Genetic and phenotypic correlations between production traits and adult body condition scores in New Zealand merino ewes

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Abstract

Genetic and phenotypic correlations between adult body condition scores (BCS) throughout the production cycle and eye muscle depth, fat depth, two-year-old greasy fleece weight, fibre diameter, staple length and staple strength were estimated from 2,007 pedigree-recorded merino ewes born between 2013 and 2015. The heritability estimates of BCS at pre-mating, mid-pregnancy, pre-lambing and weaning were 0.66, 0.39, 0.46 and 0.32 respectively. The heritability estimates for yearling greasy fleece weight, fibre diameter and staple length were 0.65, 0.86 and 0.73 respectively, and all these traits were positively genetically correlated with BCS. The genetic correlations among the four BCS measurements ranged from 0.39-0.83, while the phenotypic correlations ranged from 0.22-0.45. Genetic correlations between BCS and fat depth ranged from 0.67 to 0.83. Given the high heritability of BCS and high genetic correlations between BCS measurements, there is clear scope for selection to alter BCS. Mating appears to be the best time to record BCS for genetic selection, as it had the greatest heritability estimate and the greatest genetic correlations with ultrasound measurements of fat depth and eye-muscle depth and all wool traits except fibre diameter coefficient of variation and greasy fleece weight.

Keywords: sheep; heritability; merino; wool; ultrasound; fat depth; fibre diameter; body condition score

Introduction

Body condition score (BCS) in sheep is a practical management tool used to measure nutritional status (Jefferies. 1961). The advantages of BCS include its ability to identify animals in a state of low nutrition, its low cost, its ease of measurement and its value in comparing animals independent of their live weight and/or gut fill. The BCS is assessed subjectively using a 1-5 scale (Jefferies. 1961) in which one is emaciated and five is obese. It has been well documented that BCS of ewes can influence a number of productive traits (Gunn et al, 1991; Kenyon et al. 2012; Kenyon et al. 2014) including fleece traits such as greasy fleece weight and fibre diameter (Walkom & Brown. 2017).

Sheep farmers in New Zealand can use genetic selection to improve profitability. Traits in the current New Zealand standard maternal-worth index include number of lambs born, lamb survival, lamb growth, adult ewe size, parasite resistance and wool production (Sheep Improvement Limited. 2017). The wool traits which are generally accepted to be important in merino flocks are fibre diameter and clean fleece weight. A breeding value for BCS has recently been made available for sheep in NZ, but the trait has not yet been included in the NZ standard maternal-worth index (Sheep Improvement Limited, 2016), nor has it yet been considered in New Zealand merino flocks.

Heritability estimates of BCS have been reported for both Australian merino ewes and New Zealand crossbred ewes and ranged from 0.08 to 0.30 (Everett-Hincks & Cullen. 2009; Shackell et al. 2011; Walkom et al. 2014a; Walkom et al. 2014b; Walkom et al. 2016; Brown et al. 2017; Walkom & Brown. 2017). Heritability estimates of BCS have not been reported to date for New Zealand merinos.

Walkom and Brown (2017) reported that the genetic correlations among lamb growth traits and ewe adult BCS in Australian crossbred ewes were high, but the genetic correlations with lamb carcass traits were only moderate. In NZ crossbred sheep, the genetic correlations between BCS and live weight have been reported by Shackell et al. (2011), but there is limited publication of genetic correlations between BCS and other production traits, with no information about NZ merinos. The aim of this study was to determine the heritability of BCS at each adult measurement throughout the production cycle of merino ewes in New Zealand and estimate their phenotypic and genetic correlations to production traits.

Materials and methods

Animals

The data analysed were collected in the NZ Merino Central Progeny Trial (CPT) flock located in Omarama, Otago. The flock consisted of ewes born to 564 synchronised merino ewes in 2013, 564 synchronised ewes in 2014 and offspring from the 2013 born ewes that were born in 2015. The resulting 2,004 ewes from the three birth years were the offspring of 129 sires and were naturally mated first as two year olds. The traits recorded on the ewes included; one-year-old (yearling) greasy fleece weight (gfw1), eye-muscle depth (EMD), fat depth; two-year-old greasy fleece weight (gfw2), pregnancy diagnosis (PD) and two-year-old body condition score (BCS). The BCS at weaning was only measured in the 2013-born and 2014-born cohorts. Fat depth and EMD measurements were taken as a yearling, as measurement at that age has previously been reported as having a greater heritability than the same measures at younger post-weaning ages (Mortimer et al. 2017).

Ewes were weighed and recorded for BCS four times as two year olds, including immediately prior to mating (April), at mid-pregnancy (June), just prior to lambing (September), and at the time of weaning (December). The BCS were measured on a 1-5 scale (Russel et al. 1969), with 0.25 increments. Additional data recorded included record date, birth year, sire, dam and rearing rank. Dam was determined by visual identification of lambs to their dams at birth for the 2013-born ewes and by DNA analysis for 2014-born ewes. Sire was determined by DNA analysis. From these data, animals which had at least a sire known were included.

Statistical analysis

Estimates of (co)variance components were obtained using the Julia for Whole-Genome Analyses Software (JWAS) package. A multivariate animal model was fitted that included the fixed effects of ewe birth year (2013, 2014 or 2015), record year (2015, 2016 or 2017) and the ewes rearing rank (1 or 2) for pre-mating BCS and mid-pregnancy BCS, with the addition of an effect for number of lambs carried (0, 1 or 2) for analysis of BCS before lambing and at weaning. Animal was fitted as a random effect. Least-squares mean and standard errors of the mean for each trait were obtained using the GLM procedure of SAS 9.4 (SAS Institute Inc., Cary NC, North Carolina).

Results

The mean BCS in two year old ewes were greatest at mating and declined to weaning (Table 1), the standard deviation of BCS at the different time points ranged from 0.27-0.31. Mean number of lambs born was 1.14 and the mean fibre diameter was 18.49 microns.

The 2013-born ewes had the greatest ($P<0.01$) BCS at mating and mid-pregnancy, but the lowest BCS before lambing and at weaning (Table 2). Fibre diameter was finest ($P<0.01$) in the 2013-born ewes and greatest ($P<0.01$) in 2014-born ewes. Staple length was greatest ($P<0.01$) in the 2013-born ewes and least in 2015-born ewes.

Heritability for BCS ranged from 0.32 to 0.66 (Table 3) and was highest at the pre-mating measure. The heritability for ultrasound measurements of fat depth and EMD ranged from 0.52 to 0.64 and the wool-trait heritability ranged from 0.61 to 0.86 with fibre diameter having the highest heritability. The genetic correlations between BCS measurements ranged from 0.39-0.83, while the phenotypic correlations ranged from 0.22-0.45. Genetic correlations between BCS and fat depth ranged from 0.56-0.83 and between BCS and EMD ranged from 0.54-0.87 while the phenotypic correlations ranged from 0.20-0.47 and from 0.24-0.53 respectively. The genetic correlations between BCS and yearling greasy fleece weight, fibre diameter, staple length and staple strength were positive, whereas the correlations with fibre diameter CV and two-tooth greasy fleece weight were negative, with similar trends for the phenotypic correlations.

Table 1 Summary statistics for traits including Body Condition score (BCS) at pre-mating, mid-pregnancy, pre-lambing and weaning, yearling greasy-fleece weight (Gfw1), ultrasound fat depth, eye-muscle depth (EMD), two-year-old greasy-fleece weight (Gfw2), pregnancy rate, fibre diameter, fibre-diameter coefficient of variation (CV), staple length and staple strength.

Trait	Animals	Sires	Mean	SD	Min	Max
Mating BCS	2,004	129	2.89	0.27	2.00	4.00
Mid pregnancy BCS	1,980	129	2.89	0.31	1.75	4.00
Pre-Lambing BCS	1,433	129	2.83	0.28	1.75	3.50
Weaning BCS	964	79	2.75	0.28	2.00	4.00
Fat depth (mm)	1,323	90	2.59	0.77	1.00	7.00
EMD (mm)	1,976	41	25.11	2.86	18	37
Gfw1 (kg)	1,978	130	3.20	0.86	1.6	5.1
Gfw2 (kg)	1,255	82	4.00	0.65	2.4	6.9
Pregnancy Rate	1,287	129	1.14	0.70	0	2
Fibre diameter (μm)	2,003	129	18.49	2.16	14.3	28.3
Fibre diameter CV (%)	2,003	129	17.78	2.44	11.9	27.5
Staple length (mm)	2,003	129	92.01	11.99	56	141
Staple strength (N/tex)	2,003	129	37.46	10.05	4	81

Discussion

The mean BCS in the current study was consistent with the mean BCS reported by Shackell et al. (2011) in New Zealand crossbred ewes, but was lower than that reported by Walkom et al. (2014b) and Walkom & Brown (2017) for Australian merino and crossbred ewes. The BCS in merino-cross ewes reported by Walkom & Brown (2017) showed a decline from mating through to weaning, which was consistent with the current study. This decline in BCS is to be expected, as ewes use their body reserves to provide energy for pregnancy and lactation. The mean fat depth, EMD, fibre diameter, fibre diameter CV, staple length and staple strength in the current study are consistent with those reported by Walkom and Brown (2017). Yearling greasy fleece weight in the current study was slightly greater than that reported by Walkom and Brown (2017).

The standard deviation for BCS ranged from 0.23-0.26 in the current study and was lower than the standard deviation (0.53-0.58) reported by Walkom & Brown (2017), indicating there was less variation in the data of the current study. Mean fat depth of 2.59 mm was consistent with other studies in Merino sheep (Swan et al. 2016; Mortimer et al. 2017), whilst the standard deviation of 0.77 was lower than the standard deviation reported in these studies. It is

Table 2 Least-squares mean ± SEM of body condition score (BCS) at pre-mating, mid-pregnancy, pre-lambing and weaning, yearling ultrasound measurements of fat depth and eye muscle depth, wool traits of yearling and two-year-old greasy fleece weight, fibre diameter, coefficient of variation (CV) of fibre diameter, staple length and staple strength.

Trait	n	Birth year				Ewe Rearing Rank	
		2013	2014	2015	n	1	2 +
BCS							
Mating	2,011	2.96±0.01[a]	2.90±0.01[b]	2.83±0.01[c]	962	2.91±0.01[b]	2.95±0.01[a]
Mid-Pregnancy	1,984	3.00±0.01[a]	2.78±0.01[c]	2.88±0.01[b]	961	2.84±0.01[b]	2.89±0.01[a]
Pre-lambing	1,437	2.72±0.02[c]	2.79±0.01[b]	2.92±0.01[a]	705	2.76±0.01	2.77±0.01
Weaning	965	2.66±0.01[b]	2.85±0.01[a]		718	2.80±0.02[a]	2.74±0.01[b]
Fat depth	1,980	2.02±0.02[c]	2.98±0.04[a]	2.76±0.03[b]	578	2.99±0.04	2.96±0.05
Eye Muscle Depth	1,980	24.2±0.1[c]	26.5±0.1[a]	25.0±0.1[b]	947	25.7±0.1	25.5±0.1
GFW1	1,982	3.61±0.02[a]	3.25±0.02[b]	3.06±0.02[c]	949	3.43±0.03[a]	3.23±0.02[b]
GFW2	1,255	3.61±0.02[b]	4.39±0.02[a]		943	4.15±0.03[a]	3.98±0.03[b]
Fibre Diameter	2,007	17.7±0.08[c]	19.5±0.08[a]	18.4±0.08[b]	958	18.7±0.10	18.9±0.09
Fibre Diameter CV	2,007	17.5±0.09[b]	16.9±0.09[c]	18.8±0.09[a]	958	16.9±0.1	17.2±0.1
Staple Length	2,007	95.5±0.5[a]	91.0±0.5[b]	89.6±0.4[c]	958	91.9±0.6[b]	94.0±0.5[a]
Staple Strength	2,007	37.2±0.3[b]	44.5±0.3[a]	31.7±0.3[c]	958	41.9±0.4	41.4±0.4

[a, b, c] means with different superscripts horizontally differ ($P<0.05$) between main effects within rows

Table 3 Estimates of heritabilities (diagonal), phenotypic (above diagonal) and genetic (below diagonal) correlations ± SEM for body condition score (BCS) prior to mating, mid pregnancy, pre-lambing and weaning, ultrasound scanning measurements of fat depth and eye muscle depth (EMD) as a one-year-old, fleece weight as a one- two- and three-year-old, fibre diameter, coefficient of variation (CV) of fibre diameter, staple length and staple strength.

Trait	BCS pre-mating	BCS mid-pregnancy	BCS pre-lambing	BCS weaning	Fat Depth	EMD	GFW1	GFW2	Fibre diameter	Fibre diameter CV	Staple length	Staple strength
BCS pre-mating	0.66±0.01	0.42±0.01	0.43±0.01	0.34±0.01	0.47±0.01	0.53±0.01	0.52±0.01	0.46±0.01	0.30±0.01	–0.09±0.01	0.20±0.01	0.05±0.01
BCS mid-pregnancy	0.71±0.01	0.39±0.01	0.45±0.01	0.22±0.01	0.20±0.01	0.24±0.01	0.20±0.01	0.24±0.01	0.20±0.01	–0.09±0.01	0.09±0.01	0.02±0.01
BCS pre-lambing	0.83±0.01	0.79±0.01	0.46±0.01	0.34±0.01	0.34±0.01	0.40±0.01	0.05±0.01	–0.09±0.01	0.27±0.01	–0.09±0.01	0.11±0.01	0.03±0.01
BCS weaning	0.71±0.01	0.39±0.01	0.72±0.01	0.32±0.01	0.28±0.01	0.30±0.01	0.03±0.01	–0.10±0.01	0.17±0.01	–0.03±0.01	0.07±0.01	0.02±0.01
Fat depth	0.83±0.01	0.56±0.01	0.80±0.01	0.67±0.01	0.52±0.01	0.71±0.06	–0.09±0.01	0.09±0.01	0.31±0.01	–0.08±0.01	0.16±0.01	0.07±0.01
EMD	0.87±0.01	0.54±0.01	0.80±0.01	0.72±0.01	0.88±0.05	0.64±0.01	0.05±0.01	0.10±0.01	0.27±0.01	–0.12±0.01	0.19±0.01	0.04±0.01
GFW 1	0.19±0.01	0.10±0.01	0.19±0.01	0.09±0.01	0.49±0.01	0.53±0.01	0.65±0.01	0.69±0.01	0.19±0.01	0.06±0.01	0.17±0.01	0.06±0.01
GFW 2	0.15±0.01	–0.08±0.01	–0.18±0.01	–0.24±0.01	–0.01±0.01	–0.05±0.01	0.76±0.01	0.52±0.01	0.14±0.01	0.11±0.01	0.15±0.01	0.03±0.01
Fibre diameter	0.51±0.01	0.38±0.01	0.46±0.01	0.41±0.01	0.46±0.01	0.38±0.01	0.21±0.01	0.07±0.01	0.86±0.01	0.20±0.01	0.40±0.01	0.28±0.01
Fibre diameter CV	–0.07±0.01	–0.21±0.01	–0.09±0.01	0.17±0.01	–0.11±0.01	–0.18±0.01	0.04±0.01	0.11±0.01	0.16±0.01	0.61±0.01	0.04±0.01	–0.26±0.01
Staple length	0.27±0.01	0.17±0.01	0.17±0.01	0.10±0.01	0.21±0.01	0.26±0.01	0.19±0.01	0.09±0.01	0.06±0.01	–0.26±0.01	0.73±0.01	0.18±0.01
Staple strength	0.03±0.01	0.05±0.01	0.04±0.01	0.09±0.01	0.06±0.01	0.03±0.01	0.04±0.01	0.04±0.01	0.02±0.01	–0.44±0.01	–0.02±0.01	0.71±0.01

consistent, through all the traits in the current study, that the variation in the current study is less than the variation in the results presented by Walkom & Brown (2017) which included crossbred animals and measured BCS on 1-5 scale with 0.5 increments.

Heritability for BCS in the current study ranged from 0.32-0.66 which is greater than other published heritabilities for Australian Merino ewes of 0.08-0.11 reported by Walkom et al. (2014b) and 0.11 reported by Brown et al. (2017). Heritabilities of BCS reported in other breeds ranged from 0.15 to 0.30 (Shackell et al. 2011; Walkom et al., 2016; Walkom & Brown, 2017) which were lower than the heritabilities reported in the current study. The EMD heritability in the current study is greater than reported heritabilities of 0.24 (Safari et al. 2005) and 0.22 (Brown et al. 2017). Eye-muscle width measurements were not taken into account in this study, which is supported by Safari et al. (2005) who reported a low heritability for eye-muscle width of 0.06, representing the poor accuracy of this ultrasound measurement. Fat-depth heritability estimates in the current study were higher than those reported in previous studies of 0.19-0.26 (Safari et al. 2005; Swan et al. 2016; Mortimer et al. 2017). Yearling greasy fleece weight heritability was 0.65 ± 0.01, which is greater than other reported yearling greasy fleece weight of 0.32-0.57 (Swan et al. 2016; Mortimer et al. 2017). The fibre-diameter heritability of 0.86 in the current study is slightly higher than those reported by Mortimer et al. (2017), whereas the fibre diameter CV heritability in the current study was much higher than 0.34 reported by Mortimer et al. (2017) and slightly higher than the 0.50 reported by Swan et al. (2016). Staple strength and staple length heritabilities were 0.73 and 0.71 in the current study, which were greater than those reported by Swan et al. (2016) of 0.35 and 0.66 respectively.

The higher heritability estimates in the current study compared to those in published literature for Merino ewes could be due to the low variation in the data, which results in low estimates of phenotypic variance. The phenotypic variance is further underestimated due to contemporary groups that were not recorded, but were present in the flock, therefore could not be adjusted for, such as birth rank or age of dam. Another issue overestimating the heritability estimates are the sire and dam groups being unique to each year cohort, resulting in the year effect confounding with sire group inflating the genetic variance and the heritability estimates. The dams were unique to each year cohort and were not pedigree recorded, therefore they were missing key information to link the pedigree across cohort year.

The pre-mating, mid-pregnancy, pre-lambing and weaning BCS were moderately phenotypically correlated (Table 3), but were highly genetically correlated and also highly genetically correlated to fat depth and EMD. This is consistent with the findings of Walkom & Brown (2017) and Brown and Swan (2014), confirming that a single record of BCS each year is sufficient to assess the genetic potential for BCS. The BCS were low-to-moderately phenotypically correlated to the wool traits of fibre diameter, yearling greasy-fleece weight and staple length and moderately genetically correlated to these wool traits, which is in agreement with the phenotypic correlations reported by Walkom and Brown (2017) for yearling fibre diameter and staple length.

The pre-mating BCS has consistently had the highest genetic correlation with all traits, which is in agreement with the correlations reported by Walkom and Brown (2017). The reason for this could be that the ewes are not affected by pregnancy or lactation before mating; heritability indicates this is the BCS measurement under greatest genetic influence.

The heritabilities reported in the current study indicate that a moderate-high rate of genetic gain could be achieved for BCS and a high rate of genetic gain could be achieved for lamb growth and wool traits. The heritability estimates and genetic correlations of the current study would be strengthened by having records of the contemporary groups of birth rearing rank and age of dam recorded on the animals. The current pedigree file included only recorded data of the ewes with recorded sire whereas, if there were also data recorded for dams, it would have improved the linkage across years. In conclusion, BCS could be useful to be recorded by more breeders to include in the genetic evaluation system to improve accuracy of selection for wool traits in NZ Merino ewes. More high-quality data with linkage across sires and dams are required for BCS to confirm these associations.

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