Genetic and phenotypic correlations among production and reproduction traits in Afrino sheep

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Knowledge of genetic correlations among traits is essential for deriving a selection strategy for any breed. In this study, genetic and phenotypic correlations were estimated among weaning weight (WW), nine- (W9) and 18-month body weight (W18), clean fleece weight (CFW), mean fibre diameter (MFD), total weight of lamb weaned over three parities (TWW), as well as number of lambs born (NLB) and weaned (NLW) over three parities in the Carnarvon Afrino flock. Covariance components and genetic correlations were estimated using DFREML procedures. High genetic (0.915 to 0.980) and phenotypic (0.643 to 0.809) correlations were estimated among WW, W9 and W18. There were no significant genetic correlations between CFW and WW, W9 or W18, while the corresponding phenotypic correlations were 0.148, 0.143 and 0.095, respectively. Mean fibre diameter was neither genetically nor phenotypically significantly correlated with WW, W9 or W18, the estimated phenotypic correlations being close to zero. Low positive genetic (0.175) and phenotypic (0.163) correlations were estimated between CFW and MFD. High significant genetic (0.828 to 0.998) and phenotypic (0.791 to 0.920) correlations were obtained among the reproduction traits. High positive genetic correlations of 0.752, 0.768 and 0.892 were estimated between TWW and WW, W9 and W18 respectively. The corresponding phenotypic correlations were low positive (0.127, 0.238 and 0.264). The estimated genetic correlations of MFD and CFW with the reproduction traits were generally low to moderate negative. A negative genetic correlation of –0.523 was estimated between CFW and TWW. The results of this study imply that TWW, which is very important, but sex limited as well as a laborious and time-consuming measurement, can be improved by indirect selection for body weight at any age.

Vir die samestelling van 'n teelplan vir enige ras, is kennis van die genetiese korrelasies tussen eienskappe van kardinale belang. In hierdie studie is genetiese en fenotipiese korrelasies tussen speenmassa (WW), 9-maandemassa (W9), 18-maandemassa (W18), skoonvagmassa (CFW), veseldikte (MFD), totale massa lam gespeen oor drie lamkanse (TWW), sowel as aantal lammers gebore (NLB) en gespeen (NLW) oor drie lamkanse in die Carnarvonse Afrinokudde beraam. Kovariansie komponente en genetiese korrelasies is met behulp van DFREML-prosedures beraam. Hoë genetiese (0.915 tot 0.980) en fenotipiese (0.643 tot 0.809) korrelasies is tussen WW, W9 en W18 beraam. Daar is geen betekenisvolle genetiese korrelasies tussen CFW en WW, W9 en W18 verkry nie, terwyl ooreenstemmende fenotipiese korrelasies van 0.148, 0.143 en 0.095 beraam is. MFD was nie geneties of fenotipies met WW, W9 of W18 gekorreleerd nie. Lae positiewe genetiese (0.175) en fenotipiese (0.163) korrelasies is tussen CFW en MFD beraam. Hoë betekenisvolle genetiese (0.828 tot 0.998) en fenotipiese (0.791 tot 0.920) korrelasies is tussen TWW, NLB en NLW beraam. Hoë positiewe genetiese korrelasies van 0.752, 0.768 en 0.892 is beraam tussen TWW en WW, W9 en W18 onderskeidelik. Die ooreenstemmende fenotipiese korrelasies was laag positief (0.127, 0.238 en 0.264). Die beraamde genetiese korrelasies van MFD en CFW met die reproduksie-eienskappe was oor die algemeen laag negatief. 'n Negatiewe genetiese korrelasie van –0.523 is tussen CFW en TWW beraam. Die resultate van hierdie studie impliseer dat TWW, wat 'n baie belangrike, maar geslagsbeperkte asook arbeidsintensiewe en tydrowende meting is, deur middel van indirekte seleksie vir liggaamsmassa op enige ouderdom, verbeter kan word.

Keywords: Sheep, genetic correlations, reproduction traits, body weight, fleece traits

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Introduction

The Afrino is a white woolled breed developed under harsh conditions for wool and slaughter lamb production. Reproduction performance and growth rate are the main contributors to slaughter lamb production. In breeds such as the Afrino, the primary selection objective should be to increase the weight of lamb produced per ewe over her lifetime (Snyman *et al.*, 1996). As approximately 20% of the income from Afrino sheep is generated through wool production, fleece traits such as clean fleece weight and fibre diameter should also receive attention during selection.

In wool-producing breeds which have to produce and reproduce under adverse or sub-optimum conditions, hardiness and adaptability are of paramount importance. In studies regarding hardiness in small stock, a negative relationship between reproduction performance and fibre production relative to body weight has been indicated. Ewes which produced less wool relative to their body weight, weaned more kilograms of lamb over three parities than ewes which produced more wool relative to their body weight (Herselman *et al.*, 1998). This negative relationship was obtained irrespective of breed or environment. Before a viable breeding plan could be formulated for Afrino sheep, it was important to know the relationships between body weight, fleece weight and lifetime reproduction performance.

Numerous genetic and phenotypic correlations for different breeds have been published (see Fogarty, 1995 for a review). Some of the genetic correlations reported in these studies are highly variable, especially those estimated between fleece weight and body weight at different ages and the genetic correlations of the reproduction traits with the different body weight and fleece traits. No correlation estimates between these economically important traits are available for Afrino sheep.

The objective of this study was to estimate covariance components and genetic and phenotypic correlations among weaning weight, nine- and 18-month body weight, clean fleece weight, fibre diameter and reproduction traits in the Carnarvon Afrino flock.

Material and methods

Data

Data collected on the Carnarvon Afrino flock from 1972 to 1994 were used for this study. A detailed description of the Afrino breed, management and selection procedures followed in this specific flock is given by Snyman *et al.* (1995a).

The Carnarvon Afrino flock is kept on natural pasture at the Departmental Experimental Station near Carnarvon (30°59'S, 22°9'E) in the north-western Karoo region of the Republic of South Africa. The vegetation consists of sparse, mixed grass and karoo shrub and is described as arid karoo. The average annual rainfall is 209 mm and occurs mainly during the autumn months. The official grazing capacity is 5.5 ha per small stock unit, indicative of a very harsh environment.

Production traits included in the analysis were weaning weight (WW), 9-month body weight (W9), 18-month body weight (W18), clean fleece weight (CFW) and mean fibre diameter (MFD). The reproduction traits analysed were total weight of lamb weaned per ewe joined over three parities (TWW), number of lambs born per ewe joined over three parities (NLB) and number of lambs weaned per ewe joined over three parities (NLW). The number of animals with records for bivariate analyses was 3748 for the production traits and 618 for the reproduction traits.

Clean fleece weight (CFW) and mean fibre diameter (MFD) measurements were recorded at 16 months of age on a mid-rib fleece sample under the National Woolled Sheep Performance and Progeny Testing Scheme as follows :

CFW = Greasy fleece weight (adjusted to 365-days wool growth) × Clean yield percentage (16% moisture regain).

MFD = Determined by the air-flow procedure using a WIRA-fineness meter.

Total weight of lamb weaned per ewe joined over three parities (TWW) was calculated as follows: Firstly, within each lambing season, weaning weight for all lambs was adjusted to 120 days, followed by least-squares adjustments for sex of lamb. No adjustments were made for birth status. Secondly, total weight of lamb weaned per ewe joined for each lambing season (TWW/EJ) was calculated by adding the adjusted weaning weight for all the lambs weaned by each ewe in that specific lambing season. Subsequently, total weight of lamb weaned by each ewe over three parities (TWW) was calculated by adding TWW/EJ for the first, second and third parities.

The number of lambs born (NLB) and weaned (NLW) per ewe joined over three parities were calculated by adding the number of lambs born or weaned over the first, second and third parities.

Covariance component and genetic parameter estimation

Covariance components were estimated using the DFREML programme of Meyer (1991, 1993). Bivariate animal models, including the effects as summarised in Table 1, were fitted throughout. The fixed effects and covariates fitted for each trait are fully discussed by Snyman *et al.* (1995a), while the animal effects, as evaluated by Snyman *et al.* (1995b), were included for each trait.
It was assumed that :

$$V(a) = \Sigma_A * A \text{ and } V(e) = \Sigma_E * I$$

where A is a numerator relationship matrix, I is an identity matrix, Σ_A the q × q matrix of additive genetic covariances, Σ_E the matrix of error covariances and * denotes the direct matrix operator.

Full pedigrees were available, but parents with only a single link to one offspring were treated as unknown, as they did not contribute any information and unnecessarily increased the number of effects in the analysis (Meyer, 1994).

Initially, partial maximization of the likelihood, with respect to the covariance components only, was done by employing the Simplex procedure. For this run, variance components were fixed to their univariate values. After convergence (variance of function values in the Simplex was less than 10^{-8}), iterations were restarted, this time considering the complete parameter vector. Additional

Table 1 Fixed effects, covariates and random genetic effects[a] included for each trait[b]

	YSSEX	YSRS	RS	YSEWE	AD(Q)	AGE	DGE	MGE
WW	*	*			*	*	*	*
W9	*	*			*	*	*	*
W18	*	*			*	*	*	*
CFW	*		*		*	*	*	
MFD	*					*	*	
TWW				*			*	
NLB				*			*	
NLW				*			*	

[a] YSSEX = Subclass for year-season of birth and sex of the lamb; YSRS = Subclass for year-season of birth and rearing status of the lamb; RS = Rearing status; YSEWE = Year-season of birth of the ewe; AD(Q) = Age of dam (Quadratic covariate); Age = Age of lamb (Linear covariate); DGE = Direct genetic effect; MGE = Maternal genetic effect.

[b] See Table 2.

restarts were performed until no further improvement in log likelihood occurred. Approximate sampling errors were calculated by fitting a quadratic or cubic function to the profile likelihood for each parameter (Meyer & Hill, 1992). An estimate was considered significant when the sampling error was less than half that of the estimate.

Results

The mean and coefficient of variation (CV) for each trait are presented in Table 2. The CV for the reproduction traits is higher than for production traits (WW, W9, W18, CFW and MFD), which can be explained by the fact that some ewes produced zero and others up to eight lambs over three parities.

Table 2 Description of the data set

Trait[a]	Mean	CV (%)
WW	27.67 kg	19.69
W9	41.35 kg	17.09
W18	53.80 kg	18.98
CFW	2.01 kg	20.83
MFD	21.40 μm	7.68
TWW	116.80 kg	27.85
NLB	4.27	30.87
NLW	3.94	34.26

[a] WW = Weaning weight; W9 = Nine month body weight; W18 = Eighteen month body weight; CFW = Clean fleece weight; MFD = Mean fibre diameter; TWW = Total weight of lamb weaned per ewe joined over three parities; NLB = Number of lambs born per ewe joined over three parities; NLW = Number of lambs weaned per ewe joined over three parities.

Genetic and phenotypic correlations estimated between body weight, clean fleece weight, mean fibre diameter and the reproduction traits are presented in Table 3.

High genetic (0.915 to 0.980) and phenotypic (0.643 to 0.809) correlations were estimated among WW, W9 and W18. There were no significant genetic correlations between CFW and WW, W9 or W18, while the corresponding phenotypic correlations were 0.148, 0.143 and 0.095 respectively. Mean fibre diameter was neither genetically nor phenotypically significantly correlated with WW, W9 or W18, the estimated phenotypic correlations being close to zero. Low positive genetic (0.175) and phenotypic (0.163) correlations were estimated between CFW and MFD. High significant genetic (0.828 to 0.998) and phenotypic (0.791 to 0.920) correlations were obtained among the reproduction traits.

Inclusion of a maternal genetic effect for WW in the bivariate analysis with TWW lead to a genetic correlation of 1.00 being estimated. As DFREML forces the correlations between the parameter bounds, it is not certain whether the estimate is actually 1.00. Therefore, the genetic correlation obtained excluding a maternal effect for WW is given. High positive genetic correlations of 0.752, 0.768 and 0.892 were estimated between TWW and WW, W9 and W18, respectively. The corresponding phenotypic correlations were low positive (0.127, 0.238 and 0.264). The genetic as well as phenotypic correlations of NLB and NLW with three body weight traits increased with an increase in the age at which the body weight was recorded. None of these correlations, however, were significant.

The estimated genetic correlations of MFD and CFW with the reproduction traits were generally

Table 3 Heritabilities[a] (on diagonal), genetic (above diagonal) and phenotypic (below diagonal) correlations between body weight, clean fleece weight, fibre diameter and reproductive traits

	WW	W9	W18	CFW	MFD	TWW	NLB	NLW
WW	0.41	0.980	0.915	0.036	–0.102	0.752	–0.011	0.111
		(0.005)	(0.020)	(0.061)	(0.055)	(0.185)	(0.185)	(0.258)
W9	0.798	0.63	0.966	–0.009	–0.046	0.768	0.227	0.294
	(0.006)		(0.004)	(0.036)	(0.034)	(0.184)	(0.181)	(0.213)
W18	0.643	0.809	0.60	–0.091	–0.044	0.892	0.313	0.403
	(0.012)	(0.006)		(0.061)	(0.049)	(0.181)	(0.185)	(0.212)
CFW	0.148	0.143	0.095	0.62	0.175	–0.523	–0.328	–0.388
	(0.022)	(0.022)	(0.023)		(0.049)	(0.216)	(0.173)	(0.198)
MFD	–0.023	0.022	0.038	0.163	0.73	–0.110	–0.166	–0.085
	(0.023)	(0.023)	(0.023)	(0.023)		(0.223)	(0.176)	(0.197)
TWW	0.127	0.238	0.264	–0.055	–0.026	0.17	0.828	0.837
	(0.046)	(0.046)	(0.044)	(0.047)	(0.046)		(0.091)	(0.072)
NLB	0.041	0.120	0.155	–0.016	–0.032	0.791	0.23	0.998
	(0.038)	(0.050)	(0.048)	(0.044)	(0.047)	(0.016)		(0.000)
NLW	0.027	0.099	0.146	–0.018	–0.008	0.920	0.886	0.29
	(0.044)	(0.050)	(0.047)	(0.042)	(0.033)	(0.004)	(0.008)	

[a] Heritabilities obtained from Snyman *et al.* (1995b) and Snyman *et al.* (1996)

SE for heritabilities ranged from 0.03–0.08

low to moderate negative. The negative genetic correlation of –0.523 estimated between CFW and TWW is of special interest. It should, however, be viewed with caution because of the high standard error of the estimate. The phenotypic correlations estimated between the reproductive traits and CFW and MFD were also negative, but close to zero.

Discussion

With some exceptions, most of the correlations estimated in this study fall within the ranges reported in the literature (see Fogarty, 1995 for a review). Some of the genetic correlations reported in various studies are highly variable, especially those estimated between CFW and the different body weights and the genetic correlations of the reproduction traits with the different body weight and fleece traits.

Genetic correlation estimates are notorious for their inconsistency and large standard errors. Despite the small data set used for the present analysis, relatively low standard errors (SE) were obtained for the genetic correlations estimated among WW, W9, W18, CFW and MFD, as well as for the genetic correlations obtained among TWW, NLB and NLW. The SE obtained for the genetic correlation estimates of the reproduction traits with WW, W9, W18, CFW and MFD, were however, larger. This is obviously due to the relatively smaller data set available for the reproduction traits. All the SE obtained for the phenotypic correlation estimates were small and in accordance with those reported in the literature. Since the results of this study are of vital importance in the formulation of a selection strategy, they should be verified when more data become available.

The estimated genetic correlations which should have the most important influence on the formulation of a viable breeding plan for Afrino sheep are the high positive genetic correlations between TWW and body weight at all ages, as well as the negative correlations between CFW and the reproduction traits.

No correlation estimates between WW and TWW or W9 and TWW could be found in the literature, while only a few genetic correlation estimates between W18 and TWW are available. Most of these are lower than the estimate of 0.877 obtained for Afrino sheep in this study. Literature estimates of –0.16 and 0.62 (More O'Ferrall, 1976), 0.58 (Martin *et al.*, 1981) and 0.51 (Fogarty *et al.*, 1994) are reported for various breeds. Snyman *et al.* (1998) also estimated genetic correlations of 0.80 (0.04), 0.67 (0.13) and 0.72 (0.07) between 15–16 month body weight and TWW for Merino sheep at Tygerhoek, Grootfontein and Carnarvon respectively.

The genetic correlation between CFW and TWW (–0.523) estimated in the present study is of special interest, as it is not in line with corresponding estimates reported in the literature (0.02 by Basuthakur *et al.*, 1973; 0.53 by More O'Ferrall, 1976; 0.63 by Martin *et al.*, 1981; 0.29 by Fogarty *et al.*, 1994). It is also in contrast with those estimated by Snyman *et al.* (1998) for the Tygerhoek (0.41), Grootfontein (0.26) and Carnarvon (0.06) Merino flocks.

The small non-significant negative genetic correlation obtained between CFW and W18 (–0.091) in this study is also in contrast with the generally positive estimates, ranging from 0.04 (Gregory, 1982) to 0.63 (Blair, 1981), reported in the literature. The phenotypic correlation estimated in this study is also lower than other reported estimates.

According to the results of this study, selection for either TWW or W18 will decrease CFW, TWW more so than W18. Currently approximately 80% of the income from Afrino sheep is generated through mutton production. Selection for higher CFW would adversely affect other economically important traits, therefore less emphasis should be placed on the quantity of the wool and more on the quality. In a wool or dual-purpose breed CFW should, however, at least be maintained. MFD has low negative genetic correlations with all traits, except CFW. Negative selection pressure on MFD would therefore not adversely affect other economically important traits.

Possible selection criteria for Afrino sheep are WW, W9, W18 and TWW. The respective heritability estimates of these traits are 0.41, 0.63, 0.60 and 0.17 (Table 3).

Selection for TWW would result in an increase in body weight at all ages, as well as in NLB and NLW. This would also be accompanied by a favourable decrease in MFD, but a substantial unwanted decrease in clean fleece weight. However, TWW is sex limited as well as a laborious and time-consuming measurement. The results of this study imply that TWW can be improved by indirect selection for body weight at any age. Selection for W18 would be practical under certain circumstances, but not possible where selection takes place at an earlier age. In such instances, WW or W9 could be used as selection criteria. Preferably W9 would be a better choice, as it also includes a measure of post-weaning growth, as opposed to WW, which is largely influenced by maternal effects (Snyman *et al.*, 1995b). Furthermore W9 also has a higher heritability than WW.

Indirect selection will be more effective than direct selection if r_Ah_Y is greater than h_x, where r_Ah_Y is the correlation between breeding values of the desired trait X and phenotypic values of the selected trait Y, while h is the accuracy of direct selection (Falconer & Mackay, 1996). As r_Ah_Y (0.432) is greater than h_x (0.412), indirect selection for WW to improve TWW should be more effective than direct selection. In the case of indirect selection on W9, r_Ah_Y (0.578) is also greater than h_x (0.412). A higher selection intensity with indirect selection for body weight is also possible because males can be selected, which should make it even more effective. In practise it is, however, difficult to quantify selection intensity as other traits are also considered.

Conclusion

The holistic approach of this study, where production and reproduction traits were analysed simultaneously, provided useful information for aggregate genetic improvement and could be followed for other breeds and with other data sets. The problem with lifetime reproduction traits is that it normally takes a long time to obtain sufficient data for accurate analyses. Although results obtained in this study can be utilized in the interim, they should be verified when more data become available. An efficient and reliable selection index could then be constructed.

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