Short-term selection for yearling weight in a small experimental Iranian Afshari sheep flock

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Ghafouri-Kesbi, F., Eskandarinasab, M. and Hassanabadi, A. 2009. **Short-term selection for yearling weight in a small experimental Iranian Afshari sheep flock.** Can. J. Anim. Sci. **89**: 301–307. A selection experiment was initiated in 2000 in an Afshari sheep flock at the department of animal breeding and genetics of the University of Zanjan, Iran. The aim was to evaluate the response of Afshari sheep to selection for yearling live weight. Here, we evaluate the results of this breeding program obtained between 2000 and 2005. Traits studied were birth weight (BW), weaning weight (WW), yearling weight (YW), average daily gain from birth to weaning (WWDG) and average daily gain from weaning to yearling age (YWDG). Mixed model methodology based on a multi-trait animal model was employed to estimate (co)variance components and corresponding genetic parameters. Estimates of breeding values were obtained by the best linear unbiased prediction (BLUP) method. Generation intervals on the four genetic pathways were estimated as the average age of parents at the birth of their progeny kept for reproduction. The heritability estimates were 0.34, 0.27, 0.14, 0.20 and 0.01 for BW, WW, YW, WWDG and YWDG, respectively. Estimates of genetic correlations among traits studied were positive, and ranged from low (0.07, YW/WWDG) to high (0.76, YW/YWDG). Genetic improvements over the experiment based on estimated breeding values were 0.104, 0.824, 1.247, 0.005 and $\approx$0.00 kg for BW, WW, YW, WWDG and YWDG, respectively. Annual genetic gain for YW was relatively high, 0.311 kg yr^{-1}, which demonstrated the effectiveness of the implemented breeding program. Correlated responses in BW, WW, WWDG and YWDG were 0.021, 0.167, 0.001 and $\approx$0.00 kg yr^{-1}, respectively. Estimates of heritabilities and observed genetic trends indicated that selective breeding can lead to significant genetic improvement in Afshari sheep. The average generation interval was estimated to be 3.35 yr. The shorter generation interval was observed on the sire side compared with the dam side (3.30 yr vs. 3.78 yr), indicating faster generation turnover for sires than for dams.

Key words: Sheep, animal model, genetic trend, generation interval, heritability

Ghafouri-Kesbi, F., Eskandarinasab, M. et Hassanabadi, A. 2009. **Sélection à court terme du poids des agneaux d'un an dans un petit troupeau expérimental de moutons iraniens Afshari.** Can. J. Anim. Sci. **89**: 301–307. En 2000, les auteurs ont amorcé un essai de sélection sur un troupeau de moutons Afshari au département de génétique animale et d'hybridation de l'Université de Zanjan, en Iran. Le projet devait évaluer la réaction des moutons à la sélection pour le poids vif à un an. Cet article présente les résultats obtenus dans le cadre de ce projet, entre 2000 et 2005. Les caractères examinés comprenaient le poids à la naissance (PN), le poids au sevrage (PS), le poids à un an (PA), le gain quotidien moyen de la naissance au sevrage (GQNS) et le gain quotidien moyen du sevrage à un an (GQSA). Les auteurs ont recouru à un modèle mixte reposant sur un modèle animal à caractères multiples pour estimer les éléments de la (co)variance et les paramètres génétiques correspondants. La valeur reproductive a été estimée par la méthode de comparaison directe (BLUP). On a choisi pour intervalle entre les générations des quatre voies génétiques l'âge moyen des parents à la naissance des agneaux destinés à la reproduction. L'héritabilité a été respectivement estimée à 0,34, 0,27, 0,14, 0,20 et 0,01 pour le PN, le PS, le PA, le GQNS et le GQSA. Les caractères examinés sont génétiquement corrélés et leur corrélation va de faible (0,07, PA/GQNS) à élevée (0,76, PA/GQSA). Selon la valeur reproductive estimée, les améliorations génétiques réalisées durant l'expérience s'établissent respectivement à 0,104, 0,824, 1,247, 0,005 et $\approx$0,00 kg pour le PN, le PS, le PA, le GQNS et le GQSA. Le gain génétique annuel du PA est relativement élevé, soit de 0,311 kg par année, ce qui illustre l'efficacité du programme d'amélioration. La réaction corrélée du PN, du PS, du GQNS et du GQSA s'élevait respectivement à 0,021, 0,167, 0,001 et $\approx$0,00 kg par année. L'héritabilité estimative et les tendances génétiques observées indiquent qu'un programme de sélection peut aboutir à d'importantes améliorations génétiques chez le mouton Afshari. L'intervalle moyen entre les générations est estimé à 3,35 ans. Cet intervalle est plus court pour les mâles que les femelles (3,30 ans contre 3,78 ans), signe que les générations se succèdent plus rapidement chez les premiers que chez les secondes.

Mots clés: Mutons, modèle animal, tendances génétiques, intervalle entre génération, héritabilité

In Middle Eastern countries such as Iran, consumers have expressed a strong preference for lamb and mutton; hence, in these countries sheep are mainly farmed for meat production. In Iran, mutton is the most important

Abbreviations: **BW**, birth weight; **GSD**, genetic selection differential; **PSD**, phenotypic selection differential; **WW**, weaning weight; **WWDG**, average daily gain from birth to weaning; **YW**, yearling weight; **YWDG**, average daily gain from weaning to yearling age source of red meat and reached about 290 million kg yr^{-1} (Rashidi et al. 2008); however, meat production from the sheep does not meet the consumers increasing demand. Low productivity of the native breeds is one of the major reasons for this shortage. Therefore, it is important to increase the efficiency of sheep production by efficient selection programs. Improving growth performance is an important way of increasing meat output in a lamb production system. From the literature, it is evident that a part of the phenotypic variance of the growth traits is heritable (Safari et al. 2005); hence, genetic improvement in these traits through selection programs would be possible.

The aim of any genetic improvement program is to increase the genetic level of the population for one or more traits of interest. If a breeding program has been in operation for some time it is, of course, of interest to determine and evaluate its success by estimating the genetic change that has taken place over the years. Mixed model estimators have been widely used for estimation of genetic trends because of its well-defined statistical properties. This technique facilitates the separation of genetic effects from environmental effects, and the effective utilization of pedigree information. In the case of the mixed model estimator, it is unbiased and individual breeding values have minimum variance of prediction error (Sorensen and Kennedy 1984).

The Afshari sheep is one of the heaviest and largest mutton breeds in Iran and is widely distributed in the mountainous areas in the west of the country. Today, a large percentage of the Afshari sheep population is raised in the Zanjan province. The Afshari is a fat-tailed carpet-wool sheep with brown colour and is primarily used for meat production. This breed has a large litter size, high fertility and appropriate growth characteristics compared with other Iranian sheep breeds.

The aim of this study was to estimate the genetic parameters for growth traits and to assess genetic trends in a flock of Afshari sheep resulting from a short-term breeding program commenced in 2000.

MATERIALS AND METHODS

Study Area and Flock Management

This study was carried out at the Department of Animal Breeding and Genetics at the University of Zanjan, Zanjan, located in Iran, 1663 m above mean sea level (lat. 35°35′S, long. 47°15 E). Climatically, this location has temperate summers and cold winters with an average rainfall of approximately 360 mm yr^{-1}.

The flock was closed in 1998 with 11 fertile rams and 110 breeding ewes. The aim of this experiment was to evaluate the response of Afshari sheep to selection for yearling live weight (selection criterion). Natural service was performed for the first time in 1999 using unselected rams. The selection program commenced in 2000 and the first yield from selected rams was thus produced in 2001. In order to select superior animals, initially, contemporary groups (type of birth and age of dam) were listed and then the rams with the largest phenotypic deviation from the mean of their contemporary group were selected. The animals were maintained and raised under environmental, nutritional and management conditions that reflect the local conditions. Mating season was from November to October each year. The ewes in heat were mated with the selected rams in the afternoon. Ewes were assigned to ram breeding groups at random with the restriction that mating between very closely related animals was avoided. Each group of 10 ewes was exposed to a fertile ram in a separate mating pen. Lambing took place in February and May. Lambs that were born within each year were managed in the same way. After lambing, lambs were weighed and identified with numbered plastic ear tags within 24 h of birth. Sex, birth date, birth type, dam ID, sire ID and other relevant information were recorded and stored in a data base. The suckling program of the lambs lasted for 120 d on average. In the suckling period, lambs had all the milk yielded by their dams and were also allowed grass hay after 1 mo of age. After weaning, ewes and young animals were maintained on natural pasture as separate flocks. Range conditions were poor during the late autumn and winter months; therefore, animals were kept indoors during December, January, February and March and manually fed according to National Research Council (1985). Animals were shorn once a year, in June. Ewes were kept in the flock for a maximum of six parities; however, ewes that did not lamb in any season or were ill were culled sooner. Rams were used for 3 breeding years. The management of the animals conformed to the guide to the care and use of experimental animals of the Canadian Council on Animal Care (1993).

Evaluated Traits

The traits analysed were birth weight (BW), weaning weight (WW), yearling weight (YW), average daily gain from birth to weaning (WWDG) and average daily gain from weaning to yearling age (YWDG). Weaning weight was adjusted to 120 d of age by adding 120 times the pre-weaning average daily gain to birth weight. Adjusted yearling weight (365 d) was obtained by adding t times the post-weaning daily gain to weaning weight, where t is the number of days between weaning and yearling age. After preliminary editing for outliers, 1496 lambs born from 1204 parturitions of 526 ewes and 49 sires were used. All pedigree information available was included in the final analysis in order to increase the accuracy of estimation through the use of all available relationships between animals.

Statistical Analysis

Preliminary analyses of variance were made to find the significant non-genetic effects for each trait (SAS Institute, Inc. 2004). Fixed effects included year of birth (six classes for BW, WW and WWDG and five classes for YW and YWDG), age of dam at lambing (2–8 yr old), sex (male; female) and type of birth (single, twin, triplet). These effects were significant for growth traits and were included in models. Initially, a set of single trait analyses was done for each trait to assess the importance of maternal effects. By ignoring or including various combinations of maternal additive genetic and maternal permanent environmental effects, six different models were fitted for each trait (Table 3). The most appropriate model for each trait was selected based on the likelihood ratio tests. Maternal effects were significant only on BW (Model 3; including maternal additive genetic effects), therefore, a multi-trait animal model considering maternal additive genetic effects only for BW was used to analyse the data. The following mixed model was fitted to the data:

$$\boldsymbol{y} = \boldsymbol{X}\boldsymbol{b} + \boldsymbol{Z}_1\boldsymbol{a} + \boldsymbol{Z}_2\boldsymbol{m} + \boldsymbol{e},$$

where **y** is a vector of observations on all individuals, **b** is a vector of fixed effects, **X** represents a design matrix relating the appropriate fixed effects to each individual, **a** is a vector of direct additive genetic effects, **m** is a vector of maternal additive genetic effects fitted only for BW, $\mathbf{Z_1}$ and $\mathbf{Z_2}$ are the design matrices for the direct and maternal additive genetic effects, respectively, and **e** is a vector of residual (temporary environment) effects. The co-variance structure for the random effects was:

$$V(a) = A\sigma_a^2,\ V(m) = A\sigma_m^2,$$

$$V(e) = I_n\sigma_e^2,\ \text{and } \mathrm{Cov}(a, m) = 0$$

where A is the additive numerator relationship matrix created from the pedigree structure, $\mathbf{I}_n$ is the identity matrix of order equal to the number of records, σ_a^2, σ_m^2 and σ_e^2 are direct additive genetic variance, maternal additive genetic variance and residual variance, respectively, and $\sigma_{a,m}$ is direct-maternal additive genetic co-variance.

Estimates of (co)variance components were obtained using a multi-trait animal model combined with a derivative-free REML algorithm (DFREML) as implemented in the DXMUX program of DFREML software package (Meyer 2001). Breeding values of individual animals were obtained with the best linear unbiased prediction (BLUP) method. Genetic improvement for each trait studied over the experiment was calculated by subtracting the mean of the estimated breeding values at the beginning of the experiment from the mean of the estimated breeding values at the end of the experiment. Means for estimated breeding values of the animals by year of birth were calculated to evaluate the genetic trends.

With respect to yearling weight, genetic selection differentials (GSD) were calculated as deviations of average estimated breeding values of selected sires from the mean of their male cohort. Phenotypic selection differentials (PSD) were also calculated in similar fashion using phenotypic values.

The average age of parents at the birth of their offspring (used for reproduction or not) and the generation intervals, defined as the average age of parents at the birth of their progeny kept for reproduction (James 1977), were estimated. Both parameters were computed for the four gametic pathways, father–son, father–daughter, mother–son and mother–daughter.

RESULTS

A brief description of the pedigree structure is presented in Table 1. Of 1496 lambs that were born during the experiment, the fathers of only five lambs were not known. Number of records, means, standard deviations and coefficient of variations for traits studied are shown in Table 2.

Means of estimates of breeding value by year of birth for traits studied are shown in Fig. 1. For BW, WW, YW and WWDG the genetic trend was positive from 2000 onwards. Genetic improvements over the experiment based on estimated breeding values were 0.104, 0.824, 1.247, 0.005 and $\approx$0.00 kg for BW, WW, YW, WWDG and YWDG, respectively. Annual genetic gains for BW, WW and YW were 0.021, 0.167 and 0.311 kg yr^{-1}, respectively. Pre- and post-weaning daily gain increased by 0.001 and $\approx$0.00 kg yr^{-1}, respectively.

Table 4 presents estimates of phenotypic and genetic selection differentials (PSD and GSD, respectively) for selected sires. Both the PSD and GSD estimates were considerably high.

Estimates of variance components and heritability coefficients are shown in Table 5. Estimates of heritability for all traits ranged from 0.01 (YWDG) to 0.34 (BW). In addition, maternal heritability was estimated to be 0.16 for BW. Estimates of genetic correlations were all positive and ranged from 0.07 (YW/WWDG) to 0.76 (YW/YWDG) (Table 6).

Tables 7 and 8 show the average age of parents at the birth of their offspring and estimated generation intervals, respectively. The mean age of the parents at the birth of their offspring was 3.43 yr, and the average generation interval was estimated to be 3.35 yr.

DISCUSSION

Genetic Trends

The effectiveness of the selection procedure can be evaluated by estimating additive genetic changes over the time. Genetic trend for Afshari lambs have not been studied before, but Behroozin (2001), from a genetic study on Makooei, another Iranian fat-tailed breed of sheep, estimated annual genetic gains as 0.005, 0.014, 0.077 and 0.053 kg yr^{-1} for body weight at birth, weaning, 9- and 12-mo of age, respectively. Direct response estimated for YW (selection criterion) was relatively high, which indicates the effectiveness of the implemented breeding program yielded through

Table 1. Description of the pedigree structure

Item	No. of animals in pedigree	No. of inbred animals	No. of animals with unknown father – mother	Average inbreeding	Average relatedness
	1731	84	5–0	0.5%	2%

selecting sires with optimum GSD. In Ethiopia, Gizaw et al. (2007) found a direct response to selection for yearling weight of 0.495 kg yr^{-1} in Menz sheep. In addition, Bosso et al. (2007), who worked on Djallonké sheep, estimated annual genetic gain for yearling weight as 0.09 kg yr^{-1}. Positive genetic gains in other traits can be considered as a correlated response. It was expected, owing to the presence of a positive genetic correlation between these traits and YW, in agreement with Gizaw et al. (2007), who found positive correlated responses of 0.038, 0.271 and 0.388 kg yr^{-1}, respectively, in body weight at birth, 3 and 6 mo of age through a direct selection on yearling weight in Menz sheep.

Several investigations have reported the results of selecting for body weight in sheep. Shrestha et al. (1996) estimated annual genetic gains for Canadian sheep in birth weight and weight at 21, 70 and 90 d of age as 0.013, 0.021, 0.019 and 0.023 kg yr^{-1} in Suffolk and 0.007, 0.008, 0.016 and 0.025 kg yr^{-1} in Finnsheep, respectively. Hanford et al. (2002) found genetic improvements of 0.8 and 8 kg, respectively, in birth weight and weaning weight of Columbia sheep over a 48-yr period (1950–1998), i.e., about 0.016 and 0.160 kg yr^{-1}, respectively. Moreover, Shatt et al. (2004) worked on Rahmani and Ossimi breeds of sheep in Egypt, and reported that annual genetic gains from 1970 to 1999 for 60-, 120- and 180-d weight were 0.038, 0.092 and 0.135 kg yr^{-1} in Rahmani and 0.020, 0.021 and 0.021 kg yr^{-1} in Ossimi, respectively. In addition, Olivier et al. (1995) studied the response to selection for mature body weight in Grootfontein Merino sheep and found annual genetic gains of 0.200 kg yr^{-1} from 1966 to 1984 and 0.630 kg yr^{-1} from 1985 to 1991. In contrast, Singh and Dhillon (1991) observed a negative genetic trend in the Indian Avivastra sheep for 180-d weight as –0.136 kg yr^{-1}. Shrestha et al. (1996) reported that differences in trends among breeds can be related to selection criteria, which varied between the different sheep breeds. Also, they reported that estimates of genetic change varied according to breed, lamb weight and method of estimation.

The general paucity of literature on the subject of estimated genetic trends for pre- and post-weaning daily gain makes comparison difficult. However, Bosso et al. (2007) from a short-term selection program including post-weaning daily gain of Djallonké sheep as selection criterion, reported annual genetic gains for pre- and post-weaning daily gain as 0.11 and 0.00 kg yr^{-1}, respectively.

From the results obtained here, it is concluded that the growth of lambs during the pre-weaning period took place about three times more as compared with growth

Table 3. The random (co)variance components used in the six models

Model number	Random effect[z] σ^2_a	σ^2_c	σ^2_m	$\sigma_{a,m}$	σ^2_e
1	✓				✓
2	✓	✓			✓
3	✓		✓		✓
4	✓		✓	✓	✓
5	✓	✓	✓		✓
6	✓	✓	✓	✓	✓

[z] σ^2_a, direct additive genetic variance; σ^2_c, maternal permanent environmental variance; σ^2_m, maternal additive genetic variance; $\sigma_{a,m}$, direct-maternal additive genetic co-variance; σ^2_e, residual variance.

Table 2. Characteristics of the data structure

Item	Trait[z] BW	WW	YW	WWDG	YWDG
No. of records	1496	1235	764	1235	628
No. of animals	1731	1520	990	1520	895
No. of sires	49	48	41	48	40
No. of dams	526	489	367	489	329
No. of grandsires	32	30	24	30	21
No. of granddams	311	172	133	172	86
Mean[y]	4.812	28.719	47.714	199	77
SD[x]	0.647	5.362	7.787	41.925	21.670
CV (%)	11.866	12.518	12.236	14.201	22.498

[z] BW, birth weight; WW, weaning weight (120-d); YW, yearling weight; WWDG, average daily gain from birth to weaning; YWDG, average daily gain from weaning to yearling age.
[y,x] BW, WW and YW in kilograms; WWDG and YWDG in grams.

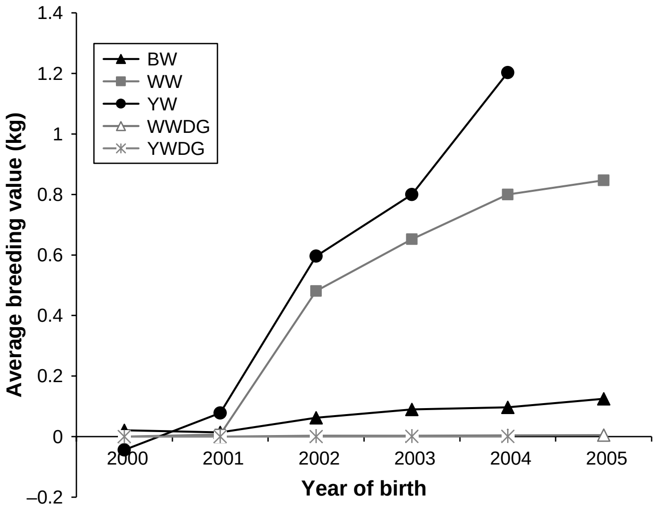

Fig. 1. Genetic trends for growth traits.

of lambs during the post-weaning period (Table 2). The post-weaning stage of growth in goats and sheep is critical, because it is the stage when there is little or no maternal protection, and the lamb is more exposed to environmental stress, which limits the rate of growth. This period of growth should be considered crucial, and proper management and feeding of lambs is required to ensure greater productivity (Dass et al. 2004). Insufficient nutrition can offset, or at least reduce, phenotypic response to selection. Under low productivity and poor nutrition, animals will respond to selection at the genetic level, but not at the phenotypic level, because genetic potential for growth cannot be expressed in the phenotype without good management and an adequate diet.

Table 4. Phenotypic (PSD) and genetic (GSD) selection differentials of selected sires with yearling weight

Year	No. of candidate sires	No. of selected sires	PSD (kg)	GSD (kg)
2001	90	5	+ 10.400	+ 1.414
2002	119	7	+ 15.468	+ 1.793
2003	139	7	+ 6.642	+ 1.321

Mavrogenis and Constantinou (1990) reported that selection for weight at later stages would be expected to lead to increased mature weight and greater maintenance energy requirements of the breeding animals. Similarly, Sakul et al. (1994) reported that selection for weight following weaning is likely to cause undesired positive correlated responses in mature weight, so, it can be a logical recommendation that superior animals should be selected at an earlier age.

Genetic Parameters

Heritability estimates are needed for the development of proper selection programs. With respect to heritability estimates, it becomes difficult to compare with results from the literature because estimates from different studies were obtained with populations of different genetic structure, different management conditions and different methods of estimation. However, our estimates of heritability for BW, WW and YW as well as maternal heritability for BW were within the range reviewed by Safari et al. (2005) for several sheep breeds word wide. The estimated value of heritability for WWDG (0.20) is intermediate between other estimates (Yazdi et al. 1997; Gizaw and Joshi 2004; Bosso et al. 2007; Rashidi et al. 2008); however, the estimated value of heritability for YWDG (0.01) is lower than other reports (Yazdi et al. 1997; Gizaw and Joshi 2004; Bosso et al. 2007). The low heritability estimated for YWDG can explain the negligible genetic change as observed for this trait. The heritability estimates for pre- and post-weaning daily gain contradict the results reported by Yazdi et al. (1997) and Gizaw and Joshi (2004). In those studies, post-weaning daily gain generally had higher heritability estimates than pre-weaning daily gain. This contradiction can probably be explained by the post-weaning feed conditions, where the growth of lambs is limited by seasonal constraints on the quality of pasture, resulting in lambs not expressing their genetic potential and,

Table 5. Variance components and heritability coefficients for growth traits obtained from multi-trait analysis

	Trait[z]				
Item[y]	BW	WW	YW	WWDG	YWDG
σ_a^2	0.102	2.868	3.954	140.760	3.050
σ_m^2	0.047	–	–	–	–
σ_e^2	0.152	7.862	23.318	580.120	271.410
σ_p^2	0.302	10.731	27.272	720.880	274.460
h^2	0.34 ± 0.04	0.27 ± 0.05	0.14 ± 0.04	0.20 ± 0.05	0.01 ± 0.02
m^2	0.16 ± 0.02	–	–	–	–

[z]BW, birth weight; WW, weaning weight (120-d); YW, yearling weight; WWDG, average daily gain from birth to weaning; YWDG, average daily gain from weaning to yearling age.
[y]σ_a^2, direct additive genetic variance; σ_m^2, maternal additive genetic variance; σ_e^2, residual variance; σ_p^2, phenotypic variance; h^2, heritability; m^2, maternal heritability.

Table 6. Genetic (above diagonal) and phenotypic (below diagonal) correlations among growth traits

Trait[z]	BW	WW	YW	WWDG	YWDG
BW	–	0.46	0.23	0.09	0.58
WW	0.19	–	0.42	0.08	0.62
YW	0.18	0.27	–	0.07	0.76
WWDG	0.03	0.04	0.03	–	0.54
YWDG	0.05	0.01	0.04	–0.01	–

[z]BW, birth weight; WW, weaning weight (120-day); YW, yearling weight; WWDG, average daily gain from birth to weaning; YWDG, average daily gain from weaning to yearling age.

consequently, lower heritability for YWDG compared with WWDG. On the other hand, Conington et al. (1995) and Miraei-Ashtiani et al. (2007) reported that the harsh or rearing environment inflates the error variance and result is low heritabilities.

The genetic correlations among growth traits were all positive, which indicates that selection for any one of them would result in positive genetic response in all of the correlated traits. Genetic correlation between BW and WW was higher than the genetic correlation between BW and YW. Such trends were also observed by Yazdi et al. (1997) in Baluchi sheep and by Ozcan et al. (2005) in Turkish Merino sheep. Genetic correlations among YWDG and other growth traits were relatively high, but, since the estimated value of heritability for YWDG is very low, these estimates have little meaning.

Generation Interval

The average age of parents at the birth of their offspring was lower on the sire side compared with the dam side (3.07 yr vs. 3.79 yr), as would be expected, replacement rates were faster for sires than for dams. Average generation interval was 3.35 yr, which was shorter than estimates of 4.34 and 4.29 yr reported by Shatt et al. (2004) for Ossimi and Rahmani breeds of sheep, respectively. Goyache et al. (2003) reported the average generation interval in Xalda sheep as 2.97 yr, which is shorter than our findings. They also reported a longer generation interval on the dam side (3.17 yr) compared with the sire side (2.76 yr). Prod'Homme and Lauvergne (1993) found that generation interval in a closed Merino Rambouillet flock during 50 generations was between 2.2 and 4.1 yr on the sire side and between 3.9 and 5.6 yr on the dam side. Similarly, in the current study, the generation interval on the sire side was shorter than the dam side (3.30 yr vs. 3.78 yr), showing faster generation turnover for sires than for dams. Since genetic response to selection depends, in part, on generation interval between selected generations, a reasonable choice of generation interval must be achieved in order to obtain a most favourable selection response (Portolano et al. 2004). In general, it is probably difficult to change the generation interval as it is constrained by the productive cycle of the species. Nevertheless, it may be shortened using biotechnologies, such as embryo transfer and genomic selection.

Table 7. Average age of parents (in years) at the birth of their offspring for the four genetic pathways

Pathway	*N*	Average age ± SE
Sire-son	734	3.01 ± 0.07
Sire-daughter	732	3.13 ± 0.07
Dam-son	734	3.84 ± 0.08
Dam-daughter	740	3.74 ± 0.08
Average	–	3.43 ± 0.04

Table 8. Generation intervals (in years) for the four genetic pathways and the average generation interval

Pathway	*N*	Generation interval ± SE
Sire-son	30	3.36 ± 0.37
Sire-daughter	307	3.24 ± 0.14
Dam-son	30	4.18 ± 0.34
Dam-daughter	309	3.38 ± 0.12
Average	–	3.35 ± 0.09

CONCLUSIONS

Genetic progress in growth traits was observed during the course of the study for Afshari sheep. Heritabilities for growth traits were moderate, except for YWDG, suggesting genetic progress will continue in the future. Moreover, the absence of genetic antagonisms among the growth traits indicates that none of the growth traits should be affected adversely through correlated response. Estimates of genetic parameters from the current study can be used for further improvement of the selection strategy. It would seem that body weight at 1 yr of age cannot be the most appropriate selection criterion, because it experienced relatively low heritability. In addition, there is variation in environmental and nutritional conditions during the post-weaning period, which can offset a portion of the phenotypic response to selection. Estimates of heritability for early growth traits indicate that breeding rams could be selected at an earlier age. Selection for weaning weight should be more effective and should also increase other growth traits.

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