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Comparison of the Fit of the Richards Model to Broiler Chicken Growth Data With Gompertz and Logistic Models

Sedat Tel[1] • Nurinisa Esenbuğa[2]

[1] Atatürk University, Institute of Science, Department of Animal Science, Erzurum, Türkiye, sedat.tel@yahoo.com
[2] Atatürk University, Agriculture Faculty, Department of Animal Science, Erzurum, Türkiye, esenbuga@atauni.edu.tr

Corresponding Author: sedat.tel@yahoo.com

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ABSTRACT

This study comparatively evaluates three nonlinear regression models (Richards, Gompertz, and Logistic) commonly used to mathematically model the growth process of commercial broilers. The primary objective of the study was to determine the model that most accurately represents the growth curve by analyzing the fit of these models to live weight data. In the study, 360 Ross 308 hybrid male broiler chicks were monitored until 50 days of age, and weekly live weight measurements were taken. Parameter estimates for each model were evaluated based on statistical fit metrics, including root mean square error (RMSE), coefficient of determination (R^2), Akaike Information Criterion (AIC), and Bayesian Information Criterion (BIC). The results showed that the Richards model showed the highest fit across all criteria. The Gompertz model ranked second, and the Logistic model ranked third. However, all three models demonstrated high performance in explaining the growth process of broilers. These results highlight the importance of growth modeling as a key decision-support tool for determining optimal slaughter timing and feeding strategies, particularly in broiler production. The flexible structure of the Richards model makes it the most desirable option in terms of biological significance and statistical relevance.

INTRODUCTION

Broiler farming is a significant livestock activity at both the global and national levels due to its advantages, including high yields at low costs and the ability to quickly market products (Topal & Bölükbaşı, 2008; İzgi et al., 2020). Accurately monitoring live weight gain during the production process and determining the ideal slaughter time are crucial for both economic efficiency and resource utilization (Bilgin & Esenbuğa, 2003). Therefore, expressing growth curves using mathematical models is becoming an important tool to support breeder decisions (Aggrey, 2002; Adamu et al., 2021).

Growth curve models are used to predict changes in live weight of animals with age and are divided into two basic groups: Linear and nonlinear models (Efe, 1990). Nonlinear models are more widely preferred in animal husbandry because they better reflect biological reality (Masoudi & Azarfar, 2017). The Richards, Gompertz, and Logistic models are among the most frequently used nonlinear models to describe growth curves in broiler chickens. However, the predictive success of these models can vary depending on the data set used and application conditions (Söğüt et al., 2005; Michalczuk et al., 2016; Falana et al., 2024).

Recent studies emphasize the importance of model selection based on growth dynamics and biological interpretation. Ghavi Hossein-Zadeh (2025) investigated alternative nonlinear models in partridges, while Xie et al. (2020) compared nonlinear models for feather growth in yellow-feathered chickens, examining variation in model performance across traits and genotypes. Similarly, Kucukonder et al. (2020) and Falana et al. (2024) evaluated model fit in broilers, demonstrating how predictive accuracy and biological realism can vary.

Despite these advances, updated evaluations of the Richards model using robust statistical criteria are needed in modern commercial broiler breeds. The novelty of this study lies in the comprehensive comparison of three key nonlinear models (Richards, Gompertz, and Logistic) based on goodness-of-fit metrics (RMSE, AIC, BIC) and biological interpretation of the parameters.

This study aims to evaluate the performance of the Richards model in explaining the growth curve of commercial broiler chickens in comparison with the Gompertz and Logistic models, and to provide recommendations based on statistical criteria for model selection.

MATERIAL AND METHODS

Animal Material

The study was conducted at the Atatürk University Food and Livestock Application and Research Center. All the experimental protocols adhered to and were approved by the guidelines of the Animal Ethics Committee of Ataturk University (Approval date: 25 December 2009; Decision No: 09/123). A total of 360 one-day-old Ross-308 hybrid male broiler chicks were used in the study. Initial weights of the chicks were determined and recorded individually on the day they were brought to the experimental area. During the 50-day trial, the chicks were provided with two different commercial feeds formulated for their growth stages (starter and grower). Feed and water were provided with free access to the birds. Environmental conditions within the coop, including temperature, humidity, and ventilation, were optimized by commercial broiler standards. The lighting program was applied continuously 24 hours a day for the first three days and continued periodically on subsequent days.

In the study, starter (broiler) and grower (broiler) feeds with two different nutrient compositions were obtained from a commercial feed factory. The composition of the compound feeds given to the animals in the trial, their feed ingredients, and their nutrient compositions are presented in Table 1.

Table 1. Nutrient composition of the feeds

Nutrient Composition	Broiler Starter Feed	Broiler Grower Feed
Moisture (%)	12.00	12.00
Crude protein (%)	22.00	20.00
Crude fiber (%)	7.00	7.00
Crude ash (%)	8.00	8.00
Ash insoluble in HCl (%)	1.00	1.00
Metabolizable energy (kcal/kg)	3000 kcal/kg	3100 kcal/kg
NaCl	0.35	0.35
Lysine	1.20	1.00
Methionine	0.50	0.40
Cystine	0.40	0.35
Calcium (Ca)	0.60-1.50	0.60-1.50
Phosphorus (P)	0.60	0.60
Sodium (Na)	0.10-0.30	0.10-3.00

Data Collection

The live weights of the chicks were measured weekly; on the 8th, 15th, 22nd, 29th, 36th, 43rd, and 50th days, it was measured and recorded separately for each individual using scales with milligram precision.

Growth Models

In this study, three different nonlinear growth models were used to describe the growth curve of broiler chickens. These models are:

$$Richards: Y_t = A[1 + \beta\ exp^{-kmt}]^{-1/m} \quad (1)$$

$$Gompertz: Y_t = A\ exp[-\beta\ exp^{-kt}] \quad (2)$$

$$Logistic: Y_t = A[1 + \beta\ exp^{-kt}]^{-1} \quad (3)$$

In these formulations, Y_t represents the live weight at time t; A represents the asymptotic weight (final size); k represents the growth rate; m and β represent the parameters that define the shape of the growth curve.

The coefficient A in nonlinear models represents the asymptotic limit of measurement that the animal can reach. This asymptotic value represents the highest measurement level that the animal can achieve, regardless of short-term changes in body size, which generally occur due to pregnancy, lactation, and environmental factors. This parameter, 'A', which defines adult body size, can be estimated by all growth curve models and is expressed in the appropriate unit depending on the measured trait. The body measurement value of an animal recorded at age t months can theoretically never exceed the parameter A (Şahin et al., 2014). Among the constants in nonlinear models, A is the most easily interpreted from a biological perspective and deserves special attention (Şireli & Ertuğrul, 2004).

The parameter β, which varies according to the initial value, is defined as the ratio of postnatal growth to the adult body size. The "±" sign in the model depends on the value of the parameter m, which represents the exponential power. Accordingly, β is negative when $m > 1$ and positive when $m < 0$ (Akbaş, 1995).

The k parameter in the model is a function representing the maturation rate. This rate varies depending on the A (adult body size) and m (curve shape) parameters in the model. A high k value indicates rapid development, while a low k value indicates a slower developmental process (Brown et al., 1976).

Estimates of the A, β, k, and m parameters obtained from nonlinear models are calculated using the generalized least squares method and the Levenberg–Marquardt iterative algorithm (Draper & Smith, 1981; Akbaş et al., 1999).

Data Analysis

Each model was compared using statistical fit metrics such as the coefficient of determination (R^2), root mean square error (RMSE), Akaike Information Criterion (AIC), and Bayesian Information Criterion (BIC). The Root Mean Square Error (RMSE), used for this purpose, represents the square root of the mean square of the difference between the model's predicted values and the actual observed values. A smaller value indicates a higher predictive accuracy of the model. The Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) jointly assess both how well the model fits the data and how simple it is in terms of the number of parameters it has. AIC imposes a relatively weaker penalty for model complexity, while BIC imposes a more stringent penalty. Lower values for both criteria indicate a more suitable and balanced model. Model fit was assessed based on the highest R^2 value and the lowest RMSE, AIC, and BIC values. Collected live weight data were analyzed using the SPSS 25.0 statistical package.

RESULTS

This study compared the performance of the Richards, Gompertz, and Logistic models to model the 50-day growth process of commercial broiler chickens. All three models are nonlinear and widely used in the literature to describe the biologically sigmoidal shape of the growth curve. The models were examined in detail for predictive accuracy using estimated parameters and fit metrics. The key parameters and standard errors estimated by all three models for the growth curve are presented in Table 2.

Table 2. Estimated parameter values for broiler chickens using nonlinear growth models

Model	A	β	k	m
Richards	3337.89±112.78	-7.986±2.56	0.079±0.0065	-1.868±0.98
Gompertz	4371.47±83.19	5.144±0.031	0.046±0.0087	—
Logistic	3024.24±29.61	40.536±0.53	0.108±0.00068	—

Table 3. RMSE, R^2, AIC, and BIC values calculated with nonlinear growth models

Model	R^2	RMSE	AIC	BIC
Richards	0.999	1711.75	30.44	26.05
Gompertz	0.998	2249.28	30.03	26.74
Logistic	0.998	2021.51	30.26	26.97

The Richards model predicts a moderate adult body weight with an estimate of 3337.89 ± 112.78 g for the asymptotic weight (*A*) parameter, which is found to be in good agreement with the final slaughter weights observed in broilers. The Gompertz model, on the other hand, provides the highest *A* estimate of 4371.47 ± 83.19 g, while the Logistic model provides the lowest value of 3024.24 ± 29.61 g (Table 2). This suggests that the Gompertz model tends to overestimate the later stages of the growth process, while the Logistic model assumes a symmetric growth process that reaches saturation early. Topal & Bölükbaşı (2008) reported that the Gompertz and Logistic models yielded similarly high and low predictions in asymptotic weight estimates. Furthermore, Knížetová et al. (1991), Ersöz & Alpan (1994), emphasized that the Richards model provided predictions closest to biological reality. Recent studies have confirmed these observations, showing that the Richards model offers a flexible and biologically realistic structure for growth modeling in poultry (Kucukonder et al., 2020; Falana et al., 2024; Ghavi Hossein-Zadeh, 2025).

The β value, one of the parameters that directs the curve shapes of the models, is negative at –7.986 ± 2.56 in the Richards model. This is due to the m parameter also being negative (–1.868 ± 0.98). This value indicates that the growth curve is asymmetric, meaning that growth is slow in the early stages and faster in the middle and late stages (Table 2). This structure is quite consistent with the growth biology of commercial broilers. Similarly, Şireli & Ertuğrul (2004) and Akbaş (1995) stated that the m parameter is a biologically meaningful indicator in describing the asymmetry in the growth curve. Because the m parameter is not included in the Gompertz and Logistic models, these models are limited by the assumption of symmetric growth. This limitation of the Logistic model has also been emphasized in recent literature (Xie et al., 2020; Adamu et al., 2021). The *β* value was found to be more stable at 5.144 ± 0.031 in the Gompertz model, while it was significantly higher at 40.536 ± 0.53 in the Logistic model. This supports the Logistic model's prediction of a very rapid increase at the beginning of growth.

For the parameter k, representing the growth rate, the highest value was obtained in the Logistic model (0.108 ± 0.00068), while the lowest value was obtained in the Gompertz model (0.046 ± 0.00087). The Richards model lies between these two extreme values (0.079 ± 0.0065) and assumes a more balanced growth process. A high *k* value suggests that the Logistic model predicts rapid maturation, while a low *k* value suggests that the Gompertz model describes a slower developmental process (Table 2). This differentiation in maturation speed predictions among models was also demonstrated by Falana et al. (2024) and Kucukonder et al. (2020), who found that Gompertz and Richards provide more biologically plausible maturation trajectories than Logistic.

Considering the obtained parameter estimates and standard errors, the Richards model appears to be the most biologically appropriate model, both because it has the m parameter, which provides curve flexibility, and because it reflects asymptotic and interim values more consistently. The Gompertz model stands out as a highly reliable alternative, particularly with its low standard errors and biologically meaningful parameter structure. However, the Logistic model has limited utility in long-term growth prediction due to its early saturation assumption. This has been corroborated by Xie et al. (2020), who noted that the Logistic model underrepresents late-stage growth in poultry, and by Ghavi Hossein-Zadeh (2025), who found Richards to outperform Logistic in similar avian species. These findings are consistent with previous studies supporting the Richards model's preference in broiler growth modeling (Ersöz & Alpan, 1994; Knížetová et al., 1991; Topal & Bölükbaşı, 2008). The fit of the models to the growth data was evaluated using various statistical criteria, and the results are presented in Table 3.

In this study, the statistical fit performances of Richards, Gompertz, and Logistic models applied to live weight data of broiler chickens were compared using basic fit metrics such as coefficient of determination (R^2), root mean squared error (RMSE), Akaike (AIC), and Bayesian (BIC) information criteria. According to the results, the Richards model demonstrated the best fit across all criteria. This model offers the highest explanatory power for growth data with $R^2 = 0.999$, while also offering the lowest errors and the highest model parsimony with RMSE = 1711.75, AIC = 30.44, and BIC = 26.05. This finding stems from the m parameter, which allows the Richards model to represent the early, middle, and late stages of the growth process with a more flexible structure. Indeed, Knížetová et al. (1991), Ersöz & Alpan (1994), and Xie et al. (2020) also reported that the Richards model provided high fit in free-feeding chickens and broilers.

The Gompertz model demonstrated a statistically strong fit with a relatively high $R^2 = 0.998$. However, the RMSE = 2249.28 reveals that it exhibits greater deviations from observed values compared to the Richards model. Notably, while the AIC (30.03) and BIC (26.74) values for the Gompertz model appear slightly lower than those for the Richards model, this difference is minimal, and in practice, the model lags behind the Richards model in terms of explanatory power and predictive accuracy. This model's tendency to overestimate asymptotic weight and its symmetrical curve structure may lead to increased prediction errors, especially in late growth stages. However, studies such as Topal & Bölükbaşı (2008) and Aggrey (2002) also indicated that the Gompertz model demonstrated successful fit in broilers, providing highly reliable predictions, particularly in the middle stages of growth. Similarly, Adamu et al. (2021) and Falana et al. (2024) reported that the Gompertz model offered biologically meaningful and statistically acceptable results in broiler growth modeling under commercial conditions.

The logistic model, however, lagged behind the other two models in terms of overall fit. Although the coefficient of determination (R^2) = 0.998 appears high, the values of RMSE = 2021.51, AIC = 30.26, and BIC = 26.97 indicate that the model does not accurately reflect the observed values, particularly in the later stages of the growth curve. The hypothetical symmetrical structure of the logistic model, which tends to saturate early, does not fully reflect the rapid growth characteristics of broilers in the late growth period. Yakupoğlu & Atil (2001) similarly reported that this model has limited application and is particularly inadequate in asymmetric growth processes. Kucukonder et al. (2020) and Xie et al. (2020) also emphasized the limitations of the Logistic model in describing asymmetrical growth in broilers and yellow-feathered chickens.

Overall, all three models successfully predicted the general shape of the broiler chicken growth curve. However, a closer look at the different stages of the growth process revealed that the Richards model showed the highest degree of agreement with observed values, particularly in the middle and late stages. While the Gompertz model performed reasonably well in the mid-term predictions, the Logistic model's accuracy was limited due to its early plateauing structure. Ghavi Hossein-Zadeh (2025) similarly found that flexible models like Richards provided superior predictions for asymmetric growth patterns in partridges, further supporting its applicability in poultry species. These results demonstrate that the Richards model is the most suitable growth model in terms of both biological consistency and statistical adequacy, while the Gompertz model is a reliable and rapidly applicable alternative.

Table 4 presents a comparison of the observed live weights of commercial broiler chickens with the values predicted using the Richards, Gompertz, and Logistic models. Based on this data, the success rates of the models at different stages of the growth process were analyzed and plotted in Figure 1. In the early growth period (days 0 and 8), the Logistic model produced significantly higher estimates than observed values. In contrast, the Gompertz model provided lower initial estimates, while the Richards model provided relatively more stable but slightly higher estimates. This suggests that the Richards model, in particular, reflects biological reality more accurately than the initial conditions. When analyzing the middle period (days 15–36), all models generally fit the curve form, but the Richards model's estimates were closest to the observed values. This indicates that the Richards model yielded the lowest deviation in this stage. In the late period (43–50 days), the Richards and Logistic models' predictions were very close to the observed values, while the Gompertz model's prediction at day 50 was overestimated. This suggests that the Gompertz model may be overly biased in predicting asymptotic magnitude. The Logistic model, on the other hand, provided closer predictions in the late period but fell short in overall curve fit (especially at the beginning).

Our findings are consistent with previous studies reporting the successful application of the Richards and Gompertz models in broiler chickens (Topal & Bölükbaşı, 2008). Our study contributes to the literature by re-evaluating these models in terms of both theoretical fit and practical predictive power.

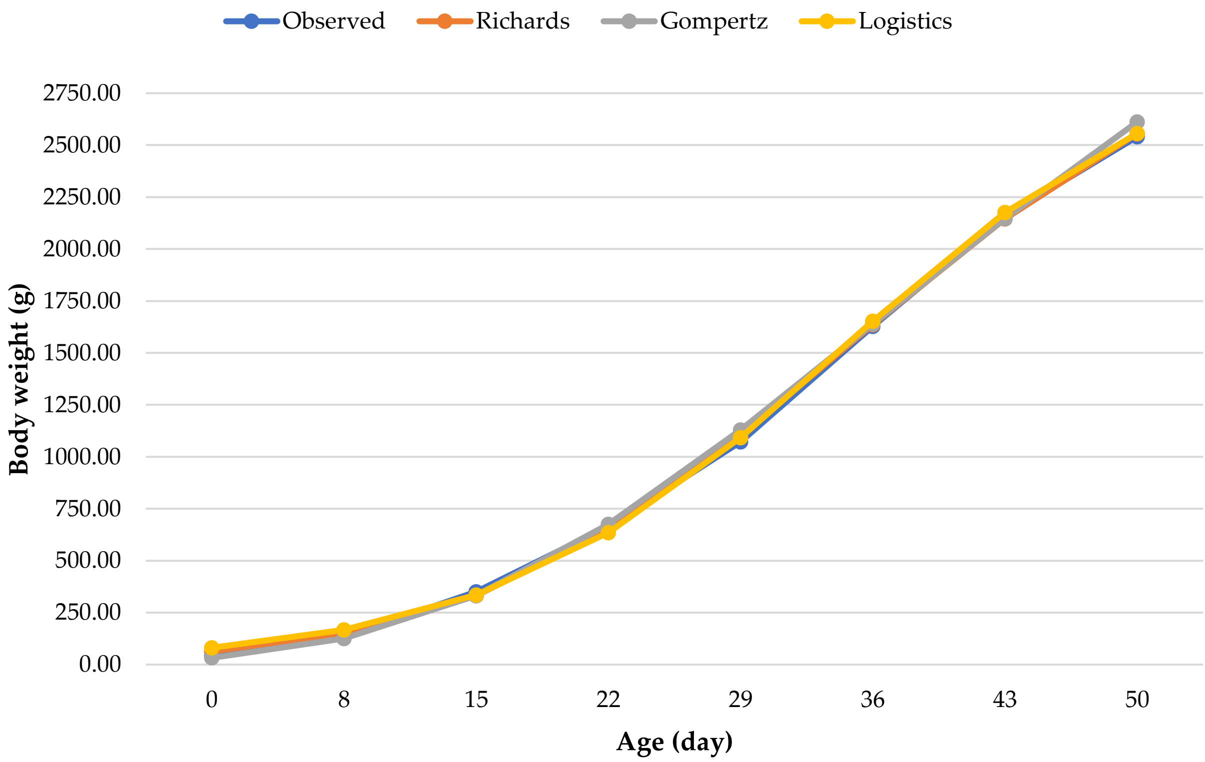

Figure 1. Growth curves estimated with nonlinear models for broilers

Table 4. Live weight values (g) for commercial broiler chickens, observed and predicted by nonlinear growth models

Day	Observed	Richards	Gompertz	Logistic
0	41.14	62.94	32.26	80.88
8	133.12	151.02	124.63	167.21
15	350.06	331.73	331.87	335.18
22	664.52	648.21	674.86	634.41
29	1072.02	1104.25	1128.75	1092.27
36	1627.25	1636.21	1638.64	1652.13
43	2156.71	2144.28	2146.85	2175.77
50	2540.31	2555.26	2611.09	2556.20

DISCUSSION

The evaluations demonstrate that the Richards model most accurately reflects the growth curve of commercial broiler chickens. Both the parameter estimates and the goodness-of-fit statistics (R^2 = 0.999, RMSE = 1711.75) confirmed the superior performance of the Richards model compared to Gompertz and Logistic models. Analyses of the data in this study reveal that the Richards model distinguishes itself from other models with its flexible parameter estimates and superior fit criteria. In particular, the ability of the "m" parameter to manipulate the shape of the curve allows it to capture the different rates of growth in early and late stages more effectively than other models. This conclusion is consistent with studies by Ersöz & Alpan (1994), Knížetová et al. (1991), and Falana et al. (2024). These studies also stated that the Richards model should be preferred for broiler growth modeling in terms of both biological significance and statistical relevance. Additionally, the Richards model provided the closest predictions to the observed data throughout all growth phases, especially from day 15 onwards, where it maintained minimal deviation from observed values.

The Gompertz model was also found to successfully represent the growth curve, yielding results similar to the Richards model. It yielded predictions consistent with the observed data, particularly in the middle stages of growth. However, it was observed that it failed to represent the asymptotic portion of the curve as well as the Richards model in later periods. Despite having strong statistical performance (R^2 = 0.998, RMSE = 2249.28), it tended to overestimate body weight during the final growth stage (day 50). However, the Gompertz model stands out as a valid alternative because it has biologically meaningful parameters and reflects the fundamental characteristics of growth. Indeed, Topal & Bölükbaşı (2008) reported that the Richards and Gompertz models performed well in broiler chickens and are generally the top two preferred models. More recent findings, such as those by Kucukonder et al. (2020), Adamu et al. (2021), and Falana et al. (2024), support this view by highlighting the Gompertz model's practical applicability despite its limitations in late-stage prediction.

The logistic model, however, was found to perform less well than the other two models. It was observed that the logistic model reached a saturation point earlier in the growth curve and did not fully conform to the long-term growth trend observed in broiler chickens. This premature plateau effect, evident from the early overestimations (0st and 8th day), caused reduced predictive accuracy in both early and late stages. This could lead to greater deviations in the prediction of observed values, especially at later ages. As stated in the literature, the assumption that the growth curve of the Logistic model is symmetrical causes it to fail to adequately represent the asymmetric growth process in broiler chickens (Yakupoğlu & Atil, 2001; Xie et al., 2020; Kucukonder et al., 2020; Adamu et al., 2021; Falana et al., 2024). Furthermore, the Logistic model yielded a relatively higher RMSE (2021.51) despite similar R^2 values, indicating a less precise fit.

The results of the present study emphasize the importance of selecting models that balance biological realism and statistical relevance when modeling growth in broiler chickens. In this context, the Richards model stands out as the most suitable model, thanks to its ability to precisely monitor the different growth stages, particularly in commercial farming. The Gompertz model also follows the Richards model, offering acceptable accuracy and biological relevance. The logistic model, however, lags behind other models due to its limited predictive capacity. This is particularly critical for applications in commercial production, where accurate modeling supports decisions related to feed planning feeding, market timing, and cost optimization.

CONCLUSION

In this study, the objective was to comparatively evaluate the fitting performances of three different nonlinear models (Richards, Gompertz, and Logistic) to growth curves in broiler chickens. The findings indicate that the Richards model, thanks to its flexible structure, provides the closest estimates to the observed weight values across all growth periods and is therefore the most suitable model in terms of both biological significance and statistical reliability. The "*m*" parameter in the model is indicative of the asymmetric structure of the growth curve, with greater accuracy in the representation of the early and late stages of growth. The Gompertz model is regarded as a favorable option in practice due to its ease of implementation and successful predictions in certain growth periods. However, it should be used with caution due to its tendency to overestimate weight in adult stages. Conversely, the logistic model is predicated on the assumption of symmetrical growth, a premise that is therefore incapable of fully reflecting the asymmetric growth structure of broilers. Consequently, its efficacy in predicting long-term growth appears to be constrained.

In conclusion, the present study demonstrates the potential of the Richards model to function as an effective decision-support tool for a number of purposes, including the monitoring of growth, the planning of feeding programs, the determination of slaughter times, and the optimization of production strategies in the context of commercial broiler production. The utilization of this model within the industry, as evidenced by extant empirical data, has the potential to engender substantial contributions to both scientific and economic domains. Subsequent analyses, encompassing diverse genotypes, rearing conditions, and sex groups, have the potential to further expand the model's validity and application.

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Compliance with Ethical Standards

Authors' Contributions

ST: Conceptualization, Investigation, Methodology, Formal Analysis, Writing – original draft, Writing – review & editing

NE: Conceptualization, Supervision, Writing – review & editing

All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

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Data Availability

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

AI Disclosure

The authors confirm that no AI was used in the writing of this article or in the presentation of images, tables or information.

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