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Modeling the growth curve of Iranian Shall sheep using non-linear growth models

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ABSTRACT

The objective of this study was to describe the growth pattern in Iranian Shall sheep using non-linear models. For this purpose, six non-linear mathematical functions (Brody, Negative exponential, Logistic, Gompertz, Von Bertalanffy and Richards) were used. The data set used in this study were obtained from the Animal Breeding Center of Iran and comprised 57,000 body weight records of lambs which were collected from birth to 400 days of age during 1982–2012. Each model was fitted separately to body weight records of all lambs, male and female lambs using the NLIN and MODEL procedures in SAS. The models were tested for goodness of fit using adjusted multiple coefficient of determination (R^2_{adj}), root means square error (RMSE), Durbin–Watson statistic (DW), Akaike's information criterion (AIC) and Bayesian information criterion (BIC). Richards model provided the best fit of growth curve in males, females and all lambs due to the lower values of RMSE, AIC and BIC and generally greater values of R^2_{adj} than other models. The negative exponential model provided the worst fit of growth curve for males, females and all lambs. According to the moderate values of DW obtained from fitting different models of growth curve it was concluded that there was positive autocorrelation between the residuals for all models, but this autocorrelation was more obvious for negative exponential model than the other equations. The negative correlation of −0.99 to −0.49 between *a* and *k* parameters obtained from fitting different growth models implied that the animal with smaller mature weight will be maturing faster. Evaluation of different growth models used in this study indicated the potential of the non-linear functions for fitting body weight records of Shall sheep.

1. Introduction

The Shall sheep is a local sheep breed of Iran with a population of more than 600,000 heads. The breed is fat-tailed, large-size, predominantly black or brown with white spots in front of head, well adapted to the harsh climate and raised mainly for its meat that is most important source of protein in Iran and sale of its surplus lambs is the main source of cash income for farmers. Ewes were randomly exposed to the rams at the age of 18 months and lambing was occurred in one season, from mid-January to mid-March. Ewes were kept in the flock up to 6 years old. Rams were kept until a male offspring was available for replacement. During the breeding season, single sire pens were used allocating 20–25 ewes per ram. Ewes usually lamb thrice every two years. Lambs remained with their dam until weaning. The flock was mainly kept on range and was fed by cereal pasture, but supplemental feed, including alfalfa and wheat straw, are provided especially around mating season (Amou Posht-e-Masari et al., 2013).

Growth is one of the most important features of livestock and is defined as increase in live weight or body dimension against age. Changes in live weight or dimension for a period of time are explained by the growth curves (Keskin et al., 2010). Analysis of the animal growth performance through their life span is helpful to establish appropriate feeding strategies and the best slaughter age. Studies focusing on growth curves have increased at recent years due to the development of new computational methods for faster and more accurate analyses as well as the availability of new models to be tested (Souza et al., 2013). In order to increase farmers' 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; Abegaz et al., 2010). Growth rate is related to rate of maturing and mature weight and these latter

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traits have been suggested to have relationship with other lifetime productivity parameters in sheep (Bedier et al., 1992; Abegaz et al., 2010).

Non-linear mathematical functions, empirically developed by depicting body weight against age, have been appropriate to characterize the growth curve in different animal classes (Malhado et al., 2009). Different growth models have been applied extensively in different species to describe the development of body weight, allowing information from multiple measurements to be combined into a few parameters with biological meaning, in order to facilitate both the interpretation and the understanding of the phenomenon (Lambe et al., 2006; Malhado et al., 2009). Growth curve parameters provide potentially helpful criteria for changing the association between body weight and age through selection and breeding (Kachman and Gianola, 1984) and an optimum growth curve can be obtained by selection for desired values of growth curve parameters (Bathaei and Leroy, 1998). The potential of changing the growth curve shape by breeding may be an attractive aspect for livestock producers through increasing early growth but restricting mature size, and hence maintenance requirements (Lambe et al., 2006). Growth curves supply several applications to animal husbandry, such as analysis of the interaction between subpopulations (or treatments) and time; evaluation of the response to different treatments over time; and identification of heavier animals at younger ages within a population (Bathaei and Leroy, 1996; Freitas, 2005; Malhado et al., 2009).

No previous studies have been conducted on growth curve characteristics of the Shall sheep. Therefore, the objective of this study was to characterize the growth pattern of Shall sheep using nonlinear models. For this purpose, six mathematical models (Brody, Negative exponential, Logistic, Gompertz, Von Bertalanffy and Richards) were compared to evaluate their efficiency in describing the growth curve of Shall sheep.

2. Materials and methods

The data set used in this study were obtained from the Animal Breeding Center of Iran and comprised 57,000 body weight records which were collected on 11,400 lambs from birth to 400 days of age during 1982 to 2012. The data were screened several times and defective and out of range records were deleted.

The non-linear growth models used to describe the growth curves of Shall sheep are presented in Table 1. The Brody, Negative exponential, Logistic, Gompertz, Von Bertalanffy and Richards functions were fit to the data to model the relationship between body weight and age. Each model was fitted separately to body weight records of all lambs, male and female lambs using the NLIN and MODEL procedures in SAS (2002) and the parameters were estimated. The NLIN procedure provides least squares or weighted least squares estimates of the parameters of a non-linear model. For each non-linear model to be analyzed, the model (using a single dependent variable) and the names and starting values of the parameters to be estimated must be specified (SAS, 2002). When non-linear functions were fitted, the Gauss-Newton method was used as the iteration method. To begin this process the NLIN procedure first evaluates the starting value specifications of the parameters. If a grid of values is specified, NLIN procedure evaluates the residual sum of squares at each combination of parameter values to determine the set of parameter values producing the lowest residual sum of squares. These parameter values are used for the initial step of the iteration (SAS, 2002). The MODEL procedure analyzes models in which the relationships among the variables comprise a system of one or more nonlinear equations. Primary uses of the MODEL procedure are estimation, simulation, and forecasting of nonlinear simultaneous equation models (Ghavi Hossein-Zadeh, 2014). The models were tested for goodness of fit (quality of prediction) using adjusted coefficient of determination (R^2_{adj}), residual standard deviation or root means square error (RMSE), Durbin–Watson statistic (DW), Akaike's information criterion (AIC) and Bayesian information criterion (BIC).

R^2_{adj} was calculated using the following formula:

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

where R^2 is the multiple coefficient of determination ($R^2 = 1 - (\text{RSS}/\text{TSS})$), TSS is total sum of squares, RSS is residual sum of squares, n is the number of observations (data points) 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 and 1, and the fit of a model is satisfactory if R^2 is close to unity.

RMSE is a kind of generalized standard deviation and was calculated as follows:

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

where RSS is residual sum of squares, n is the number of observations (data points) 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.

DW was used to detect the presence of autocorrelation in the residuals from the regression analysis. In fact, the presence of autocorrelated residuals suggests that the function may be inappropriate for the data. The Durbin–Watson statistic ranges in value from 0 to 4. A value near two indicates non autocorrelation; a value toward 0 indicates positive autocorrelation; a value toward 4 indicates negative autocorrelation (Ghavi Hossein-Zadeh, 2014). DW was calculated using the following formula:

$$\text{DW} = \frac{\sum_t^n (e_t - e_{t-1})^2}{\sum_{t=1}^n e_t^2}$$

where e_t is the residual at time e, and e_{t-1} is residual at time $t-1$.

AIC was calculated as using the equation (Burnham and Anderson, 2002):

$$\text{AIC} = n \times \ln(\text{RSS}) + 2p$$

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

BIC combines maximum likelihood (data fitting) and choice of model by penalizing the (log) maximum likelihood with a term related to model complexity as follows:

$$\text{BIC} = n\ln\left(\frac{\text{RSS}}{n}\right) + p\ln(n)$$

A smaller numerical value of BIC indicates a better fit when comparing models.

After selecting the best fitted function, the absolute growth rate (AGR) was calculated based on the first derivative of the function in relation to time ($\partial y/\partial t$). In fact, the AGR represents the weight gained per time unit which, in this case, equals the daily weight gain estimated throughout a growth period; thereby it corresponds to the mean animal growth rate within a population (Malhado et al., 2009).

Table 1
Functional forms of equations used to describe the growth curve of Shall sheep.

Equation	Functional form
Brody	$y = a(1 - be^{-kt})$
Negative exponential	$y = a - (ae^{-kt})$
Logistic	$y = \frac{a}{1+be^{-ct}}$
Gompertz	$y = ae^{-be^{-kt}}$
Von Bertalanffy	$y = a(1 - be^{-kt})^3$
Richards	$y = a(1 - be^{-kt})^{-m}$

y represents body weight at age t (day); a represents asymptotic weight, which is interpreted as mature weight; and b is an integration constant related to initial animal weight. The value of b is defined by the initial values for y and t; k is the maturation rate, which is interpreted as weight change in relation to mature weight to indicate how fast the animal approaches adult weight; m is the parameter that gives shape to the curve by indicating where the inflection point occurs.

3. Results

Estimated parameters of non-linear growth models for Shall sheep are presented in Table 2. Also, goodness of fit statistics for the six growth models fitted to body weight records are presented in Table 3. R^2_{adj} values had little differences among the models for all lambs, males and females, but Richards equation provided the greatest R^2_{adj} value for all lambs, males and females and negative exponential model provided the lowest values of R^2_{adj} for males, females and all lambs (Table 3). Also, negative exponential function had the lowest values of DW for males, females and all lambs, but other functions had little differences in this regard and Richards function provided the greatest value. Richards equation provided the lowest values of RMSE, AIC and BIC for males,