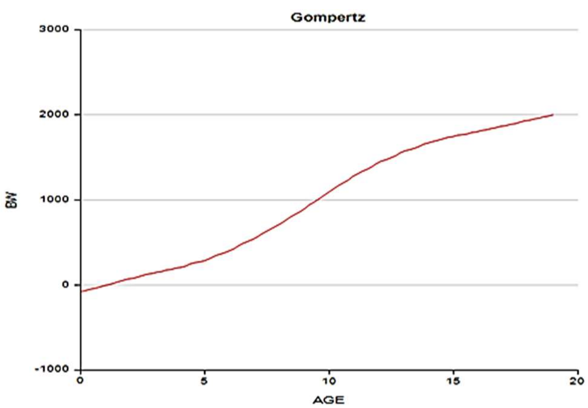

Fig. 1: Growth curve of Boschveld indigenous chicken using Gompertz.

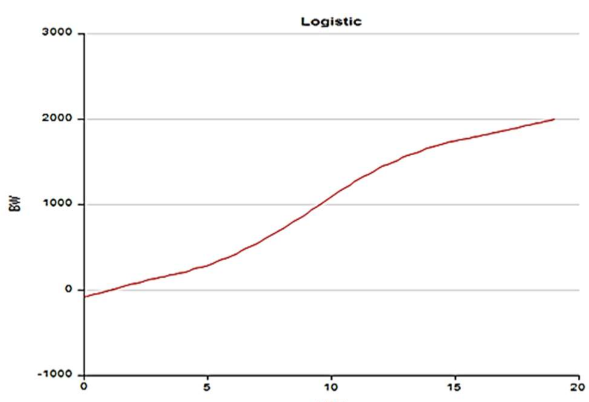

Fig. 2: Growth curve of Boschveld indigenous chicken using Logistic.

Selection of the best fitted model using goodness-of-fit test

Table 3 shows the values of the various model selection criteria. The values of R^2 and Adj.R^2 for Gompertz and Logistic were higher than 90% and for Von Bertalanffy and Richard's it was lower than 90% standing at 0.91, 0.91; 0.92, 0.91 and 0.89,0.88; 0.88, 0.88, respectively. Based on AIC Von Bertalanffy was the best fitting model followed by Gompertz model. Based on BIC Von Bertalanffy was also the best fitting model followed by Richard's model.

Visualization of the growth models

Fig. 1 to 4 show the visualization of the Boschveld indigenous chicken growth patterns using model parameters. Body weight increased with age but at different rates which slightly differed from one model. The growth rate presented by the steepness of the Gompertz model showed a higher growth rate of the chickens from week 5 to week 13 compared to other models. Von Bertallanffy steepness partially indicated a uniform growth rate, at which the growth rate of the chickens was not higher compared to Gompertz model. The growth rate represented by the steepness of Logistic and Richard's models were similar.

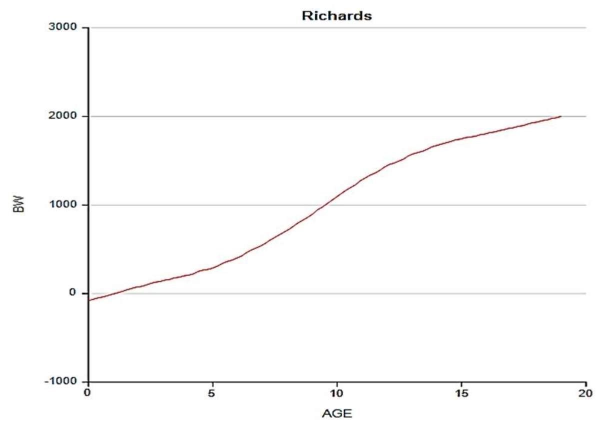

Fig. 3: Growth curve of Boschveld indigenous chicken using Richards.

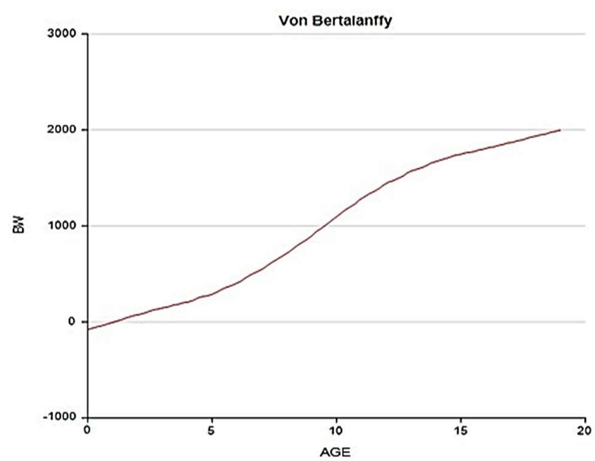

Fig. 4: Growth curve of Boschveld indigenous chicken using Von Bertalenffy.

DISCUSSION

The genetic characterisation of native chickens is imperative, not only for conservation purposes but also for the progress of breeding programs (N'dri et al. 2018). The first objective of the study was to estimate the growth pattern of indigenous Boschveld chicken using non-linear models. The growth functions were fitted by a non-linear procedure using regression, to the measurements of live weights associated with age. The growth trajectory observed in Boschveld chickens is comparable to patterns

Table 3: Best fit model selection for Boschveld indigenous chicken using goodness-of-fit tests values arranged in increasing order

PS	R^2	Adj.R^2	Order	MSE	AIC	Order	BIC	Order
Intensive	0.89	0.88	Rch	48444.31	1087.93	Bev*	1084.63	Bev*
Intensive	0.89	0.88	Bev	49536.03	1088.62	Gp	1085.03	Rch
Intensive	0.91	0.91	Gp	65756.12	1088.66	Lg	1085.31	Gp
Intensive	0.92	0.91	Lg*	65803.68	1089.93	Rch	1085.36	Lg

Gp = Gompertz, Lg = logistic, Bev = Bertalanffy, Rch = Richard models and PS = production system while R^2 = coefficient of determination, Adj.R^2 = adjusted coefficient of determination, MSE = mean square error, AIC = Akaike information criterion, BIC = Bayesian information criterion. * =best fit model.

reported by N'dri et al. (2018) for African indigenous breeds, where a distinct phase of accelerated growth during the mid-growth period was also evident. This period represents a strategic opportunity for feed optimization and health interventions. Sanusi and Oseni (2022) emphasized the significance of this growth phase in Nigerian indigenous chickens, highlighting its importance for reducing production costs and improving market weights. Growth curve parameters from the Logistic and Gompertz models were biologically realistic, reflecting moderate maturity rates and suitable asymptotic weights. These findings align with previous studies by Nguyen Hoang et al. (2021), Zhao et al. (2015), Sanusi and Oseni (2022) and Al-Ali et al. (2022), all of which support the reliability of these two models in describing growth in indigenous and commercial chicken breeds. The poor performance of the Richards model, both in this study and in those by Mancinelli et al. (2023) and Soglia et al. (2020), further confirms its limitations in this context. The difference in this study can be due to environmental conditions, breed type, management procedures, nutritional level and sample size. The findings of this study suggest that only growth curve parameters cannot be used to accurately predict the growth pattern of the indigenous Boschveld chicken as the parameters cannot be directly compared across models because they are derived from the specific derivatives of their respective growth functions, making them unique to each model.

Hence, the second objective of the study was to compare the performance of different non-linear models in estimating the growth pattern of the Boschveld chicken. This study found that the Von Bertalanffy model was the best fit for modelling the growth trajectory of Boschveld indigenous chickens. This outcome is consistent with the findings of Mata-Estrada et al. (2020), who also identified the Von Bertalanffy model as the most suitable for poultry growth data. Similarly, a study conducted on Thai Black Bone chickens by Plaengkaew et al. (2021) and on Japanese quail by Sheikhlou et al. (2023) further supports the effectiveness of this model in capturing growth patterns across different poultry genotypes. However, this finding contrasts with a number of studies that favoured other models. For instance, the Gompertz model was reported to perform reliably by Zhao et al. (2015), Soglia et al. (2020), Nguyen Hoang et al. (2021), Al-Ali et al. (2022), and Mancinelli et al. (2023). In the case of FUNAAB Alpha chickens, Akpan et al. (2025) also identified the Gompertz model as the most suitable for growth prediction. Machado et al. (2022) identified the Richards model as the best fit for Canela-Preta chickens; this was supported by findings on broilers by Nematzadeh et al. (2022). In a breed- and sex-specific analysis of Andalusian turkeys, Arando et al. (2021) reported that the Logistic model best fit males, while Richards was more appropriate for females based on R^2, MSE, AIC, and BIC values. Likewise, Durosaro et al. (2021) found model preferences varied with feather types: Gompertz for normal and naked neck chickens, Brody for frizzle-feathered birds, and Von Bertalanffy for males. The difference in this study can be due to environmental conditions, breed type, management procedures, nutritional level, and sample size. The results suggest that the Von Bertalanffy is best fit and can be used for estimating the growth pattern of the Boschveld indigenous chickens. The use of non-linear models to estimate the growth pattern of chickens enables genetic approaches to optimize production systems.

Conclusion

In conclusion, the Von Bertalanffy is the best fitted and performing model based on AIC and BIC for estimating the growth pattern of the Boschveld chicken. The findings of this study suggest that body weight gain is dependent on the age of an animal and that Von Bertalanffy model can be used to estimate the growth pattern of the Boschveld chicken breed.

DECLARATIONS

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Conflicts of Interest: There is no conflict of interest

Data Availability: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Ethics Statement: Ethical approval was given by the University of Limpopo Animal Research Ethics Committee (AREC) under the number: AREC/39/2024:4H before the commencement of the study.

Author's Contributions: CMM, KM and TLT contributed to experimental design. CEM, KM and SM analyzed the data and wrote the manuscript. CMM and TLT revised and edited the manuscript. All the authors approved the final manuscript.

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