Determination of a New Characterization Point for Nonlinear Mathematical Models Applied to Sheep

Mohammed Balafrej

Department of Agriculture, Production Chains Development Directorate, Rabat, Morocco

Email address: balafrejmed@hotmail.com


Received: October 1, 2019; Accepted: October 15, 2019; Published: October 23, 2019

Abstract: Improvement of sheep productivity requires selection, the use of nonlinear mathematical models provides a good means of condensing information and facilitates the interpretation and understanding of the growth phenomenon. However, few studies have addressed the optimal age of slaughter and focused on determining which models fit best with their sheep growth data. This age should meet the production objectives which differ upstream according to the production systems and downstream according to the nature of the demands expressed by all the actors in the sector, namely from slaughter to consumption. Some studies have concluded that it corresponds to the age of inflection where the growth rate is at its maximum. But according to the findings, for some production systems, this age is not suitable since it is very far from the slaughter age with the risk of hasty decision making about the judgment of the growth potential of animals. Therefore, the objective of this study is to develop a new landmark located further down the growth curve than the inflection point and that meets the specific needs of these systems. To do this, we have calculated for the models Logistic, Gompertz, Richards and Von Bertalanffy, the point \( f(t_{bm}) \) corresponding to the age \( t_{bm} \) which satisfies two conditions namely the third derivative which is cancelled and the second derivative which is negative. For the function of Brody this point does not exist. The weights at this point represent 79%, 68% and 61% of the asymptotic weight respectively for the models Logistic, Gompertz and Von Bertalanffy. Subsequently, this point was compared with the inflection point for slaughter statistics (live slaughtering weights), using the Von Bertalanffy model as an example and then illustrating the changes in trends that may occur during animal growth and may bias judgments about precocity if decision-making is hasty about growth potential. It can be concluded that the point \( f(t_{bm}) \) could provide a better assessment of the growth potential relative to the inflection point for some sheep production systems and therefore, efforts should be made by researchers in the countries concerned by this problematic, in order to characterize the point \( f(t_{bm}) \) from a biological point of view that is corporal and morphological compositions for different breeds and production systems.

Keywords: Slaughter Age, Slaughter Weight, Inflection Point, Nonlinear Model, Brody, Logistic, Gompertz, Richards, Von Bertalanffy

1. Introduction

With a headcount of 1.2 billion worldwide and a production of 9.5 million tonnes [1], the sheep herd contributes to meeting the animal protein needs of the population and creating jobs and incomes for local populations. Improving the productivity of these animals requires selection. For this purpose, the use of mathematical growth models provides a good way to condense information into a few biologically meaningful parameters, to facilitate both interpretation and understanding of the growth phenomenon [2-3].

In fact, these models provide a set of parameters that describe growth over time and estimate the potential weight of animals at certain ages. Moreover, these parameters obtained from growth functions are very hereditary [4]. This models also provide several applications to animal production, such as the evaluation of the response to treatments as time goes by; analysis of the interaction between subpopulations (or treatments) and time and identification of heavier and younger animals in a population [5-6]. For livestock and poultry, the parameters obtained
during the adjustment and the analysis of the growth curves constitute the basic work for breeding and production. The growth curve parameters determination, effectively, describe issues such as growth, livestock performance, and optimum slaughter age, as well as preparing an appropriate feeding process and selection [7].

In animal biology, growth functions have been used mainly since the beginning of the 20th century. The key works in the development of this concept are those of Benjamin Gompertz in 1825 [8], that of Brody in 1945 [9] and Ludwig von Bertalanffy in 1957 [10].

The growth curve is represented mathematically as a sigmoidal function, defined in a real line, bounded and differentiable with positive derivative. Its graph has a typical S shape showing slow growth at the beginning, followed by a fast (exponential) growth that slows down gradually until it reaches an equilibrium value (usually named carrying capacity or level of saturation) [11].

Nonlinear models describing body weight can be formulated as follows:

\[ Y_{ij} = f(\beta_{ij}, u_{ij}) + \varepsilon_{ij}, \varepsilon_{ij} \sim N(0, \sigma^2) \]  \hspace{1cm} (1)

where \( Y_{ij} \) is the response value of the jth observation of the individual (\( i = 1, ..., M, j = 1, ..., n_i \)); \( M \) is the total number of individuals, and \( n_i \) is the number of observations for the ith individual; \( f \) is the nonlinear function linking body weight to age and other possible covariates \( u_{ij} \) varying with the individual; \( \beta_{ij} \) is a vector with the parameters of the nonlinear function; \( \varepsilon_{ij} \) is the residual term; and \( \sigma^2 \) is the variance for the residues [12].

The mathematical representation of growth functions and their properties is given in Table 1.

<table>
<thead>
<tr>
<th>Model name</th>
<th>Mathematical expression ( f(t) )</th>
<th>Expression of B</th>
<th>Inflection Point</th>
<th>Inflection Age</th>
<th>Growth rate ( f'(t) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brody [13]</td>
<td>( A(1 - Be^{-Kt}) ) ( A )</td>
<td>( 1 - \frac{Ae}{A} )</td>
<td>Does not exist</td>
<td>Does not exist</td>
<td>( K(A - f(t)) )</td>
</tr>
<tr>
<td>Logistic [14]</td>
<td>( \frac{A}{1 + Be^{-Kt}} )</td>
<td>( A ) ( \frac{A}{Be} - 1 )</td>
<td>( \frac{A}{Be} )</td>
<td>( \frac{A}{Be} )</td>
<td>( \frac{A}{Be} )</td>
</tr>
<tr>
<td>Gompertz [15]</td>
<td>( Ae^{-Be^{-Kt}} )</td>
<td>( \ln \frac{A}{Be} )</td>
<td>( \ln B )</td>
<td>( \ln B )</td>
<td>( \ln B )</td>
</tr>
<tr>
<td>Richards [16]</td>
<td>( A(1 - Be^{-Kt})^M )</td>
<td>( 1 - \frac{Ae}{M} ) ( M )</td>
<td>( \frac{A}{Be} )</td>
<td>( \frac{A}{Be} )</td>
<td>( \frac{A}{Be} )</td>
</tr>
<tr>
<td>Von Bertalanffy [17]</td>
<td>( A(1 - Be^{-Kt})^2 )</td>
<td>( 1 - \frac{A}{2} )</td>
<td>( \frac{A}{Be} )</td>
<td>( \frac{A}{Be} )</td>
<td>( \frac{A}{Be} )</td>
</tr>
</tbody>
</table>

Table 1. Mathematical description of growth patterns and the resulting biological parameters.

The biological interpretation of the parameters of these equations is as follows:

A: Adult or mature weight corresponding to \( t = 0 \)

B: The ordinate at the origin, describes the weight at time zero, which corresponds to the initial weight of the animal. This value is called the integration constant and has no biological interpretation

K: The slope of the growth curve which is also a measure of the approximation rate for its asymptotic value and represents the postnatal maturation rate. A large value of k indicates an early maturity of the animal. An important aspect is the negative correlation between the A and k parameters, demonstrating that the higher the animal growth rate, the lower its asymptotic size. [19-20]

M: The determining parameter of the Richards model curve [21].

Understanding the biological implications of model parameters and their relationships to other production traits provides a solid foundation for developing a breeding strategy to change the growth trajectory [22]. Earliness is sought with higher carcass weight and quality [23]. But for Sarmento [24], the nonlinear models make it possible to evaluate the genetic and environmental factors which influence the shape of the growth curve and, consequently, modify it by the selection, that is to say by identifying the animals with a higher growth rate without altering the weight of the adult rather than selecting larger animals.

Growth curves are used for investigating optimum feeding programs, determining optimum slaughtering age and the effects of selection on curve parameters and on live weight at a certain age [25].

Rapid growth early in the period can minimize breeding costs; thus, provide more profit for the farmer. Birth weight and early growth rate of animals are determined not only by genetic potential, but also by maternal and environmental factors [26].

Precocity can be inferred from the slope of the curve, whereas the best time for slaughter can be inferred from the inflection point. This information is also useful for marketing and commercial forecasts, giving information regarding predictions of production, as well as for creating feeding plans, to match feeding supply to production. [19]

In Iran, it was found that the age of inflection in males and females of the Lori Bakhtiari breed occurs around 3 months and it was recommended to use this age as the slaughter age [27].

One of the most important goals of the sheep breeding research as in any other production is to satisfy the consumer’s demand which is recently the healthy nourishment. Therefore, to avoid the increased fatness livestock should be fattened till an ideal slaughter weight. This is the end of the intensive stage of lean growth. During that time the live weight gain slows down and the tissue
which is suitable for production systems where the slaughter weight and far from the inflection point and which would provide more precision to the selection so as not to make hasty decisions that could penalize individuals with high growth potential.

As shown in Figure 1, the point \( f(t_{bm}) \) must satisfy mathematically two conditions. The first is that this point corresponds to the cancellation of the third derivative \( f^{(3)}(t) = 0 \). The second condition is that it is a point where the second derivative is negative \( f^{"}(t) < 0 \) and at its minimum. The graphical interpretation is that we are in the concave part of the growth function \( f(t) \) and at the trend change of the speed \( f^{'}(t) \) decrease which passes from a decelerated phase to an accelerated phase of decrease.

If at the inflection point, the growth velocity is at its maximum \( f(t_{i}) = 0 \), this velocity remains fairly steady up to the point \( f(t_{bm}) \).

Therefore, in this work, we will compute the third derivative \( f^{(3)}(t) \) for the models of Brody, Logistic, Gompertz, Richards and Von Bertalanffy and then find the point that satisfies the two conditions that are \( f^{(3)}(t) = 0 \) and the negative second derivative \( f^{"}(t) < 0 \).

### 2. Determination of the Third Derivative and Corresponding Points \( f(t_{bm}) \) and \( t_{bm} \)

#### 2.1. Brody Function

Determination of \( f^{(3)}(t) \)

\[
f(t) = A(1 - B e^{-Kt})
\]

\[
f^{'}(t) = K(A - f(t))
\]

\[
f^{"}(t) = -K^2(A - f(t))
\]

\[
f^{(3)}(t) = K^2 f^{'}(t) \quad \text{and so} \quad f^{(3)}(t) = K^3(A - f(t))
\]

\( f^{(3)}(t) \) of Brody is strictly positive. Therefore, this model does not have a point \( f(t_{bm}) \) that satisfies the conditions \( f^{(3)}(t) = 0 \) et \( f^{"}(t) < 0 \).

#### 2.2. Logistic Function

Determination of \( f^{(3)}(t) \)

\[
f(t) = \frac{A}{1 + Be^{-Kt}}
\]

\[
f^{'}(t) = K f(t) \left(1 - \frac{f(t)}{A}\right)
\]

\[
f^{"}(t) = K f^{'}(t) \left(1 - \frac{2f(t)}{A}\right)
\]

\[
f^{(3)}(t) = K u(t)v(t) \quad \text{where} \quad u(t) = f^{'}(t) \quad \text{and} \quad v(t) = 1 - \frac{2f(t)}{A} \quad u^{'}(t) = f^{"}(t) \quad \text{and}
\]

\[
v^{'}(t) = -\frac{2f^{'}(t)}{A} f^{(3)}(t)
\]
$$= K \left\{ f''(t) \left(1 - \frac{2f(t)}{A}\right) - \frac{2f'(t)^2}{A} \right\}$$

$$f^{(3)}(t) = K \left\{ f'(t) \left(1 - \frac{2f(t)}{A}\right)^2 - \frac{2f'(t)^2}{A} \right\}$$

$$f^{(3)}(t) = K^2 f'(t) \left\{ \left(1 - \frac{2f(t)}{A}\right)^2 - \frac{2f'(t)^2}{A} \right\}$$

$$f^{(3)}(t) = K^2 f'(t) \left\{ \left(1 - \frac{2f(t)}{A}\right)^2 - \frac{2f(t)(A - f(t))}{A} \right\}$$

$$f^{(3)}(t) = K^2 \frac{\alpha}{\beta^2} f'(t) \left[6f(t)^2 - 6Af(t) + A^2\right] \quad (9)$$

First condition:

$$f^{(3)}(t) = 0 \text{ this implies that } 6f(t)^2 - 6Af(t) + A^2 = 0$$

There are two solutions to this equation:

$$f(t_1) = \alpha A \text{ where } \alpha = 0.211, \quad \frac{A}{1 + B e^{-\alpha t_1}} = \alpha A$$

implies

$$t_1 = \frac{1}{K} \ln \frac{B}{1 - \alpha}$$

$$f(t_2) = \beta A \text{ where } \beta = 0.789, \quad \frac{A}{1 + B e^{-\beta t_2}} = \beta A$$

implies

$$t_2 = \frac{1}{K} \ln \frac{B}{1 - \beta}$$

Second condition:

$$f''(t) < 0 \text{ which corresponds to } t > \frac{\ln B}{K}$$

We have $\ln \frac{B}{1 - \alpha} = \ln B + \ln \alpha - \ln(1 - \alpha)$ and since

$$\ln \alpha - \ln(1 - \alpha) < 0 \quad \text{therefore} \quad \frac{1}{K} \ln \frac{B}{1 - \alpha} < \frac{\ln B}{K}$$

Thus, $t_1 < \frac{\ln B}{K}$

The same way $\ln \beta - \ln(1 - \beta) > 0$ therefore

$$\frac{1}{K} \ln \frac{B}{1 - \beta} > \frac{\ln B}{K}$$

So $t_2 > \frac{\ln B}{K}$

So it's $t_2$ that meets both conditions and that corresponds to $t_{bn}$

$$t_{bn} = \frac{\ln 3.732 B}{K} \quad (10)$$

$$f(t_{bn}) = 0.789 A \quad (11)$$

2.3. Gompertz Function

Determination of $f^{(3)}(t)$

$$f(t) = A e^{-Be^{-Kt}} \quad (12)$$

$$f'(t) = K f(t) \ln \left(\frac{A}{f(t)}\right) \quad (13)$$

$$f''(t) = K f'(t) \ln \left(\frac{A}{f(t)} - 1\right) \quad (14)$$

$$f^{(r)}(t) = K u(t) \nu(t) \quad \text{where } u(t) = f'(t) \text{ and } \nu(t) = \ln \left(\frac{A}{f(t)} - 1\right)$$

$$u^{(r)}(t) = f^{(r)}(t) \text{ and } \nu'(t) = -f'(t)$$

2.4. Richards Function

Determination of $f^{(3)}(t)$

$$f(t) = A (1 - B e^{-Kr})^M \quad (18)$$

$$f'(t) = MK f(t) \left(1 - \frac{1}{M}\right) (A - f(t)) \quad (19)$$
\[ f''(t) = K f'(t) \left[ (M - 1) A f(t)^{-\frac{1}{M}} - M \right] \] (20) \[ f''(t) = K u(t)v(t) \quad \text{where} \quad u(t) = f'(t) \quad \text{and} \quad v(t) = u'(t) = f''(t) \quad \text{and} \quad v'(t) = - \frac{(M-1)}{M} f'(t) A f(t)^{-\frac{1}{M} - 1} \]

\[ f^{(3)}(t) = K^2 f'(t) \left[ \left( (M - 1) A f(t)^{-\frac{1}{M}} - M \right)^2 - \left( (M - 1) \left( A f(t)^{-\frac{1}{M}} - \left( A f(t)^{-\frac{1}{M}} \right) \right) \right) \right] \]

\[ f^{(3)}(t) = K^2 f'(t) \left[ \left[ (M^2 - 3M + 2) A f(t)^{-\frac{1}{M}} \right]^2 + \left[ (2M^2 + 3M - 1) A f(t)^{-\frac{1}{M}} \right] + M^2 \right] \] (21)

First condition:
\[ f^{(3)}(t) = 0 \quad \text{this implies that} \quad \left[ (M^2 - 3M + 2) A f(t)^{-\frac{1}{M}} \right]^2 + \left[ (2M^2 + 3M - 1) A f(t)^{-\frac{1}{M}} \right] + M^2 = 0 \]

With M > 1, there are two solutions to this equation:
\[ A f(t_1)^{-\frac{1}{M}} = \theta \quad \text{where} \quad \theta = \frac{(2M^2-3M+1)-\sqrt{5M^2-6M+1}}{2M^2-6M+4} \] which corresponds to \( f(t_1) = A \frac{\theta}{\theta} \)
\[ A (1 - B e^{-K t_1})^M = A \frac{\theta}{\theta} \quad \text{which implies} \quad t_1 = \frac{1}{K} \ln \frac{\theta^B}{\theta - 1} \]
\[ A f(t_2)^{-\frac{1}{M}} = \mu \quad \text{where} \quad \mu = \frac{(2M^2-3M+1)+\sqrt{5M^2-6M+1}}{2M^2-6M+4} \] which corresponds to \( f(t_2) = A \frac{\mu}{\mu} \)
\[ A (1 - B e^{-K t_2})^M = A \frac{\mu}{\mu} \quad \text{which implies} \quad t_2 = \frac{1}{K} \ln \frac{\mu^B}{\mu - 1} \]

Second condition:
\[ f''(t) < 0 \quad \text{which corresponds to} \quad t > \frac{\ln MB}{K} \]
\[ t_1 = \frac{1}{K} \ln MB + \frac{1}{K} \ln \frac{\theta}{M(\theta - 1)} \quad \text{and since} \quad \ln \frac{\theta}{M(\theta - 1)} > 0 \quad \text{therefore} \quad t_1 > \frac{\ln MB}{K} \]
\[ t_2 = \frac{1}{K} \ln MB + \frac{1}{K} \ln \frac{\mu}{M(\mu - 1)} \quad \text{and since} \quad \ln \frac{\mu}{M(\mu - 1)} < 0 \quad \text{therefore} \quad t_2 < \frac{\ln MB}{K} \]

So it's \( t_1 \) that meets both conditions and that corresponds to \( t_{bm} \)
\[ t_{bm} = \frac{1}{K} \ln \frac{\theta^B}{\theta - 1} \]
\[ f(t_{bm}) = \theta^{-M} A \] (22)

2.5. Von Bertalanffy Function

Determination of \( f^{(3)}(t) \)
\[ f(t) = A (1 - B e^{-K t})^3 \] (24)
\[ f'(t) = 3 K f(t)^2 \left( A f(t)^{-\frac{1}{3}} - f(t)^{\frac{2}{3}} \right) \] (25)
\[ f''(t) = K f'(t) \left( 2A f(t)^{-\frac{2}{3}} - 3 f(t)^{\frac{1}{3}} \right) \] (26)
\[ f'''(t) = 3 K^2 \left( A f(t)^{-\frac{1}{3}} - f(t)^{\frac{2}{3}} \right) \left( 2A f(t)^{-\frac{2}{3}} - 3 f(t)^{\frac{1}{3}} \right) \]
\[ f^{(4)}(t) = 3K^2 u(t)v(t) \quad \text{where} \quad u(t) = A f(t)^{-\frac{1}{3}} - f(t)^{\frac{2}{3}} \quad \text{and} \quad v(t) = 2A f(t)^{-\frac{2}{3}} - 3 f(t)^{\frac{1}{3}} \]
\[ u'(t) = \frac{1}{3} f'(t) \left( A f(t)^{-\frac{2}{3}} - 2 f(t)^{\frac{1}{3}} \right) \quad \text{and} \quad v'(t) = - f'(t) f(t)^{-\frac{2}{3}} \]
\[ f^{(3)}(t) = 3K^2 \left[ \frac{1}{3} f'(t) \left( A f(t)^{-\frac{2}{3}} - 2 f(t)^{\frac{1}{3}} \right) \left( 2A f(t)^{-\frac{2}{3}} - 3 f(t)^{\frac{1}{3}} \right) \right] - \left[ f'(t) f(t)^{-\frac{2}{3}} \left( A f(t)^{-\frac{2}{3}} - f(t)^{\frac{2}{3}} \right) \right] \]
\[ f^{(3)}(t) = K^2 f'(t) \left[ \left( A f(t)^{1/2} - 2 f(t)^{-1/2} \right) \left( 2 A t f(t)^{1/2} - 3 f(t)^{3/2} \right) - \left[ 3 f(t)^{-2} \left( A f(t)^{1/2} - f(t)^2 \right) \right] \right] \]

First condition: \[ f^{(3)}(t) = 0 \]
this implies that
\[ 2 \left( A f(t)^{1/2} \right)^2 - 10 \left( A f(t)^{1/2} \right)^2 + 9 = 0 \]

There are two solutions to this equation:
\[ A f(t_1)^{1/2} = \varepsilon \text{ where } \varepsilon = 1.177 \text{ which corresponds to }\]
\[ A (1 - B e^{-K t_1})^3 = \frac{A}{\varepsilon^3} \text{ which implies } t_1 = \frac{1}{K} \ln \frac{eB}{\varepsilon-1} \]
\[ A f(t_2)^{1/2} = \theta \text{ where } \theta = 3.823 \text{ which corresponds to }\]
\[ A (1 - B e^{-K t_2})^3 = \frac{A}{\theta^3} \text{ which implies } t_2 = \frac{1}{K} \ln \frac{\theta B}{\theta-1} \]

Second condition: \[ f''(t) < 0 \text{ which corresponds to } t > \frac{\ln 3B}{K} \]

\[ t_1 = \frac{1}{K} \ln 3B + \frac{1}{K} \ln \frac{\varepsilon}{3(\varepsilon-1)} \text{ and since } \ln \frac{\varepsilon}{3(\varepsilon-1)} > 0 \]

therefore \[ t_1 > \frac{\ln 3B}{K} \]

\[ t_2 = \frac{1}{K} \ln 3B + \frac{1}{K} \ln \frac{\theta}{3(\theta-1)} \text{ and since } \ln \frac{\theta}{3(\theta-1)} < 0 \]

therefore \[ t_2 < \frac{\ln 3B}{K} \]

So it's \( t_1 \) that meets both conditions and that corresponds to \( t_{bm} \)
\[ t_{bm} = \frac{\ln 6.646 B}{K} \]
(28)

\[ f(t_{bm}) = 0.613A \]
(29)

3. Comparison Between the Point of Inflection and \( f(t_{bm}) \)

<table>
<thead>
<tr>
<th>Model name</th>
<th>Required conditions</th>
<th>( f'(0) = 0 )</th>
<th>Inflection point</th>
<th>Inflection age</th>
<th>( f^{(3)}(t) = 0 ) et ( f(t) &lt; 0 )</th>
<th>( t_{bm} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brody</td>
<td>Does not exist</td>
<td>( A )</td>
<td>Does not exist</td>
<td>Does not exist</td>
<td>( \frac{\ln (2.618 B)}{K} )</td>
<td></td>
</tr>
<tr>
<td>Logistic</td>
<td>( \frac{\theta}{A} )</td>
<td>( \frac{K}{\ln B} )</td>
<td>( \frac{7}{A} )</td>
<td>( \frac{\ln B}{K} )</td>
<td>( \frac{25}{7} )</td>
<td></td>
</tr>
<tr>
<td>Gompertz</td>
<td>( \frac{1}{e^3} )</td>
<td>( \frac{K}{\ln B} )</td>
<td>( \theta )</td>
<td>( \frac{A}{\theta^3} )</td>
<td>( \frac{6.646 B}{K} )</td>
<td></td>
</tr>
<tr>
<td>Richards</td>
<td>( A \left( 1 - \frac{1}{M} \right)^{1/2} )</td>
<td>( \frac{K}{\ln MB} )</td>
<td>( \frac{8}{A} )</td>
<td>( \frac{\ln 3B}{K} )</td>
<td>( \frac{\ln 6.646 B}{K} )</td>
<td></td>
</tr>
<tr>
<td>Von Bertalanffy</td>
<td>( \frac{e^{-K t}}{\theta} )</td>
<td>( \frac{K}{\ln B} )</td>
<td>( \frac{6}{27} )</td>
<td>( \frac{K}{6} )</td>
<td>( \frac{1}{\theta - 1} )</td>
<td></td>
</tr>
</tbody>
</table>

(\(*) \theta = \frac{\left( \frac{2K^2 - 3BM + 1}{2K^2 - 3BM + 1} \right)^4}{A, B, K \text{ positive and } M>1.}

Table 2 shows that the inflection points represent 50%, 37% and 30% of the asymptotic weight (A) respectively for the models of Logistic, Gompertz and Von Bertalanffy, whereas for \( f(t_{bm}) \) which corresponds to an age \( t_{bm} \) further down the growth curve, the weights at this point represent 79%, 68% and 61% of the asymptotic weight respectively for these models.

As shown in Figure 1, relating to the graphical representation of inflection points and \( f(t_{bm}) \) for the Von Bertalanffy model applied to moroccan sheep "Sardi", \( f(t_{bm}) \) corresponds perfectly to the production objectives of the breeds intended almost exclusively for the "Eid al-Adha" Feast of Sacrifice, where the slaughter age is between 6 and 18 months and would certainly be used for the breeding of animals of this breed rather than the point of inflection. Especially since the growth rate \( f'(t) \) remains quite important up to this point and that the degree of fat of these animals is appreciated by the moroccan consumers. In addition, this activity of fattening for this feast is very lucrative despite the increase in the food cost of the kilogram of gain of these animals, because the selling prices of these animals allow that as they are significantly higher compared to the rest of the year. These prices are up more than 60% during this period compared to the rest of the year.

Moreover, to elucidate the importance of this feast throughout the world, the statistics show that it concerns the slaughter of about 100 million heads per year [30] is approximately the fifth of the number of sheep heads slaughtered in the world (568 million heads) [1]. This activity also plays a very important role in the industry of exporting countries of (18 months of age) living muttons such as Australia to the Middle East [31].

<table>
<thead>
<tr>
<th>Réf.</th>
<th>Country of study</th>
<th>Breed</th>
<th>A</th>
<th>B</th>
<th>K</th>
<th>( f(t_{j})(kg) )</th>
<th>( t_{j}(days) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>[18]</td>
<td>Espagne</td>
<td>Segurena</td>
<td>67.707</td>
<td>0.628</td>
<td>0.009</td>
<td>20.1</td>
<td>70</td>
</tr>
<tr>
<td>[32] (*)</td>
<td>Brésil</td>
<td>Santa Inés</td>
<td>125.6</td>
<td>0.4496</td>
<td>0.0039</td>
<td>37.2</td>
<td>77</td>
</tr>
</tbody>
</table>
Table 3. Continued.

<table>
<thead>
<tr>
<th>Réf.</th>
<th>Country of study</th>
<th>Breed</th>
<th>( f(t) ) (kg)</th>
<th>( t_{bm} ) (days)</th>
<th>Carcass weight (kg) [1]</th>
<th>Live weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[33]</td>
<td>Mexique</td>
<td>Pelibuey</td>
<td>44.7</td>
<td>13.2</td>
<td>57</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Suffolk</td>
<td>61.6</td>
<td>18.3</td>
<td>46</td>
<td></td>
</tr>
<tr>
<td>[34] (*)</td>
<td>Pakistan</td>
<td>Hampshire</td>
<td>53.2</td>
<td>15.8</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>[35] (*)</td>
<td>Pakistan</td>
<td>Mengali</td>
<td>46.73</td>
<td>13.8</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thalli</td>
<td>48.247</td>
<td>14.3</td>
<td>71</td>
<td></td>
</tr>
</tbody>
</table>

(*) the data of these authors have been adjusted to the model of Von Bertalanffy without it being chosen as the best model but as an explanation.

Table 3 shows through a simplified approach that the results of the first two authors in comparison with the average slaughter weight in Spain and Mexico, confirm that the age at the inflection point corresponds to the optimal age of slaughter. Moreover, Lupi [19] made it clear in his conclusions.

For J. Domínguez-Viveros [33] and F. Iqbal [34-35] who worked respectively in Mexico and Pakistan, the slaughter weights in these countries are respectively 42kg and 31kg. These weights are very far from inflection points resulting from adjustments to growth curves that are between 13 and 18kg. Therefore, these are the weights at the point \( f(t_{bm}) \) that are close to the slaughter age and are better positioned at the curve level to rule on the precocity.

\[
\text{\textit{Von Bertalanffy function}} \quad f(t) = 70.4739 \left(1 - 0.6015e^{-0.00794t}\right)^3
\]

Figure 1. Graphic representation of the inflection point and \( f(t_{bm}) \) for the Von Bertalanffy model applied to Moroccan sheep Sardi.*
purposes rather than the point of inflection. This holiday point for some sheep production systems, using light breeds points. To characterize the point the researchers in the countries concerned by this problem, in concerns the fifth of the number of sheep heads slaughtered of the nonlinear growth models is not suitable. Thus, the for a certain production system for which the inflection point concerning the determination of the optimal age of slaughter curve closer to slaughter ages for the above-mentioned systems. For the function of Brody this point does not exist. The weights in growth potential. Indeed, according to the individual fit to the von Bertalanffy model, the performance trends for some animals of sardi breed, in terms of precocity, can be reversed with age. This is the case of the individuals carrying the identifier 52 and 156 where the latter is early at the age of inflection whereas with the advancement of the age this tendency has reversed and has become accentuated to the point \( f(t_{bm}) \) which is closest to the slaughtering age. This confirms the recommendations of the Canadian report [29] on taking measures closest to slaughter weights.

4. Conclusion

This study made it possible to answer the problematic concerning the determination of the optimal age of slaughter for a certain production system for which the inflection point of the nonlinear growth models is not suitable. Thus, the points \( f(t_{bm}) \) have been formulated for the models Logistic, Gompertz, Richards and Von Bertalanffy, the point \( f(t_{bm}) \) corresponding to the age \( t_{bm} \) is located further at the growth curve closer to slaughter ages for the above-mentioned systems. For the function of Brody this point does not exist. The weights in \( f(t_{bm}) \) represent 79%, 68% and 61% of the asymptotic weight respectively for the models Logistic, Gompertz and Von Bertalanffy. This could provide a better assessment of the growth potential relative to the inflection point for some sheep production systems, using light breeds or animals slaughtered late or for a demand for heavier carcasses on the market. Otherwise, there is a risk of making hasty decisions and a risk of disqualifying animals with a high earliness potential but who have been judged at a distant age in relation to production objectives. For example, \( f(t_{bm}) \) fits perfectly with the production objectives of the “Eid al-Adha” sacrifice breeds where the slaughter age is between 6 and 18 months and would certainly be used for breeding purposes rather than the point of inflection. This holiday concerns the fifth of the number of sheep heads slaughtered annually in the world. Therefore, efforts should be made by the researchers in the countries concerned by this problem, in order to characterize the point \( f(t_{bm}) \) from a biological point of view, namely body compositions (muscular and adipose deposition) and morphological composition for different races and production systems.

Table 4. Example illustrating the change in trends for some individuals of the sardi breed.

<table>
<thead>
<tr>
<th>ID</th>
<th>A</th>
<th>B</th>
<th>K</th>
<th>inflexion point (kg)</th>
<th>inflexion age (days)</th>
<th>( f(t_{bm})(kg) )</th>
<th>( t_{bm}(days) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>64.5364</td>
<td>0.5529</td>
<td>0.0083</td>
<td>19</td>
<td>61</td>
<td>40</td>
<td>157</td>
</tr>
<tr>
<td>52</td>
<td>75.4164</td>
<td>0.6395</td>
<td>0.0091</td>
<td>22</td>
<td>71</td>
<td>46</td>
<td>158</td>
</tr>
<tr>
<td>156</td>
<td>69.9715</td>
<td>0.5720</td>
<td>0.0077</td>
<td>21</td>
<td>70</td>
<td>43</td>
<td>174</td>
</tr>
</tbody>
</table>

Table 4 shows the risks of making hasty decisions about growth potential. Indeed, according to the individual fit to the von Bertalanffy model, the performance trends for some animals of sardi breed, in terms of precocity, can be reversed with age. This is the case of the individuals carrying the identifier 52 and 156 where the latter is early at the age of inflection whereas with the advancement of the age this tendency has reversed and has become accentuated to the point \( f(t_{bm}) \) which is closest to the slaughtering age. This confirms the recommendations of the Canadian report [29] on taking measures closest to slaughter weights.

References


[29] Frédéric F, Catherine E and Johanne C 2017 Estimation des courbes de croissance, de déposition musculaire et adipeuse de deux races maternelles, pour cibler le moment idéal de l’évaluation génétique visant la qualité carcase, rapport final CEPOQ.


[31] Newsletter of the Department of Primary Industries and Regional Development Australia, Issue number: 7 May 2018 Based on ABS data, DPIRD analysis.


