Small Ruminant Research xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Small Ruminant Research

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

Estimates of covariance functions for growth of Kordi sheep in Iran using random regression models

Davoud Ali Saghi[a,*], Ali Reza Shahdadi[a], Fatemeh Kazemi Borzelabad[b], Kourosh Mohammadi[c]

[a] Department of Animal Science, Khorasan Razavi Agricultural and Natural Resources Research and Education Center, AREEO, Mashhad, Iran
[b] Kordi Sheep Breeding Station, Shirvan, Bojnord, Iran
[c] Young Researchers and Elite Club, Khorramabad Branch, Islamic Azad University, Khorramabad, Iran

A R T I C L E I N F O

Keywords:
Legendre polynomials
Growth curve
Variance components
Eigenvalue
Kordi sheep

A B S T R A C T

In the current paper, restricted maximum likelihood estimates of covariance functions for growth records from birth to 360 days of age in Kordi sheep population were estimated using random regression models (RRM). Kordi sheep is an important breed known for adaptability and resistance to unfavorable climatic conditions and suitable feed efficiency in mountainous regions of Iran. Data included 23,720 body weight records of 6730 Kordi lambs collected from 1989 to 2012 at Hossein Abad Kordi sheep Breeding Station in Shirvan city, North Khorasan province, Iran. Fixed effects in the model were lamb sex, birth type, and birth year as well as dam age. Legendre polynomials (LP) of order 3 was used for age to illustrate the average growth curve. In the random part, the functions with different orders were included to model variances associated to direct and maternal effects. Results showed that a model with LP of order 4,3,4,3 for direct additive genetic effects, animal permanent environmental effects, maternal additive genetic and maternal permanent environmental effects was sufficient to model changes in (co)variances with age, according to Akaike's Information Criterion (AIC) and Bayesian information criterion (BIC). Direct additive genetic and animal permanent environment variances increased with age. Direct heritability (h_a^2) increased with age from 0.133 ± 0.021 at birth to 0.391 ± 0.034 at 360 days of age. The ratio of animal permanent environmental variances to phenotypic variance (pe^2) was 0.047 ± 0.083 at birth, increased with age and reached 0.537 ± 0.034 at the end of the growth trajectory. Maternal heritability (h_m^2) was 0.152 ± 0.025 at birth decreased to 0.067 ± 0.016 until weaning and then fluctuated between 0.06 and 0.10. The ratio of maternal permanent environmental variances to phenotypic variance (mpe^2) was 0.082 ± 0.02 at birth; however, it gradually decreased until the end of trajectory. The first eigenvalues of the coefficient matrices explained 69% and 91% of the total direct additive variance and maternal genetic variance, respectively. Direct genetic correlations ranged from low and negative to positively high, and generally decreased as the distance between tests increased. Current study has demonstrated that RRM have potential for modeling growth of Kordi sheep and a greater response to selection would be expected, if selection focuses on body weights from 30 days of age to 120 days of age.

1. Introduction

Small ruminants play an important role to enhance husbandry economy of Iran. According to the study of Vatankhah et al. (2004), approximately 50 million sheep from 27 breeds are reared in Iran. Kordi sheep is an important Iranian dual-purpose (meat and milk) fat-tailed breed, numbering approximate 3.5 million heads and distributed in North Khorasan, South Khorasan and Razavi Khorasan provinces.

Modeling of repeated measurements over time or age (also termed longitudinal data) with Legendre polynomials (LP) was proposed by Kirkpatrick et al. (1990) to describe direct additive genetic covariance among records at any pair of ages in a continuous form. The LP properties allow describing patterns of genetic variation through a growth trajectory. Continuous functions representing covariance among records called covariance functions (Kirkpatrick et al., 1990). An appropriate model for the analysis of longitudinal data should be accounted for the mean and covariance structure that changes with time or age and should be feasible in terms of estimating the required genetic parameters (Mrode, 2005; Ghafouri Kesbi et al., 2008; Kariuki et al., 2010; Venkataramanan, 2016). Random regression models (RRM) accommodate repeated records for traits changing gradually and continuously, overtime, and do not require stringent assumptions about the

* Corresponding author. Tel.: +98 915 506 4613.
E-mail address: davoudali@yahoo.com (D.A. Saghi).

https://doi.org/10.1016/j.smallrumres.2018.03.007
Received 10 April 2017; Received in revised form 13 March 2018; Accepted 14 March 2018

constancy of variances and correlations (Venkataramanan, 2016) and allow the researcher to study the changes in genetic variability with time and allow selection of individuals to alter the general patterns of response over time (Schaeffer, 2004). Advantages of RRM over multiple trait models involve the inclusion of all available data without pre-adjustment to particular ages, no loss of records taken outside certain age ranges, and reduction in the number of parameters to estimate by fitting parsimonious models (Kirkpatrick et al., 1990; Meyer and Hill, 1997). Furthermore, the application of the RRM enhance the selection accuracy and calculate (co)variances between or at every age or time points and describe the growth stages and behavior of the variance components and estimate parameters and breeding values more accurately (Bertipaglia et al., 2015). In recent years, the RRM was applied in the analysis of longitudinal growth data in different sheep breeds (Molina et al., 2007; Kariuki et al., 2010; Wolc et al., 2011; Bohlouli et al., 2013; Jannoune et al., 2015; Venkataramanan, 2016; Zamani et al., 2016).

Modeling the growth curve of sheep allows a mathematical description of growth and is useful in estimating the average weight of lambs at all ages (Jannoune et al., 2015). Increasing growth depends on the precise genetic evaluate through appropriate parameter values affecting profitability in meat production and improve breeding efficiency (Mohammadi et al., 2015). There is no such study, to our knowledge, concerned to growth in Kordi sheep. Thus, an efficient and consistent genetic evaluation strategy of growth trajectory is necessary to genetically improve body weight of Kordi sheep and genetically identify superior animals used as parents of the next generation. Considering these facts, in the current study the RRM was applied to investigate the genetic variation in growth curve of Kordi lambs.

2. Materials and methods

2.1. Geographical location and flock management

The data used were obtained from Hossein Abad Kordi sheep Breeding Station located in Shirvan city, North Khorasan province, north-east of Iran and collected from 1989 to 2012. The breeding station was established in 1989 and started its activity by purchasing and collecting about 400 purebred sheep from privileged flock, with the aim of improving the weaning weight in Kordi lambs. This breed has an average litter size of 1.11 and its growth rate is noticeable as 200–250 g/day until weaning and 150–100 g/day after weaning. Average mature live weight in this breed is 55 kg and 95 kg for ewes and rams, respectively. Milk yield ranges from 80 to 90 kg in a 120-day-period, with annual greasy fleece weight as 1.9 kg and 2.9 kg and rump weight between 2–2.5 kg and 3.5–4 kg in ewes and rams, respectively. Coat color of lambs is dark brown and black at birth, but gradually changed to gray in adult animals. This breed is mainly valued due to its disease resistance, tolerance to harsh environmental conditions and suitable feed efficiency as well as adaptability to mountainous pastures.

Maiden ewes were bred to rams for first time at 18 months of age. Generally, a group of rams were tested each year, and each one was mated to 25 randomly selected ewes, in a separate paddock for about 45 days from early October until mid-November to control paternity of the lambs born. Lambing was commenced from mid-February and continued to late March. Newborn lambs identified by an ear tag, birth date, sex, birth weight, birth type and pedigree information were individually recorded within 24 h of birth. Lambs were weaned when approximately reached an average age of 90 days of age. Rams and ewes were typically maintained in flock for 2–3 and 7 years, respectively. Animals were kept on natural pasture during spring and summer seasons. Pasture availability is seasonal and depends on availability of rainfall. During fall both lambs and ewes grazed on stubble-fields of wheat and barley, with occasional additional access to alfalfa, wheat straw, barley straw, barley bran, and other supplemental forages and were kept indoors during the winter months and fed with a ration composed of wheat and barley stubble and dry alfalfa.

Table 1
General descriptive information of Growth data available over consecutive ages for Kordi sheep.

Weight at	No. of records	No. of sires	No. of dams	No. of dams with own records and progeny	Mean ± S.E.	S.D. (kg)
Birth	6688	217	2207	1839	4.34 ± 0.01	0.72
Weaning	5891	210	2094	1603	22.54 ± 0.07	5.46
6-Month	5265	211	1954	1537	31.19 ± 0.09	6.75
9-Month	3794	169	1542	1202	34.78 ± 0.11	6.97
12-Month	2082	156	777	394	40.59 ± 0.18	8.12

S.E.: Standard error; S.D.: Standard deviation.

2.2. Data and statistical procedure

Data consisted of weights recorded from birth to yearling age of Kordi lambs born from 1989 to 2012. Totally, 23,720 weight records were analyzed. Records corresponded to 8291 lambs resulting from 220 sires and 2702 ewes. Some general descriptive information of data set is presented in Table 1.

To carry out the analyses, body weights were clustered in 30-day courses to cover yearling growth trajectory of Kordi sheep. Data were checked for consistency of pedigree information and the correct date of birth and records with anomalies in pedigree information and dates were discarded. Body weight records out of the range defined by the mean ± 3.5 SD were excluded. Only the animals with at least three weight records within their 12 months of life were used for analyses. The average number of records per individual was 3.52 and overall mean was 22.87 ± 0.09 kg. Distribution of records and mean of body weight records at different ages are illustrated in Fig. 1.

To determine the factors significantly influenced growth and finding the best order of fit for fixed regression on age to model the population trajectory, preliminary fixed effect analyses were performed by a general linear model analysis via the GLM procedure of SAS software (SAS, 2014). The statistical model included fixed effects of lamb sex (2 levels), birth type (three levels: single, twin and triplet), birth year (23 levels: 1989–2012) and age of dam (six levels: 2–7 years old). All of the mentioned effects were significant ($P < 0.05$) and were included in the final model.

Random effects included direct additive genetic effects, animal permanent environmental effects, maternal additive genetic and maternal permanent environmental effects were estimated from restricted maximum likelihood (REML) using the Wombat software (Meyer, 2007). The fixed and random regressions were represented by continuous functions and covariates described by LP. The random regression model was as follows:

$$Y_{ij} = F_{ij} + \sum_{m=0}^{f} \beta_m \varphi_m(t_{ij}) + \sum_{m=0}^{k_{A-1}} \alpha_{im}\varphi_m(t_{ij}) + \sum_{m=0}^{k_{C-1}} \delta_{im}\varphi_m(t_{ij}) + \sum_{m=0}^{k_{M-1}} \gamma_{im}\varphi_m(t_{ij}) + \sum_{m=0}^{k_{Q-1}} \rho_{im}\varphi_m(t_{ij}) + \varepsilon_{ij}$$

where Y_{ij} = body weight of i^{th} animal at j^{th} month of age, F_{ij} = a set of fixed effects, β = fixed regression coefficients for modelling the population mean, $\varphi_m(t_{ij})$: m^{th} LP of age, t_{ij} = the standardized age at recording ($-1 < t < 1$), α_{ij}, δ_{ij}, γ_{ij} and ρ_{ij} = the random regression coefficients for direct additive genetic effects, animal permanent environmental effects, maternal additive genetic and maternal permanent environmental effects, respectively, k = order of fit for variance function and $k_{A\text{-}1}$, $k_{C\text{-}1}$, $k_{M\text{-}1}$, $k_{Q\text{-}1}$ = the corresponding order of LP fit for each effect and ε_{ij} = the residual (measurement error) effect. Residual variance was considered to be heterogeneous using a variance function