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Non-linear growth modelling in Mecheri breed of sheep

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Abstract
Fitting growth curves of Mecheri sheep was carried out using the data on body weights available at Mecheri Sheep Research Station, Pottaneri during the period from 1991 to 2014. Non-linear growth models, *viz.,* Brody, Von Bertalanffy, Gompertz, Logistic and Richards models were used for estimating the growth curve parameters. The best fitted model was identified to describe the growth pattern in Mecheri lambs based on the growth parameters. The highest R^2 value and the lowest MSE, MAE, MAPE values were observed in Brody model fitted. Brody growth model was found to be the best followed by Von Bertalanffy, Gompertz, Logistic and Richards growth models in the order of their goodness. The predicted body weights through Brody model at birth, 3, 6, 9 and 12 months of age were 2.57, 8.92, 13.03, 15.70 and 17.50 kg, respectively in Mecheri sheep.

Keywords: Mecheri Sheep, Growth curve, Non-linear model, Brody

Introduction

A major portion of income in sheep husbandry is through the sale of males at the market age. Therefore, faster growth rate and early maturity are important components of profitable sheep production. The growth rate and body weight of hairy sheep are lower than those of wool type sheep. However, hairy sheep mature earlier and better adapted to hot and humid tropical environment even with low quality forages. Growth curves explaining the relationship between weight and age in sheep are influenced by breed, management, environment, and selection procedures [1]. Growth curve models are of great importance for animal production, as they provide information essential to frame strategic plans for improving management, determining nutritional requirement, ascertaining genetic variability of characteristics linked to growth and assessing the genetic potential of animals for growth. Growth curves are also used to predict the expected weight of a group of animals at a specific age [19]. Among various statistical procedures available for analyzing growth data, fitting a non-linear function offers an opportunity to summarize the information contained in the entire sequence of size- age points into a small set of parameters that can be interpreted biologically and used to derive other growth traits [17].

Mecheri sheep is one of the recognized breeds of sheep in Tamil Nadu being reared mainly for meat. Mecheri sheep is a meat type breed, native of the hot and dry part of western Tamil Nadu, distributed mainly across Salem, Dharmapuri and Coimbatore districts.

They constitute 24.28 per cent of total sheep population of Tamil Nadu. The growth curve analysis of this popular sheep breed has not been done yet. In this context, the present research study was undertaken to fit non-linear model growth curves for Mecheri sheep.

Materials and Methods

Data

Data on body weights of Mecheri sheep born between the years 1991 and 2014 of Mecheri Sheep Research Station, Pottaneri (Tamil Nadu) were utilized for this study and presented in Table 1. Body weights measured in kilograms at various ages, *viz.*, at birth, 3 months (age at weaning), 6 months, 9 months and 12 months (yearling weight) of both males and females were used for analysis.

Table 1: Distribution of sheep by period and sex of the lamb subclasses at different ages in Mecheri sheep

Age	Period of lambing						Number of lambs born		
	(1991-94)	(1995-98)	(1999-02)	(2003-06)	(2007-10)	(2011-14)	Male	Female	Total
At Birth	192	475	540	629	762	850	1806	1642	3448
At Weaning	172	428	507	509	736	741	1607	1486	3093
6 months	159	381	451	422	464	371	998	1250	2248
9 months	138	317	396	281	357	249	704	1035	1738
12 months	115	255	276	228	343	191	480	928	1408

Non-linear model

Non-linear growth curve model parameters were estimated by Levenberg-Marquardt iterative algorithm with the help of SPSS software (PASW- 16.0) with a convergence criterion $[(SSE_{m-1} - SSE_m)/(SSE_m + 10^{-6})] < 10^{-8}$ where SSE_m is the residual sum of square resulting from the m^{th} round of iteration [3]. Five non-linear models *viz.,* Brody, Richards, Von Bertalanffy, Gompertz and Logistic models were fitted using the data collected as listed below:

(i) Brody Model [6]

$Y_t=A(1-Be^{-kt})+\varepsilon$

(ii) Richards Model [18]

$Y_t=A/(1+B\exp(-kt))^{1/m}+\varepsilon$

(iii) Von Bertalanffy Model [1]

$Y_t=A(1-Be^{-kt})^3+\varepsilon$

(iv) Gompertz Model, [22]

$Y_t=A\exp(-Be^{(-kt)})+\varepsilon$

(v) Logistic Model, [16]

$Y_t=A(1-B^{e-kt})+\varepsilon$

where,

Yt = body weight at age 't'

A = asymptotic weight or mature weight when age 't' approaches infinity

B = integration constant determined by initial values of 'Y' and age 't'

k = maturation rate

m = shape parameter of the growth curve

ε = random error

Criteria adopted to describe the growth curve

Mean Squares Error (MSE)—calculated by dividing the residual sum of square by the number of observations, which represents the estimator of the maximum likelihood of the residual variance.

(i) Coefficient of determination (R^2)—calculated through a linear regression analysis between observed and estimated weights, considering the predicted weight by the function as dependent variable and the observed weight as independent variable.

(ii) Chi-square test (**χ^2**) was used to designate the relationship between actual and predicted weights.

(iii) Following Topal and Bolukbasi (2008) the Mean Absolute Error (MAE) and the Mean Absolute Percentage Error (MAPE) were calculated as below:

$$MAE=\frac{\sum_t^n |Y_t - \hat{Y}_t|}{n}$$

$$MAPE=1/n \sum_t^n \frac{|Y_t - \hat{Y}_t|}{Y_t}$$

where,

Y_t = observed weight at age 't'

$\hat{Y}_t$ = predicted weight at age 't'

The highest R^2 value coupled with the least MSE, MAE and MAPE values were determined to be the indicators of the best fit of the model. All the above analyses were performed using IBM SPSS Statistics® 20.0.

Results and discussion

Estimation of parameter 'A', 'B' and 'K' were determined using all the five non-linear models for the body weights of males, females and overall population separately.

The estimated non-linear growth model parameters 'A', 'B' and 'K' along with goodness of fit statistics, *viz.,* R^2, MSE, MAE and MAPE values of Mecheri sheep are presented in Table 2. Estimated parameter 'A' was the highest for males than females and overall population in all the five non-linear growth models, while, the parameters 'B' and 'K' did not show any such trend.

The highest values of parameter 'A' for males and females were observed in Richards (30.319±6.232 and 24.448±6.039) and lowest values were obtained in Logistic (19.341 ± 2.489 and 16.760±1.585) growth models. Further, the estimated standard errors for parameter 'A' were found to be smaller for females than males in all the non-linear growth models. The highest and lowest values of parameter 'B' for males and females were observed in Richards (4.056 ± 3.085 and 4.068 ± 2.803) and Von Bertalanffy (0.472 ± 0.061 and 0.468 ± 0.050) growth models, respectively, while the highest and lowest values of parameter 'k' for males and females were observed in Richards (0.013 ± 0.007 and 0.014 ± 0.008) and Brody (0.004 ± 0.001 and 0.005 ± 0.001) growth models, respectively. The coefficient of determination (R^2) estimated more than 96 per cent in all Non-linear growth models and it showed that all the models fitted where good fits. The estimation of the predicted body weights at various ages based on each function fitted are shown in Table 3 and Figure 1 which showed that the growth curves for the predicted values of body weights at different ages were almost similar to the observed weights.

Table 2: Estimated model parameters (± S.E) and goodness of fit statistics for the non-linear models of body weights of male, female and overall lambs in Mecheri sheep

Model	Parameters ± SE			Goodness of fit statistic					
	A	B	K	m	R^2	MSE	MAE	MAPE	χ^2
Male									
Brody	23.618 ±3.867	0.884 ±0.036	0.004 ±0.001	-	0.99	0.86	0.55	0.06	0.172^{NS}
Gompertz	20.230 ±2.632	1.821 ±0.355	0.009 ±0.003	-	0.98	2.01	0.86	0.12	0.509^{NS}
Logistic	19.341 ±2.489	4.056 ±1.814	0.013 ±0.005	-	0.96	3.26	1.07	0.18	0.943^{NS}
Von Bertalanffy	20.862 ±2.793	0.472 ±0.061	0.007 ±.002	-	0.98	1.58	0.77	0.10	0.374^{NS}
Richards	30.319 ±6.232	4.056 ±3.085	0.013 ±0.007	1.570 ±0.320	0.96	6.52	1.07	0.18	0.943^{NS}
Female									
Brody	19.799 ±1.78	0.876 ±0.027	0.005 ±0.001	-	0.99	0.32	0.34	0.04	0.067^{NS}
Gompertz	17.453 ±1.534	1.812 ±0.303	0.01 ±0.002	-	0.98	1.03	0.62	0.09	0.275^{NS}
Logistic	16.760 ±1.585	4.068 ±1.684	0.014 ±0.005	-	0.97	1.93	0.85	0.14	0.596^{NS}
Von Bertalanffy	17.924 ±1.549	0.468 ±0.050	0.008 ±0.002	-	0.99	0.75	0.53	0.07	0.187^{NS}
Richards	24.448 ±6.039	4.068 ±2.803	0.014 ±0.008	1.430 ±3.600	0.97	3.86	0.85	0.14	0.596^{NS}
Overall									
Brody	20.604 ±2.241	0.875 ±0.032	0.005 ±0.001	-	0.99	0.51	0.42	0.05	0.104^{NS}
Gompertz	18.202 ±1.796	1.798 ±0.332	0.010 ±0.003	-	0.98	1.38	0.72	0.10	0.353^{NS}
Logistic	17.502 ±1.812	3.989 ±1.755	0.014 ±0.005	-	0.96	2.43	0.95	0.15	0.716^{NS}
Von Bertalanffy	18.683 ±1.843	0.466 ±0.056	0.008 ±0.002	-	0.98	1.05	0.63	0.08	0.253^{NS}
Richards	27.282 ±4.470	3.989 ±2.484	0.014 ±0.008	1.559 ±0.255	0.97	4.87	0.95	0.15	0.716^{NS}

^{NS}- Not significant; R^2- Coefficient of determination; MSE- Mean squares error; MAE- Mean absolute error; MAPE- Mean absolute percent error; χ^2- Chi-square goodness of fit test value.

Table 3: Observed mean body weights and predicted weights by different growth models in Mecheri sheep

Age (months)	Observed weights (kg)	Predicted weights by each model (kg)				
		Brody	Von Bertalanffy	Logistic	Gompertz	Richards
0	2.37	2.57	2.85	3.51	3.01	3.51
3	9.61	8.92	8.65	8.21	8.53	8.21
6	12.56	13.03	13.17	13.25	13.22	13.25
9	15.32	15.70	15.85	16.04	15.91	16.04
12	17.87	17.50	17.32	17.09	17.24	17.09

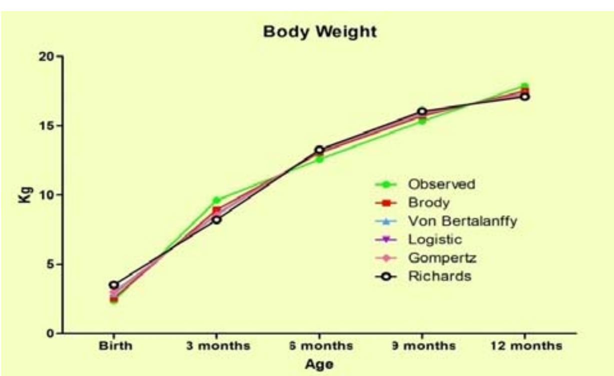

Fig 1: Growth curve for observed body weights along with non-linear models predicted weights

Richards model had a highest mean square error (MSE), followed by Logistic, Gompertz, Von Bertalanffy and Brody growth models in males, females and overall sample of Mecheri sheep. Chi-square values between the predicted and the observed body weights of males, females and overall population were not significant (P>0.05) in all the five non-linear models indicating predicted and actual body weights were not different in males, females and overall population of Mecheri sheep.

The models adopted were compared using R^2, MSE, MAE and MAPE values to identify the best model in explaining the body weights of males, females and overall population. The goodness of fit of the models to explain the growth in Mecheri sheep was found in the order Brody, Von Bertlanffy, Gompertz, Logistic and Richards models. Thus, Brody model was found to be the best model for growth traits in Mecheri sheep due to the lowest values of MSE, MAE and MAPE for body weights of males, females and overall population. Similar results were obtained in Morkaraman, Awassi and Tushin sheep [7, 5], Bergamasca sheep [14], Awassi sheep [23], West African Dwarf (WAD) sheep [9], autumn born single male commercial sheep in Pakisthan [25], Baluchi sheep [4] and

Madras Red sheep [8] while fitting growth curves in medium size breeds like Mecheri breed of sheep. However, the Gompertz function was found appropriate for describing the growth curve of Suffolk sheep [12], Akkaraman sheep [10], Norduz female lambs [11] and Malya lambs [2]. Also, Logistic function was described as the best fit for Santa Ines sheep [13, 20] and for Mengali sheep [21].

On the basis of indicators viz., the highest R^2, least MSE, MAE and MAPE values, it is concluded that the Brody function is the best fitted model for the growth curve analysis of Mecheri sheep among the five non-linear models including viz. Brody, Richards, Von Bertalanffy, Gompertz and Logistic models.

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