Data Article

Dataset on growth curves of Boer goats fitted by ten non-linear functions

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ABSTRACT

Data on the description of growth of female Boer goats from the Mexican national breeding flock are presented. Goat meat is highly appreciated for the preparation of traditional dishes of Mexican cuisine, and its demand is on the rise. Boer goats are of relatively recent arrival in Mexico and the size of the performance-recorded flock has been increasing steadily in the last ten years. Repeated measures of body weight at different ages from birth to adulthood of Boer goats are scarce. When available, such data can be used to describe the growth pattern and the meat production potential of goat meat breeds such as the Boer. This paper presents data on estimators of growth curve parameters, plots of average predicted growth curves, plots of residuals on age, and data on goodness of fit statistics of ten non-linear functions fitted to describe the growth curve of Boer goats.

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How data was acquired

For the 2017 genetic evaluation of the Boer breed in Mexico, animal unique identification, sex, birth date, date of weight recording, body weight records, and age at weight recording, were obtained from the national database during the data edition phase.

Data format

Processed, analyzed

Experimental factors

Only data from females with valid individual identification number, known farm of origin, known birth date, and with three or more weight records were included in the analysis.

Experimental features

Ten non-linear functions were fitted to the same dataset comprising age-weight records of individual Boer goats from the National Breeding Flock to produce growth curve parameters, goodness of fit estimators, plots of predicted average growth curves and plots of residuals.

Data source location

Laboratorio de Evaluaciones Genéticas, Universidad Autónoma Chapingo, Departamento de Zootecnia, Posgrado en Producción Animal, km 38.5 carretera México-Texcoco, Chapingo, Estado de México.

Data accessibility

Data is with this article.

Related research article

García-Muñiz J.G., Ramírez-Valverde R., Núñez-Domínguez R., Hidalgo-Moreno J.A. 2018. Genetic parameters for direct and maternal effects on accumulated productivity to weaning of Boer goats in Mexico. Proceedings of the World Congress on Genetics Applied to Livestock Production, 11.92

Value of the data

- Small ruminants such as meat goats are expected to play an increasingly important role in food production worldwide.
- Efficient meat production requires appropriate description of the growth pattern of populations of animals.
- Data required to describe the growth trajectory of female goats may be available from national databases used for genetic evaluation. Often, however, this information needs to be compiled and edited in an appropriate format to undertake growth curve analysis.
- National datasets with repeated weight records of female Boer goats covering the interval from birth to maturity are scarce. Thus, the data presented may be used with sets of similar data to compare the growth pattern of Boer goats from different populations.

1. Data

Weight-age records \( (n = 3783) \) and animal unique identification number, birth date, date of weight recording, farm of origin and farm location were obtained from the national database of the Boer goat breed in Mexico (Appendix A). Data represented females \( (n = 1055) \) born from 2006 to 2016, that belonged to 31 farms distributed across 8 states in the country. The animal and farm variables recorded represented the variability of the national Boer flock (Table 1). For the growth

| Variable                        | \( N \) | Minimum | Maximum | Mean  | Std. Dev. |
|---------------------------------|--------|---------|---------|-------|-----------|
| Age (days)                      | 3783   | 1.0     | 1944.0  | 159.0 | 315.1     |
| Weight (kg)                     | 3783   | 1.2     | 80.2    | 21.5  | 17.7      |
| Weight-age records per animal \( n \) | 1055   | 3.0     | 5.0     | 3.6   | 0.7       |
| Weight-age records per farm \( n \) | 3783   | 12.0    | 865.0   | 122.0 | 172.7     |

Table 1

Descriptive statistics for age, weight and number of records per farm and per animal of female Boer goats from the Mexican national breeding flock.
Fig. 1. Visual display of average fixed growth curves of Boer goats fitted by 10 non-linear functions. The horizontal broken line corresponds to the estimated asymptotic (mature) body weight, and the black dots are observed weights.
interval from 1 to 1944 days of age, scatter plots of sigmoid trajectories of weight-age data (Fig. 1) along with the estimated average growth curve, and the asymptotic (mature) weight are displayed for each of 10 non-linear functions fitted to the data.

2. Experimental design, materials and methods

2.1. Description of models fitted

Ten non-linear functions describing sigmoid trajectories of age-weight data were fitted separately to the same data set (Table 2).

The first five models from Table 2 are models with three-parameters \((A, W_0, k)\), whereas the last five, are models that include a fourth parameter \((A, W_0, k, n)\). Except for the models of Bridges, and the Generalized Michaelis-Menten, that both have initial weight \((W_0)\) as a parameter, the remaining models were reparameterized to contain \(W_0\) as a model parameter. To achieve this end, the procedure of Koya and Goshu [7] was followed to obtain an expression for the \(b\) parameter of the model general form. The re-parameterized version of the model was obtained by substituting \(b\) by its expression in the model general form (Table 2). Each of the ten models containing \(W_0\) as a parameter was fitted separately to the dataset using the NLMIXED procedure of SAS [8]. For the ten models fitted, only the parameter related to asymptotic weight \((A)\) was fitted as a random effect. Thus, the statistical model fitted for each of the growth functions compared can be expressed as follows:

\[
\begin{align*}
\text{Brody:} & \quad W_{it} = (A + a_i) \left( 1 - be^{-kt} \right) + \epsilon_{it} \quad (1) \\
\text{Logistic:} & \quad W_{it} = (A + a_i) \left[ 1 + \left( \frac{A + a_i}{W_0} - 1 \right)e^{-kt} \right]^{-1} + \epsilon_{it} \quad (2) \\
\text{Von Bertalanffy:} & \quad W_{it} = (A + a_i) \left\{ 1 - \left[ 1 - \left( \frac{W_0}{A + a_i} \right)^{\frac{1}{n}} \right]e^{-kt} \right\}^3 + \epsilon_{it} \quad (3) \\
\text{Gompertz:} & \quad W_{it} = (A + a_i) \left( \frac{W_0}{A + a_i} \right)e^{-kt} + \epsilon_{it} \quad (4) \\
\text{Michaelis–Menten:} & \quad W_{it} = \frac{W_0K + (A + a_i)t}{K + t} + \epsilon_{it} \quad (5) \\
\text{Generalized\-Michaelis–Menten:} & \quad W_{it} = \frac{W_0K + (A + a_i)t^n}{K^n + t^n} + \epsilon_{it} \quad (6) \\
\text{Richards:} & \quad W_{it} = (A + a_i) \left\{ 1 - \left[ 1 - \left( \frac{W_0}{A + a_i} \right)^{\frac{1}{n}} \right]e^{-kt} \right\}^n + \epsilon_{it} \quad (7) \\
\text{Janoscheck:} & \quad W_{it} = A + a_i - (A + a_i - W_0)e^{-kt^n} + \epsilon_{it} \quad (8) \\
\text{Bridges:} & \quad W_{it} = W_0 + (A + a_i)(1 - e^{-kt^n}) + \epsilon_{it} \quad (9) \\
\text{Generalized\-Weibull:} & \quad W_{it} = (A + a_i) \left[ 1 - \left( 1 - \frac{W_0}{A + a_i} \right)e^{-(kt)^n} \right] + \epsilon_{it} \quad (10)
\end{align*}
\]

Where \(W_{it}\) is body weight of animal \(i\) recorded on day \(t\) of age, \(e\) is the base of natural logarithms (i.e. 2.718281), \(A\) is the predicted mature (asymptotic) weight, \(a_i\) is the random effect of animal \(i\) for the parameter \(A\) of the growth curve \(\sim Normal(0, \sigma_a^2)\), \(t\) is age in days, \(W_0\) is initial (birth) weight (kg), \(k\) is maturation rate, \(n\) is an inflection parameter, and \(\epsilon_{it}\) is the residual \(\sim Normal(0, \sigma^2)\). The terms \(W_{it}\) and the parameters \(A\) and \(W_0\) of the Michaelis-Menten and its generalized equation are as...
| Model                  | Reference                     | Model general form | Expression for \( b \)                                                                 | Model’s re-parameterization fitted |
|------------------------|-------------------------------|--------------------|--------------------------------------------------------------------------------------------|-----------------------------------|
| Brody                  | Fitzhugh [1]                  | \( W_t = A(1 - \beta e^{-kt})^l \) | \( 1 - \frac{W_t}{A} \) \( \frac{A}{\beta} - 1 \) \( W_t = A \left[ 1 - \left( \frac{W_t}{A} \right)^{1/n} e^{-kt} \right] \) |                                    |
| Logistic               | Tjørve and Tjørve [2]         | \( W_t = A(1 + \beta e^{-kt})^{-1} \) | \( \frac{A}{\beta} - 1 \) \( W_t = A \left[ 1 + \left( \frac{A}{\beta} - 1 \right) e^{-kt} \right]^{-1} \) |                                    |
| Von Bertalanffy        | Tjørve and Tjørve [2]         | \( W_t = A(1 - \beta e^{-kt})^n \) | \( 1 - \left( \frac{W_t}{A} \right)^{1/n} \) \( W_t = A \left[ 1 - \left( \frac{W_t}{A} \right)^{1/n} e^{-kt} \right]^n \) |                                    |
| Gompertz               | Tjørve and Tjørve [3]         | \( W_t = A e^{-\beta t} \) | \( \ln \left( \frac{A}{\beta} \right) \) \( W_t = A \left( \frac{W_t}{A} \right)^{1/n} \) |                                    |
| Michaelis-Menten       | López et al. [4]              | \( W_t = \frac{W_0 K t}{K + t} \) | \( - \) \( W_t = \frac{W_0 K t}{K + t} \) |                                    |
| Generalized Michaelis-Menten | López et al. [4]      | \( W_t = \frac{W_0 K t + A t}{K t + t} \) | \( - \) \( W_t = \frac{W_0 K t + A t}{K t + t} \) |                                    |
| Richards               | Tjørve and Tjørve [2]         | \( W_t = A(1 - \beta e^{-kt})^n \) | \( 1 - \left( \frac{W_t}{A} \right)^{1/n} \) \( W_t = A \left[ 1 - \left( \frac{W_t}{A} \right)^{1/n} e^{-kt} \right]^n \) |                                    |
| Janoschek              | Wellock et al. [5]            | \( W_t = A - (A - b) e^{-kt} \) | \( W_0 \) \( W_t = A - (A - W_0) e^{-kt} \) |                                    |
| Bridges                | Wellock et al. [5]            | \( W_t = W_0 + A(1 - e^{-kt}) \) | \( - \) \( W_t = W_0 + A(1 - e^{-kt}) \) |                                    |
| Generalized Weibull    | Henderson and Seaby [6]       | \( W_t = A \left[ 1 - be^{-kt} \right] \) | \( 1 - \frac{W_t}{A} \) \( W_t = A \left[ 1 - \left( 1 - \frac{W_t}{A} \right) e^{-kt} \right] \) |                                    |
described before. For these two functions the parameter \( K \) represents the time (days) at which 50% of total asymptotic weight is achieved [4]. Models were fitted iteratively and initial values were given for the parameters of the growth curve, \( A \) (from 50 to 100 by 10), \( W_0 \) (from 1 to 5 by 0.5), \( k \) (from 0.0001 to 0.0005 by 0.0001), \( n \) (from 1 to 5 by 1), \( \sigma_A^2 = 550, \sigma_\varepsilon^2 = 15 \). Bounds were established for \( \sigma_A^4 \) and for \( \sigma_\varepsilon^4 \). The double-dogleg optimization method was specified (method = DBLDOG) and the number of iterations was set to 200.

### 2.2. Goodness of fit estimators

At model convergence, the fitting of these functions generated estimators for the parameters describing the growth curve (Table 3), estimators for age and weight at inflection (Table 4) using

| Model                      | Parameter | Estimate | Std. Error | 95% Confidence Limits |
|----------------------------|-----------|----------|------------|-----------------------|
| Brody                      | \( A \)   | 67.3     | 0.6558     | 66.0 68.6             |
|                           | \( W_0 \) | 3.05     | 0.0862     | 2.88 3.22             |
|                           | \( k \)   | 0.00354  | 4.8E-5     | 3.4E-3 3.6E-3         |
| Logistic                   | \( A \)   | 49.5     | 0.5147     | 48.5 50.5             |
|                           | \( W_0 \) | 4.84     | 0.0631     | 4.71 4.96             |
|                           | \( k \)   | 0.01931  | 1.6E-4     | 0.0190 0.0196         |
| Von Bertalanffy            | \( A \)   | 57.4     | 0.5121     | 56.4 58.4             |
|                           | \( W_0 \) | 3.69     | 0.0731     | 3.55 3.83             |
|                           | \( k \)   | 0.00783  | 7.5E-5     | 0.0077 0.0080         |
| Gompertz                   | \( A \)   | 54.7     | 0.5027     | 53.7 55.7             |
|                           | \( W_0 \) | 3.98     | 0.0679     | 3.85 4.12             |
|                           | \( k \)   | 0.01047  | 9.1E-5     | 0.0103 0.0106         |
| Michaelis-Menten           | \( A \)   | 88.5     | 1.0122     | 86.5 90.5             |
|                           | \( W_0 \) | 2.84     | 0.0862     | 2.67 3.00             |
|                           | \( K \)   | 338.1    | 5.8021     | 326.6 349.6           |
| Generalized Michaelis-Menten| \( A \)   | 71.8     | 1.0576     | 69.7 73.9             |
|                           | \( W_0 \) | 3.45     | 0.0913     | 3.27 3.63             |
|                           | \( K \)   | 213.5    | 5.6034     | 202.5 224.5           |
|                           | \( n \)   | 1.2813   | 0.0221     | 1.2379 1.3248         |
| Richards                   | \( A \)   | 59.5     | 0.6828     | 58.1 60.8             |
|                           | \( W_0 \) | 16.35    | 1.3197     | 13.8 18.9             |
|                           | \( k \)   | 0.00609  | 1.8E-4     | 5.7E-3 6.4E-3         |
|                           | \( n \)   | 1.6603   | 0.0568     | 1.5489 1.7718         |
| Janoscheck                 | \( A \)   | 67.1     | 0.9149     | 65.3 68.9             |
|                           | \( W_0 \) | 3.06     | 0.0956     | 2.8704 3.2497         |
|                           | \( k \)   | 0.00349  | 2.0E-4     | 3.0E-3 3.9E-3         |
|                           | \( n \)   | 1.0039   | 0.0146     | 0.9753 1.0324         |
| Bridges                    | \( A \)   | 64.0     | 0.9422     | 62.2 65.9             |
|                           | \( W_0 \) | 3.06     | 0.0967     | 2.87 3.25             |
|                           | \( k \)   | 0.00349  | 2.0E-4     | 3.0E-3 3.9E-3         |
|                           | \( n \)   | 1.0038   | 0.0146     | 0.9753 1.0324         |
| Generalized Weibull        | \( A \)   | 67.1     | 0.9267     | 65.3 68.9             |
|                           | \( W_0 \) | 3.06     | 0.0996     | 2.86 3.26             |
|                           | \( k \)   | 0.00356  | 1.0E-4     | 3.4E-3 3.8E-3         |
|                           | \( n \)   | 1.0038   | 0.0157     | 0.9730 1.0346         |

\( a \) \( A \) = asymptotic (mature) weight; \( W_0 \) = initial (birth) weight; \( k \) = maturation rate parameter; \( K \) = age at which 50% of asymptotic weight is achieved (for Michaelis-Menten and Generalized Michaelis-Menten functions).
Table 4
Age and weight at inflection derived from parameters estimated for ten non-linear functions fitted to describe the growth curve of Boer goats from the Mexican national breeding flock.

| Model                              | Parameter | Expression for calculation | Parameter value |
|------------------------------------|-----------|----------------------------|-----------------|
| Brody                              | \( t_i \) | –                          | –               |
|                                    | \( W_i \) | –                          | –               |
| Logistic                           | \( t_i \) | \( \left( \frac{1}{k} \right) \ln \left( \frac{A}{W_0} - 1 \right) \) | 115.1 ± 0.9 |
|                                    | \( W_i \) | \( A \)                 | 24.8 ± 0.3     |
| von Bertalanffy                    | \( t_i \) | \( \left( \frac{1}{k} \right) \ln \left( 3 \left[ 1 - \left( \frac{W}{W_0} \right)^3 \right] \right) \) | 74.9 ± 0.7 |
|                                    | \( W_i \) | \( \left( \frac{1}{k} \right) A \)             | 17.0 ± 0.2     |
| Gompertz                           | \( t_i \) | \( \left( \frac{1}{k} \right) \ln \left( \ln \left( \frac{W}{W_0} \right) \right) \) | 92.0 ± 0.7    |
|                                    | \( W_i \) | \( A \)                 | 20.0 ± 0.2     |
| Michaelis-Menten                   | \( t_i \) | –                          | –               |
|                                    | \( W_i \) | –                          | –               |
| Generalized Michaelis-Menten       | \( t_i \) | \( \frac{1}{K} \left( \frac{K}{W_0} - 1 \right)^{\frac{1}{n}} \) | 293.0 ± 4.5 |
|                                    | \( W_i \) | \( \left( \frac{1}{K} \right) W_0 \left( 1 - \frac{1}{W_0} \right)^{\frac{1}{n}} \) | 11.0 ± 0.4    |
| Richards                           | \( t_i \) | \( \left( \frac{1}{K} \right) \ln \left( \frac{n}{W_0} \left[ 1 - \left( \frac{W}{W_0} \right)^{\frac{1}{n}} \right] \right) \) | 51.5 ± 2.1    |
|                                    | \( W_i \) | \( A \left( \frac{W_0}{W_0} \right)^{\frac{1}{n}} \) | 12.9 ± 0.4    |
| Janoscheck                         | \( t_i \) | –                          | –               |
|                                    | \( W_i \) | –                          | –               |
| Bridges                            | \( t_i \) | –                          | –               |
|                                    | \( W_i \) | –                          | –               |
| Generalized Weibull                | \( t_i \) | –                          | –               |
|                                    | \( W_i \) | –                          | –               |

\(^a\) \( t_i \) = age at inflection (days); \( W_i \) = weight at inflection (kg).

\(^b\) \( A \) = asymptotic (mature) weight; \( W_0 \) = initial (birth) weight; \( k \) = maturation rate parameter; \( n \) = inflection parameter; \( \ln \) = natural logarithm; \( K \) = age at which 50% of asymptotic weight is achieved (for Michaelis-Menten and Generalized Michaelis-Menten functions).

notation derived by Goshu and Koya [9], estimators of variance (\( \sigma_A^2 \)) for the \( A \) parameter and the residual variance (\( \sigma_\varepsilon^2 \)) (Table 5), and the goodness of fit estimators -2 Log Likelihood, Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) generated by the NLMIXED procedure of SAS [8]. The standard error of the regression (\( S_{y|x} \)) was calculated as an additional goodness of fit criteria for each of the models fitted (Table 6), using the following expression:

\[
S_{y|x} = \sqrt{\frac{1}{n-p} \sum_{i=1}^{n} e_i^2}
\]

Where, in this case, \( n \) is the number of age-weight observations in the data set; \( p \) is the number of parameters estimated by the model; \( e_i^2 \) are the squared deviations of the observed minus the average predicted weight of the respective model fitted.

2.3. High resolution plots

The SAS code (Appendix B) included an expression to calculate the predicted values for the fixed average growth curve as well as the residuals for each of the ten growth functions fitted. The SGPLOT
The procedure of SAS [8] was used to produce the high-resolution plots displaying the average growth curves (Fig. 1) and the residual plots (Fig. 2). The $A$ parameter calculated for the fixed regression curve of each function was included as a constant in the SAS code to produce the horizontal asymptote of the respective growth curve plots.

### Table 5

Estimates of variance for asymptotic (mature) weight and residual variance, after fitting ten non-linear functions to describe the growth curve of Boer goats from the Mexican national breeding flock.

| Model             | Parameter | Estimate | Std. Error | 95% Confidence Limits |
|-------------------|-----------|----------|------------|------------------------|
| Brody             | $\sigma^2_A$ | 160.3    | 8.8075     | 143.0 177.5            |
|                   | $\sigma^2_e$  | 9.08     | 0.2457     | 8.60 9.57              |
| Logistic          | $\sigma^2_A$ | 246.3    | 13.3308    | 220.1 272.4            |
|                   | $\sigma^2_e$  | 9.07     | 0.2428     | 8.59 9.54              |
| Von Bertalanffy   | $\sigma^2_A$ | 164.1    | 8.5240     | 147.4 180.9            |
|                   | $\sigma^2_e$  | 8.63     | 0.2327     | 8.17 9.08              |
| Gompertz          | $\sigma^2_A$ | 182.3    | 9.4439     | 163.8 200.8            |
|                   | $\sigma^2_e$  | 8.41     | 0.2269     | 8.00 8.90              |
| Michaelis-Menten  | $\sigma^2_A$ | 294.3    | 16.9740    | 261.0 327.7            |
|                   | $\sigma^2_e$  | 8.68     | 0.2351     | 8.22 9.14              |
| Generalized Michaelis-Menten | $\sigma^2_A$ | 189.9    | 11.0145    | 168.3 211.6            |
|                   | $\sigma^2_e$  | 8.21     | 0.2221     | 7.78 8.65              |
| Richards          | $\sigma^2_A$ | 179.8    | 10.0324    | 160.0 199.0            |
|                   | $\sigma^2_e$  | 8.64     | 0.2333     | 8.20 9.10              |
| Janoscheck        | $\sigma^2_A$ | 159.6    | 9.2122     | 141.5 177.6            |
|                   | $\sigma^2_e$  | 9.09     | 0.2456     | 8.60 9.60              |
| Bridges           | $\sigma^2_A$ | 159.6    | 9.2247     | 141.5 177.7            |
|                   | $\sigma^2_e$  | 9.09     | 0.2457     | 8.60 9.60              |
| Generalized Weibull | $\sigma^2_A$ | 159.6    | 9.1388     | 141.6 177.5            |
|                   | $\sigma^2_e$  | 9.09     | 0.2456     | 8.60 9.60              |

* AIC = Akaike Information Criterion.  
* BIC = Bayesian Information Criterion.  
* Sy/x = Standard error of the regression.

### Table 6

Model ranking and model goodness of fit estimators after fitting ten non-linear functions to describe the growth curve of Boer goats from the Mexican national breeding flock.

| Model             | Model ranking with: | -2 Log Likelihood | AIC<sup>a</sup> | BIC<sup>b</sup> | Sy/x<sup>c</sup> |
|-------------------|----------------------|--------------------|-----------------|-----------------|-----------------|
|                   | AIC      | BIC      |                     |                 |                 |
| Brody             | 5        | 5        | 21,292              | 21,302          | 21,327          | 5.26            |
| Logistic          | 6        | 7        | 21,622              | 21,632          | 21,657          | 6.77            |
| Von Bertalanffy   | 4        | 4        | 21,284              | 21,294          | 21,319          | 5.80            |
| Gompertz          | 5        | 5        | 21,291              | 21,301          | 21,325          | 6.09            |
| Michaelis-Menten  | 2        | 2        | 21,204              | 21,214          | 21,239          | 5.31            |
| Generalized Michaelis-Menten | 1      | 1        | 21,012              | 21,024          | 21,054          | 5.22            |
| Richards          | 3        | 3        | 21,230              | 21,242          | 21,272          | 5.60            |
| Janoscheck        | 5        | 6        | 21,292              | 21,304          | 21,334          | 5.26            |
| Bridges           | 5        | 6        | 21,292              | 21,304          | 21,334          | 5.26            |
| Generalized Weibull | 5      | 6        | 21,292              | 21,304          | 21,334          | 5.26            |

<sup>a</sup> AIC = Akaike Information Criterion.  
<sup>b</sup> BIC = Bayesian Information Criterion.  
<sup>c</sup> Sy/x = Standard error of the regression.
Fig. 2. Visual display of raw residuals for body weight (kg) plotted against age (days) of growth data from Boer goats fitted by 10 non-linear functions.
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Transparency document. Supplementary material

Transparency document associated with this article can be found in the online version at https://doi.org/10.1016/j.dib.2019.01.020.

Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.dib.2019.01.020.

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