A comparison of methods to pre-adjust data for systematic environmental effects in genetic evaluation of sheep

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Short title: Adjustment of data prior to genetic evaluation of sheep

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Abstract

Sheep performance data are routinely adjusted to account for systematic environmental effects but little attention has been given to the choice between the methods available. This study compares methods to adjust liveweight measurements for individual age (within group regression versus age intercept) and age of dam (dam age class versus quadratic polynomial on dam age) and fat and eye muscle depth for liveweight (within group regression versus quadratic polynomial on weight). Criteria for comparison included: 1) changes in phenotypic variance and heritability estimates; 2) predictive ability of resulting estimated breeding values (EBVs); 3) correlation between adjusted and adjustor variables; and 4) ease of computation. With the exception of dam age adjustment of liveweight, adjustment methods did not influence the phenotypic variance of the trait being adjusted. Increases in the direct heritability were observed for liveweight adjusted using the age intercept, dam age class and quadratic methods, and fat depth using quadratic adjustment for liveweight. Within group regression based adjustments generally resulted in a reduction of direct heritability. Maternal heritability and permanent environment due to dam were unaffected by the adjustment methods utilised. The regression of progeny performance on sire estimated breeding value also indicated that the age intercept produced estimated breeding values that were closer to the expectation than those using the within group regression adjustment. The age intercept and quadratic polynomial methods of adjustment appear to be slightly more appropriate for genetic evaluation purposes.

Keywords: Data adjustment, sheep, liveweight, age, dam age, fat depth, eye muscle depth

Introduction

Accurate genetic evaluation of animals requires data to be corrected to accommodate differences in known systematic environmental effects that influence the growth and performance of livestock. These effects usually relate to differences between animals within contemporary groups (CG) that influence phenotypic performance but are not a direct result of genetic differences between these animals. Adjustment of performance records for known environmental effects aims at reducing the non-genetic or environmental components of phenotypic variance (Raymond 1982). In the lamb industry examples include age of the animal, age of the animal's dam, birth type and rearing type.

The methods used to adjust data for these effects are varied and have been compared by Raymond (1982). Methods of adjustment can be classed as additive, where a pre-determined number of units of the trait are added for each unit of time or weight, or multiplicative in which the observation is increased or decreased on a percentage basis. Recent genetic evaluation has utilised five main methods of adjustment: 1) Simple multiplicative factors calculated from class means; 2) linear regression; 3) ordered polynomials which work additively; 4) additive class effects; and 5) age intercept adjustment which is a multiplicative adjustment.

A regression of liveweight (LWT) on age has been commonly used to adjust LWT to a standard age. This is achieved by using the within group relationship between age and weight. Within group regression adjustments are additive type adjustment methods. Instead, the age intercept method is a multiplicative adjustment method based on extrapolation from a straight line that runs from the age-weight record to an age-intercept on the x-axis corresponding to zero weight. The age intercept methods are routinely used in BREEDPLAN (Johnston *et al.* 1999) and now in OVIS (Brown *et al.* 2000) for national genetic evaluation of beef cattle and sheep, respectively. The reasoning behind the age intercept adjustment is that it allows differences in weights across animals within a CG to get larger or smaller over time, as would be biologically anticipated. The age-intercept is calculated by estimating the linear relationship between liveweight and age over all animals after accounting for fixed and random effects. The equation for this relationship is then back-solved to obtain the value where weight is equal to zero (x axis intercept).

A number of other methods for correcting liveweight for age have been investigated. These include pooled regression (within sire groups), average daily gain and least squares (Gregory *et al.* 1976; Gregory *et al.* 1977a). The method used to correct liveweight observation for age must also be capable of eliminating variations in weights caused by non-random use of sires during the mating period (Gregory *et al.* 1977b). Non-random use of sires can lead to age being heritable (Gregory *et al.* 1977b). For example if a particular sire is consistently used in as a back-up sire in an AI program all of the progeny of this sire are going to be above average. Given the likelihood of these mating structures in today’s sheep flocks this is an important consideration.

The influence of age of dam on progeny performance has been identified in most livestock species (Gregory *et al.* 1977c; Wilson *et al.* 1996; Bourdon, 1997, pp. 170-173). Data are commonly adjusted to a standard age when dams are at peak production. If the dam is younger or older than this standard age the LWT will be adjusted up to compensate accordingly. Animals can be allocated to dam age classes and their data adjusted using a simple additive adjustment factor for the respective dam age class. Alternatively, one could use higher order polynomial adjustments. BREEDPLAN and OVIS routinely use quadratic functions to multiplicatively adjust LWT for dam age effects.

Strong phenotypic and genetic relationships exist between age, LWT, fat depth (FATD) and eye muscle depth (EMD) (Atkins *et al.* 1991; Brash *et al.* 1992; Gilmour *et al.* 1994). As a result, FATD and EMD are commonly adjusted for differences in age or LWT at measurement to compensate for these relationships. In beef cattle, heritability estimates for carcase traits tend to be higher when adjusted for weight rather than age (Meyer 1999). The two main methods used are regression of FATD and EMD on LWT within CG and quadratic adjustment. These two methods are similar to those described above.

Optimal selection of adjustment methods should involve the comparison of actual and adjusted observations with the adjuster variables, variances of the actual observations and adjusted observations and the effects of the adjustment factors on the heritability estimates (Raymond 1982). Further, the predictive ability of EBVs as computed from the regression of progeny performance of parents EBVs should also help identify the optimum adjustment methods.

Based on these criteria, the aim of this paper is to compare a number of methods used to adjust performance data for systematic environmental effects due to individual age, dam age and LWT prior to genetic evaluation.

Materials and Methods

Post-weaning data on LWT and ultrasound scans of FATD and EMD were retrieved from the White Suffolk breed in the LAMBPLAN (Banks 1994) database, based on pedigree known and observations recorded. Initial edits removed records beyond 3 standard deviations within CG for age, LWT, FATD and EMD. Also, only those animals with dams younger than 10 years of age and from CGs with more than 40 animals were included. This editing resulted in 8418 animals being in the data file with 164 CGs and 19236 animals in the pedigree file. There were 5411 dams and 539 sires with progeny with data. These data were used to calculate adjusted observations using two methods each for individual age and age of dam adjustment of LWT, and FATD and EMD adjustment for LWT.

Adjustment of LWT for individual age

Regression

LWT observations were adjusted using a linear regression of LWT on age for all animals within a CG. For the ith CG this regression coefficient was calculated from a weighted average using the following formula:

$$\frac{(Ns \times bs) + (Ni \times bi)}{Ns + Ni},$$

where Ns = number of animals in a standard CG,

Ni = number of animals in the ith CG,

bs = standard regression of weight on age,

bi = actual regression of weight on age for the ith CG.

Hence the influence of the standard regression coefficient will diminish as the size of the ith CG increases. The standard CG size was the most common (mode) CGs size in the data file. This regression coefficient was then used to adjust all LWT measurements to the average age of all animals in that CG.

Age Intercept

Adjusted LWT using the age intercept method was calculated using the following formula:

$$Y_a = Y_o (A_a - A_i) / (A_o - A_i)$$

Where: Y_a = Adjusted weight,

Y_o = Observed weight,

A_a = Standard age,

A_i = Age intercept corresponding to zero weight,

A_o = Observed age.

Expectation of adjusting LWT for age using these methods

To illustrate how within group regression and age intercept adjustment work a data set was deterministically simulated using SAS (1990). This data set consisted of 180 animals ranging in age from 100 to 280 days. Animals were allocated to three CGs based on age. Liveweight were assigned using the following growth function, $wt=70*(1-0.93e^{-0.005Age})$, which resulted in similar weights at the start, middle and end of the growth period to those in the data used in this study. Adjustment factors were then estimated using SAS (SAS 1990) and applied to these fabricated data. Results are illustrated in Figure 1.

[Please insert Figure 1 near here]

Both the within group regression and age intercept adjustment methods nullify the relationship between age and liveweight within groups. However over all data there is a positive relationship between within group regression adjusted liveweight and age.

Adjustment of LWT for age of dam

Dam age classes

Animals were classified into three dam age classes: 1 to 2 years, 3 to 5 years and 6 to 10 years old. Animals within each of these classes received a simple multiplicative adjustment. For example, if the estimated adjustment factor for dam age class 1 is 1.02 then all animals with a dam age class of 1 would have their liveweight observations multiplied by 1.02.

Quadratic

LWT was adjusted for dam age using the following formula;

$$Y_a = Y_o / ((I + Lx + Qx^2) / I)$$

Where: Y_a = Adjusted weight
Y_o = Observed weight
x = Age of dam - standard age of dam
I = Intercept value
L = Linear component
Q = Quadratic component

The standard age of dam used in this equation was the age at which dams were at maximum production.

Combined adjustment of LWT for individual age and age of dam

It is common practice to adjust LWT for both individual age and age of dam. Four additional adjusted observations were created by adjusting LWT for age by within group regression or age intercept and then adjusting this weight for dam age using dam age class or quadratic adjustment.

Adjustment of FATD and EMD for LWT at measurement

Regression

The regression based adjustments of FATD and EMD to a standard LWT were achieved using the same method as described in the regression adjustment of LWT for age.

Quadratic

Adjustment of carcase traits for LWT using the quadratic method was performed in the same manner as described for the quadratic adjustment of LWT for age of dam.

Estimation of adjustment factors

The standard regression coefficient was the average regression coefficient of LWT on age from all groups in the data. For each CG a regression coefficient was calculated as described earlier which weighted the observed coefficient by the number of animals in each CG. This coefficient for each group was used to adjust the LWT of each animal in that group to the standard age. The standard age used was the average age of all the animals in the CG.

The age intercept and the coefficients for the intercept, linear and quadratic components for adjustment of liveweight for dam age were estimated using an animal model in ASREML (Gilmour *et al.* 1999). The model included adjusted age (i.e. observed age minus standard age), adjusted dam age (i.e. observed minus the standard age of dam), and adjusted dam age squared as covariates, the fixed effect of CG (defined as flock, sex, year of measurement, management group, birth type and rearing type) and the random effects of direct and maternal genetic components, permanent environment due to dam, and residual. The age-intercept was calculated by back-solving the linear regression equation based on the solution estimates from the ASREML analysis. This analysis was then re-run after removing the dam age covariates and replacing them with a dam age class. Solutions for dam age class from this analysis were used to calculate the adjustment factors. Multiplicative factors were computed from the ratio of dam age class 2 to dam age classes 1 and 3 respectively.

Adjustment factors for within group regression adjustment of carcase traits for LWT were calculated in the same manner as described for the regression based adjustment of LWT for age.

Coefficients for the intercept, linear and quadratic components to adjust carcase traits for LWT were estimated using an animal model in ASREML (Gilmour *et al.* 1999). The model included adjusted weight (i.e. observed weight minus the standard weight) with linear and quadratic components, the fixed effect of CG (defined as flock, sex, year of measurement, management group, birth type, rear type and dam age class) and the random effects of additive genetic and residual components.

Statistical Analysis

Variance components were estimated for each observed and adjusted trait using an animal model in a univariate analysis with ASREML (Gilmour *et al.* 1999). CG was the only fixed effect fitted. CG was defined using flock, sex, year of measurement, management group, birth type and rearing type. All possible combinations of adjustment methods for each trait were explored to yield a total of 15 models (Table 1).

When LWT was not adjusted for dam age, dam age class was also included in the definition of CG (models 1, 2 and 3 in Table 1). The analysis of LWT included the random effects of direct genetic, maternal genetic, direct-maternal genetic covariance and permanent environment due to dam. The analysis of FATD and EMD included the random effect of animal.

[Please insert Table 1 near here]

To further investigate the differences between models 1, 6, 7, 8 and 9 an additional analysis was performed. A random 10% of the animals in the data file were removed. An ASREML analysis was then performed using the remaining 90% of the data to produce EBVs. LWT observations from previously removed animals were regressed against the EBVs of their sires. This regression analysis included the fixed effect of contemporary group in the model using the GLM procedure of SAS (1990). This analysis was repeated 20 times to produce the mean, minimum and maximum regression coefficients for each model.

The phenotypic relationships between observed traits, adjusted traits and the adjustment variables were compared using simple and residual correlations. The simple correlations were estimated over all data without fitting any fixed effects and using the CORR procedure of SAS (1990). The phenotypic correlations were estimated using the GLM procedure of SAS. For LWT the model included the fixed effect of CG and covariates of age and dam age. The model for FATD and EMD included the fixed effect of CG and covariate for LWT with linear and quadratic components.

Results

Descriptive statistics for the observed traits are presented in Table 2. With the exception of EMD, positively skewed distributions were observed for all traits. Values in Table 2 are similar to post-weaning observations presently recorded in the LAMBPLAN database for the White Suffolk breed.

[Please insert Table 2 near here]

Estimates of the adjustment factors are given in Table 3. These adjustment factors were used to adjust observations for each trait. Standard points in Table 3 are very similar to the means for these traits given in Table 2. Within CG regression coefficients ranged from 0 to 0.87 kg/d, 0 to 0.16 mm/kg and 0 to 0.52 mm/kg for the regression adjustment of LWT for age, FATD for LWT and EMD for LWT, respectively. Quadratic components for adjustment of LWT for dam age and, FATD and EMD for LWT were all negative, indicating a decrease in performance after the standard point has been reached.

[Please insert Table 3 near here]

Mean, standard deviation, minimum and maximum for the adjusted observations are given in Table 4. The means of the adjusted traits are similar to those of the unadjusted traits. The variation and range in the adjusted LWT were greater than those for the observed LWT for age-intercept and the combined adjustment for individual age and dam age. Within group regression and quadratic adjustment of FATD and EMD for weight resulted in less variation between adjusted observations compared to the observed measurements. This reduction in variance was more apparent for the quadratic methods of adjustment. Variation between animals in adjusted LWT was greater for the age-intercept adjustment method.

[Please insert Table 4 near here]

Variance components estimated from the genetic analysis of the LWT traits are tabulated in Table 5. Observed LWT was moderately heritable (0.27). Maternal heritabilities for LWT were low (0.09 to 0.12) and so were the permanent environment effects due to dam (10 to 16% of the phenotypic variance).

Both maternal heritability and permanent environment due to dam were similar across methods of adjustment. While within group regression adjustment of LWT for age did not affect the estimate of phenotypic variance, direct heritability was reduced. The age intercept however resulted in higher phenotypic variance (27.55) and direct heritability (0.30).

[Please insert Table 5 near here]

[Please insert Figure 2 near here]

The two methods used to adjust LWT for age of dam produced adjusted observations with similar phenotypic variances and heritabilities. The combined adjustment of individual age using within CG regression and age of dam using both dam age class and quadratic methods (models 6 and 7) produced estimates that were generally similar to each other but with lower direct and slightly lower maternal heritabilities compared to the analysis of observed LWT. This reduction in phenotypic variance and direct heritability was not observed when age-intercept adjustment was used in combination with dam age class or quadratic adjustment methods (models 8 and 9). Regression coefficients of progeny performance on sire EBV for models 8 and 9 were closer to 0.50, the expectation, and had a small range across replicates than those for models 6 and 7.

The effect of the quadratic dam age adjustment is illustrated in Figure 2. While the quadratic adjusted method is removing the majority of the dam age effect it appears that animals out of very young dams are under adjusted and those out of older dams are slightly over adjusted.

Estimates of phenotypic variance, direct and maternal heritabilities of the observed and adjusted carcase traits of FATD and EMD are illustrated in Table 6. Regression adjustment of FATD and EMD resulted in adjusted observations with slightly lower phenotypic variance and similar heritability of FATD and EMD. The quadratic adjustment slightly decreased phenotypic variance and tended to increase the heritability of FATD and EMD.

[Please insert Table 6 near here]

The relationships between age, LWT and adjusted LWT are given in Table 7. A positive phenotypic relationship between observed LWT and age existed (r=0.26). The expectation is that once a trait is adjusted, its relationship with the adjustor variable will be broken. While the simple correlation suggested that this relationship remained after using within group regression adjustment, the phenotypic correlation suggests that the relationship between regression adjusted liveweight and age was removed. Within groups age intercept adjusted LWT was not significantly correlated with age (r=0.04, P>0.05) however across all data there was a significant negative correlation between adjusted liveweight and age (-0.41, P<0.05). Adjusted LWT using both within group regression and age intercept methods were highly correlated with observed LWT and each other.

[Please insert Table 7 near here]

While there were significant positive relationships between LWT and FATD and EMD (r=0.49 and 0.59 respectively, P<0.05) there were no significant relationships of the regression and quadratic adjusted FATD and EMD with LWT (r=-0.03 to 0.02, P>0.05). Adjusted FATD and EMD using both regression and quadratic methods were highly correlated with the actual observations (r=0.79 to 0.86 respectively, P<0.05).

Discussion

The data used in this study originated from the White Suffolk LAMBPLAN database. This breed was chosen because of their good performance recording scheme, especially on the dam's side. The procedures described in this study were also explored using the Poll Dorset and Texel breeds (data not shown) with similar results to those reported here for the White Suffolk. It is anticipated that these results would be applicable to most sheep genetic evaluation systems.

Heritability of observed liveweight, fat and eye muscle depth are similar to those previously reported (Atkins *et al.* 1991; Brash *et al.* 1992; Gilmour *et al.* 1994; Fogarty 1995). With the exception of age intercept and dam age adjustment of liveweight all of the adjustment methods used in this study did not influence the phenotypic variance of the trait. This result is anticipated and agrees with the results of Raymond (1982). There were also increases in the heritability of the age intercept adjusted liveweight and quadratic adjustment of fat depth for liveweight. Gregory *et al.* (1978) also observed that adjusting liveweight for age can lead to increases in the heritability of post-weaning liveweight and gain. These results indicate that the adjustment processes are performing as expected towards reducing systematic environmental differences between animals.

While the regression adjustment of liveweight for individual age had slightly greater reductions in the phenotypic variance of liveweight the heritability was lower than that of the age intercept adjusted liveweight. The difference in heritability estimates indicates that the age intercept method of adjustment of liveweight for individual age is preferable to the regression adjustment. The latter appears to have more potential to remove genetic variation.

The regression of progeny performance on sire estimated breeding values also illustrated that the age intercept produced estimated breeding values that were closer to the expectation. This relationship was also more consistent across the 20 random samples of data for the age intercept adjustments. The method used to adjust for age of dam did not appear to influence the relationship between progeny performance and sire EBV.

Both age intercept and within group regression adjustment removed the relationship between liveweight and age within groups. As anticipated there was a positive relationship between within group regression adjusted liveweight and age across all data. However there was also a moderate negative correlation between age intercept adjusted liveweight and age across all data. This negative correlation arises from over-adjusting older animals. The cause of this over adjustment is a non-linear growth curve, which was modelled as linear. The age intercept adjustment method is only designed to adjust animals in a linear growth pattern. The measurements used in this study were all recorded as post-weaning weights but covered a large age range (110 to 320 days). Splitting the data into two age groups, firstly all animals less than 190 days of age and secondly all animals greater than 190 days, illustrated that animals in the first data set were growing at a quicker rate than those in the second data set. This resulted in the age intercept method expecting the average animals to be heavier at older ages than they were actually observed. The age intercept method adjusts these older animals to be below average at the standard age when in fact they were at an average weight for their age. These results agree with the findings of Boggess *et al.* (1991) who concluded that linear age adjustment for weaning weight at 90 days is only adequate for ages ranging up to 28 days either side of weaning. Outside this range quadratic regression adjustment may be more appropriate. This highlights the need to restrict the use of age intercept to groups of animals that have a linear growth pattern during that period.

When dam age operated as the sole adjustment, differences between adjustment methods were small. Both techniques slightly increased the phenotypic variance but did not influence the heritability estimates of liveweight. Results indicate that both techniques used in this study adjusted the data adequately. Differences between adjustment methods may have been influenced by the fact that in this particular data set the influence of dam age was not as great as commonly found in other sheep data at similar stages of growth (Gilmour 1993). The influence of dam age in this study can also be gauged from the multiplicative factors used for the dam age class adjustments. The differences were 1.7 to 2.4% of the liveweight of the middle dam age class (Table 3). These dam age adjustments are slightly smaller than the 2 to 4 % previously reported (Gilmour 1993). Dam age adjustments were also influenced by the fact that 80% of the animals in the data file had dam ages within the range of 3 to 6 years. Alternatively 36, 60 and 4% of animals were in dam age classes 1, 2 and 3 respectively. Therefore there were insufficient animals at the lower and upper bounds of dam age to produce a large dam age effect or to estimate its effect with sufficient accuracy. However, when dam age adjustment methods were combined with individual age adjustment the advantage of the age intercept and quadratic methods (model 9) were apparent.

Quadratic adjustment of carcase traits slightly reduced the phenotypic variance but tended to increase the direct heritability. The residual correlations between fat and eye muscle depth with liveweight were also very small for both methods of adjustment. These results indicate that both methods produce very similar adjusted observations however the heritability estimates tend to indicate that the quadratic method may be slightly more appropriate for genetic evaluation purposes.

When computational performance is considered, the age intercept adjustment method has the additional appeal of being less demanding. Within group regression requires additional base parameters to be estimated and stored for the adjustment routine. Furthermore, the actual adjustment process contains an additional level of complexity, which requires 5 floating-point computations for each CG. As a result the programming and running of the age intercept adjustment method is substantially more efficient and less prone to programming errors.

Conclusions

Liveweight observations used in this study were successfully adjusted for individual age and dam age. Similar conclusions can be drawn when adjusting fat and eye muscle depth for liveweight. While within group regression adjustments generally had the greatest reduction in phenotypic variance they also produced the greatest reductions in heritability and had the strongest phenotypic relationships with their adjustment variables. Furthermore, within group regressions were also more computationally demanding to perform. Results indicate that age intercept and quadratic methods of adjustment for age and liveweight respectively may be more appropriate for genetic evaluation purposes. These trends are apparent in at least the three major Australian meat sheep breeds.

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Figure 1 Illustration of the expected relationships between weight and age before and after adjustment

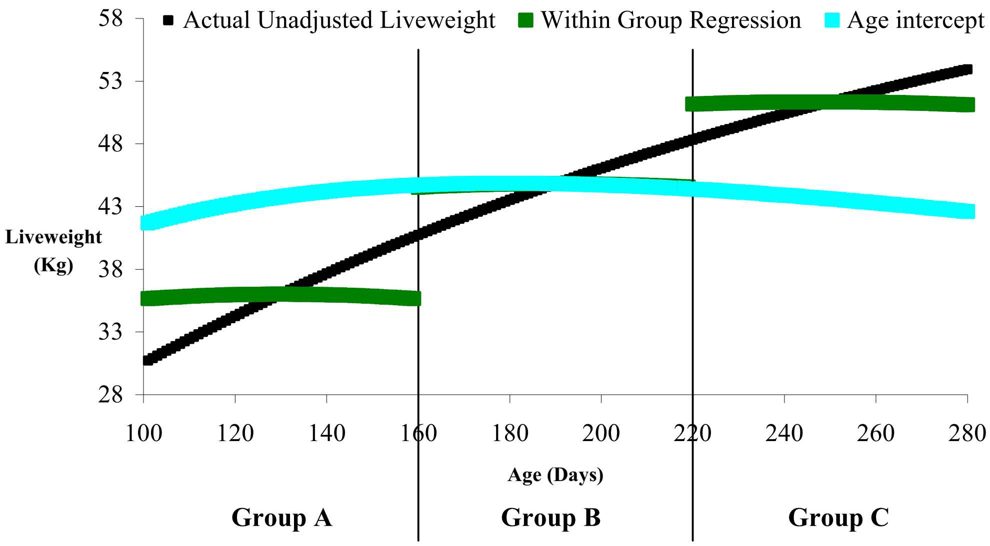

Figure 2 The observed and adjusted liveweight of sheep within dam age groups

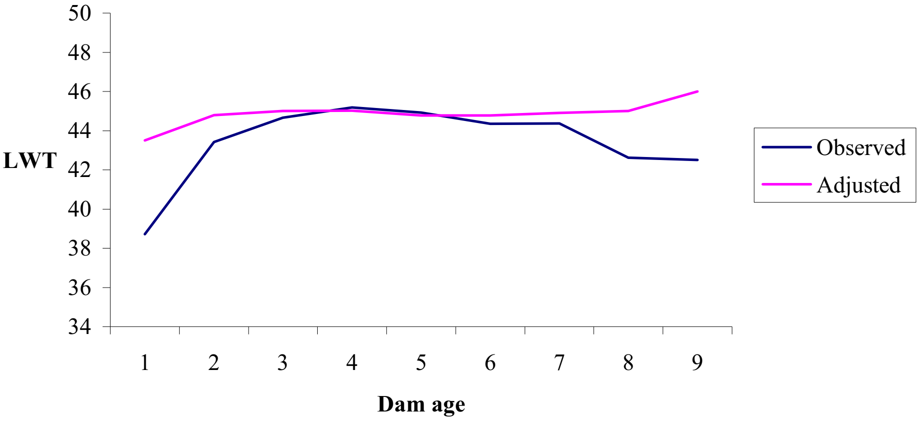

Table 1 Description of the adjustment combinations for each trait analysed

Model	**Dependent Variable**	**Adjustment for Age**[a]	**Adjustment for Dam Age**[b]	**Adjustment for Weight**[c]
1	**LWT**	-	-	-
2	**LWT**	LR	-	-
3	**LWT**	AI	-	-
4	**LWT**	-	DAC	-
5	**LWT**	-	QUA	-
6	**LWT**	LR	DAC	-
7	**LWT**	LR	QUA	-
8	**LWT**	AI	DAC	-
9	**LWT**	AI	QUA	-
10	**FATD**	-	-	-
11	**FATD**	-	-	LR
12	**FATD**	-	-	QUA
13	**EMD**	-	-	-
14	**EMD**	-	-	LR
15	**EMD**	-	-	QUA

LWT = post-weaning liveweight, FATD = fat depth, EMD = eye muscle depth

[abc] LR = Linear regression, AI = Age intercept, DAC = Dam age class, QUA = Quadratic Regression

Table 2 Descriptive statistics for the observed traits (N=8418)

Trait[a]	Model[b]	Mean	Std Dev	Min	Max
Individual age, days		192	51	107	321
Age of dam, years		3.4	1.3	1	9
LWT, Kg	1	44.23	10.05	16.50	86.00
FATD, mm	10	2.85	1.01	0.50	7.00
EMD, mm	13	26.84	4.09	13.00	39.00

[a] LWT = liveweight, FATD = fat depth, EMD = eye muscle depth

[b] Refer to Table 1 for model specifications

Table 3 Estimates of the adjustment factors to standard points

	Standard Points		
Standard LWT	45 kg		
Standard age	190 days		
Standard age of dam	3.5 years		
Standard CG size	50 animals		
	Regression Adjustment		
	Standard	**Min**	**Max**
LWT for age	0.2845	0	0.8674
FATD for LWT	0.0666	0	0.1556
EMD for LWT	0.2911	0	0.5174
	Quadratic Adjustment		
	Intercept	**Linear**	**Quadratic**
LWT for dam age	44.0992	0.4846	-0.2698
FATD for LWT	2.6936	0.0668	-0.0003
EMD for LWT	26.7249	0.2971	-0.0018
	Dam Age Class Adjustment[a]		
	1	**2**	**3**
Multiplicative factor	1.0237	1.00	1.0171
	Age Intercept Adjustment		
X-Intercept (days)	-38.5		

[a] 1 = 1 to 2 year old dams, 2 = 3 to 5 years, 3 = 6 to 10 years

Table 4 Descriptive statistics for the adjusted variable

Trait	Model[a]	Mean	Std Dev	Min	Max
***LWT for age**, Kg*					
Regression	2	44.07	10.16	10.68	86.16
Age Intercept	3	45.13	11.47	19.16	93.89
***LWT for dam age**, Kg*					
Dam age classes	4	44.63	10.17	16.78	86.00
Quadratic	5	44.70	10.17	16.75	86.61
***LWT for age and dam age**, Kg*					
Regression and dam age class	6	44.46	10.28	10.68	86.16
Regression and quadratic	7	44.53	10.29	10.63	86.78
Age Intercept and dam age class	8	45.53	11.60	19.50	96.04
Age Intercept and quadratic	9	45.61	11.59	19.42	94.72
***FATD for LWT**, mm*					
Regression	11	2.85	0.95	0.26	7.13
Quadratic	12	2.72	0.79	0.37	6.75
***EMD for LWT**, mm*					
Regression	14	26.82	3.78	14.39	39.47
Quadratic	15	26.16	2.73	15.06	38.82

[a] Refer to Table 1 for model specifications

Table 5 Phenotypic variance, direct and maternal heritability estimates and mean, minimum and maximum regression of progeny performance on sire EBV for the observed and adjusted liveweight traits from the genetic analysis

Model[a]	σ^2_p	h^2	m^2	**PE**	**dmr**	**Regression**[b]		
						Mean	**Min**	**Max**
1	25.190	0.27	0.11	0.14	-0.66	0.57	0.26	0.82
2	24.720	0.23	0.11	0.14	-0.63			
3	27.550	0.30	0.11	0.13	-0.59			
4	28.100	0.28	0.11	0.15	-0.59			
5	27.950	0.28	0.09	0.16	-0.56			
6	25.050	0.23	0.11	0.14	-0.63	0.59	0.30	0.91
7	25.070	0.22	0.09	0.14	-0.67	0.59	0.28	0.92
8	28.020	0.29	0.11	0.13	-0.60	0.56	0.32	0.83
9	27.880	0.28	0.09	0.13	-0.55	0.55	0.31	0.80
s.e.	0.40 to 0.50	0.04 to 0.05	0.04	0.03	0.10 to 0.17			

[a] Refer to Table 1 for model specifications

[b] Values from 20 replicates

σ^2_p = Phenotypic variance, h^2 = direct heritability, m^2 = maternal heritability, PE = permanent environment due to dam, dmr = direct to maternal correlation

Table 6 Phenotypic variance, direct heritability and maternal heritability estimates for the observed and adjusted FATD and EMD traits from the genetic analysis

Model	**σ^2_p**	**h^2**
10	0.327	0.30
11	0.317	0.30
12	0.312	0.33
s.e.	0.01	0.05
13	3.632	0.29
14	3.548	0.29
15	3.548	0.30
s.e.	0.10	0.05

σ^2_p = Phenotypic variance, h^2 = direct heritability

Table 7 Simple (above diagonal) and phenotypic (below diagonal) correlations between LWT, regression adjusted LWT, age intercept adjusted LWT and age

	Age	**LWT**	**Regression adjusted LWT**	**Age intercept adjusted LWT**
Age	-	0.35	0.33	-0.41
LWT	0.26	-	0.97	0.85
Regression adjusted LWT	-0.04	0.95	-	0.83
Age intercept adjusted LWT	0.04	0.95	0.97	-

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