



Original Research

Estimation of Growth Curve Parameters Using Non-Linear Growth Curve Models in Sonadi Sheep

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Abstract

Sonadi sheep rearing is an important livelihood for a large number of small and marginal farmers in Southern Rajasthan. Growth, defined as changes of body weight over time is an economically important trait in sheep that directly determines meat production. The present study was aimed to estimate the growth curve parameters for live-weight from birth to 12 months age in Sonadi sheep. Data on 56 Sonadi sheep, including 28 males and 28 female which were born in year 2016 maintained at Mega Sheep Seed Project, Vallabh Nagar, Udaipur were used. Non-linear growth models, viz. Gompertz, Brody, negative exponential, logistic and Von Bertalanffy were used for estimating the growth curve parameters. Average of live weight (Kg.) in Sonadi sheep from birth to 12th month of age were 3.27 ± 0.081 , 6.72 ± 0.202 , 9.06 ± 0.267 , 12.19 ± 0.388 , 15.01 ± 0.44 , 16.21 ± 0.51 , 16.75 ± 0.54 , 18.54 ± 0.586 , 18.59 ± 0.599 , 20.86 ± 0.586 , 21.51 ± 0.517 , 22.10 ± 0.522 and 23.15 ± 0.512 , respectively. The value of growth parameters for lamb from Brody model; "A", "B" and "K" were 26.033 ± 1.109 , 0.872 ± 0.016 and 0.160 ± 0.018 , respectively. Adjusted determination coefficient (R^2_{adj}), RMSE and AICc were 0.991, 0.599 and -5.08, respectively. As a result of highest R^2_{adj} and lowest RMSE, AICc, Brody model can be said an appropriate model for drawing growth curve.

Key words: Body Weight, Growth Curve Parameters, Sonadi Sheep, Non-Linear Model

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Introduction

Sheep rearing play a significant role in livestock sector and is essential for the livelihood for a large number of small and marginal farmers of India. Sheep are efficient converters of unutilized poor quality grass and crop residues into meat and fiber. The evaluation of increase in the productivity of an animal is important with respect to sale of lamb, body weight gain and income from sheep by culling of the inferior animals in the flock. Approximately, Rajasthan with 9.08 million of sheep population, Livestock census (2012) is the



3rd largest sheep rearing state of India. Sonadi sheep is an important mutton breed of southern Rajasthan and prevails in southern sub-humid zone comprising Udaipur, Chittorgarh, Rajasamand, Dungarpur and Banswara district of Rajasthan. Sonadi sheep has the unique characteristics like it is devoid of wool on face, legs and has white fleece. This breed can survive under harsh conditions of Rajasthan.

Growth, defined as changes of body weight over time is an economically important trait in sheep that directly determines meat production. Knowing the growth traits of a sheep is important for number of reasons such as relating to breeding, feeding, healthcare and monitoring growth pattern. Changes in live weight or dimension for a period of time are explained by the growth curves Keskin *et al.* (2009). This is often sigmoid in shape. Sigmoid curve has three phases; preparing, increasing and quietness. Different mathematical growth models express the life time growth curve. Growth curve parameters can be used as phenotypic traits and to analyze relationship between them. Growth curve parameters provide potentially helpful criteria for changing the association between body weight and age through selection and breeding Kachman and Gionola (1984) and an optimum growth curve can be obtained by selection for desired values of growth curve parameters Bathaei and Leroy (1998). Growth curve is useful in several applications to animal husbandry, such as analysis of the interaction between sub-population and time; evaluation of the response to different treatments over time; and identification of heavier animal at younger ages with in a population Bathaei and Leroy (1996); Fretas (2005) and Malhado *et al.* (2009). In order to increase farmer's income, there needs to be improvement in the production of these animals. Slow growth rate resulting in low market weight has been identified to be one of the factors limiting profitability in any production system Noor *et al.* (2001). No previous studies have been conducted on growth curve characteristics of the Sonadi sheep. Brown *et al.* (1976) compared different non-linear models, viz. Von Bertalanffy, Logistic, Gompertz, Brody and Richards to fit weight-age data of beef and dairy cows. Therefore, the present study was taken up to characterize the growth pattern of Sonadi sheep using nonlinear regression models which can be used as selection criterion in the breeding programmes and to evaluate the present status of the breed under field conditions. For this purpose, five non-linear models (Gompertz, Brody, Negative exponential, Logistic and Von Bertalanffy) were compared to evaluate their efficiency in describing the growth curve of Sonadi sheep.

Material and Methods

The experiment was carried out at the College of Veterinary and Animal Science, Navania, Vallbhnagar, Udaipur, Rajasthan ,under the Mega Sheep Seed Project in which a flock of about 400 Sonadi sheep is being maintained. It is situated at 582m above mean sea level (24°35' N and 73°43' E) characterized by semi-arid climatic conditions with undulated topography having an average rainfall of 800 mm mainly during monsoon season from July to September. Similarly, the temperature ranges from 2.3°C to 42.3°C.

In this research, monthly live weight from birth to 12 month of age for 28 males and 28 females were measured with 50 g sensitivity scale.

Statistical Analysis

For drawing growth curves, early growth periods can be explained the linear model but after these periods linearity is distorted. Five asymptotic non-linear functions models were considered for fitting the average monthly body weight data. The five nonlinear growth models viz. Brody; Brody (1945), Von bertalanffy; Bertalanffy (1957), Logistic; Nelder (1961), Gompertz; Laird (1965) and Negative exponential; Brown *et al.* (1976) were used for drawing growth curves. Nonlinear regression models (Table 1) were considered in this study to describe body weight growth by age in Sonadi sheep were as follows-

Table 1: Nonlinear regression models

Equation	Functional Form
Gompertz	$W_t = A * \exp(-B * e(-K * t))$
Brody	$W_t = A * (1 - B * e(-K * t))$
Negative exponential	$W_t = A * (1 - e(-K * t))$
Logistic	$W_t = A / (1 + B * e(-K * t))$
Von Bertalanffy	$W_t = A * (1 - B * e(-K * t))^3$

The growth curve parameters used in the different functions can be interpreted as follows: W_t Observed live weight at age t , A time to infinite predicted mature live weight; the parameter A is average weight at maturity, that is asymptotic limit of the weight when age (t) approaches infinity, B Folding point of growth $t = 0$; The proportion of the asymptotic mature weight to be gained after birth, K Growth rate; the rate with which weight approaches A , the asymptote, Large value of k indicate that the animal would mature early, e Natural logarithm base and t time at when weight was observed.

The five non-linear growth models in Table 1 were fitted separately for general, males and females and parameters of model were estimated by Levenberg-Marquardt irritation methods Bates, D.M. and Watts, D.G. (1988), which minimize sum of squared errors. In this research SPSS 22 software was used for parameters prediction and goodness of fitness test.

To examine model performance (quality of prediction), adjusted coefficient of determination (R^2_{adj}) is used. However, (Kvalseth, 1985) has emphasized that, although R^2_{adj} is quite appropriate even for non-linear models, uncritical use of and sole reliance on R^2_{adj} statistics may fail to reveal important data characteristics and model inadequacies. Hence, in addition to R^2_{adj} , Root Mean Square Error (RMSE) and corrected Akaike's information criteria (AICc) (Table 3) were used as the goodness of fit criterion to access the suitability of models fitted. Adjusted coefficient of determination (R^2_{adj}) was calculated using the following formula-

$$R_{adj}^2 = 1 - \left[\frac{(n-1)}{(n-p)} \right] (1 - R^2)$$

Where R^2 is the multiple coefficient of determination ($R^2 = 1 - \text{RSS}/\text{TSS}$). TSS is total sum of square, RSS is residual sum of square, n is the number of observation (data point) and p is the number of parameters in the equation. The R^2 value is an indicator measuring the proportion of total variation about the mean of the trait explained by the growth curve model. The coefficient of determination lies always between 0 to 1, and the fit of a model is satisfactory if R^2 is close to unity. Root mean square error (RMSE) is a kind of generalized standard deviation and was calculated as follows-

$$RMSE = \sqrt{\frac{RSS}{n-p-1}}$$

Where RSS is residual sum of square, n is the number of observation (data point) and p is the number of parameters in the equation. RMSE value is one of the most important criteria to compare the suitability of used growth curve models. Therefore, the best model is the one with the lowest RMSE. Akaike's information criteria (AIC) was calculated as using the equation Burnham and Anderson (2004)-

$$AIC = n * \ln(RSS) + 2p$$

Corrected Akaike's information criteria (AICc) was calculated as using the equation Motulsky and Christopoulos (2004)-

$$AIC_c = AIC + \frac{2p(p+1)}{n-p-1}$$

AICc is a good static for comparison of models of different complexity because it adjust the RSS for number of parameters in the model. A smaller numerical value of AICc indicates a better fit when comparing models.

Result and Discussions

Descriptive values of Sonadi sheep live weight from birth to 12th month of age is given in Table 2. General mean of live weight (Kg.) in Sonadi sheep from birth to 12th month of age were 3.27±0.081, 6.72±0.202, 9.06±0.267, 12.19±0.388, 15.01±0.44, 16.21±0.51, 16.75±0.54, 18.54±0.586, 18.59±0.599, 20.86±0.586, 21.51±0.517, 22.10±0.522 and 23.15±0.512, respectively. At the result of analysis, every month of age live weight of Sonadi sheep except birth to 5th month influenced statistically significant from sex factor ($P < 0.05$); and on these month male weight higher than female. Similar results were agreement with Gansan *et al.* (2015) in Madras Red sheep, Tatar *et al.* (2009) in Young hair goat. Because of sex factor significantly influence live weight data were standardized according to this factor. Standardized data were used for drawing growth curves.

Table 2: Descriptive statistics of live weight in Sonadi sheep

Periods	Sex	N	Mean ± SE	Minimum	Maximum	Coefficient of Variation (%)
At birth	Male	28	3.17±0.101	2.1	4.2	16.96
	Female	28	3.36±0.125	2.4	5.8	19.72
	General	56	3.27±0.081	2.1	5.8	18.53
1 st Month	Male	28	6.68±0.313	4.4	10.5	24.79
	Female	28	6.75±0.262	3.8	9.7	20.59
	General	56	6.72±0.202	3.8	10.5	22.56
2 nd Month	Male	28	9.03±0.386	6	14.2	22.65
	Female	28	9.09±0.377	4.9	13	21.98
	General	56	9.06±0.267	4.9	14.2	22.12
3 rd Month	Male	28	12.34±0.585	7.3	21	24.18
	Female	28	12.05±0.525	8	17.2	23.07
	General	56	12.19±0.388	7.3	21	23.43
4 th Month	Male	28	15.12±0.702	9.8	24.4	25.59
	Female	28	14.91±0.559	9.6	20.5	19.83
	General	56	15.01±0.445	9.6	24.4	22.21
5 th Month	Male	28	16.80±0.853	10.6	29.3	26.87
	Female	28	15.62±0.581	11.1	22.7	19.69
	General	56	16.21±0.517	10.6	29.3	23.9
6 th Month	Male	28	17.89±0.907	12.5	33.5	26.84
	Female	28	15.61±0.526	10.2	23.5	17.86
	General	56	16.75±0.542	10.2	33.5	24.22
7 th Month	Male	28	19.85±0.962	13.2	35.5	25.64
	Female	28	17.22±0.592	11.7	24	18.19
	General	56	18.53±0.586	11.7	35.5	23.69
8 th Month	Male	28	20.71±0.896	14.6	33.6	22.88
	Female	28	16.47±.571	10.6	22.6	18.35
	General	56	18.59±0.599	10.6	33.6	24.1
9 th Month	Male	28	22.60±0.866	16	35	20.82
	Female	28	19.13±0.654	12.6	25.4	18.08
	General	56	20.86±0.586	12.6	35	21.01
10 th Month	Male	28	23.10±0.816	16.4	32.4	18.69
	Female	28	19.92±0.487	14	25.3	12.44
	General	56	21.51±0.517	14	32.4	17.99
11 th Month	Male	28	24.17±0.682	19	32.5	14.94
	Female	28	20.03±0.573	14	27.1	15.14
	General	56	22.10±0.522	14	32.5	17.96
12 th Month	Male	28	25.15±0.723	20.1	33.7	15.21
	Female	28	21.15±0.500	16.4	25.6	12.51
	General	56	23.15±0.512	16.4	33.7	16.55

The estimated nonlinear regression model growth parameters, their standard error and goodness of fit statistically namely adjusted coefficient of determination (R^2_{adj}), root mean square error (RMSE) and corrected akaike's information criteria (AICc) for the Gompertz, Brody, Negative exponential, Logistic and

Von Bertalanfy models are presented (Table 3). There was a variety on the parameter estimates of the models. The A parameter which estimates mature weight was the largest for the Brody model in both male and female sheep 30.20 ± 0.923 and 22.39 ± 1.068 , respectively and the lowest for the logistic in male and female sheep 24.74 ± 0.728 and 20.050 ± 0.734 , respectively (Table 3). The A parameter for male sheep is higher in female sheep. The k parameter describes earliness of maturing and helpful to define the shape of curve. This parameter offers a unique trait to evaluate animals, and the relationships between size and productivity. The ability of an animal to reach puberty at a younger age given an asymptotic weight in an important consideration. The estimate for k was highest for logistic model for both male and female sheep (0.425 ± 0.040 and 0.465 ± 0.069), respectively. Whereas, k value was found smallest for Brody's model for both male and female sheep (0.137 ± 0.010 0.190 ± 0.027), respectively. The estimate B parameter was highest for Gompertz model in both male and female (1.856 ± 0.083 and 1.587 ± 0.104) and lowest for Von Bertalanfy model (0.480 ± 0.014 and 0.426 ± 0.028). The similar findings were reported in Madras Red sheep Ganasan *et al.* (2015) and Balan *et al.* (2017) in Mecheri sheep. Different parameter estimates for the various models fit on the same data is a possibility and reported by many Akbas *et al.* (1999); Bilgin *et al.* (2004_a); Keskin *et al.* (2009) and Kopuzlu *et al.* (2014) in similar studies conducted earlier.

Table 3: Estimated model parameters \pm SE and goodness of fit statistics of the nonlinear regression growth models of body weights of ram and ewe lambs

Items	Model	Parameters			Goodness of Fit		
		A	B	K	R ² _{adj}	RMSE	AICc
Male Lambs	Gompertz	25.999 \pm 0.692	1.856 \pm 0.083	0.284 \pm 0.021	0.992	0.627	-3.87
	Brody	30.204 \pm 0.923	0.897 \pm 0.008	0.137 \pm 0.010	0.997	0.376	-17.17
	Negative Exponential	26.798 \pm 0.000	1.000 \pm 0.026	0.201 \pm 1.489	0.968	1.318	15.41
	Logistic	24.744 \pm 0.728	1.528 \pm 0.178	0.425 \pm 0.040	0.984	0.934	6.46
	Von Bertalanffy	26.800 \pm 0.685	0.480 \pm 0.014	0.236 \pm 0.016	0.995	0.517	-1.06
Female lambs	Gompertz	20.698 \pm 0.781	1.587 \pm 0.140	0.330 \pm 0.045	0.971	0.973	7.51
	Brody	22.396 \pm 1.068	0.844 \pm 0.025	0.190 \pm 0.027	0.982	0.782	1.84
	Negative Exponential	20.516 \pm 0.000	1.000 \pm 0.045	0.289 \pm 1.066	0.928	1.552	19.65
	Logistic	20.050 \pm 0.734	1.159 \pm 0.206	0.465 \pm 0.069	0.958	1.179	12.5
	Von Bertalanffy	21.070 \pm 0.825	0.426 \pm 0.028	0.285 \pm 0.038	0.976	0.902	5.55
Overall lambs	Gompertz	23.303 \pm 0.787	1.719 \pm 0.112	0.302 \pm 0.032	0.984	0.822	3.14
	Brody	26.033 \pm 1.109	0.872 \pm 0.016	0.160 \pm 0.018	0.991	0.599	-5.08
	Negative Exponential	23.440 \pm 0.000	1.000 \pm 0.034	0.239 \pm 1.270	0.952	1.445	17.8
	Logistic	22.386 \pm 0.761	1.330 \pm 0.193	0.437 \pm 0.053	0.973	1.072	10.04
	Von Bertalanffy	23.861 \pm 0.824	0.453 \pm 0.021	0.256 \pm 0.026	0.988	0.734	0.21

Goodness of Fit

The models adopted were compared using R^2_{adj} , RMSE and AICc values to identify the best model in explaining the body weights of males, females and overall population (Fig. 1 and 2). The goodness of fit of the models to explain the growth in Sonadi sheep was found in the order Gompertz, Brody, Negative Exponential, Logistic and Von Bertalanffy. The values of R^2_{adj} , RMSE and AICc for different models are presented in Table 3.

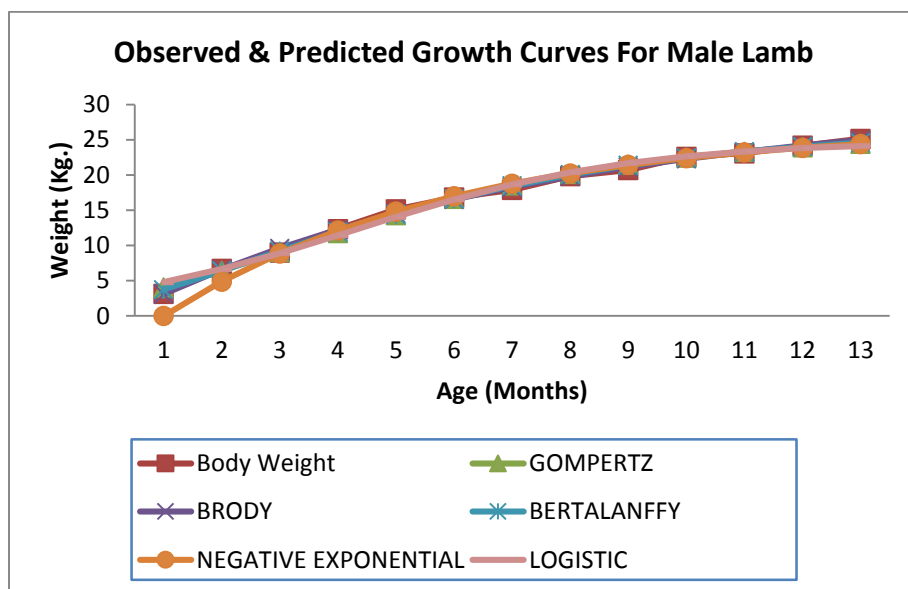


Fig. 1: Observed weight (kg) and estimated weight (kg) as a function of age (months) with the non-linear models in Sonadi male lambs

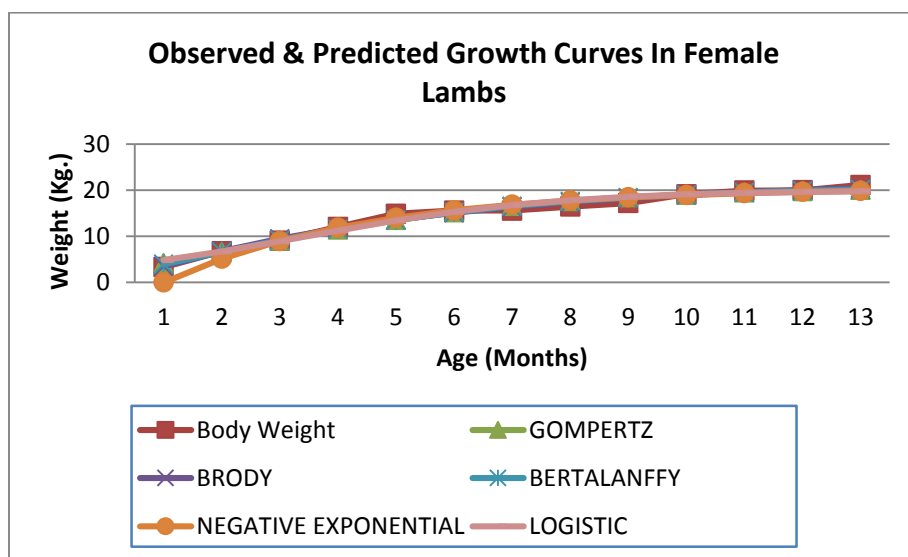


Fig. 2: Observed weight (kg) and estimated weight (kg) as a function of age (months) with the non-linear models in Sonadi female lambs

Thus, Brody model was found to be the best model for growth traits on Sonadi sheep due to the lowest values of RMSE and AIC_c as well as highest value of R²_{adj} for body weights of males, females and overall population. Similar results were obtained in Mecheri sheep by Balan *et al.* (2017), Morkaraman, Awassi and Tushin sheep by Esenbuga *et al.* (2000), Bergamasca sheep by McManus *et al.* (2003), Awassi sheep by Topal *et al.* (2004), West African dwarf sheep by Gbangboche *et al.* (2008), Baluchi sheep by Behzaldi *et al.* (2014) and Madras red sheep by Ganesan *et al.* (2015). However, the Gompertz function was found appropriate for describing the growth curve of Suffolk sheep by Lewis *et al.* (2002), Akkaraman sheep by Kuculk *et al.* (2009), Norduz female lambs by Kum *et al.* (2010) and Malya lambs by Aytakin *et al.* (2010). Also, logistic function was described as the best fit for Santa Ines sheep by Malhado *et al.* (2009) and Silva *et al.* (2012) and for Mengali sheep by Tariq *et al.* (2013).

Conclusion

On the basis of indicators viz., the highest R²_{adj}, least RMSE and AIC_c values, it is concluded that the Brody function is the best fitted model for the growth curve analysis of Sonadi sheep among the five non-linear models including viz. Gompertz, Brody, Negative Exponential, Logistic and Von Bertalanffy.

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