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RESEARCH ARTICLE

COMPARISON OF NONLINEAR MODELS FOR DESCRIBING THE GROWTH OF LOCAL CHICKENS RAISED IN TOGO

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Abstract

Growth is a trait of economic importance in chicken genetic improvement that is often described by mathematical models having biologically significant parameters. The local chicken,commonly raised in rural areas of Togo, is generally described as a slow-growing chicken, but little is known about his growth parameters. Therefore, this study was designed to determine the nonlinear model that best describes the growth curve of local chickens. The Gompertz, Logistic and Richards growth models were used to fit growth weights recorded from 126 males and 150 female chickens using GCFIT program of SIMFIT package (version 8.1.4).Coefficient of determination (R^2), mean square error (MSE), Akaike's information criterion (AIC) and Bayesian information criterion (BIC) were used as criteria for models' comparison. By estimating the highest value of R^2 and the lowest values of MSE, AIC and BIC, Gompertz model appeared to be the best-fitting model for local chickens'growth. The estimated asymptotic weight was 1992 g for males and 1367 g for females. Thus, male and female chickens weighed 732.86g and 502.98g and aged 10.57 weeks and 9.77 weeks respectively at inflection point. Maturation rates of the chicks were similar (0.139 week^{-1} for males and 0.141 week^{-1}for females). The growth parameters of this model may therefore be useful in defining selection criteria for local chickens in Togo.

Introduction:-

Poultry plays a vital role in developing countries by providing protein through meat and eggs (Moula et al., 2013). Domesticated chickens (*Gallus gallus domesticus*) are the main poultry genetic resources worldwide and over 80 % of chicken populations in Sub-Saharan Africa are local chickens (Ngeno et al., 2015) which contribute to reduce malnutrition and alleviate poverty (Osei-Amponsah et al., 2015). Local chickens are the commonly raised poultry in Togoby about 79.3% of rural farming households, mainly for their own consumption and/or to generate additional income that can be easily mobilized to meet various needs (Talaki et al., 2020).These chickens, well-adapted in different agroecological zones,have beenreported to possesshigh phenotypic variability (Dao et al., 2015), highgenetic diversity but weak subpopulations structuring and therefore considered a unique mix genetics(Kossoga

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et al., 2023). However, the availableinformation on the growth performance and growth curve parameters of these chickens are limited.

Defined as any change in body size such as body weight or length per time unit (Narcinç et al., 2017), growth is considered a trait of economic importance for farm animals (Nguyen Hoang et al., 2021)and has become the main characteristic taken into account during genetic selection because of its significance in the production process and easy control procedures (Michalczuk et al., 2016). Thus, growth modelling consists of summarising the increase in body weight with age into simpler, biologically interpretable parameters using nonlinear growth models (Mata-Estrada et al., 2020). These parameters can be very useful for predicting the expected body weights of a group of individuals at specific ages (Osei-Amponsah et al., 2014) or for defining new selection criteria that take into account animals' intrinsic specificities (Balafrej et al., 2020). Moreover, these parameters have been shown to be highly heritable and have been successfully used in selection studies(Mignon-Grasteau et al., 2000; Nguyen Hoang et al., 2021). Thus, Michalczuk et al. (2016) andSariyel et al. (2017) considered that mathematical models applied to describe growth curves are useful tools in the analysis of results of genetic selection and depicting differences between genetic groups or for optimizing growth rate and appropriate feeding.

Several nonlinear growth models with three or four parameters have been used to model the growth of different ecotypes of local chickens(Al-Ali et al., 2022; Mata-Estrada et al., 2020; N'dri et al., 2018; Osei-Amponsah et al., 2014; Rizzi et al., 2013; Yapi-Gnaore et al., 2011; Youssao et al., 2012; Zhao et al., 2015), but no specific model could be adequately fitted to the growth data of all ecotypes. Indeed, these growth models differ in their characteristics, level of complexity, number of parameters and quality of adaptation to different sets of weight records. Therefore, identifying the most suitable growth model is vital in the process of characterizing local chickens raised in Togo. Subsequently, this study was performed to compare Gompertz, Logistic and Richards in order to determine the most accurate for describing local chickens' growth in Togo

Materials and Methods:-

Study site

The study was carried out at ITRA's research station of Avétonou, located between latitudes 6°40' and 6°55' N and longitudes 0°40' and 0°55' E, in the Forest agroecological zone, characterised by a humid tropical climate with bimodal rainfall. The average monthly temperatures ranged from 25 to 31 degrees Celsius and relative humidity varied between 88 and 96%.

Chicks and environmental conditions

A total of 150 male and 172 female chicks that were healthy and wellconformed at hatching were selected and wing banded for easy identification and individual body weight recording.

The chickens were raised from day 1 to 20 weeks of age on floor pens with deep wood shavings litter and supplied *ad libitum*feed and water. They were fed two diets: a starter diet (hatching to 8 weeks) containing 20.88% crude protein (CP) and 2,900 kcal ME/kg and a grower diet (9-20 weeks) containing 18.61% CP and 2,846 kcal ME/kg. They were administrated all the required vaccinations and medications to prevent the occurrence of diseases.

Data collection

Individualchicken body weights were recorded every week from day 1 and to 20 weeks of age (i.e. 21 records per chicken). The initial body weight database consisted of 6,320 records from 312 chickens. Subsequently, records from chickens that had not reached 20 weeks of age were removed, and the final data set made of 5,796 body weight records (2,646 for males and 3,150 for females) was used for statistical analysis.

Nonlinear growth models

Three nonlinear growth models (Gompertz, Logistic and Richards) were selected for describing local chickens' growth curve. Each model has a sigmoid curve with two phases separated by the inflection point. The mathematical equations of the models and formula used to estimate the age and the weight at inflection point are given in Table 1.

Table 1:- Equations of growth curves and age and weight at inflection point for models used.

Model	Equation	Age at inflection	weight at inflection
Gompertz	$W_t = Ae^{(-Be^{(-kt)})}$	$(lnB)/k$	A/e

Logistic	$W_t = A/\left(1 + Be^{(-kt)}\right)$	$(lnB)/k$	$A/2$
Richards	$W_t = \left(A^{(1-m)} - Be^{(-kt)}\right)^{\frac{1}{1-m}}$	$ln(\frac{1}{(1-m)}B)/k$	$Am^{(\frac{1}{1-m})}$

W_t: Body weight (g) at the time t (week); A: Asymptotic or mature weight, which represents the limit of each model as age (t) tends to infinity; B: Integration constant related to the ratio of the hatch weight to the asymptotic weight; k: Maturation rate and represents the rate at which the weight tends towards the asymptotic weight;m: Shape parameter which determines the position of the inflection point relative to the asymptotic weight; e: Euler's number, the basis of the natural logarithm (2.7182818)(Osei-Amponsah et al., 2014 ; Bo et al., 2022).

Statistical analysis

Estimation of growth curve parameters for local chickens

The Gompertz, Logistic and Richards models were fitted to the body weight records for each sex separately using the 'Fitting growth curve models' procedure in GCFIT program of SIMFIT package (version 8.1.4). The Levenberg-Marquardt optimization method, which minimize the sums of the squared deviations between measured and fitted values, was used to estimate the growth parameters of the models

Determination of the best-fitting model

The best-fitting model was determined on the basis of four goodness-of-fit criteria including coefficient of determination (R^2), mean square error (MSE), Akaike's Information Criterion (AIC) and Bayesian Information Criterion (BIC), which values were estimated for each model using formula presented in table 2. The best-fitting model was selected as the one with an R^2 value close or equal to 1 and the smallest values of MSE, AIC and BIC..

Table 2:- Mathematical equations ofmodel’s goodness-of-fit criteria.

Model selection criteria	**Abbreviation**	**Formula**
Coefficient of determination	R^2	$1 - SSE / SST$
Mean Square Error	MSE	$SSE / (N - K)$
Akaike’s Information Criterion	AIC	$N * \ln(SSE / N) + 2K$
Bayesian Information Criterion	BIC	$N * \ln(SSE/N) + K \ln(N)$

R^2: Coefficient of determination; MSE: Mean square error; AIC: Akaike’s Information Criterion; BIC: Bayesian Information Criterion;SSE: Sum of squares of errors; SST:Sum of squares of total, N: Number of observations; K: number of parameters; ln:Natural logarithm (Sanusi and Oseni, 2020; Bo et al., 2022)

The predicted weight of the Gompertz and Logistic models and the recorded weights were then plotted together for male and female local chickens separetly.

Results:-

Growth parameters of the local chickens estimated by the Gompertz, Logistic and Richards models

The growth parameters (*A*, *B*, *k* and *m*) of the local chickens estimated by the three nonlinear models were shown by sex in Table 3.

The asymptotic weights (parameter A) estimated by the Gompertz and Richards models were the highest for each sex of local chickens. For all models, males had the highest estimated asymptotic weights. In general, the estimated maturation rates (parameterk) were significantly different from 0 for all models and ranged from 0.139 to 0.402 for males and 0.141 to 0.384 for females, with the highest estimated by the Logistic model. For the Richards model, the shape parameter (m), which determines the position of the inflection point on the growth curve, was estimated to be lower but closer to 1.

Table 3:- Growth curve parameter estimates (± SE) for male and female local chickens.

Model	**Sex**	***Parameters***			
		***A* (g)**	***B***	***k* (week^{-1})**	***m***
Gompertz	Female	1367,2±33,4	3,97±0,02	0,141±0,003	-
	Male	1992,1±47,4	4,35±0,02	0,139±0,002	-
Logistic	Female	970,0±24,0	32,34±1,1	0,384±0,008	-
	Male	1339,7±36,5	44,4±1,7	0,402±0,008	-
Richards	Female	1367,7±73,6	0,002±0,02	0,141±0,014	0,9996

Male	1992,5±104,6	0,001±0,01	0,139±0,017	0,9998

A:Asymptotic weight, representing mature body weight; B:Integration constant;*k*: Maturation rate (k); *m*:Shape parameter influencing the point of inflection; M±SE: Mean plus or minus standard error of the mean (Bo et al., 2022)

Furthermore, compared to the Gompertz estimates, the Richards model estimated similar ages and weights at different growth phases (Table 4), while the Logistic model estimated the lowest ages and weights. This is reflected in growth curves of male and female local chickens showing early maturity, with lower asymptotic weights for the Logistic model (Figures 1)).

Table 4:- Age (weeks) and weight (g) of male and female local chickens estimated at the different growth phases using the Gompertz, Logistic and Richards models.

Model	Sex	Start of growth acceleration phase[1]		Inflection point[2]		End of growth deceleration phase[3]	
		Age	Weight	Age	Weight	Age	Weight
Gompertz	Female	3,9	137	9,8	503	25,7	1230
	Male	4,5	199	10,6	733	26,8	1793
Logistic	Female	3,3	97	9,1	485	14,8	873
	Male	4,0	134	9,4	670	14,9	1206
Richards	Female	3,9	137	9,8	503	25,7	1230
	Male	4,5	199	10,6	733	26,8	1793

[1]Age at which the chick attains 10% of its final body weight and represents the beginning of the growth acceleration phase (Osei-Amponsah et al., 2014; Bo et al., 2022)
[2]Representsthe end of the growth acceleration phase and the beginning of the deceleration phase (Osei-Amponsah et al., 2014; Bo et al., 2022).
[3]Age at which the chick attains 90% of its final body weight and represents the end of the growth deceleration phase (Osei-Amponsah et al., 2014; Bo et al., 2022).

Determination of the best-fitting model for local chickens' growth data

The goodness-of-fit criteria (R^2, MSE, AIC and BIC) values obtained with the three growth models are shown in Table 5. The three nonlinear models perfectly fit the local chickens' growth data, each having R^2 value greater than 0.97for each sex. The Logistic model showed theworst quality of fit, estimating the highest values of the MSE, AIC and BIC.On the other hand, the Gompertz model gave the lowest values of MSE, AIC and BIC (values in Bold in table 5). Therefore, the Gompertz model seems to be the best-fitting model for local chickens' growth data.

Table 5:- Goodness-of-fit criteria values obtained with the Gompertz, Logistic and Richards models for each sex

Model	Sex	R^2	MSE	AIC	BIC
Gompertz	Female	0.9938	**4.0978**	**352.8019**	**353.0166**
	Male	0.9947	**2.7253**	**327.1050**	**327.3197**
Logistic	Female	0.9814	15.0925	434.9383	435.1530
	Male	0.9783	13.4682	427.7646	427.9793
Richards	Female	0.9938	4.1686	354.8223	355.1086
	Male	0.9947	2.7723	329.1252	329.4115

R^2: Coefficient of determination; MSE: Mean square error; AIC:Akaike's Information Criterion;BIC: Bayesian Information Criterion(Bo et al., 2022)

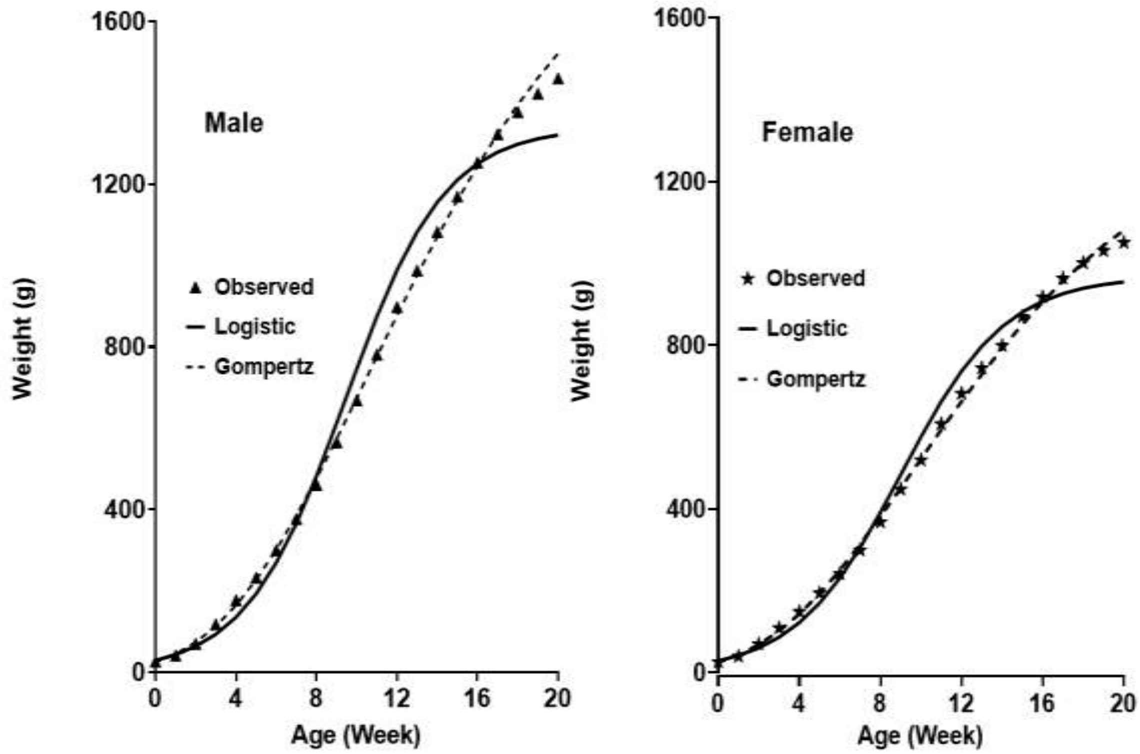

Figure 1:- Growth curves of male and female chickens according to Gompertz and Logistic models in comparison to the observed data.

Discussion:-

The Gompertz, Logistic and Richards models were usedin this study to determine the mostappropriate for describing the growth curve of local chickens raised in Togo. These models, along with the Von Bertalanffy model, are the main used formodelling the growth of domestic poultry (Narinç et al., 2017). In result, the Gompertz model appeared to be the best-fitting model for male and female chickens. This result is similar to the previous reports thathad also founded the Gompertz to be the best for modelling chicken growth (Moula et al., 2011; Al-Nasrawi, 2013; Zhao et al., 2015; Michalczuk et al., 2016; Sariyel et al., 2017; Bayu Putra et al., 2021; Nguyen Hoang et al., 2021; Al-Ali et al., 2022; Zárate-Contreras et al., 2022). However, our result is different from those of some authors who reported Richards model(Rizzi et al., 2013; Osei-Amponsah et al., 2014; Machado et al., 2023, Nguyen et al, 2023) or Logistic model(Eleroğlu et al., 2014; Adenaike et al., 2017) or Von Bertalanffy(Mata-Estrada et al., 2020; Kumar et al., 2022a)best describing the growth of local chickens or slow-growing broilers. Other authors reported that the Gompertz and Von Bertalanffy(Sanusi and Oseni, 2020), Gompertz and Bridges (Bo et al., 2022), Logistic and Gompertz (Kumar et al., 2022b) or Gompertz and Logistic (Kausar et al., 2016) models were the best at describing the growth of chickens of different strains.

The differences observed between the different results regarding the model(s) that best fit the chicken growth data could be due to differences in the genetic potential of the chickens studied, differences in the interval between successive data recordings or differences in the data recording periods (Zárate-Contreras et al., 2022) as well as the environmental variables (feed, pathological conditions and other factors) that prevailed during the studies (Kumar et al., 2022a).

Eleroğlu et al. (2014) suggested that once the best growth model has been selected, parameters including asymptotic weight, maturation rate and age of maximum growth (age at inflection point) could be manipulated by geneticists to improve performance. These parameters are also useful for comparing different results from studies using the same models.

Thus, the asymptotic weights (parameter A) estimated using the Gompetz model are comparable to the values reported by Osei-Amponsah et al. (2014) for local Ghanaian male (1,777 g) and female (1,322 g) chickens. However, the asymptotic weights estimated using the Gompertz model are higher than the results reported by Ait Kaki and Moula (2013) for local Kabyle chickens (675.3 to 886 g), N'dri et al. (2018) for local Ivorian chickens (823.7 g), Nguyen Hoang et al. (2021) for Vietnamese Ri chickens (1181.70 to 1620.83 g),), Abe et al. (2022) for local Nigerian chickens and locally adapted genotypes (1446 to 1627 g) and Faraji-Arough et al. (2019) for Iranian Khazak chickens (1051.77 g for females and 1285.42 g for males). Nevertheless, asymptotic weights estimated of over 2000 g for males and 1500 g for females have been estimated using the Gompertz model for local chicken ecotypes in various countries : China (Zhao et al., 2015), Côte d'Ivoire (Yapi-Gnaore et al., 2011), India (Kumar et al., 2022a), Iran (Nyesi et al., 2023), Iraq (Al-Ali et al., 2022), Italy (Rizzi et al., 2013; Selvaggi et al., 2015), Mexico (Mata-Estrada et al., 2020; Zárate-Contreras et al., 2022), Niger (Guisso Taffa et al., 2023), Nigeria (Ridho et al., 2021; Sanusi and Oseni, 2020) and Vietnam (Moula et al., 2011; Nguyen Hoang et al., 2021; Bo et al., 2022).

For the maturation rate (parameter k), the values estimated by the Gompertz model in this study (0.139 to 0.141 week^{-1}) were comparable to the results reported by Yapi-Gnaore et al. (2011), Ndegwa et al. (2012),Rizzi et al. (2013), Osei-Amponsah et al. (2014),Selvaggi et al. (2015), Faraji-Arough et al. (2019),Mata-Estrada et al. (2020),Nguyen Hoang et al. (2021),Al-Ali et al. (2022) andGuisso Taffa et al. (2023).Our results were higher than those obtained by (Sanusi and Oseni, 2020) (k = 0.013 week^{-1}), (Kumar et al., 2022a) (k = 0.016 to 0.018 week^{-1}) and Ridho et al. (2021) (k = 0.013 to 0.010 week^{-1}). On the other hand,Ait Kaki and Moula (2013), Nguyen Hoang et al. (2021), Bo et al. (2022) and Kumar et al. (2022b) reported k values ranging from 0.026 to 0.034 week^{-1} for males and 0.024 to 0.036 week^{-1}for females, which were higher than our results. The parameter k is an indicator of how fast the asymptotic weight is approched, and a high value of k indicates reaching adult weight at a young age(Güler et al., 2023). Thus,local chickens reach their adult weight at an advanced age, as indicated by the relatively low values obtained in this study. Furthermore, the highest estimates of parameter k generally coincided with the lowest estimates of parameter A.

The age at inflection point obtainedusing the Gompertz model for local chickens is similar to results reported by Yapi-Gnaore et al. (2011) for local chickens of savannah and forest ecotypes in Côte d'Ivoire,Osei-Amponsah et al., 2014 for local chicken ecotypes in Ghana,Faraji-Arough et al. (2019) for local Khazak chickens in Iran, and Al-Ali et al. (2022) for local Iraqi chickens in Iraq. However, our estimated values were lower than those obtained for other local chicken ecotypes(Selvaggi et al., 2015; Sanusi and Oseni, 2020; Guisso Taffa et al., 2023). On the other hand, the estimated values for the male: female pair were higher than those of 9.9:8.7; 9.3:8.5; 8.3:7.9 and 7.6:6.9 weeks reported by Mata-Estrada et al. (2020), Nguyen Hoang et al. (2021), Bo et al. (2022) and Nguyen et al. (2023) for local Creole chickens from Mexico, Mia chickens from Vietnam and Ri chickens from Vietnam, respectively.

Conclusion:-

The present study compared the Gompertz, Logistic and Richards models to determine the most appropriate model for describing the growth of local chickens raised in Togo. On the basis of the R^2, AIC and BIC criteria, the Gompertz model best fit the growth data of male and female local chickens. This growth model estimated the asymptotic weight, maturation rate and age of maximum growth to be 1992 g, 0.139 week^{-1} and 10.57 weeks for males and 1367 g, 0.141 week^{-1} and 9.77 weeks for females. The growth parameters obtained from this model may therefore be useful in defining selection criteria for local chickens in Togo.

References:-

1. Abe, O. S., Ilori, B. M., andOzoje, M. O. (2022): Modeling growth of Nigerian indigenous and tropically adapted chicken genotypes using developmental parameters. *Nigerian J. Anim. Sci.*, *24*(2): 39–49.
2. Adenaike, A. S., Akpan, U., Durosaro, S. O., Sanda, A. J., andIkeobi, C. O. N. (2017): Comparative Evaluation of Growth Functions in Three Broiler Strains of Nigerian Chickens. *Pertanika J. Trop. Agric. Sci.*, *40*(4): 611–620. http://www.pertanika.upm.edu.my/
3. Ait Kaki, A., and Moula, N. (2013). Performances de productions de la poule locale Kabyle. *Revue Agriculture*, *5*: 1–4. http://revue-agro.univ-setif.dz/
4. Al-Ali, M. R., Razuki, W. M., and Al-Anbari, E. H. (2022): Characterization of Growth Curve Patterns for Iraqi Indigenous Chickens through Nonlinear Growth Models. *Indian J. Ecol.*, *49*(20): 324–331.
5. Al-Nasrawi, M. A. M. (2013): Description of growth curve in broiler by using some nonlinear functions. *Al-Anbar J. Vet. Sci.*, *6*(2): 26–30.

6. Balafrej, M., Sahnoun, A., and Sadik, M. (2020): Comparaison des modèles mathématiques non linéaires et détermination du modèle qui décrit au mieux la croissance de la race Sardi. *Rev.Elev. Méd.Vét. Pays Trop.*, *73*(4): 255–261. https://doi.org/10.19182/remvt.31945
7. Bayu Putra, W. P., Riaz, R., Gunawan, A. A., and Orman, A. (2021): Comparison of Growth Curve in Male Layer Chickens. *J. Res. Vet. Med.*, *40*(1): 49–53. https://doi.org/10.30782/jrvm.779699
8. Bo, H. X., Hoa, D. V., Nhung, D. T., Hue, D. T., and Luc, D. D. (2022): Nonlinear growth models for indigenous Vietnamese Ri chicken. *J. Anim. Plant Sci.*, *32*(6): 1535–1541. https://doi.org/10.36899/JAPS.2022.6.0562
9. Dao, B., Kossoga, A., Lombo, Y., Ekoué, S., Talaki, E., Dayo, G. K., andBonfoh, B. (2015): Caractérisation phénotypique des populations locales de poulets (*Gallus gallus domesticus*) au Togo. *Bull. Anim. Hlth. Prod. Afr.*, *63*(4):15–33.
10. Eleroğlu, H., Yıldırım, A., Şekeroğlu, A., Çoksöyler, N., and Duman, M. (2014): Comparison of Growth Curves by Growth Models in Slow-Growing Chicken Genotypes Raised the Organic System. *Int. J. Agric. Biol.*, *16*: 529–535. http://www.fspublishers.org
11. Faraji-Arough, H., Rokouei, M., Maghsoudi, A., and Mehri, M. (2019): Evaluation of non-linear growth curves models for native slow-growing Khazak chickens. *Poult. Sci. J.*, *7*(1): 25–32. https://doi.org/10.22069/psj.2019.15535.1355
12. Guisso Taffa, A., Issa, S., Bachir, H., Mahamadou, C., Johann, D., and Nassim, M. (2023): Zootechnical Performance and Growth Curve Modelling of the Niamey Local Chickens in Niger. *World's Vet. J.*, *13*(1): 183–190. https://doi.org/10.54203/SCIL.2023.WVJ19
13. Güler, S., Çam, M., and Atik, A. (2023): Determination of the effect of the dam age, birth type, and sex on growth curve traits of hair goat kids. *Trop. Anim. Health Prod.*, 55(6):371. http://doi.org/10.1007/s11250-023-03785-z
14. Kausar, H., Verma, M. R., Kumar, S., Sharma, V. B., Das, A. K., andDilliwar, L. (2016): Modelling of Rhode Island Red chicken strains. *Indian J. Anim. Sci.*, *86*(5): 612–615. https://doi.org/10.56093/ijans.v86i5.58536
15. Kossoga, K. A., Dayo, G. K., Bilalissi, A., N'nanle, O., Oke, E. O., and Tete-Benissan, K. A. (2023): Genetic Diversity and Structure of Local Chicken Populations Raised in Five Agroecological Zones of Togo. *J. World's Poult. Res.*, *13*(3): 352–363. https://doi.org/10.36380/JWPR.2023.38
16. Kumar, A., Kumar, S., Pandey, M., Chaudhari, C., Aruna, T., Meena, R., L Kanadkhedkar, H., Chandrahas, and Ram Verma, M. (2022): Growth Modelling in Aseel Native Chicken. *Acta Scient. Vet. Sci.*, 4(8): 36–41. https://doi.org/10.31080/asvs.2022.04.0460
17. Kumar, A., Kumar, S., Pandey, M., Chaudhari, C., Verma, M. R., Chandrahas, and Chauhan, A. (2022):Bertalanffy Model Reflects Growth Trajectory in Aseel Chicken. *Indian J. Vet. Sci. Biotech.*, *18*(5): 59–62. https://doi.org/10.48165/ijvsbt.18.5.12
18. Machado, L. P. M. M., Figueiredo Fo, L. A. S., Carvalho, D. A., Sarmento, J. L. R., Rocha, A. O., Sousa Jr, A., Torres, T. S., Cavalcante, D. H., and Sena, L. S. (2023): Growth Curve of Brazilian Creole Chickens (CanelaPreta Breed) Raised in Two Different Rearing Systems under Tropical Climate. *Braz. J. Poult. Sci.* 25(03): 1-8. https://doi.org/10.1590/1806-9061-2022-1726
19. Mata-Estrada, A., González-Cerón, F., Pro-Martínez, A., Torres-Hernández, G., Bautista-Ortega, J., Becerril-Pérez, C. M., Vargas-Galicia, A. J., and Sosa-Montes, E. (2020): Comparison of four nonlinear growth models in Creole chickens of Mexico. *Poult. Sci.*, *99*(4), 1995–2000. https://doi.org/10.1016/j.psj.2019.11.031
20. Michalczuk, M., Damaziak, K., and Goryl, A. (2016): Sigmoid models for the growth curves in medium-growing meat type chickens, raised under semi-confined conditions. *AnnalsAnim.Sci.*, *16*(1): 65–77. https://doi.org/10.1515/aoas-2015-0061
21. Mignon-Grasteau, S., Piles, M., Varona, L., de Rochambeau, H., Poivey, J., Blasco, A., and Beaumont, C. (2000):Genetic analysis of growth curve parameters for male and female chickens resulting from selection in shape of growth curve. *J. Anim. Sci.*, *78*, 2515–2524.
22. Moula, N., Duc Luc, D., Dang, K., Farnir, F., Dinh Ton, V., Vu Binh, D., Leroy, P., and Antoine-Moussiaux, N. (2011): The Ri chicken breed and livelihoods in North Vietnam: characterisation and prospects. *J. Agr. Rural. Develop. Trop.Subtrop.*, *112*(1): 56-69.
23. Moula, N., Tandiang Diaw, M., Salhi, A., Farnir, F., Antoine-Moussiaux, N., and Leroy, P. (2013): Egg production performance of the local kabyle hen and its crossbreeds with ISA-Brown strain in semi-intensive conditions. *Inter. J. Poult. Sci.*, *12*(3): 148–152. https://doi.org/10.3923/ijps.2013.148.152
24. Narinç, D., Öksüz Narinç, N., and Aygün, A. (2017): Growth curve analyses in poultry science. *World's Poult. Sci. J.*, *73*(2): 395–408. https://doi.org/10.1017/S0043933916001082

25. Ndegwa, J. M., R. Mead, R., Norrish, P., Shephered, D. D., Kimani, C. W., and Wachira, A. M. (2012): Growth Characteristics of Six Reciprocal Crosses of Kenyan Indigenous Chicken. *J. Agric. Sci.*, *4*(6), 160-170. https://doi.org/10.5539/jas.v4n6p160
26. N'dri, A. L., Koua, B. H. W., Ahouchi, V. S., and Adepo-Gourene, A. B. (2018): Body weight and growths curve parameters evaluation of three chicken genotypes (*Gallus gallus domesticus*) reared in claustration. *J. Adv. Vet. Anim. Res.*, *5*(2): 188-195. https://doi.org/10.5455/javar.2018.e265
27. Neysi, S., Ghaderi-Zefrehei, M., Rafeie, F., Dolatabady, M. M., Elahi Torshizi, M., Zakizadeh, S., and Smith, J. (2023). Estimation of genetic parameters for production, reproduction, and growth curve of Fars indigenous chicken. *Anim. Sci. J.*, 94(1), e13808. https://doi.org/10.1111/asj.13808
28. Ngeno, K., van der Waaij, E. H., Megens, H. J., Kahi, A. K., van Arendonk, J. A. M., andCrooijmans, R. P. M. A. (2015): Genetic diversity of different indigenous chicken ecotypes using highly polymorphic MHC-linked and non-MHC microsatellite markers. *Anim. Genet.Resour.,56*: 1–7. https://doi.org/10.1017/s2078633614000484
29. Nguyen Hoang, T., Do, H. T. T., Bui, D. H., Pham, D. K., Hoang, T. A., and Do, D. N. (2021): Evaluation of non-linear growth curve models in the Vietnamese indigenous Mia chicken. *Anim. Sci. J.*, *92*e13483. https://doi.org/10.1111/asj.13483
30. Nguyen, T. H., Nguyen, C. X., Luu, M. Q., Nguyen, A. T., Bui, D. H., Pham, D. K., and Do, D. N. (2023): Mathematical models to describe the growth curves of Vietnamese Ri chicken. *Brazilian J. Biol.*, *83*e249756. https://doi.org/10.1590/1519-6984.249756
31. Osei-Amponsah, R., Kayang, B. B., Naazie, A., Barchia, I. M., and Arthur, P. F. (2014): Evaluation of Models to Describe Temporal Growth in Local Chickens of Ghana. *Iranian J. Appl. Anim. Sci.*, *4*(4): 855–861. Online version is available on www.ijas.ir
32. Osei-Amponsah, R., Kayang, B. B., Naazie, A., Tixier-Boichard, M., and Rognon, X. (2015): Phenotypic characterization of local Ghanaian chickens: egg-laying performance under improved management conditions. *Anim. Genet.Resour.*, *56*: 29–35. https://doi.org/10.1017/s2078633615000041
33. Ridho, M., Putra, W. P. B., and Sola-Ojo, F. E. (2021): The growth curve of Gompertz and logistic models in body weight of Ecotype Fulani Chickens (Gallus domesticus). *IOP Conf. Ser.: Earth Environ. Sci.*, *637* 012098. https://doi.org/10.1088/1755-1315/637/1/012098
34. Rizzi, C., Contiero, B., and Cassandro, M. (2013): Growth patterns of Italian local chicken populations. *Poult. Sci.*, *92*(8): 2226–2235. https://doi.org/10.3382/ps.2012-02825
35. Sanusi, A. R., and Oseni, S. O. (2020): Nigerian Fulani ecotype chickens: Estimation of growth curve parameters. *Genet.Biodiv. J.*, *4*(1): 1–13. http://ojs.univ-tlemcen.dz/index.php/GABJ
36. Sariyel, V., Aygun, A., and Keskin, I. (2017): Comparison of growth curve models in partridge. *Poult. Sci.*, *96*(6): 1635–1640. https://doi.org/10.3382/ps/pew472
37. Selvaggi, M., Laudadio, V., Dario, C., andTufarelli, V. (2015): Modelling growth curves in a nondescript italian chicken breed: An opportunity to improve genetic and feeding strategies. *J. Poult. Sci.*, *52*(4): 288–294. https://doi.org/10.2141/jpsa.0150048
38. Talaki, E., Dzogbema, K. F. X., Adjrah, Y., and Tona, K. (2020): Current Status of Family Poultry Production in Togo. *Int. J. Poult.Sci.*, *19*(12): 568–576. https://doi.org/10.3923/ijps.2020.568.576
39. Yapi-Gnaore, V. C., Loukou, E. N., Konan, J.-C., Toure, G., Kreman, K., Youssao, I., Kayang, B., Rognon, X., and Tixier Boichard, M. (2011): Poids vif et paramètres de la courbe de croissance des poulets de race locale (Gallus domesticus) en Côte d'Ivoire. *Agro.Afric.*, *23*(3): 273–281.
40. Youssao, I. A. K., Alkoiret, I. T., Dahouda, M., Assogba, M. N., Idrissou, N. D., Kayang, B. B., Yapi-Gnaore C V, Assogba, H. M., Houinsou, A. S., Ahounou, S. G., Tougan, U. P., Rognon, X., and Tixier-Boichard, M. (2012): Comparison of growth performance, carcass characteristics and meat quality of Benin indigenous chickens and Label Rouge (T55SA51). *Afric J. Biotech.*, *11*(89): 15569–15579. https://doi.org/10.5897/ajb11.1747
41. Zárate-Contreras, D., González-Cerón, F., Cuca-García, J. M., Pro-Martínez, A., Ramírez-Valverde, G., Aggrey, S. E., Hernández-Mendo, O., Gallegos-Sánchez, J., and Sosa-Montes, E. (2022): Mexican Creole chickens: effect of data collection periods on goodness-of-fit and parameter precision of growth models. *Poult. Sci.*, *101*: 101903. https://doi.org/10.1016/j.psj.2022.101903
42. Zhao, Z., Li, S., Huang, H., Li, C., Wang, Q., and Xue, L. (2015): Comparative Study on Growth and Developmental Model of Indigenous Chicken Breeds in China. *Open J. Anim. Sci.*, *5*(2): 219–223. https://doi.org/10.4236/ojas.2015.52024.