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ORIGINAL RESEARCH ARTICLE

Comparative Application of Nonlinear Models to Describe the Growth of Broilers and Noiler Chicken Strains

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ABSTRACT
Growth pattern is crucial in the rearing of meat-type chickens, as it enables managerial decisions at specific development phases and guides improvement programs. This study used four nonlinear (Gompertz, Logistic, Weibull, and Brody) models to fit the growth curves of two commercial broiler (Cobb 500 and Marshall) and one indigenous (Noiler) chicken strain reared in the semi-arid environment of Sokoto. Body weight (BW) was recorded weekly starting from the first week until 56 days of age, and the average daily gain was computed from the records. Model fit was evaluated using the coefficient of determination (R^2), Akaike information criterion (AIC), Bayesian information criterion (BIC), root mean square error (RMSE), and mean square error (MSE). The results showed that the Marshall strain had superior growth performance (asymptotic body weight >3000 g and BW at inflection of 1334), whereas the Noiler strain showed higher BW variability (CV of 21.7%). Estimates of maturity differed across models, with the Weibull and Brody models estimating the highest and lowest rates, respectively. The age at inflection varied from 5.5 weeks for Cobb (Gompertz) to 8 weeks for Marshall (Weibull). Overall, the Gompertz model best described the growth of the three chicken strains, with the lowest AIC, BIC, RMSE, and MSE residuals as well as the highest R^2. These results enhance our understanding of chicken growth dynamics reared in semi-arid environments and identify strain-specific critical growth ages to guide feeding strategies for the three strains. Future studies extending for 12 weeks or beyond are recommended to validate the asymptote and improve the predictive reliability of the fitted growth functions.

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INTRODUCTION

Poultry production is critical for improving food security, nutrition, and income generation in Nigeria, particularly in rural areas (Baba et al., 2025; Emegha & Oliomogbe, 2024; Salisu et al., 2021, 2022). They have a short generation interval and low capital requirements, and hence a quick return on investment. Indigenous chicken strains are well adapted to local conditions and are raised alongside exotic breeds in semi-arid regions, such as Sokoto, where climatic and environmental factors can pose significant challenges to productivity. Understanding the growth patterns of these chicken strains is essential for optimising their management and enhancing their production potential.

Traditional linear growth models often fail to capture the complex nonlinear dynamics of growth, which is influenced by environmental factors, genetics, and management practices. In contrast, nonlinear growth models such as Gompertz, Logistic, von Bertalanffy, Weibull, Brody, and Richard more accurately describe the growth curves of animals reared under varying environmental conditions. Hence, the growth of commonly reared exotic broiler strains in Nigeria, including Cobb 500, Marshall, Abor Acr,e and Ros,s has been described using such nonlinear models, demonstrating their effectiveness in predicting growth curves and identifying optimal growth parameters (Durosaro et al., 2021; Ilori et al., 2022). Specifically, the Gompertz and Logistic functions accurately describe the growth pattern of Marshall chickens reared in South-western Nigeria (Adenaike et al., 2017; Ogunpaimo et al., 2020). Additionally, Gompertz also fits the growth trajectory of the Cobb and Noiler strains (Vargas et al., 2020; Gous et al,. 2024). While the Gompertz and Weibull functions exhibit the ability to accurately describe the asymmetric sigmoidal growth pattern of chickens in addition to providing biologically meaningful parameters (Akramullah et al., 2025), the Logistic model fits adequately under certain parameterizations but is generally limited by its assumption of symmetrical growth (Prasad et al., 2006). In contrast, the Brody model fits the growth pattern of chickens poorly because it cannot capture the inflection point of rapid early growth. Nonetheless, there is limited research on the application of these models to describe the growth patterns of chickens commonly

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reared in the semi-arid environments of Nigeria (Akinsola et al., 2021; Achimugu et al., 2024). The few studies focused on exotic birds or those managed on-farm. This indicates that indigenous chicken strains are often overlooked in favor of exotic strains in research, despite their resilience and their role in meat supply and in enhancing the livelihoods of rural Nigerians.

This study explored nonlinear growth models to describe and compare the growth patterns of broiler and indigenous dual-purpose chicken strains reared in the semi-arid environment of Sokoto, Nigeria. By utilizing these models, this study provides a baseline understanding of the growth dynamics of different chicken strains kept under challenging environmental conditions. The findings of this study provide a scientific basis for informed strain selection by producers and support the development of optimized feeding strategies to enhance the economic efficiency of poultry production under semi-arid environmental conditions. Additionally, it could guide the proper design and implementation of breeding programs to improve the sustainability and profitability of poultry production in Nigeria's semi-arid regions.

MATERIALS AND METHODS

Experimental site

This study was conducted at the Livestock Teaching and Research Farm of the Department of Animal Science, Usmanu Danfodiyo University, Sokoto, Nigeria. Sokoto State is located in northwestern Nigeria and has a semi-arid agroecology. Sokoto State is situated between latitudes 11°30" to 13°50" N and longitudes 4° to 6° E, at an altitude of 300m above sea level. Sokoto experiences annual rainfall of 380–763 mm. The annual temperature ranges from 28.3℃ to 40 °C (Jibrillah et al., 2019). The dry season begins in October and ends in May or June. The wet season begins in June or July and ends in September or October. In addition to backyard poultry production, small-scale broiler production has gained popularity among households in urban and peri-urban areas of Sokoto. Producers rear fast-growing exotic broiler strains and dual-purpose improved and unimproved strains in the region.

Ethics approval statement

This study was approved by the Department of Animal Science, Usmanu Danfodiyo University, Sokoto, and followed the international guidelines for animal use and care.

Management of experimental birds

A total of 135 unsexed birds of Cobb 500, Marshall, and Noiler strains were used in this study, with 45 birds each from the three strains. A completely randomized design was used in this study, with three replicates per strain and 15 birds per replicate. The birds were raised for eight weeks and fed a commercial diet *ad libitum*. The birds were supplied with fresh water at all times during the experiment. Additionally, the birds were vaccinated against Newcastle disease and Gumboro disease. Heating was provided during the brooding phase of rearing.

Data collection

Body weight was recorded on the first day of the experiment and weekly thereafter through the eighth week. Weight was measured on the recording day in the morning using a scale with a sensitivity of 10 g. The average daily gain was computed as a measure of growth rate by dividing the weekly weight gain by 7.

Growth curves

Four nonlinear models, including Gompertz, Logistic, Weibull, and Brody, were used to fit the curves for the weekly body weights of the three strains of chickens reared in this study. The models were used based on their ability to describe chicken growth in previous studies (Adenaike *et al.,* 2017; Santos et al., 2018; Şengül *et al.,* 2024). The details of the models used to fit the growth curves are listed in Table 1.

Table 1: Equations of the nonlinear growth models

Model	Equation	Inflection point	Weight at inflection
⁑Logistic	$Wt = \frac{A}{(1 + b * exp(-k * t))}$	$\frac{lnb}{k}$	$\frac{A}{2}$
⁑Gompertz	$Wt = A * exp\ (-b * \exp(-k * t))$	$\frac{lnb}{k}$	$\frac{A}{e}$
⁑Weibull	$Wt = A - b * exp\ (-k * t\lambda)$	$\left(\frac{\lambda-1}{k\lambda}\right)^{1/\lambda}$	$A - b * exp(-\left(1 - \frac{1}{\lambda}\right))$
**Brody (Mechanistic growth)	$Wt = A * (1 - b * \exp(-k * t))$		

Wt is the estimated weight at age t (week); A is the asymptotic weight(g); b is the initial body weight; k is the growth rate; λ is a scale parameter. ⁑Şengül et al. (2024) **Santos et al. (2018).

Data analysis

The data were subjected to descriptive analysis and tested for normality and equality of variance assumptions using the Shapiro-Wilk and Levene tests, respectively. Additionally, the data were analyzed using ANOVA to determine the effect of strain on initial and final body weights. Means were separated using Tukey's test. Furthermore, Weekly body weight was fitted to the Logistic, Gompertz, Weibull, and Brody models, as described. Model functions were fitted using the minpack.lm and tidyverse packages in the R statistical environment. The starting values for the model parameters were determined using the guess function as follows (A = max_BW*1.1, b = log(A/BW), and k = .025). The convergence criteria of the models were parameter tolerance (ptol = 1e-10), function tolerance (ftol = 1e-10), and maximum iteration (maxiter = 100). Plots were generated using the ggplot2 package.

RESULTS AND DISCUSSION

Body weight change

The descriptive and inferential statistics of the body weights of the Cobb 500, Marshall, and Noiler chicken strains revealed significant variations in growth performance (Table 2). Birds of the Marshall strain were heavier at the beginning and end of the experiment, with a remarkable weight gain of 2123.12 g by the eighth week, compared to Noiler chickens. In contrast, Cobb 500 showed body weights similar to those of Marshall and Noiler strains at the end of the experiment. Therefore, the weight gain of the Marshall strain indicates superior growth performance, consistent with previous studies (Sa'adu et al., 2018; Gous et al., 2024). The lowest weight of Noiler chickens observed in this study corroborated previous findings, where they demonstrated lower performance than exotic broiler chickens (Obienyem et al., 2023; Olusola et al., 2023). Body weights lower than those observed in the current study (1645 g) for birds of the Marshall strain have been reported at similar ages (Udeh et al., 2015). This is expected because modern broiler chickens are continuously improved for better performance, and more genetic gain is expected in the commercial tier after a decade. Nonetheless, a higher mean BW was reported for Cobb chickens reared elsewhere in Africa than that observed in the current study (Gous et al., 2024). The body weight of Noiler birds observed in the current study is comparable to 1179.29 g reported at 56 days for birds managed on-station (Bamidele et al., 2020). Although a lower BW has been reported in previous studies with larger sample sizes than that used in the current study (Ajayi et al., 2020; Adamu et al., 2021; Akinsola et al., 2021; Animashahun et al., 2022), a higher body weight at the same age was documented for birds reared in the humid conditions of southwestern Nigeria (Ayoola *et al.*, 2022). At eight weeks of age, the coefficient of variation for body weight was highest in Noiler (21.70%), followed by Marshall (12.74%) and Cobb 500 (11.26%) in descending order.

Table 2: Summary Statistics for body weight of Marshall, Cobb 500, and Noiler chicken strains

	Cobb 500 (N=45)			Marshall (N=45)			Noiler (N=45)		
Time	**Mean**	**SD**	**CV**	**Mean**	**SD**	**CV**	**Mean**	**SD**	**CV**
Start	37.01[a]	0.57	1.54	39.44[a]	1.17	2.97	32.84[b]	1.32	4.02
End	1964.16[ab]	221.17	11.26	2162.56[a]	275.58	12.74	1322.82[b]	286.99	21.70

BW: body weight (g), SD: Standard Deviation, CV: Coefficient of variation

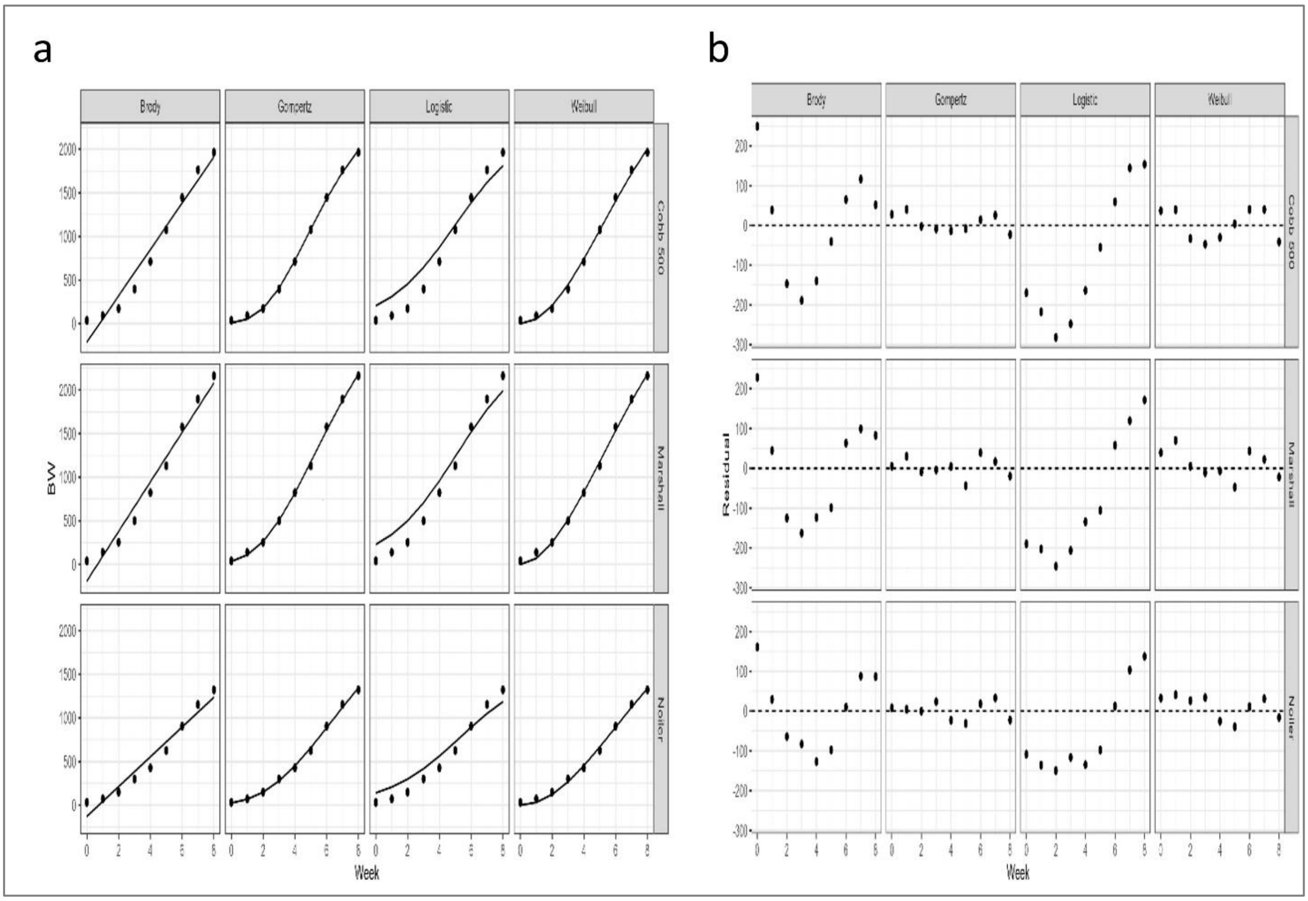

Figure 1: Growth curves for Cobb 500, Marshall and Noiler chickens. a). Fitted models showing observed and predicted BW. b) Residual plots for each fitted model in the three strains

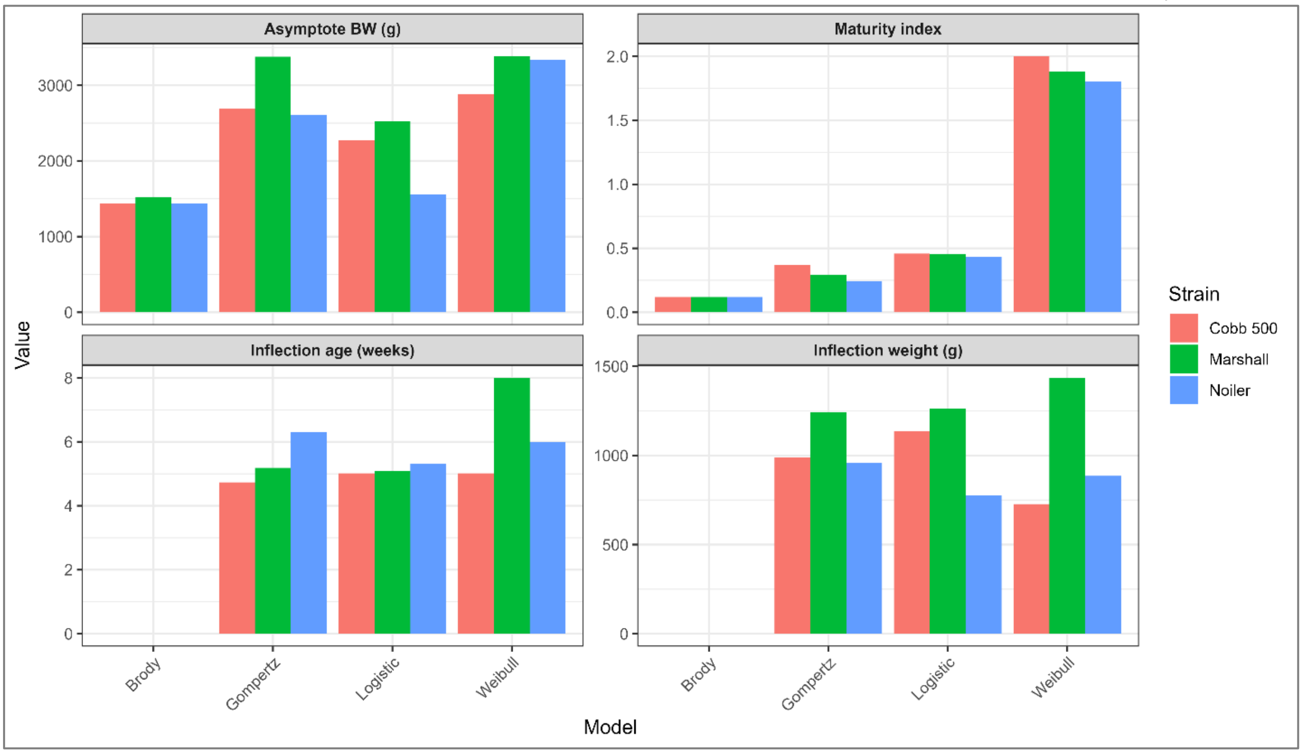

Figure 2: Model parameters estimated using nonlinear models

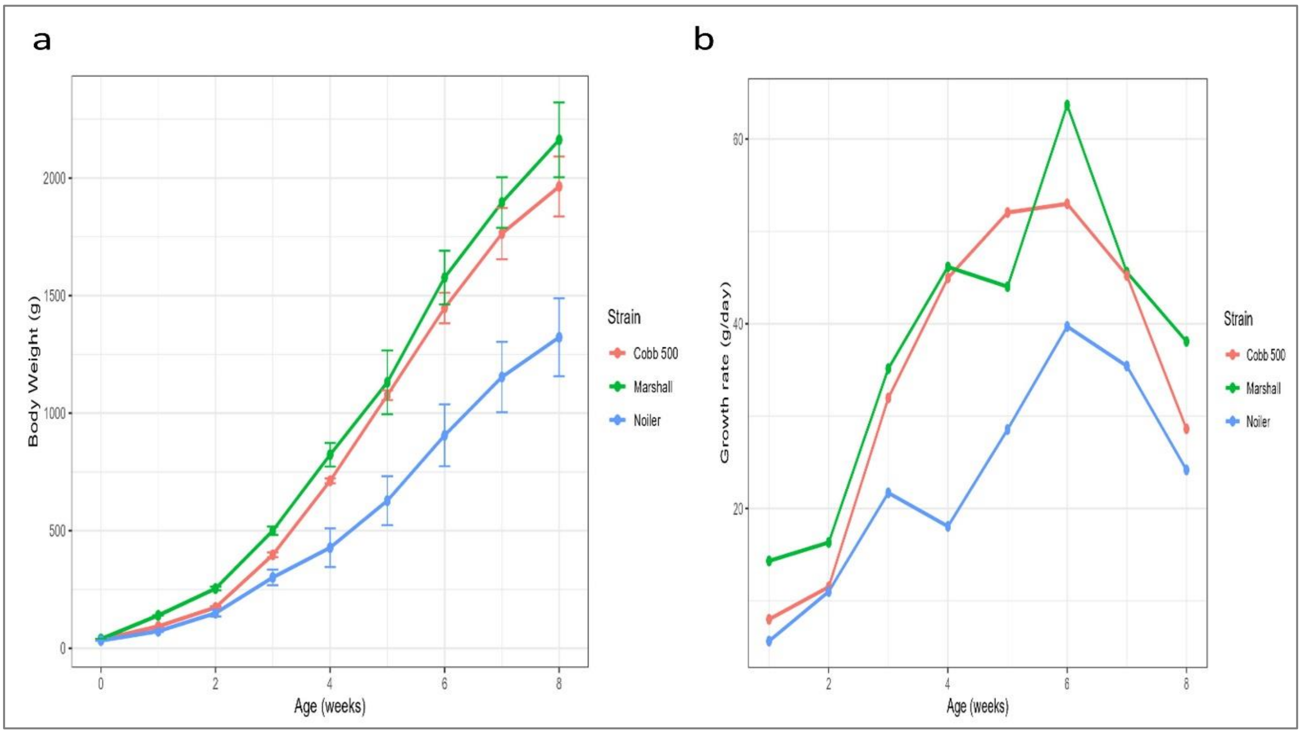

Figure 3: Weekly body weight and growth rate of Marshall, Cobb 500, and Noiler chicken strains.

In a related study, Ajayi *et al.* (2020) reported a CV for body weight ranging from 4.63 to 32.24% in six dual-purpose tropically adapted chicken strains reared across different agroecological zones of Nigeria. The high variability observed in the indigenous Noiler strain indicates potential genetic diversity within the population. This provides the raw material required for genetic improvement by selecting birds with superior performance (Oleforuh-Okoleh & Wagoha, 2017). Additionally, variability may indicate greater adaptability among certain individuals to specific environmental conditions. Overall, the variability in growth performance among the studied strains is attributable to inherent genetic differences and genotype-by-environment interactions, since the management conditions were uniform throughout the study.

Growth parameters

The curves for the observed and predicted weights of the chicken strains using the nonlinear growth models are presented in Figure 1a. The Gompertz and Weibull models produced BW predictions that were closer to the observed values throughout the growth period in the three strains. In contrast, the Logistic model showed the greatest deviation from the observed BW, whereas the Brody model lacked the flexibility of the other nonlinear models.

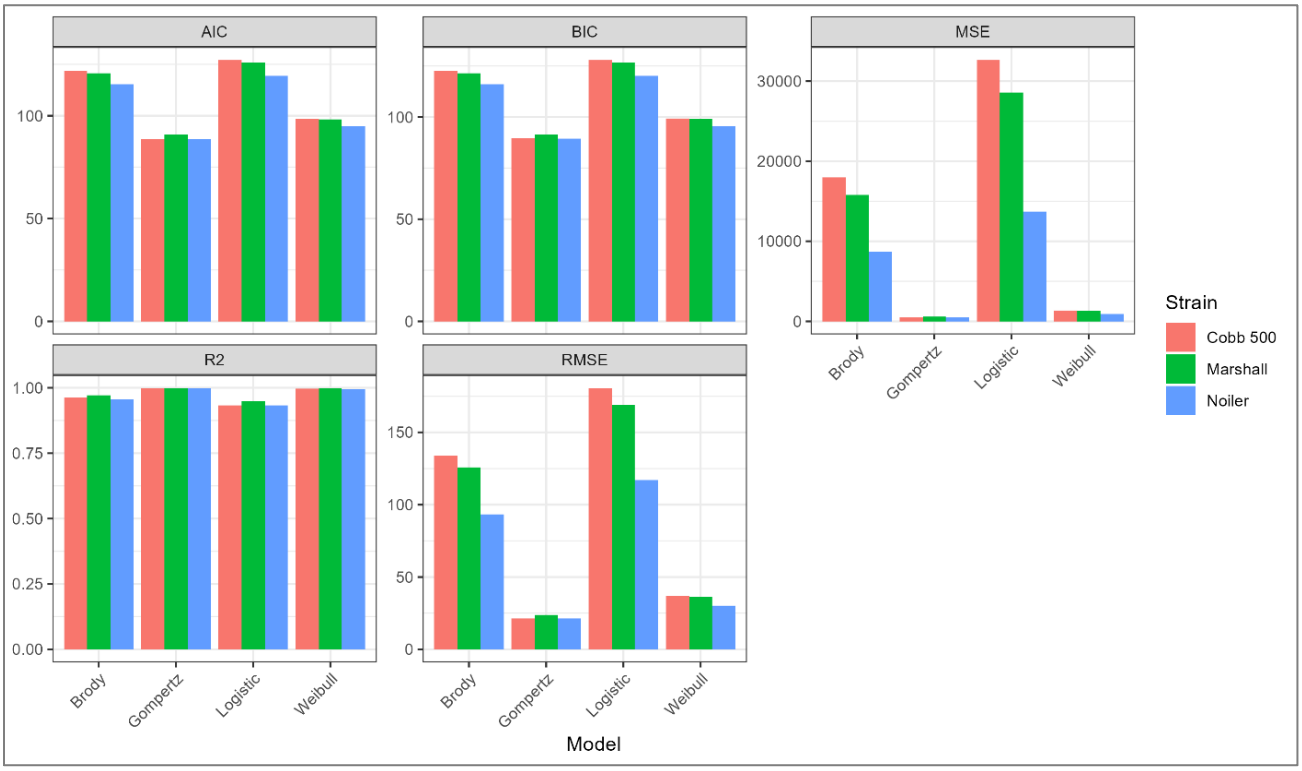

Figure 4: Goodness of fit criteria for nonlinear models in describing growth of chicken strains

Consequently, the Logistic and Brody models showed more residuals than the Weibull and Gompertz models (Figure 1b). Additionally, during the early growth stage, the Brody model predicted BW approximately 200 g higher than the observed BW for the Cobb 500 and Marshall strains. Conversely, the Logistic model predicted a BW lower than the observed BW during the same stage. These indicate the limitations of the Brody and Logistic models in predicting BW for the three chicken strains. Similar observations for both lower and higher residuals were reported when the Gompertz and Logistic models were fitted to BW in Ross 308 and indigenous Algerian chickens (Mouffok et al., 2019; Osaiyuwu et al., 2024).

Furthermore, growth parameters for the three chicken strains estimated using the nonlinear models are presented in Figure 2. Different growth models predicted variable asymptotic weights, ages, and inflection point for the three chicken strains.

In the Marshall strain, the mean asymptotic weights were estimated at 3382, 3378, 2522, and 1522 g using the Weibull, Gompertz, Logistic, and Brody models, respectively. In Cobb 500 chickens, the Weibull model estimated the highest asymptotic body weight (2879 g), whereas the Brody model estimated the lowest (1441 g). For the Noiler strain, the only dual-purpose strain used in this study, the Brody model estimated the lowest asymptotic BW (1441 g) compared to the other models (1553-3334 g). Previous studies estimated higher asymptotic weights using the same nonlinear models for Cobb 500 and Ross strains reared between 105 and 192 days of age (Vargas et al., 2020; Gous et al., 2024; Şengül et al., 2024). This could be attributed to the longer rearing duration and variation in the rearing environment. However, lower asymptotes were estimated using the Logistic, Gompertz, Brody, and von Bertalanffy models for Nigerian indigenous chickens, including Naked-neck, Normal feathered, and Funaab alpha (Adenaike et al., 2017; Ogunpaimo et al., 2020; Durosaro et al., 2021).

The maturity index estimates for the study strains vary widely between different models. The Brody model estimated the lowest index (0.12) while the Weibull model estimated the highest maturity index (1.8-2.0). The Gompertz and Logistic models estimated a moderate maturity index (0.24-0.46). Based on the Gompertz model, it is clear that Marshall is the earliest-maturing strain, whereas the Noiler is the slowest to reach the asymptote. A comparable maturity index was reported for tropically adapted dual-purpose chicken strains estimated using Gompertz and Logistic models (Akinsola et al., 2021). Although a lower maturity index was reported for the Cobb 700 strain (Gous et al., 2024), Marshall and Abor Acre Plus chickens reared in the dry subhumid regions of central Nigeria were reported to have a faster maturity index (Achimugu et al., 2024).

The inflection point as a model parameter is absent in the Brody model, making it less flexible than the other nonlinear models. Hence, inflection age and weight were not estimated using the Brody model. In the Marshall strain, inflection was estimated at 5.5 weeks by both the Gompertz and Logistic models, whereas the Weibull model estimated a delayed inflection at 8 weeks. For the Cobb strain, all three models estimated the inflection age around 5 weeks. Similarly, the Gompertz and Weibull models estimated the inflection point for Noiler chickens around six weeks of age, while the Logistics model estimated it a week earlier. Previous studies reported a lower age at inflection of 4 weeks for Marshall, Abor Acre Plus, and Ross PM3 strains using Logistic and Gompertz models (Achimugu et al., 2024; Şengül et al., 2024), whereas a higher age at inflection ranging from 10 to 13 weeks was reported for tropically adapted dual-purpose chicken strains (Akinsola et al., 2021). These differences could be attributed to differences in rearing duration across studies. In practice, broiler production takes a maximum of eight weeks. However, the growth of the birds takes longer to reach their asymptote. Hence, the short duration of the current study may influence the detection of early inflection age and lower asymptote. This could be more pronounced in Noiler chickens, which are slow-growing and capable of continuous growth until reproductive age, which sets in around 20 weeks (Mosobalaje 2020; Chimezie et al., 2025).

Furthermore, the results of the current study showed varying weights at inflection, ranging from 776 g for Noiler estimated using the Logistic model to 1435 g for Mashall estimated by the Weibull model. Generally, estimates for Marshall chickens were higher at inflection than in other strains. Previous studies reported higher BW at inflection, as estimated by the Gompertz, in Kuroiler, Sasso, Fulani, and Shika Brown chickens (Akinsola et al., 2021). A recent study also reported the highest BW at inflection in Ross PM3 chickens using the Weibull model (Şengül et al., 2024).

Growth rates of Noiler and exotic broiler chicken strains

The weekly body weight and growth rates for Cobb 500, Marshall, and Noiler chickens are presented in Figure 3. As can be seen in Figure 3a, birds of the Marshall strain maintained superior growth since the beginning of the experiment, whereas chickens of the Cobb 500 demonstrated growth superiority over the native Noiler after the second week. Hence, Marshall and Cobb 500 demonstrated faster growth compared to the Noiler chickens. Additionally, results presented in Figure 3b indicated that the weight gain in the three strains increased steadily until 42 days of age, when it reached a peak of 63g/day in Marshall, 52g/day in Cobb 500, and 39g/day in Noiler. Thereafter, it declined steadily until the experiment's completion. Results also highlighted significant differences in growth among the three strains, with Marshall being the most efficient for rapid meat production, Cobb 500 a close competitor, and Noiler better suited for alternative farming systems. The results underscore the importance of selecting chicken strains based on production goals and resource availability.

Goodness of fit criteria of the growth models

The models' performance in describing the growth of the Marshall, Cobb 500, and Noiler strains was assessed using multiple goodness-of-fit metrics, including R^2, AIC, BIC, RMSE, and MSE (Figure 4). All models achieved convergence within 20 iterations.

As shown in Figure 4, most of the fit criteria were within a reasonable range for all the models in predicting body weight of the three strains. However, MSE and RMSE showed extreme variation across models, and the Brody and Logistic models had much higher values than the other models. The Gompertz model achieved the lowest AIC, BIC, MSE, and RMSE. In the same vein, it explained the highest variation in body weight across the three strains, with R^2 values ranging from 0.995 to 0.998. While the Weibull model has comparable R^2 values to the Gompertz model across the chicken strains, it has slightly higher values for other fit criteria. Therefore, the Gompertz model was identified as the most suitable for predicting BW in all the three chicken strains, based on comprehensive performance criteria, corroborating previous findings (Ogunpaimo et al., 2020; Achimugu et al., 2024; Gous et al., 2024). Other studies have emphasized the applicability of the Weibull model for characterizing the growth of various avian species, such as chickens and ostriches, thereby validating it as an alternative to modeling the growth of Marshall, Cobb 500, and Noiler chickens (Topal et al., 2008; Bo et al., 2025).

Contrary to the results of the present study, Adenaike et al. (2017) reported that the Logistic model provided best fit for predicting BW of Marshall chickens. The finding that the Logistic model yielded the poorest fit in this study is consistent with previous research involving both native and exotic broiler chickens (Topal et al., 2008). Overall, these findings highlight the importance of selecting appropriate models for different strains, owing to genetic variations in growth patterns, to guide management and breeding decisions.

CONCLUSIONS

In this study, Marshall and Cobb 500 birds showed superior growth performance, whereas the Noiler strain showed the highest variability within strain. Interestingly, the Gompertz model provided the best fit for the growth of all three strains, despite their inherent genetic specificity and growth potential. The Weibull model proved to be an alternative to the Gompertz model, while the Logistic model poorly describes chickens' growth. The study also highlights the differences in maturity rate, with the Weibull and Brody models estimating the highest and lowest maturity rates, respectively. The study enhances our understanding of the growth dynamics of broiler and dual-purpose chicken strains reared in the semi-arid environment of Nigeria and emphasizes the importance of selecting an appropriate strain of chickens for management decisions, especially in implementing restricted feeding, which should be avoided during the inflection of growth.

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