Abstract. Four models expressing standard weight (Wt) at age t were used to estimate growth in West African Dwarf Sheep reared in Betecoucou breeding farm of Benin: Brody, \( W_t = A(1-Be^{-Kt}) \); Gompertz, \( W_t = A \exp (-Be^{-Kt}) \); Logistic, \( W_t = A/ (1+Be^{-Kt}) \) and Von Bertalanffy, \( W_t = A (1-Be^{-Kt})^3 \). The model parameters were solved using the language Matlab® R2006a and were substituted into the formula to estimate mean weight at age t and to calculate the Average Prediction Error (APE) that quantifies the relative disagreement between observed and predicted weight. Akaike’s Information Criterion (AIC) was accessed by full maximum likelihood estimation. Final equations were as follow: Brody \([W_t = 46.9 (1-0.96 \exp (-0.002t)), r^2=0.821, AIC=32395.1]\); Gompertz \([W_t = 40.9exp (-2.80exp (-0.0072t)), r^2=0.841, AIC=32893.4]\); Logistic \([W_t = 31.0/ (1+11.11exp (-0.016t)), r^2=0.846, AIC=33408.6]\); Von Bertalanffy \([W_t = 62.50 (1-0.658 \exp (-0.004t)^3), r^2=0.846, AIC=32889.0]\). Average monthly weight (kg) observed from birth (d.0) to d.180 was respectively 2.0 kg and 17.3 kg and ranged from 1.8 to 2.0 kg (d.0) and 17.6 to 19.1 kg (d.180) for predicted weight. Based on the coefficients of determination of the specific model, Akaike’s Information Criterion (AIC) and Duncan's Multiple Range Test, the Brody model was found to be statistically most acceptable grow function followed by Von Bertalanffy model.

1. Introduction

Knowledge of growth parameters (an economically important trait) is a prerequisite for the formulation of effective genetic improvement programs to increase efficiency lifetime production ([1]). The animal growth has been described as the change in live bodyweight per unit of time ([2]).

In Benin, the West African Dwarf sheep or Djallonke sheep ([3], [4], [5]) constitutes the most economically important domesticated livestock where the presence of the tsetse fly places a significant constraint on animal production. However there is no study to provide a comprehensive growth curve description in this sheep breed. The growth parameters study have been concentrated on birth weight, weaning weight and yearling weight and their relationships with non-genetic factors ([6], [7]). A new approach of lifetime weight–age relationships becomes subjects of major interest of sheep industry, due to the economic importance of mature weight, rate of maturing and related characteristics. This approach has advantage that it describes growth from birth to maturity rather than weight at one specific point and interpolates the non-observed intervals. Early estimation of these parameters can be of importance for selection purposes, given their association with other traits and the economy of production ([8], [2], [9]). Then, growth curve have been fully explored using a few parameters defined by a deterministic equation: Brody ([10]), Logistic, Gompertz ([11]) and Von Bertalanffy ([12]) and must depend on how accurately it fits the data at each specific age ([13]).
In order to face meat demand, in Republic of Benin, a solution may be found in local mutton production improvement. The knowledge of the growth parameters should be helpful to the producer in determining proper management systems under a variety of objective functions and constraints. For this purpose, the objectives of this experiment were to examine the suitability of four non-linear functions to fit live bodyweight of Djallonke sheep reared in Betecoucou breeding farm in Benin.

2. Material and methods

The growth of West African Dwarf Sheep was monthly monitored from birth to 180 days of age. The primary data set consisted on 891 weights of individuals records. The lambs were born and reared at the Betecoucou farm in the Soudano–Guinean zone of Benin, between 2°20-2°28E longitude and 7°45-7°52N latitude. Animal management in this area have been reported ([6]). Four asymptotic (Von Batailanffy, logistic, Gompertz, and Brody) nonlinear functions (Table 1) were applied to model weight–age relationship. The biological interpretation of the parameters in these models is as follows: W_t; weight of body at age t; A the upper asymptotic weight as age approach infinity (an estimation of mature weight); B, integration constant; K rate of maturing refers to growth rate relative to weight and measures the relative rate at which asymptotic value is attained; t the age in days.

Table1. Non-linear models applied in this study to describe weight growth by age in days in West African Dwarf Sheep.

<table>
<thead>
<tr>
<th>Models</th>
<th>Function</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gompertz</td>
<td>W_t=A exp (-Be^{Kt})</td>
<td></td>
</tr>
<tr>
<td>Logistic</td>
<td>W_t=A/(1+Be^{Kt})</td>
<td></td>
</tr>
<tr>
<td>Von Batalanffy</td>
<td>W_t=A (1-Be^{Kt})³</td>
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</table>

MATLAB language (version R2006a) was used to compute the parameters of these non-linear functions. For each model, these estimated parameters were used to estimate the least square mean weight. The Average Prediction Error (APE) that quantifies the relative error between observed and predicted weight values for each specific age ([13]) was computed for each function as follows:

\[ APE (%) = 100(O-P)/O, \]

were O and P are respectively the average of the observed and predicted weight for each specific group.

The adequacy of the fit of various models was compared by examining (1) the adjusted coefficient of determination (R^2) ([18]) ; (2) the least (APE) methods given a good indication of the goodness-fit of the model ([13]); (3) the minimum value of Akaike’s Information Criterion (AIC) using maximum likelihood method (Proc Mixed ml) in SAS; (4) a test of heterogeneity in order to determine if the specified equations were homogenous among all individuals. Heterogeneity of the models was tested using an F test ([9]). After fitting the data from each individual separately and then fitting the combined data, having repeated values for specific time points, to the model, we calculated the following F statistic:
\[ F = \frac{SSC - SSI}{DFC - DFI} \cdot \frac{SSI}{DFI}, \]

where SSI and DFI are total sums of squares and degrees of freedom from each individual fit, and SSC and DFC are sum-of-squares and degrees of freedom from the combined data.

3. Result and discussion

Coefficients of growth curves computed using the Brody, Gompertz, Logistic and Bertalanffy models for West African Dwarf Sheep are presented in Table 2. Due the culling and mortality, the number of animal decreased from birth to 180 d of age.

As given the growth curve in Figure 1, fits lines from all models are closed to the observed values at 180d of age and extrapolated at 360d; The models fitted were as follows:

Brody: \[ W_t = 46.9(1 - 0.96\exp(-0.002t)); \]
Gompertz: \[ W_t = 40.9\exp(-2.80\exp(-0.0072t)); \]
Logistic: \[ W_t = 31.0/(1 + 11.1\exp(-0.016t)); \]
Von Batalanffy: \[ W_t = 62.50(1 - 0.658\exp(-0.004t))^3. \]

Table 2. Parameter estimates, coefficient of determination (R²) and Akaike’s information criterion (AIC) for non-linear curves describing growth of weight in West African Dwarf sheep.

<table>
<thead>
<tr>
<th>Models</th>
<th>Parameters</th>
<th>A</th>
<th>B</th>
<th>k</th>
<th>R²</th>
<th>AIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brody</td>
<td></td>
<td>46.9</td>
<td>0.962</td>
<td>0.0024</td>
<td>0.8215</td>
<td>32395.1</td>
</tr>
<tr>
<td>Gompertz</td>
<td></td>
<td>40.9</td>
<td>27.994</td>
<td>0.0072</td>
<td>0.8415</td>
<td>32893.4</td>
</tr>
<tr>
<td>Logistic</td>
<td></td>
<td>31.0</td>
<td>111.156</td>
<td>0.0166</td>
<td>0.8212</td>
<td>33408.6</td>
</tr>
<tr>
<td>Von Batalanffy</td>
<td></td>
<td>62.5</td>
<td>0.6588</td>
<td>0.0039</td>
<td>0.8462</td>
<td>32889.0</td>
</tr>
</tbody>
</table>

Figure 1. Live weight growth curves described by four non-linear models in West African Dwarf sheep from birth (d0) to 180 d of age and extrapolated to 360d.
The estimate of $A$ derived from growth curves was an extreme in the von Batalanffy model and too small in the Logistic model (62.5 kg vs 31.5 kg). The estimate of $B$ and $k$ derived from the Logistic growth model was higher than each other. All models have considerably high $R^2$ values ranged between 0.82 and 0.84 but smaller than those reported (0.98-0.99) for the same models in Morkaraman and Awassi lambs ([9]). Minimum value of $AIC$ was found in this study for the Brody model (Table 2). Similarly in fish growth study, the Gompertz model of which $AIC$ was the lowest between von Bertalanffy Logistic and Richards models have been accepted as the best growth model ([19]; [20]). The results of the heterogeneity tests, using the $F$ distribution to compare individual fits to the estimated mean curve for each model are presented in Table 3. No function provided homogeneity of curves ($P < 0.001$). This result indicates that parameter values of nonlinear functions in this study cannot uniformly represent live bodyweight in all animals. Instead, every animal has its own parameter values, providing a better fit. Similar results have been reported by [9].

Table 3. Observed and predicted least square means weight of West African Dwarf Sheep from birth (d0) to 180d of age, computed using specified non-linear curves.

<table>
<thead>
<tr>
<th>Age (day)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>30</td>
<td>60</td>
<td>90</td>
<td>120</td>
<td>150</td>
<td>180</td>
<td></td>
</tr>
<tr>
<td>Number</td>
<td>891</td>
<td>864</td>
<td>831</td>
<td>778</td>
<td>728</td>
<td>594</td>
<td>590</td>
<td></td>
</tr>
<tr>
<td>Observed (kg)</td>
<td>1.98&lt;sup&gt;c&lt;/sup&gt;</td>
<td>4.28&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.61&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10.98&lt;sup&gt;a&lt;/sup&gt;</td>
<td>13.62&lt;sup&gt;a&lt;/sup&gt;</td>
<td>14.80&lt;sup&gt;a&lt;/sup&gt;</td>
<td>17.14&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Predicted (kg)</td>
<td>Brody</td>
<td>Gompertz</td>
<td>Logistic</td>
<td>Von Batalanffy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brody</td>
<td>1.78&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>4.91&lt;sup&gt;b&lt;/sup&gt;</td>
<td>7.81&lt;sup&gt;ec&lt;/sup&gt;</td>
<td>10.51&lt;sup&gt;e&lt;/sup&gt;</td>
<td>13.00&lt;sup&gt;e&lt;/sup&gt;</td>
<td>15.28&lt;sup&gt;b&lt;/sup&gt;</td>
<td>17.47&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Gompertz</td>
<td>2.49&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.28&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.62&lt;sup&gt;d&lt;/sup&gt;</td>
<td>9.42&lt;sup&gt;d&lt;/sup&gt;</td>
<td>12.50&lt;sup&gt;d&lt;/sup&gt;</td>
<td>15.67&lt;sup&gt;c&lt;/sup&gt;</td>
<td>18.87&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Logistic</td>
<td>2.56&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.99&lt;sup&gt;c&lt;/sup&gt;</td>
<td>6.05&lt;sup&gt;c&lt;/sup&gt;</td>
<td>8.83&lt;sup&gt;c&lt;/sup&gt;</td>
<td>12.25&lt;sup&gt;c&lt;/sup&gt;</td>
<td>15.99&lt;sup&gt;d&lt;/sup&gt;</td>
<td>19.73&lt;sup&gt;d&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Von Batalanffy</td>
<td>2.48&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.42&lt;sup&gt;d&lt;/sup&gt;</td>
<td>6.53&lt;sup&gt;b&lt;/sup&gt;</td>
<td>9.60&lt;sup&gt;b&lt;/sup&gt;</td>
<td>12.60&lt;sup&gt;b&lt;/sup&gt;</td>
<td>15.71&lt;sup&gt;c&lt;/sup&gt;</td>
<td>18.95&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
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</tbody>
</table>

The plots of weights versus ages in Gompertz, Logistic and Von Bertalanffy models (Figure 1) have shown an initial period of growth, a period of exponential growth followed by an indefinite period of slow growth. This shape is not similar in Brody model, which is slightly convex without inflection point and definition of increasing and decreasing acceleration phase of sigmoid function. Similar trends have been reported in beef cattle ([13]). In this study, the data collection at 180d age before animals reach maturity in growth could likely cause this. According to [21], a best fit of asymptotic models require entire life time data presenting all of the phases of growth that give best curve estimation.

The pattern of the statistic APE, associated to the weight prediction for each specific age is shown in Figure 2. The APE values calculated for Gompertz, Logistic and Von Bertalanffy functions have shown a similar pattern, very different from those calculated for Brody function. The Gompertz, Logistic and Von Batalanffy function under predicted weight at birth (d0), 150 and 180d of age, and over predicted at birth from 30d to 120d of age. The APE values calculated for the Brody function presented a small deviation from 60d to 180d of age, between observed and predicted growth value and however provide a better fit than the APE values for the Logistic, Gompertz and Von Batalanffy. The Brody function seem to be the best model for biological interpretation of growth curve in this study due to a best pattern of APE and a minimum value of AIC. In cattle breed, Body growth function have been preferred to other non linear models because of it goodness of fit ([22], [23]) and it ability to accommodate missing growth points while easily converging ([24]). Other authors consider the efficiency of model explained by the highest coefficient of determination and the lowest
mean square error ([16]; [13]). Recently, [25] proposed the use the Gompertz model to a better fit of the growth of Suffolk sheep. The better fitting models reported in Morkaraman and Awassi lambs were Gompertz and Bertalanffy models ([9]); Gompertz model in a Suffolk sheep ([25]) and Brody, Bertalanffy, Gompertz, Negative exponential and Logistic model in Kývýrycýk and Daglýc male lambs ([18]).

4. Conclusion

Brody functions have been proposed as a reference model to characterize the growth curves of Djallonke sheep in Betecoucou breeding farm of Benin. This study analyzing growth has not collected data for the entire growth period. It is difficult, therefore, to accurately describe growth to maturity in Djallonke sheep because applications of these previous results are limited.

References


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