Small Ruminant Research 130 (2015) 81–89

Contents lists available at ScienceDirect

Small Ruminant Research

journal homepage: www.elsevier.com/locate/smallrumres

# Modelling of growth curves and estimation of genetic parameters for growth curve parameters in Peruvian young llamas (*Lama glama*)

A.W. Canaza-Cayo[a,*], T. Huanca[b], J.P. Gutiérrez[c], P.A. Beltrán[a]

[a] Facultad de Ciencias Agrarias, Universidad Nacional del Altiplano, Avda. Ejército 329, Apartado postal 291, Puno, Peru
[b] Instituto Nacional de Innovacion Agraria (INIA) Illpa, Rinconada Salcedo s/n., Puno, Peru
[c] Departamento de Producción Animal, Facultad de Veterinaria, Universidad Complutense de Madrid, Avda. Puerta de Hierro s/n., E-28040 Madrid, Spain

ARTICLE INFO

*Article history:*
Received 1 May 2014
Received in revised form 5 August 2014
Accepted 30 January 2015
Available online 11 February 2015

*Keywords:*
Non-linear functions
Environmental effects
Genetic parameters
Heritabilities
Genetic correlation
Llamas

ABSTRACT

The objectives of this study were to describe the growth of young llamas by the application of four non-linear functions (Gompertz, Logistic, Von Bertalanffy and Brody), evaluate the importance of fixed (environmental) effects (sex, type of llama, month and year of birth) on growth curve parameters and finally estimate the genetic parameters for growth curve parameters (*A*: asymptotic body weight and *k*: specific growth rate). A total of 35,691 monthly body weight records from birth up to 16 months of age from 2675 young llamas, collected from 1998 to 2008 in the Quimsachata Experimental Station of the Instituto Nacional de Innovación Agraria (INIA) in Peru were used. Growth curve parameters were estimated by non-linear procedures while genetic parameters were estimated by application of a bivariate animal model and the restricted maximum likelihood (REML) method. All non-linear functions closely fitted actual body weight measurements, while the Gompertz function provided the best fit in describing the growth data of young llamas. All environmental effects significantly influenced the asymptotic weight (*A*), while the specific growth rate (*k*) was only affected by the month and year of birth. Heritability estimates for parameters *A* and *k* were 0.10 and 0.01, respectively. Genetic correlation between *A* and *k* was high and negative (−0.82), indicating that a rapid decrease in growth rate after inflection point is associated with higher mature weight. Despite the low heritability estimates obtained herein, slight genetic gain(s) were observed in the current study suggesting that a selection program to change the slope of the growth curve of llamas may be feasible.


## 1. Introduction

It is estimated that more than four million South American camelids live in Peru, of which, the llama (*Lama glama*) represents more than 24% of the total. Majority of the animals are found in the districts of Puno (35.7%), Cusco (17.7%) and Junin (11.2%) (FAO, 2005). The habitat of the llama and other South American camelids is mainly the high mountain areas and it extends from northern Peru to northern Argentina, the respective highlands zones from Bolivia and Chile (Rossi, 2004), included. Llamas and alpacas constitute the most important social and economical species in Peru, where more than 2.9 million inhabitants (11% of the population) are dependent on these species through more than 100,000 producers (Brenes et al., 2001).

Llamas are very well adapted to the Andean highlands and provide the farm households with a variety of products such as fibre, meat and dung while being used as pack animals. A large part of the products is consumed within the local community, but are also source of some cash income from selling fibre and meat. In Peru, llamas are traditionally classified into two different types: Ch'accu, characterized by increased coverage

* Corresponding author. Tel.: +51 51 336821.
*E-mail address:* awcanaza@gmail.com (A.W. Canaza-Cayo).

http://dx.doi.org/10.1016/j.smallrumres.2015.01.026
0921-4488/

**Table 1**
Number of animals, mean, standard deviation and coefficient of variation for body weight from young llamas at different ages.

| Ages (months) | N° of animals | Mean (kg) | Standard deviation (kg) | Coefficient of variation (%) |
|---|---|---|---|---|
| 0 | 2675 | 9.56 | 1.66 | 17.33 |
| 1 | 999 | 17.63 | 9.51 | 53.96 |
| 2 | 2272 | 18.10 | 4.31 | 23.83 |
| 3 | 2503 | 21.85 | 5.55 | 25.39 |
| 4 | 2628 | 24.71 | 5.63 | 22.79 |
| 5 | 2663 | 27.65 | 6.32 | 22.87 |
| 6 | 2560 | 29.79 | 7.11 | 23.87 |
| 7 | 2512 | 31.24 | 7.84 | 25.10 |
| 8 | 2510 | 32.56 | 8.06 | 24.76 |
| 9 | 2654 | 33.34 | 8.31 | 24.92 |
| 10 | 2550 | 34.82 | 8.88 | 25.50 |
| 11 | 2545 | 37.13 | 9.13 | 24.58 |
| 12 | 2462 | 39.52 | 9.94 | 25.16 |
| 13 | 2211 | 41.42 | 11.30 | 27.27 |
| 14 | 1315 | 43.09 | 12.37 | 28.71 |
| 15 | 415 | 43.22 | 13.59 | 31.44 |
| 16 | 216 | 46.06 | 9.68 | 21.01 |

of fleece, covering the extremities, the neck and the head and K'ara, with no fibre on extremities, head and ears and a reduced fibre growth on the neck, but of greatest strength often used by Andean people as a pack animal (Flores, 1988; Leyva, 1991). Both llama types provide meat with high protein content (San Martín, 1996) representing the main source of food of animal origin for the Andean people (Flores, 1988; Leyva, 1991).

More llama meat and fibre is progressively being marketed reflecting a growing demand for these products. The absence of infrastructure and standard quality and quantity of llama meat and fibre are, however, the main factors preventing a more market oriented husbandry. This problem occurs because llamas are handled and produced in small production systems and with low-income producers, confronting the aftermath of marginalization of livelihood systems (Quispe et al., 2009). On the other hand, the lack of production goals does not allow the application of breeding programs. Under these production conditions an important phenotypic indicator of the meat production capacity is the description of animals' body weight by time.

The most important characteristic of live material is growth, described as an increase in both the weight and size in a certain period of time (Thornley and Johnson, 1990). Meat production is therefore influenced by growth rate and the animals' body size, which are dependent on live weight or dimension for a period of time. Better understanding of animal growth using mathematical modelling of growth data allows better explanation and interpretation of growth events which in turn contributes to improving overall productivity (Efe, 1990).

Growth curves are one way of describing growth in a certain period of time. There are many non-linear mathematical functions (e.g., Gompertz, Richards, Von Bertalanffy and Logistic) that have been extensively used in different livestock species to describe the development of body weight (e.g., Kaps et al., 2000; Menchaca et al., 1996, in cattle, Bathaei and Leroy, 1998, in sheep, Schinckel et al., 2004, in pigs and Mignon-Grasteau et al., 2000, in chicken). However, little information in the literature on the growth curve modelling as well as estimation of genetic parameters of the growth curve parameters is found in llamas. Furthermore, the growth characteristics of llamas from birth to first year-old have not been adequately studied. Most investigations are limited to the prediction of live weight from body measurements (Wurzinger et al., 2005; Llacsa et al., 2007). Riek and Gerken (2007) fitted growth curves in llamas using both simple linear regression and the Gompertz equation and concluded that that a linear regression may be adequate to describe body weight development from birth to 27 week post partum.

Several studies have reported significant heritability estimates for growth curve parameters in different livestock species (Mignon-Grasteau et al., 2000; Koivula et al., 2008; Silva et al., 2012; Lopes et al., 2012), demonstrating that these parameters are heritable and thus could be modified by selection through the implementation of an effective breeding program. In that sense, it is important to know the relationship between the growth curve parameters to properly define the breeding objectives. However, this knowledge does not exist for many breeding populations, including the South America's Camelids.

Aiming at providing more knowledge on body weight development of llamas we have elaborated the present study. The goals of the present study are: (a) to describe growth from birth to 16 months of age by application of four non-linear functions, (b) to evaluate the environmental effects on growth curve parameters and (c) to estimate the genetic parameters and genetic trend for growth curve parameters in a population of young llamas.

## 2. Materials and methods

### 2.1. Data

Data comprised individual body weights of males and females llamas belonging to two types: K'ara and Ch'accu. Data were made available by the Quimsachata Experimental Station, of the National Institute of Agricultural Research (INIA) located in Puno, Peru. The Quimsachata Station is located at 4025 meters above sea level, 15°45′38.9″ south latitude, 70°34′18.9″ western length, whose temperatures vary between −5 and 18 °C and rainfall reaching 700 mm/year. The database consists of 35,691 records of body weight of 2675 young llamas (Table 1). Individual body weight of animals was obtained by using a digital weighing scale at monthly intervals from birth to 16th month of age, collected during 1998–2008. The total number of records and animals used in the present study are shown in Fig. 1.

### 2.2. Statistical analysis

#### 2.2.1. Growth curves parameters

The description of the growth trajectory of animals was performed by application of four non-linear models of Brody, Von Bertalanffy, Logistic and Gompertz (Table 2), where $y_{ij}$ is the observed body weight of individual $i$ ($i = 1, \ldots, n$) at measurement time $j$ ($j = 1, \ldots, n_i$) for animal $i$, $t_{ij}$ is age of animal $i$ in days at time $j$ and $\varepsilon_{ij}$ is the random residual term. The growth curve parameters for the $i$th animal are: $A_i$, the asymptotic body weight of animal $i$, which is interpreted as mature weight; $B_i$, the proportion of the asymptotic mature weight to be obtained after birth for animal $i$; $k_i$, the maturation rate of animal $i$, which is interpreted as weight change in relation to mature weight to indicate how fast the animal approaches adult weight. The NLIN procedure from the SAS software package was used to estimate the least-squares estimates and the standard errors of

**Table 2**
Equations of non-linear models will be used to describe the growth of young llamas.

| Model | Formula |
|---|---|
| Brody (Brody, 1945) | $y_{ij} = A_i(1 - B_i e^{-k_i t_{ij}}) + \varepsilon_{ij}$ |
| Von Bertalanffy (Von Bertalanffy, 1957) | $y_{ij} = A_i(1 - B_i e^{-k_i t_{ij}})^3 + \varepsilon_{ij}$ |
| Logistic (Nelder, 1961) | $y_{ij} = A_i(1 - B_i e^{-k_i t_{ij}})^1 + \varepsilon_{ij}$ |
| Gompertz (Laird, 1965) | $y_{ij} = A_i e^{-B_i e^{-k_i t_{ij}}} + \varepsilon_{ij}$ |