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Heritability and additive breeding value in sheep obtained through industrial crossing

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Abstract

This study aimed to estimate the heritabilities, the most assertive selection gain for each characteristic of sheep genetic improvement, together with the reference additive genetic value for industrial crosses in the Southern Region of Brazil. The study was carried out in the municipality of Boa Vista do Cadeado - RS, with data collection from 2020 to 2023. The animals were stratified by gender and separated into stalls, with free access to water. The measurements inherent to the parents (50 dams and 5 rams) were carried out at the time of crossing. For the 100 progenies, the height and weight of male and female lambs at birth were measured. The average daily gain of the progenies was obtained, and a standard weighing and height measurement at 80 days after birth. The final weight and carcass yield of the lambs were obtained at the time of animal slaughter. High genetic variability and narrow-sense heritability were obtained in the characteristics weight at birth of male lambs and height at birth of lambs in both genders. Average daily weight gain revealed high heritability with restricted meaning, this attribute being unrelated to the expressed meteorological variables, identifying effective potential for selection. Pressures of 10% and selection intensities of 1.76 can be employed for most traits to be improved through industrial sheep crossbreeding. Industrial crossing is effective not only due to heterotic effects but also due to additive genetic effects expressed in heritability.

Keywords: Genetic breeding; small ruminants; sheep meat production; heterosis; genetic gain; Bayesian inference; narrow sense heritabilities.

Introduction

The production of small ruminants contributes significantly to the national economy of several countries, as the rising price of meat has led to an increase in the importance of sheep meat production, in terms of quality and quantity (Abasi-Mousa, Varkoohi, Joezy, Salary, & Khansefid, 2023). In Brazil, the production of goats and sheep is relevant to the livestock sector. The national herd of these ruminants is 11 and 19 million heads, respectively (Monteiro, Brisola, & Vieira Filho, 2021), knowing that the Brazilian population consumes 400 grams of meat per capita (Anuário da Pecuária Brasileira [ANUALPEC], 2020).

Crossbreeding between sheep breeds promotes heterosis, which is a technique widely used in countries where sheep meat is economically relevant. Heterosis is the result of highly complex interactions, based on additive effects, deviations from dominance and over dominance, as well as allelic complementarity and gene interactions (Petrovic et al., 2019), capable of resulting in gains in certain characteristics. In this sense, body weight and growth rate are important economic characteristics that require attention when the aim is to increase meat production (Tesema et al., 2022).

Genetic evaluation studies depend on the availability of correct estimates of genetic parameters for the characteristics of interest (Barbosa, Santos, Muniz, Azevedo, & Fagundes, 2015). In this sense, heritability is an essential population parameter in animal genetic evaluation, defined as heritable genetic gain between generations of parents and progenies (Giannotti, Packer, & Mercadante, 2005). The potential for genetic gain is largely dependent on narrow-sense heritability and the genetic relationship between traits of economic importance, as well as the selection pressure and intensity that will be applied (Habtegiorgis, Haile, Getachew, Kirmani, & Gemiyo, 2022).

Among the most varied techniques for obtaining genetic components and parameters, Bayesian inference is the most suitable, mainly for ensuring reliable parameters in conditions where the normal distribution is not met, with estimates based on a priori pedigree information and the construction of an accurate probability density function that will constitute a consolidated posterior distribution, which allows the use of selections in the most varied scenarios and conditions (Rodrigues, Sarmento, Leal, Araújo, & Figueiredo Filho, 2021). Therefore, the use of the reduced animal model has contributed to inferences and selections, as well as growth curves in animal genetic improvement (Mohammadi, Mokhtari, Saghi, & Shahdadi, 2019; Oliveira et al., 2017; Shiotsuki, Cardoso, & Albuquerque, 2018; Müller et al., 2021). Due to the lack of information that brings together narrow sense heritabilities used in the various selection gains of animal genetic improvement using industrial sheep crossbreeding, this study aimed to estimate the heritabilities, the most assertive selection gain for each characteristic of sheep genetic improvement, together with the reference additive genetic value for industrial crosses in the Southern Region of Brazil.

Materials and Methods

The study was carried out in the municipality of Boa Vista do Cadeado - RS (28º 31'35"S, 53º46'40"W, altitude of 406 meters), with data collection from 2020 to 2023. According to Köeppen, the climate of region is of type Cfa. A herd based on industrial crosses (Texel and Ile-de-France breed) was used, created under semi-intensive management, kept on *Avena byzantina* pasture from April to August and on *Panicum maximum* pasture from September to March, with daily supplementation using *Avena sativa* grains. The animals were stratified by gender and separated into stalls, with free access to water. Phytosanitary management of the animals was carried out on a schedule for endo and ecto parasites, to minimize the biotic effects on the results of the experiment.

The measurements inherent to the parents (50 dams and 5 rams) were carried out at the time of crossing, where height (RH; EH, cm) and body weight (RW; EW, kg) were measured. For the 100 progenies, the height and weight of male (HBML, cm; WBML, kg) and female (HBFL, cm; WBFL, kg) lambs at birth were measured. Based on monitoring, the average daily gain (ADGML; ADGFL, g day^{-1}) of the progenies was obtained, and a standard weighing and height measurement at 80 days after birth (W80ML; W80FL, kg, H80ML; H80FL, cm). The final weight (WFINAML; WFINAFL, kg) and carcass yield (CYFL; CYML, %) of the lambs were obtained at the time of animal slaughter. In order to understand the influence of meteorological variables on the birth, growth and maintenance of contemporary breeding stock, radiation (RadFL; RadML, Mj m^{-2} s^{-1}), thermal sum (TSFL; TSML, ºDay), maximum air temperature (TmaxFL; TmaxML, ºC), mean air temperature (TmeanFL; TmeanML, ºC), minimum air temperature (TminFL; TminML, ºC), relative air humidity (RHFL; RHML, %) and wind speed (WSFL; WSML, m s^{-1}). These were obtained through satellite tools in the three years of study (NASA POWER, 2023), with these estimates being stratified by the gender of the progeny.

A descriptive analysis of the information took place, using measures of central tendency and dispersion. The degree of relationship between the variables was obtained through linear correlation with significance based on the t test at 5% probability.

The animal model used was $\gamma_i = \mu + \alpha_i + e_i$, where μ consists of the phenotypic value of the measurement for each individual of the contemporary herd, α_i consists of the value of the industrial crossing and the influence of the additive effect of the alleles on the phenotypic expression and e_i consists of the residue not controllable by the model (Villemereuil, 2012). To determine the degree of precision and genetic effects, a Bayesian inference model was used based on the Monte Carlo algorithm through Markov chains (MCMC) using the functions of the MCMCglmm package (Hadfield, 2010), under these conditions it was considered a matrix of a priori known information, random effects for the genotypes, 100000 iterations and burnin of 10000. In this context, we estimated the parameters post mean (mean of the character in the posterior distribution), Low-95% CI (confidence interval less than 95% probability), Up-95% CI (confidence interval greater than 95% of probability), pMCMC (significance of the probabilistic model using the Markov chain Monte Carlo method), H^2 (broad and narrow sense heritability), HPDlower (Lower limit of the parameter for the posterior distribution), HPDupper (Upper limit of the parameter for the posterior distribution). The models used was: $y = X\beta + Z_1\delta_1 + Z_2\delta_2 + e$, where y is considered the vector of phenotypic values; X and β are, respectively, the incidence matrix and the corresponding vector of systematic effects (general average); Z_1 and Z_2 are the random effects incidence matrices, δ_1 is vector of block effects; δ_2 is the vector of genetic values and; e is the residual vector.

Heritability parameters were estimated in the broadest sense ($H^2 = V_P/V_G$), where V_P consists of phenotypic variance and V_G consists of genotypic variance. Narrow-sense heritability was calculated by $h_a^2 = V_a^2/V_a^2 + V_d^2 + V_e^2$, where V_a^2 consists of additive genetic variance, V_d^2 consists of the genetic variance of dominance and V_a^2 consists of environmental genetic variance. Based on the narrow-sense heritability parameters, phenotypic standard deviation and selection intensity, selection gains based on pressures were estimated (90, 80, 70, 60, 50, 40, 20, 10, 5, 4, 3, 2.1%), as described by Falconer (1987), with the equation $R = h^2r(i)\left(\sqrt{V_P}\right)$, where R consists of the selection gain, h^2r consists of heritability in the strict sense, i consists of the intensity of selection and V_P consists of phenotypic variance.

The additive genetic value was estimated according to Falconer (1987), using the equation $AGV = h^2(P - \mu)$, where h^2 consists of the restricted sense heritability of each characteristic, P is the performance of the progeny and μ is the average of the contemporary group plus AGV 10%. All analyzes were performed using the R software (R CORE TEAM, 2023).

Results and Discussion

Based on the a priori results, the descriptive analysis (Table 1) reveals an average height of 62.79 cm for ewes and 67.83 cm for rams, with the paternal line being 5.04 cm higher than the maternal line. The average weight of the ewes was 65.71 kg and 65.91 kg for the rams. When analyzing the progenies through crosses, it was shown that the lambs' height at birth was 38.00 cm and 53.27 cm at 80 days after birth. Females measured 38.88 cm at birth and 49.86 cm at 80 days, being heavier at birth but with a slower growth rate than males. The average weight of the progenies at birth and at 80 days was 4,945 kg and 27.93 kg for males and 5,175 kg and 27.30 kg for females, respectively. The average daily weight gain was higher for males at 0.383 kg day^{-1}, compared to 0.368 kg day^{-1} for females. The results obtained for final weight, carcass and carcass yield were 42.45 kg, 22.35 kg and 51.04% for males and 44.71 kg, 23.04 kg and 50.93% for female lambs.

Knowing that the meteorological variables were stratified by the gender of the progeny, it is observed that there were no major variations between the magnitudes measured, expressing differences only in the accumulation of precipitation, where females were subjected to 483,698 mm during their development and 474,870 mm for males, as well as 70.43% relative humidity for females and 69.88% for males.

The linear correlation (Figure 1) demonstrates that the ewe weight (EW) is negatively related (r=-0.23*) with the height at 80 days of male lambs (H80ML), weight at birth (r=-0.15*) of female lambs (WBFL), height at birth (r=-0.13*) of male lambs (HBML), this attribute being positively related (r=0.13*) to the ram height (RH) and weight at 80 days after birth (r=0.18*) of male lambs (W80ML). Parent ewes with adequate gestation weights provide female lamb with higher initial weights, however, the concern about dystocic births is highlighted. The lambs' height is linked to the genetic performance of the ram, directly influencing the male lambs.

The precipitation accumulated during the birth, growth and development of male lambs (PrecML) and weight at birth of these lambs (WBML) increase the weight at 80 days after birth W80ML (r=0.27* and r=0.26*). Weight at birth of male lambs (WBML) showed a positive correlation (r=0.23*) with the ram weight (RW) and inversely proportional to (r=-0.22*) the incident radiation (RadML). However, the ram height (RH) together with the maximum air temperature (TmaxFL) contribute positively to (r=0.25*) the rapid weight gain until 80 days of female lambs (W80FL). The average daily gain of female lambs (ADGFL) is directly proportional (r=0.17*) to weight at birth (WBFL) and height at birth (HBFL) of these female lambs. These interrelationships demonstrate that not only the genetic complementarity between parents is important, but also the creation and development environment of these progenies, listing precipitation in balance, as excess can compromise the growth rate, relative humidity presents itself as a thermoregulator of the ambience for the breeding stock, and direct or diffuse radiation must be minimized, with the help of adaptations in the breeding facilities.

The Bayesian models using Markov chains were significant at 5% probability of error (pMCMC) (Table 2), allowing to obtain the posterior distributions of each variable of interest, from which the general average of each attribute was estimated, along with its lower and upper limit. The ram height was higher than the ewe height (68.24 cm and 62.75 cm), on the other hand, the weight did not express high variability (65.750 kg and 65.180 kg). The lambs at birth showed minimal differences between males (38.07 cm) and females (38.13 cm).

Weight at birth of the female lambs was 600 grams higher than the weight of the male lambs. At 80 days after birth, the height of male lambs was 52.50 cm while females were 49.12 cm. Weight at 80 days showed low variability for progenies of both genders, being 28.78 kg for males and 28.93 kg for females. Final weight, average daily gain, carcass weight and carcass yield revealed magnitudes of 43.54 kg, 0.367 kg, 22.46 kg and 50.59% for male lambs and 43.96 kg, 0.373 kg, 22.79 kg and 51.18% for female lambs. Carcass yield was higher than those obtained by Lira et al. (2017), where it obtained 44.38 to 45.39% and Landim et al. (2017), with only 38.9% carcass yield through progenies from the industrial crossing of the Rabo Largo x Santa Inês breeds.

Table 1. Descriptive analysis of priori information on the herd of sheep and climatic variables in Boa Vista do Cadeado between the years 2021, 2022 and 2023.

Variables	CV(%)	HPDlower	Mean	HPDupper
H80FL[1]	9.523	66.303	49.861	40.307
H80ML	7.409	62.302	53.273	45.474
RH	6.905	79.595	67.837	56.881
HBFL	8.155	46.230	38.885	30.017
HBML	4.333	42.340	38.003	33.148
EH	2.578	66.900	62.795	58.935
CWFL	19.282	35.474	23.041	13.104
WFINAFL	14.005	58.123	44.712	28.613
CYFL	3.891	55.287	50.933	45.294
CWML	17.850	29.709	22.358	12.915
WFINAML	16.083	60.617	42.453	25.143
CYML	6.482	58.791	51.043	43.617
ADGFL	24.406	0.598	0.368	0.162
ADGML	27.327	0.641	0.383	0.124
W80FL	27.276	46.243	27.304	12.034
W80ML	23.484	44.996	27.936	11.147
RW	6.936	80.591	65.912	55.923
WBFL	19.285	7.279	5.175	2.690
WBML	19.508	8.229	4.945	3.105
EW	10.627	81.231	65.714	45.968
PrecFL	2.304	509.912	483.698	455.073
PrecML	3.100	517.856	474.870	440.610
RadFL	10.541	45.696	36.209	24.738
RadML	2.946	39.401	36.952	34.141
TSFL	9.227	4100.874	3326.373	2570.582
TSML	1.893	3515.275	3359.180	3201.263
TmaxFL	0.940	37.814	37.072	36.118
TmaxML	0.938	38.022	37.122	36.203
TmeanFL	8.588	27.720	22.170	16.673
TmeanML	2.111	23.746	22.426	21.345
TminFL	42.386	13.236	6.852	0.525
TminML	29.587	9.434	5.965	1.676
RHFL	2.794	75.629	70.438	65.616
RHML	0.800	71.343	69.881	68.575
WSFL	2.043	0.697	0.657	0.629
WSML	0.679	0.661	0.650	0.638

[1]Approximate height at 80 days for female lambs (H80FL), approximate height at 80 days for male lambs (H80ML) , ram height (RH), ewe height (EH), final carcass weight for female lambs (CWFL), final carcass weight for male lambs (CWML), carcass yield for female lambs (CYFL), carcass yield for male lambs (CYML), average daily weight gain for female lambs (ADGFL), average daily weight gain for male lambs (ADGML), approximate weight at 80 days for female lambs (W80FL), approximate weight at 80 days for male lambs (W80ML), ram body weight (RW), ewe body weight (EW), body weight at birth for female lambs (WBFL), body weight at birth for male lambs (WBML), precipitation for female lambs (PrecFL), precipitation for male lambs (PrecML), radiation for female lambs (RadFL), radiation for male lambs (RadML), thermal sum for female lambs (TSFL), thermal sum for male lambs (TSML), maximum temperature for female lambs (TmaxFL), maximum temperature for male lambs (TmaxML), mean temperature for female lambs (TmeanFL), mean temperature for male lambs (TmeanML), minimum temperature for female lambs (TminFL), minimum temperature for male lambs (TminML), relative humidity for female lambs (RHFL), relative humidity for male lambs (RHML), wind speed for female lambs (WSFL), wind speed for male lambs (WSML), coefficient of variation (CV), parameter lower limit for the posterior distribution (HPDlower), upper limit of the parameter for the posterior distribution (HPDupper).

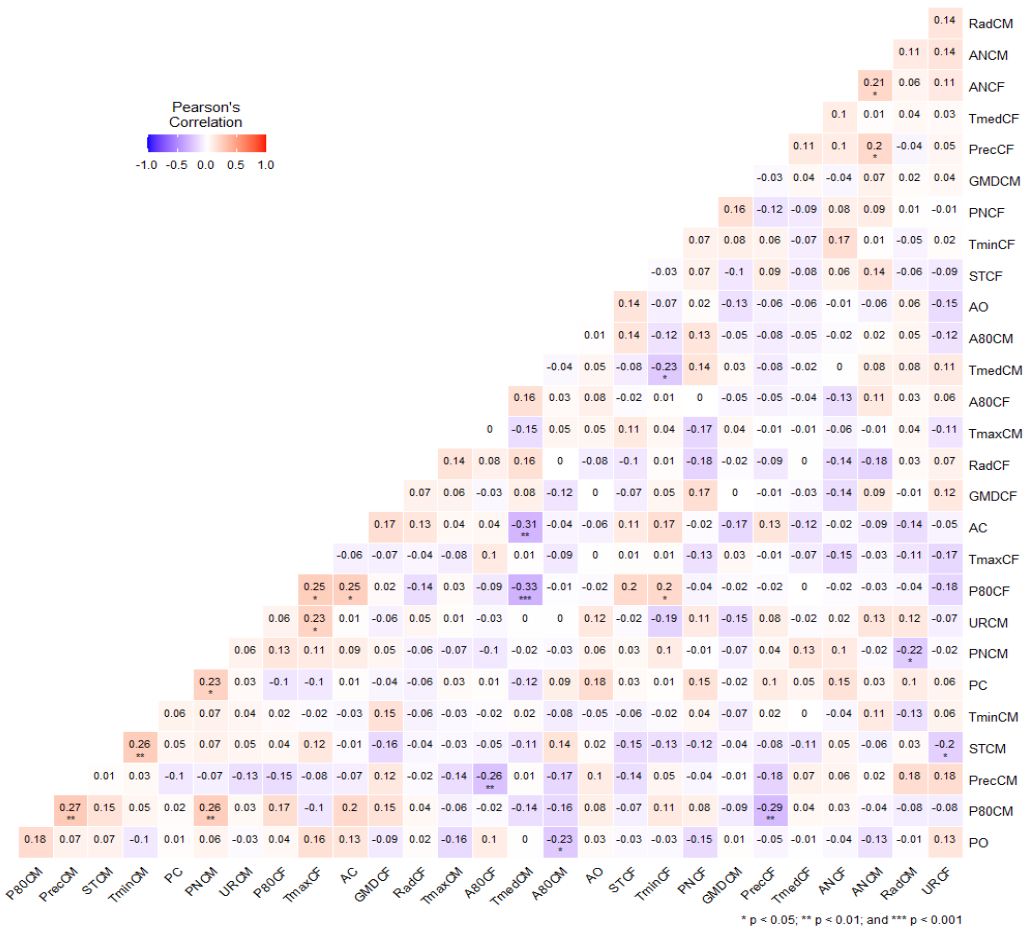

Figure 1. Pearson's linear correlation for the herd of sheep and climatic variables in Boa Vista do Cadeado between the years 2021 and 2022. Approximate height at 80 days for female lambs (H80FL), approximate height at 80 days for male lambs (H80ML), ram height (RH), ewe height (EH), final carcass weight for female lambs (CWFL), final carcass weight for male lambs (CWML), carcass yield for female lambs (CYFL), carcass yield for male lambs (CYML), average daily weight gain for female lambs (ADGFL), average daily weight gain for male lambs (ADGML), approximate weight at 80 days for female lambs (W80FL), approximate weight at 80 days for male lambs (W80ML), ram body weight (RW), ewe body weight (EW), body weight at birth for female lambs (WBFL), body weight at birth for male lambs (WBML), precipitation for female lambs (PrecFL), precipitation for male lambs (PrecML), radiation for female lambs (RadFL), radiation for male lambs (RadML), thermal sum for female lambs (TSFL), thermal sum for male lambs (TSML), maximum temperature for female lambs (TmaxFL), maximum temperature for male lambs (TmaxML), mean temperature for female lambs (TmeanFL), mean temperature for male lambs (TmeanML), minimum temperature for female lambs (TminFL), minimum temperature for male lambs (TminML), relative humidity for female lambs (RHFL), relative humidity for male lambs (RHML), wind speed for female lambs (WSFL), wind speed for male lambs (WSML).

The variance components and genetic parameters obtained through posterior distributions (Table 3) reveal the heritability for weight at birth of female lambs (h^2=0.14) and for male lambs (h^2=0.20). For weight at 80 days, males reveal heritability of h^2=0.25 and females h^2=0.13. Tesema et al. (2022) estimated heritability values of additive genetic effects of h^2=0.37 for birth weight and h^2=0.21 for weaning weight performed 90 days after birth of progenies arising from the industrial crossing of the Dorper x indigenous sheep breeds. Carvalho et al. (2014), evaluating Santa Inês lambs, estimated the restricted heritability of weight at 90 days with a magnitude of h^2=0.04, which is lower than the average daily gain of female (h^2=0.12) and male lambs (h^2=0.13). Pires et al. (2015) reported obtaining a birth weight of 4.22 kg in crosses of Suffolk parents, which is lower than the industrial cross obtained in this work, with magnitudes of 4.95 kg for males and 5.18 kg for females. This study demonstrated weight gain of 0.26 kg day^{-1}, which is also lower than the weight gain for males (0.38 kg day^{-1}) and females (0.37 kg day^{-1}). For carcass yield, Garcia, Perez and Oliveira (2000) showed 53.4% in industrial crosses of the Texel and Santa Inês breeds, which are higher than the 50.93% for females and 51.04% for males in this work.

When assigning a base additive genetic value of 10% for each trait of interest, it was observed that the selection values tended to be closer with milder selection pressures, since the proportion of selected individuals is greater. By applying a selection pressure of 10% with a selection intensity of 1.76 it was possible to achieve values higher than the parameter for lamb height (0.24 cm), lamb weight (1.31 kg) and carcass yield of male lambs (0.94%). When using a pressure of 20% and an intensity of 1.4, animals were obtained with a height at 80 days greater than the parameter independent of the gender of the progeny (0.98 cm for males and 1.38 cm for females), as well as height at of male lambs of 0.48 cm.

Table 2. Posteriori average parameters for a herd of sheep in Boa Vista do Cadeado between the years 2021 and 2022.

Variables	pMCMC	Posteriori Average	LI	LS
RH	0.001*	68.240	66.380	69.970
EH	0.001*	62.750	62.120	63.340
RW	0.001*	65.750	63.950	67.430
EW	0.001*	65.180	62.490	67.840
HBML	0.001*	38.070	37.410	38.680
HBFL	0.001*	38.130	36.950	39.440
WBML	0.001*	4.840	4.480	5.250
WBFL	0.001*	5.000	4.600	5.380
H80ML	0.001*	52.500	50.960	54.020
H80FL	0.001*	49.120	47.280	51.000
W80ML	0.001*	28.760	26.110	31.180
W80FL	0.001*	28.930	26.420	32.470
WFINAML	0.001*	43.540	41.080	46.120
WFINAFL	0.001*	43.960	41.160	46.340
ADGML	0.001*	0.367	0.324	0.406
ADGFL	0.001*	0.373	0.336	0.405
CWML	0.001*	22.460	20.920	23.900
CWFL	0.001*	22.790	21.030	24.550
CYML	0.001*	50.590	49.390	51.850
CYFL	0.001*	51.180	50.440	51.960

Approximate height at 80 days for female lambs (H80FL), approximate height at 80 days for male lambs (H80ML), ram height (RH), ewe height (EH), final carcass weight for female lambs (CWFL), final carcass weight for male lambs (CWML), carcass yield for female lambs (CYFL), carcass yield for male lambs (CYML) , average daily weight gain for female lambs (ADGFL), average daily weight gain for male lambs (ADGML), approximate weight at 80 days for female lambs (W80FL), approximate weight at 80 days for male lambs (W80ML), ram body weight (RW), ewe body weight (EW), body weight at birth for female lambs (WBFL), body weight at birth for male lambs (WBML).

Table 3. Heritability and selection for additive genetic value for a herd of sheep in Boa Vista do Cadeado between the years 2021 and 2022.

Variables	H^2	h^2	X	S	Pressure (%)													AGV
					90	80	70	60	50	40	20	10	5	4	3	2	1	(10%)
					Intensity													
					0.2	0.35	0.5	0.64	0.8	0.97	1.4	1.76	2.08	2.16	2.27	2.44	2.7	
RH	0.12	0.03	67.84	4.68	0.03	0.05	0.07	0.09	0.11	0.13	0.19	0.24	0.29	0.3	0.31	0.33	0.37	0.20
EH	0.44	0.11	62.79	1.62	0.04	0.06	0.09	0.11	0.14	0.17	0.25	0.31	0.37	0.38	0.40	0.43	0.48	0.69
W80FL	0.51	0.13	27.30	7.45	0.19	0.33	0.47	0.60	0.76	0.92	1.32	1.66	1.97	2.04	2.14	2.31	2.55	0.35
H80ML	0.71	0.18	53.27	3.95	0.14	0.25	0.35	0.45	0.56	0.68	0.98	1.23	1.46	1.51	1.59	1.71	1.89	0.94
HBFL	0.43	0.11	38.88	3.17	0.07	0.12	0.17	0.22	0.27	0.33	0.48	0.60	0.71	0.74	0.78	0.84	0.92	0.42
HBML	0.77	0.19	38.00	1.65	0.06	0.11	0.16	0.20	0.25	0.31	0.44	0.56	0.66	0.68	0.72	0.77	0.85	0.73
RW	0.65	0.16	65.91	4.57	0.15	0.26	0.37	0.48	0.60	0.72	1.05	1.31	1.55	1.61	1.7	1.82	2.02	1.08
EW	0.62	0.16	65.71	6.98	0.22	0.38	0.54	0.70	0.87	1.06	1.53	1.92	2.27	2.35	2.47	2.66	2.94	1.03
ADGFL	0.50	0.12	0.37	0.09	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.00
ADGML	0.51	0.13	0.38	0.10	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.03	0.03	0.03	0.03	0.04	0.00
H80FL	0.83	0.21	49.86	4.75	0.2	0.35	0.49	0.63	0.79	0.96	1.38	1.74	2.05	2.13	2.24	2.41	2.67	1.04
W80ML	0.99	0.25	27.94	6.56	0.32	0.57	0.81	1.04	1.30	1.57	2.27	2.85	3.37	3.50	3.68	3.95	4.37	0.69
WBFL	0.58	0.14	5.18	1.00	0.03	0.05	0.07	0.09	0.12	0.14	0.20	0.25	0.30	0.31	0.33	0.35	0.39	0.07
WBML	0.78	0.20	4.95	0.96	0.04	0.07	0.09	0.12	0.15	0.18	0.26	0.33	0.39	0.41	0.43	0.46	0.51	0.10
WFINAML	0.44	0.11	42.45	6.83	0.15	0.26	0.38	0.48	0.60	0.73	1.06	1.33	1.57	1.63	1.72	1.84	2.04	0.47
WFINAFL	0.61	0.15	44.71	6.26	0.19	0.33	0.48	0.61	0.76	0.92	1.33	1.67	1.98	2.05	2.16	2.32	2.57	0.68
CWML	0.55	0.14	22.36	3.99	0.11	0.19	0.27	0.35	0.44	0.53	0.77	0.96	1.14	1.18	1.24	1.34	1.48	0.31
CWFL	0.58	0.14	23.04	4.44	0.13	0.22	0.32	0.41	0.51	0.62	0.90	1.13	1.33	1.39	1.46	1.57	1.73	0.33
CYFL	0.42	0.11	50.93	1.98	0.04	0.07	0.10	0.13	0.17	0.20	0.29	0.37	0.43	0.45	0.47	0.51	0.56	0.54
CYML	0.65	0.16	51.04	3.31	0.11	0.19	0.27	0.34	0.43	0.52	0.75	0.94	1.11	1.15	1.21	1.30	1.44	0.82

Approximate height at 80 days for female lambs (H80FL), approximate height at 80 days for male lambs (H80ML), ram height (RH), ewe height (EH), final carcass weight for female lambs (CWFL), final carcass weight for male lambs (CWML), carcass yield for female lambs (CYFL), carcass yield for male lambs (CYML), average daily weight gain for female lambs (ADGFL), average daily weight gain for male lambs (ADGML), approximate weight at 80 days for female lambs (W80FL), approximate weight at 80 days for male lambs (W80ML), ram body weight (RW), ewe body weight (EW), body weight at birth for female lambs (WBFL), body weight at birth for male lambs (WBML), H^2: broad-sense heritability; h^2: heritability in the strict sense; X: original population mean; S: standard deviation; AGV: additive genetic value.

Conclusions

High genetic variability and narrow-sense heritability were obtained in the characteristics weight at birth of male lambs and height at birth of lambs in both genders.

Average daily weight gain revealed high heritability with restricted meaning, this attribute being unrelated to the expressed meteorological variables, identifying effective potential for selection.

Pressures of 10% and selection intensities of 1.76 can be employed for most traits to be improved through industrial sheep crossbreeding.

Industrial crossing is effective not only due to heterotic effects but also due to additive genetic effects expressed in heritability.

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