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Characterization of the commercial growth curves of Spanish Merino, Fleischschaf, and crossbred lambs in an associative economy context

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ABSTRACT

We examined commercial growth curves of three sheep genotypes in a Second-Grade cooperative context, with Spanish Merino used as a maternal base, Fleischschaf as a paternal base, and crossbred (Fleischschaf × Merino) lambs as the commercial product. We included weight-age data collected from 2013 to 2016 for 9846 lambs of both sexes belonging to 14 herds across the three genotypes. Five of the most-cited models (Brody, von Bertalanffy, Verhulst, Logistic, and Gompertz) were applied to the data, using the determinative coefficient, mean square error, number of iterations, Akaike information coefficient, and the biological coherence of the estimated parameters as best-fitting criteria. The dataset included lamb weights at different ages and sexes, grouped across nine age levels, for a total of 23,299 wt records. Models were fitted according to non-linear regression. The von Bertalanffy model was found to best fit lambs of both sexes for the Spanish Merino breed, whereas the Verhulst model best fit Fleischschaf and crossbred lambs. Parameters of the best-fit curve and derived parameters (inflection age and weight, asymptotic value, growth rate, maturity degree) were estimated for all sex-genetic groups to examine capacities for use as complementary selection criteria in the breeding program, resulting in promising traits for this purpose. Our findings demonstrate that current crossbreeding strategies implemented at the OVISO cooperative, which seek complementarities and/or heterosis, are not achieving the expected results; therefore, we recommend a new strategy for the breeding program. We also found that artificially conceived Spanish Merino lambs exhibited better performance than those conceived naturally, likely due to superior genetics of carefully selected sires.

1. Introduction

Spanish Merino is the origin of all Merino-derived genotypes worldwide and one of the most emblematic genotypes in Spain (Barajas et al., 2007). Despite its remarkable census and distribution, the breed underwent considerable genetic erosion in the recent past. The downfall of wool prices during the second half of the 20th century obligated breeders to shift to a dual wool-meat purpose.

Intense crossbreeding with meat-specialized Precoce genotypes placed the original Merino breed near extinction. Breeders developed strategies to conserve the breed and implement genetic improvements to meet current demands (Barajas et al., 2007, MAPAMA, 2011).

Simultaneously, a Second-Grade Cooperative focused on the extensive production of crossbred lambs using Spanish Merino as a maternal base and Precoce genotypes as paternal sources, implementing their own genetic program. The complementarities between the genotypes led to the standardization of a final product that consisted of 60–140-day-old crossbred lambs of 21 kg live weight at the end of the stage of growth in farms, to be finished in fattening stations. One of the selection initiatives of this genetic program is the productive characterization of lamb growth by studying their commercial growth curve (Loaiza-Echeverri et al., 2013).

The aim of our study is the definition and analysis of the best fitting commercial growth curve in Merino, Fleischschaf, and crossbred lambs to characterize and compare their growing capacities, and to use these to detect possible selection traits related to physiology. We studied the weight gain of the animals during the stage of growth in farms to assess the inclusion of commercial curve parameters into the selection

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program with breeding and economic purposes. To the best of our knowledge, this is the first study to assess the commercial growth curve of purebred and crossbred Fleischschaf and Merino lambs in a cooperative context.

2. Material and methods

Weight-age data were collected from 2013 to 2016 for 9846 lambs of both sexes belonging to three genetic groups: 458 Fleischschaf (1457 records); 8575 Spanish Merino (19,506 records), and 813 crossbred Fleischschaf × Merino lambs (2336 records). These animals belonged to 14 herds involved in the selection nucleus of the genetic program.

The data included a total of 23,299 wt records. After purging, 0.13% of the data was considered anomalous and removed. Additionally, individual records included farm, birth date, genealogy, and other contextual information.

Models were fitted using multiple observations of weight as a dependent variable and age as an independent variable to assess which model adjusted to each genetic group. Brody (1945), Von Bertalanffy (1957), Verhulst (1838), Logistic (Blumberg, 1968), and Gompertz (Winsor, 1932) models were fitted, as they are the most commonly used models for this purpose in ruminant animals. Fitting was carried out using non-linear regression in IBM SPSS Statistics v.21. The mathematical expressions for the models and biological parameters that were used in our study followed Lupi et al. (2015).

Sex distribution was balanced, with 50.03% of the records belonging to males and 49.97% to females. Homogeneity of variances and means between males and females were analyzed to decide if a single analysis was sufficient or if two separate analyses would be required. An F-test of homogeneity of variance and a T-test of homogeneity of means were performed using IBM SSPS v.21. Since a single analysis was not sufficient, we added sex as a second factor of variation, along with genetic groups (Spanish Merino, Fleischschaf, and crossbred), to produce more specific models.

We carried out a simultaneous study assessing the empirical growth differences between artificial insemination and natural mating pure Merino lambs that had previously been observed during registration of lamb weight records. This suggested a possible difference in the growth behavior of the two groups.

To decide which function best fits each genetic group, we focused on five criteria, per trends in recent papers (Gbangboche et al., 2008; Loaiza-Echeverri et al., 2013; Tariq et al., 2013; Lupi et al., 2015). First, we chose four objective or quantitative parameters, including the lowest number of iterations, that indicated the ease of finding solutions. The first of three remaining parameters was the largest nonlinear determinative coefficient (pseudo R^2), which is an indicator of the fraction of the variance explained by the function, and is described by the following equation.

$$\text{Pseudo } R^2 = 1-(SS_{Residual}/SS_{TotalCorrected})$$

The second was the lowest mean square error (m.s.e.), which is indicative of the minimum variance excluded in the function control. The third was the lowest Akaike information criterion (AIC) (Thomas et al., 2009), which considers changes in fitness related to differences in the number of parameters between the compared curves (Posada and Rosero, 2007). The AIC is defined by the following equation,

$$AIC = n \times \ln(SSE/n) + 2p$$

where n is the number of observations, ln(SEE/n) the natural logarithm of SSE/n, SSE indicates the sum of squares of the residuals, and p = number of parameters + 1.

Next, we computed the biological coherence of the parameters of the curve, which is subjective. Parameter a represents the asymptotic weight of the animal. The b parameter allows calculation of the inflection age. Parameter k represents the relative growth rate (rate of exponential growth); this parameter is related to maturity, with high values indicating precocity and low values indicating slow maturation. Parameter m represents the shape of the growth curve, determining its inflection point (McManus et al., 2003).

Because commercial curves do not matter past slaughter age, our study focused on the parameters of commercial interest such as inflection point, representing the beginning of the auto-deceleration stage until the animal reaches slaughter age (around 120 days (McManus et al., 2003; Loaiza-Echeverri et al., 2013; Lupi et al., 2015)), and growth rate, representing estimated daily weight gain (Freitas, 2005). These parameters, derived from the information of the curve, were centered in the best-fit function for each genetic group, and were calculated according to the algorithms defined by inflection point (weight and age), growth rate, asymptotic value, and the degree of maturity.

After defining the best-fitting function and the physiological parameters mentioned above, predicted weights were estimated according to the best model for each sex and genetic group. We compared predicted weights, through graphical representations, with the observed weights for the same ages for all the genetic groups.

3. Results

Statistical differences among genetic groups and sexes were detected in the data distributions; therefore, we performed specific growth curves for each group and developed separate tests for the best-fitting selection criteria. Table 1 provides values for the curve parameters of each sex-breed group, together with the values for the best-fitting selection criteria. In the present study, a/k relationships for Merino, Fleischschaf and crossbred males were −0.987, −0.937, and −0.817 and for females −0.937, −0.936, and −0.797, respectively.

Fig. 1 shows a graphical comparison of predicted and observed weights. Fig. 1A shows von Bertalanffy curves for Spanish Merino males and females, in comparison to observed weights at the same ages. Fig. 1B shows Fleischschaf lamb growth curves. Homogeneity between sexes is maintained up to 40 days, after which it diverges. Finally, representations of the crossbred animals are given in Fig. 1C.

Table 2 gives inflection point (age and weight), asymptotic value, and maturity degree estimated with the von Bertalanffy model for Merino lambs and the Verhulst model for Fleischschaf and crossbred lambs, with the best-fitting curve for each class.

For the Merino breed, the inflection age was 47.7 days for males and 35.4 days for females, with inflection weights of 15.93 kg and 11.85 kg, respectively. Crossbred animals presented a similar inflection age in both sexes at 35.5 days, and inflection weights were slightly different for males (12.59 kg) and females (11.65 kg).

Fig. 2 shows corresponding growth rates at different points along the model curves. Merino lambs of both sexes maintained a stable growth rate throughout the study. Fleischschaf lambs maintained crescent-shaped growth rates, reaching a maximum rate between 60 and 65 days, then trailing off rapidly. Crossbred animals showed growth rates with a shorter period of increase (until 30 days of age) and a smoother decrease until the end of the period.

A comparison of growth in Merino lambs conceived using artificial insemination and natural mating is shown in Fig. 3. Using the von Bertalanffy model for Merino lambs of both sexes, we observed that both males and females belonging to the natural-mating group had a higher birth weight, but within 21–24 days (indicated in Fig. 3 with the letters b and c), both males and females from the artificial-insemination group surpassed the weight of the naturally conceived lambs, reaching values significantly higher at the end of the growing period.

Table 3 shows values for physiological parameters calculated using best-fit curves and Fig. 4 shows the growth rates found in Merino lambs (males and females) conceived via artificial insemination or natural mating. Animals conceived with artificial insemination showed the maximum growth rates within each sex, also reaching earlier maximum values. Males conceived through natural mating showed the most stable

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