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Studies on the relationship between live weight and body condition score and estimation of standard reference weight of ewes from the Icelandic sheep breed

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ABSTRACT

The aim of the study was to define the mature live weight of Icelandic sheep breed ewes. Data on body condition scores (BCS) and live weight (LW) spanning 22 production years from the Hestur research farm were analyzed to fit the linear relationship LW = **a** + **b** x BCS of ewes in different age categories. Ewe live weight continued to increase until 5 years of age. A general estimate of standard reference weight (SRW) of a mature Icelandic ewe is 70.4 ± 3.4 kg, standardized at BCS 3. For mature ewes, approximately 8.5 kg LW is needed to raise BCS by one unit. SRW creates opportunities for studies relating mature weight to other important genetic traits and for analysing the independent effects of SRW, degree of maturity, and BCS on animal performance.

Keywords: mature weight, mixed model, ewe age, nutrient requirements, herd data, growth.

YFIRLIT

Rannsókn á samhengi lífþunga og holdastiga og ákvörðun staðlaðs fullorðinsþunga íslenskra áa

Markmið rannsóknarinnar var að ákvarða fullorðinsþunga íslenskra áa. Gögn um holdastig (BCS) og lífþunga (LW) sem náðu yfir 22 framleiðsluár á fjárbúinu að Hesti voru greind tölfræðilega, út frá hinu línulega samhengi LW = **a** + **b** x BCS fyrir ær á mismunandi aldursárum. Ærnar náðu að jafnaði fullum þroska á fimmta aldursári. Fullorðinsþungi (SRW) fyrir íslenskar ær, staðlaður að holdastigi 3, reyndist vera 70,4 ± 3,4 kg. Hjá fullþroskuðum íslenskum ám þarf um 8,5 kg lífþunga til að auka hold um sem nemur einu holdastigi. Greiningin skilaði einnig mati á stöðluðum fullorðinsþunga einstakra gripa í gagnasafninu. Það gefur möguleika á rannsóknum sem tengja fullorðinsþunga við aðra mikilvæga eiginleika í kynbótastarfi. Við þetta skapast einnig möguleikar á að greina aðgreind áhrif fullorðinsþunga, þroskastigs og holda á framleiðslugetu ánna.

INTRODUCTION

Growth and development of an animal and its components in relation to size (Hammond 1932, Huxley 1932) can be fitted to functions that are common across domestic mammals when scaled according to their mature body size (Brody 1945). These genetic scaling rules were first tested for sheep by McClelland et al. (1976), and it is well established that the pattern of fat and protein deposition in sheep is remarkably similar across genotypes when scaled as a proportion of mature size (Oddy & Sainz 2002). Empty body gain in very young animals can contain a protein to fat in the ratio of 2:1, whereas in an animal approaching full maturity this ratio can be 1:7. The energy content per kg fat is more than double that of protein; for each kg protein growth approximately 3.5 kg water and ash will be added. Therefore, the energy content of gain of an almost mature animal is typically 2.5 times greater than the energy content of gain of a very young animal, but protein content is the opposite (CSIRO 1990).

An animal that has reached full maturity does not have constant live weight or fat to protein ratio in an empty body. Fat reserves decrease at times of negative energy balance, such as in late pregnancy and lactation, but increase in the easier times of the production cycle. It is important to have methods to account for this mobilization of body reserves, for key tasks such as nutrition planning. Weight changes alone are not accurate measures, due to changes in gut fill and stage of the production cycle. Body condition score is a common assessment of the amount of muscle and fat (Kenyon et al. 2014). Jefferies (1961) proposed a body condition scoring system for sheep, with grades defined according to specific anatomical features in the lumbar region, assessed by palpation. Russel et al. (1969) further adapted this system and demonstrated its superiority over live weight alone to estimate the fat content of an animal.

The frame size of mature animals differ among breeds of the same species, sexes and individuals of the same sex. While frame size is an important determinant of an animal's live weight, so is the animal's body condition. A large-framed animal in poor condition can have the same live weight as a smaller-framed animal in good condition. A concept that connects frame size, live weight and body condition is the Standard Reference Weight (SRW), which was defined for any particular breed and sex of cattle or sheep as the approximate liveweight (LW) achieved by that animal when skeletal development is complete and the empty body contains 250 g fat/kg (CSIRO 1990), corresponding to body condition score (BCS) 3.0 for sheep on the 0-5 scale described by Russel et al. (1969).

The SRW is a useful concept for several purposes: 1) to relate live weight and body condition for mature animals; 2) to define the maturity of growing animals; 3) to estimate with higher accuracy, with the animal‘s estimated degree of maturity, its energy and protein requirements for growth, due to more accurate estimates of the fat, protein, and energy content of the gain.

The rules of scaling growth functions, according to mature size as described above, were adapted into ruminant nutrient formulation through the concept of SRW and generalized equations (CSIRO 1990). These principles were adapted into nutrient requirement estimates for Icelandic sheep (Sveinbjörnsson & Ólafsson 1999). However, the SRW used was only a rough estimate, as is the case with much of the mature weights for different breeds, when it is used for selecting slaughter weights and estimating nutrition requirements in different countries and production systems (CSIRO 1990, AFRC 1993, NRC 2007). Among the reasons for this inaccuracy has been a lack of data and/or analysis of data that takes into account physiological principles and different production systems.

One of the issues that arises when adult weight is determined is to what level of body condition should the mature weight be standardized. This can depend on the purpose for which the determination of mature weight is intended. When the purpose is to improve lamb meat production by fulfilling nutrient requirements according to lamb growth curves derived in nutrient non-limiting environment, it seems logical to standardize adult weight at high BCS (Friggens et al. 1997, Zygoyiannis et al. 1997a & 1997b). However, when the challenges are related to the growth, development and management of ewes in extensive or semi-extensive production systems, it has been concluded that a standardized mature weight should use a BCS in the middle of the scale, at BCS 2.5 (Cannas and Boe 2003) or 3 (CSIRO 1990).

In Iceland, most ewes are mated in their first year of life, and their fertility and overall production throughout their life is high. There is, however, no clear focus on increasing ewe growth and development in dry periods in their early years. Data of actual mature weight, both for the breed in general and, if possible, for individual animals will aid in defining more accurate nutrition and management strategies. There is a well-known positive relationship between animal metabolic live weight and maintenance requirements (CSIRO 1990, AFRC 1993, NRC 2007). Furthermore, mature size has important genetic correlations with feed intake, methane emissions, feed efficiency, carcass composition and meat quality (Rose et al. 2023). The optimal mature weight can depend on the nature of the production system.

Studies of the relationships between ewe live weights and body condition score (McHugh et al. 2019, Semakula et al. 2020 & 2021) have demonstrated the importance of using datasets, not only with a high number of animals, but also with repeated measurements on the same animal at different ages and in different stages of the annual production cycle. The effect of pregnancy on ewe live weight is too large to ignore, but data points in pregnancy need to be corrected for the estimated weight of the conceptus (McHugh et al. 2019, Semakula et al. 2021).

The aim of the current study was to define the standard reference weight at body condition score 3.0 (SRW@BCS3) for ewes of the Icelandic breed kept in a semi-extensive system: (1) for the breed in general, for use in defining nutrient requirements and (2) for individual animals in the flock under study, for use in follow-up studies.

MATERIALS AND METHODS

Animals and management

This study used data from the Agricultural University of Iceland Hestur experimental sheep farm, based in Borgarfjörður, Southwest-Iceland. The farm is managed under conditions typical for Icelandic sheep production: indoor feeding from November to May, grazing cultivated land and natural pastures surrounding the farm from May to June, extensive grazing on common mountain pastures or highland ranges from late June to mid-September, grazing cultivated or improved grassland land until housing in November. Mating takes place in December and lambing in May. Icelandic sheep breed ewes (Aðalsteinsson 1981, Dýrmundsson and Niznikowski 2010) were shorn at the onset of the indoor feeding in November, and again in early March. Transabdominal ultrasound pregnancy scanning took place in February. The winter feed was predominantly grass haylage conserved in round bales, fed ad lib. The quality of the haylage was controlled for different feeding periods as far as possible to meet feeding standards at any time (Sveinbjörnsson & Ólafsson, 1999). Haylage was supplemented with concentrate (100-300 g d^{-1} ewe^{-1}) in the last 3-6 weeks before lambing and the first week after lambing. For more details about the production system, see Sveinbjörnsson et al. (2021).

Data

The study included data from production years 2001-2022. The database included ewe and lamb records with different variables as described in Sveinbjörnsson et al. (2021). For this study ewe records with the following variables were used: ewe ID number, year of birth, year of age, lambing date, number of lambs born and number of lambs reared within each production year. Live weight (LW) and body condition score (BCS) were recorded at five week intervals from October till late April. Body condition scoring was conducted according to the 0-5 scale with 0.25 units, as described by Russel et al. (1969).

Stages of the annual cycle are defined as follows, with abbreviations and approximate dates (± 1 to 2 days) of LW and BCS measurements in parentheses: Post-weaning (Post-W, 18 October); Pre-mating (Pre-M, 1 December); Post-mating (Post-M, 4 January); 2-Month pregnant (2 Mo-preg, 10 February); Mid-pregnancy (Mid-preg, 15 March); Late-pregnancy (Late-preg, 20 April).

The estimated weight of the conceptus was calculated using the formulas reported by Robinson et al. (1977) for crosses of Finnish Landrace and Dorset Horn ewes. These breeds have a closer resemblance to the Icelandic sheep breed in gestation length, prolificacy and adult size (Robinson et al. 1977, Anderson et al. 1981, Dýrmundsson and Ólafsson 1989) than other breeds in similar studies, e.g. the Merino sheep (Wheeler et al. 1971). Information required for the use of the formulas of Robinson et al. (1977) was available in our database, i.e., date of mating or lambing, number of foetuses and weight of the ewe at a date close to the date of mating. During pregnancy, ewe live weight was corrected for the estimated weight of the conceptus, thereby creating a new variable, pregnancy-free live weight (PFLW).

Statistical analyses

Statistical analyses were performed using SAS (2015). PROC GLM was used for simple ANOVA analysis and calculating least square means as presented in Table 1, Figure 1 and Figure 2. Simple linear regression was used for the analysis presented in Tables 2 and 3, where within year of age, pregnancy-free live weight (PFLW) was regressed against BCS for data from each year of age (Table 3) and stage of the annual cycle (Table 2). Some more complex relationships were tested, but none gave a better prediction than the simple linear relationship: PFLW = **a** + **b** x BCS. Mixed model analysis (PROC MIXED) was used for the results presented in Table 4, where PFLW was regressed against BCS for data from each year of age and the effect of an individual ewe in the dataset was considered as a random classification effect.

Definition of sub-datasets for different statistical analysis

For the analysis reported in Tables 2-7, we used a subset of the dataset, where "full" records for LW and BCS (at least 22 of 24 possible) were available for individual ewes on their 2nd to 5th year of age. The 1266 ewes in this dataset were born in the years 1999 to 2017, the lowest number in 1999 (n=31) and the highest in 2010 (n=89). Figure 1 was generated from a sub-dataset containing ewes with full records from 2 to 6 years of age (n=889). Figure 2 and Table 1 contain data from a larger group of ewes that had full records during their 5th year of age, irrespective of whether they had full records at younger age (n=1577). The additional 311 ewes included were either born before 1999 or had several missing values at younger ages. The analysis to determine Equation 1, for prediction of PFLW from BCS, ewe age and random intercept for individual ewe, was based on records of 3344 ewes. This included all ewes between 2 to 5 years of age with LW and BCS data in production years 2001-2022, but not necessarily with full records.

RESULTS

Records for ewes with live weight and BCS from 2 to 6 years of age showed a significant increase in LW at each stage of the annual cycle each year of age up to 5 years, but not between their 5th and 6th year (Figure 1). There was, however, a significant decrease in BCS at each stage of the annual cycle by each year of age up to 6 years.

For all ewes with records during their 5th year of age, LW gain was driven by the number of foetuses and the progression of pregnancy (Figure 2a). The most rapid pregnancy-free LW gain (PFLW) was observed between weaning and mating (Figure 2b). By correcting live weight for the estimated weight of the

Table 1. The ratio of PFLW/BCS at different stages of the production year for 1577 ewes at 5 years of age, dataset defined as for Figure 2.

Production stage	Barren	Single	Twin	Triplet
Post-W	23.70^{b}	23.15^{c}	23.03^{d}	23.66^{b}
Pre-M	23.43^{b}	23.11^{c}	22.62^{c}	23.39^{b}
Post-M	23.41^{b}	22.57^{b}	22.15^{b}	22.91^{a}
2 Mo-preg	23.07^{b}	22.44^{b}	22.15^{b}	22.87^{a}
Mid-preg	21.68^{a}	21.64^{a}	21.50^{a}	22.75^{a}
Late-preg	21.38^{a}	22.70^{b}	22.47^{c}	23.75^{b}
N	41	206	1118	212
SEM	0.47	0.25	0.13	0.22

a, b, c: Values with different superscripts within a column are statistically different, $p<0.05$.

SEM: standard error of the means

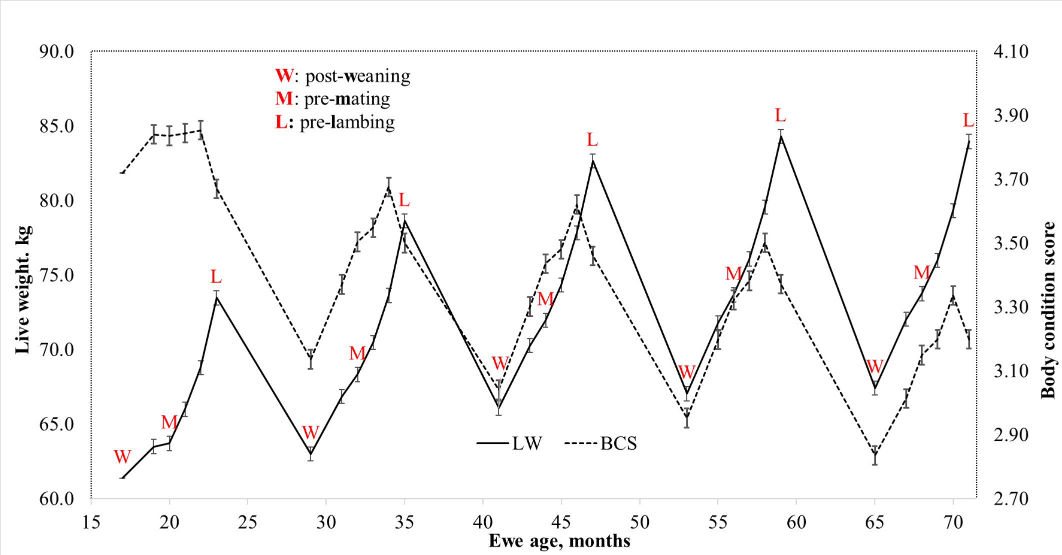

Figure 1. Ewe live weight (LW) and body condition score (BCS) of 889 ewes between 18 months and six years of age at post-weaning (W), pre-mating (M) and pre-lambing (L). Error bars indicate 95% confidence interwals.

conceptus, the weight differences related to litter size disappeared for single and twin ewes, but the triplet-bearing ewes were still heavier troughout the production cycle.

For all litter sizes, BCS (Figure 2c) increased from weaning to mating but then increased at a slower rate with progressing pregnancy. Immediately before mating (Pre-M), ewe BCS was similar among litter size classes. After mating, BCS increased for all litter sizes, until it decreased in Late-preg for twin- and triplet-bearing ewes. The ratio PFLW/BCS was highest in autumn (Table 1). Among twin-bearing ewes, the ratio decreased steadily through winter until increasing again between Mid-preg and Late-preg. There was a similar trend for single- and triplet-bearing ewes but with fewer statistical differences, due to smaller group sizes. In periods when BCS was increasing, the ratio PFLW/BCS decreased, and vice versa. This pattern was seen among barren ewes, which gained the same amount of condition (Figure 2c) from weaning (Post-W) to mating (Pre-M) as the other groups, but less BCS in the first half of the pregnancy period and more in the latter half, with a decrease in the ratio PFLW/BCS (Table 1).

The regression coefficients for the simple linear relationship PFLW = **a** + **b** x BCS for each year of age and production stage are reported in Table 2 and compared statistically, according to 95% confidence limits. The constant **a** generally had a lower value and the slope **b** higher value for 2-year-old ewes than for other age categories in the different stages of the production cycle. By using the prediction equations derived by the regressions, LW at BCS=3 was calculated for each age category and production stage (Table 2). Similarly, Table 3 reports the linear regression coefficients within each year of age, with all production stages combined. Here, the constant **a** increased significantly with increasing age, but the slope **b** was stable irrespective of age.

In the mixed model analysis presented in Table 4, a random intercept for the effect of individual animals in the dataset is included. The random effect of ewe was not separated between intercept and slope, therefore all the individual differences were collected in the random intercepts, which add up to zero for all animals within each year of age. The prediction error (RMSE) of the regression models generated by the mixed model analysis

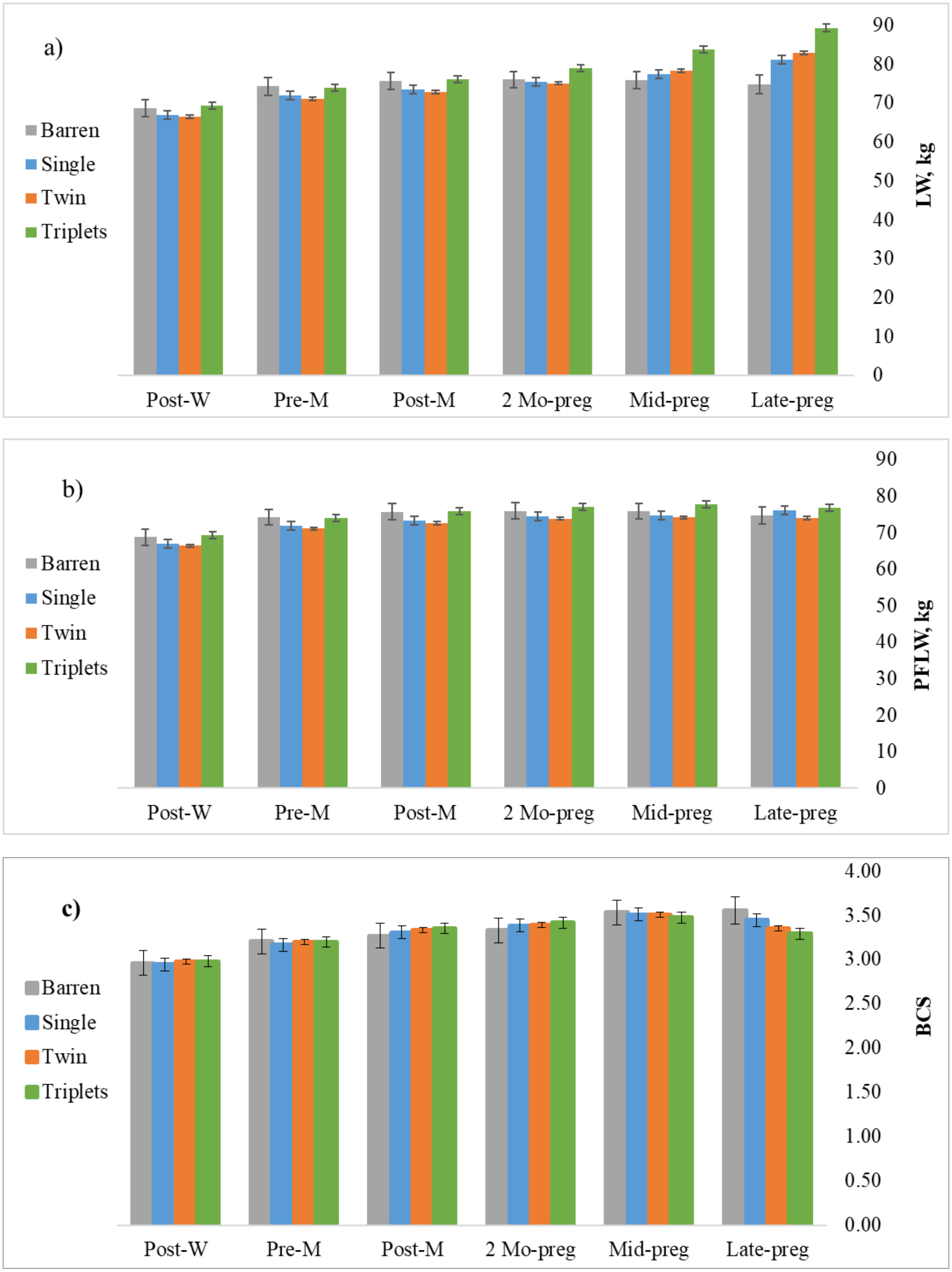

Figure 2. a) Ewe live weight (LW), b) pregnancy-free LW (PFLW) and c) body condition scores (BCS) of 1577 ewes (212 with triplets, 1118 with twins, 206 with single lamb and 41 barren) at 5 years of age. All ewes in the database with LW ands BCS records on their 5th year were included in this analysis, except for 11 ewes with quadruplets. Error bars indicate 95% confidence interwals.

Table 2. Coefficients **a** and **b** for the regressions PFLW= **a** + **b** x BCS within each year and months of age and stage of the production cycle, for 1266 ewes with at least 22 of 24 possible records of LW and BCS between their 2 to 5 years of age.

Production stage	year no	age mo	a	b	R^2	PFLW at BCS 3.00
Post-W	2	17	28.1^{a}	8.93^{B}	0.41	54.9
Pre-M	2	19	31.7^{ab}	8.33^{B}	0.35	56.7
Post-M	2	20	30.4^{ab}	8.62^{B}	0.36	56.3
2 Mo-preg	2	21	32.9^{b}	8.27^{B}	0.35	57.7
Mid-preg	2	22	29.6^{ab}	9.18^{B}	0.37	57.1
Late-preg	2	23	34.3^{b}	8.47^{B}	0.30	59.7
Post-W	3	29	42.6^{c}	6.46^{A}	0.23	62.0
Pre-M	3	31	42.9^{cd}	7.09^{AB}	0.22	64.2
Post-M	3	32	43.2^{cd}	7.12^{AB}	0.21	64.6
2 Mo-preg	3	33	41.7^{c}	7.79^{AB}	0.25	65.1
Mid-preg	3	34	37.0^{bc}	8.91^{B}	0.28	63.8
Late-preg	3	35	37.3^{bc}	9.41^{B}	0.29	65.5
Post-W	4	41	45.7^{cd}	6.61^{AB}	0.22	65.5
Pre-M	4	43	47.8^{d}	6.93^{AB}	0.19	68.6
Post-M	4	44	47.9^{d}	6.95^{AB}	0.20	68.8
2 Mo-preg	4	45	46.6^{cd}	7.64^{AB}	0.24	69.5
Mid-preg	4	46	41.1^{c}	8.97^{B}	0.27	68.1
Late-preg	4	47	44.6^{cd}	8.43^{B}	0.24	69.9
Post-W	5	53	47.7^{d}	6.57^{A}	0.21	67.4
Pre-M	5	55	48.5^{d}	7.31^{AB}	0.19	70.5
Post-M	5	56	50.4^{d}	6.92^{AB}	0.18	71.1
2 Mo-preg	5	57	47.4^{d}	8.07^{B}	0.24	71.6
Mid-preg	5	58	44.1^{cd}	8.88^{B}	0.27	70.7
Late-preg	5	59	43.3^{cd}	9.42^{B}	0.29	71.5

$^{a, b, c}$ or $^{A, B, C}$: Values with different superscripts within a column are statistically different, $p<0.05$. PFLW = pregnancy-free live weight

(Table 4) was approximately half of those from the linear model (Table 3). Here, the slope **b** increases with increasing age of the ewes. There was a good agreement between the linear (Table 3) and mixed (Table 4) model analysis in estimated LW at different BCS, according to the regression equations, especially with increasing age.

By using all records for ewes with some, but not necessarily all, LW and BCS data between 2 to 5 years of age in production years 2001-2022, Equation 1 was derived:

Eq. 1: $PFLW=R_{ewe} + 19.52(0.215)+7.95(0.039)\cdot BCS+8.72(0.051)\cdot year-0.64(0.006)\cdot year^2$

where R_{ewe} is the random intercept for individual ewe and year is the ewe's year of age. The values in parentheses are the standard errors for the respective regression coefficients, the prediction error (RMSE) for the whole equation is 3.67 kg. A total of 3344 ewes were included in this analysis.

Predictions of LW at BCS=3 for individual animals at specific ages based on the mixed

Table 3. Coefficients **a** and **b** for linear regressions PFLW= **a** + **b** x BCS within each year of age, combined for the six stages of the production cycle, for 1266 ewes with at least 22 of 24 possible records of LW and BCS between 2 to 5 years of age. Predicted LW at different BCS as calculated from the respective regression equations.

			LW at BCS:			
Year	**a** (SE)	**b** (SE)	2.00	3.00	4.00	RMSE
2	31.6^{a} (0.53)	8.51^{A} (0.139)	48.6	57.1	65.7	5.8
3	38.2^{b} (0.53)	8.59^{A} (0.153)	55.4	64.0	72.5	6.1
4	42.2^{c} (0.53)	8.66^{A} (0.156)	59.5	68.1	76.8	6.4
5	43.6^{c} (0.53)	8.90^{A} (0.162)	61.4	70.3	79.2	6.8

$^{a, b, c}$ or $^{A, B, C}$: Values with different superscripts within a column are statistically different, $p<0.05$.

RMSE = root-mean-squared error

Table 4. Coefficients **a** and **b for** PFLW= **a** + **b** x BCS for mixed model regressions including random intercept for the effect of individual animals; within each year of age, combined for the six stages of the production cycle, for 1266 ewes with at least 22 of 24 possible records of LW and BCS between 2 to 5 years of age. Predicted LW at different BCS as calculated from the respective regression equations.

			LW at BCS:			
Year	**a** (SE)	**b** (SE)	2.00	3.00	4.00	RMSE
2	43.6^{bc} (0.53)	5.37^{A} (0.134)	54.3	59.7	65.0	2.8
3	40.2^{a} (0.45)	8.00^{B} (0.123)	56.2	64.2	72.3	3.1
4	42.7^{b} (0.45)	8.49^{C} (0.124)	59.7	68.2	76.6	3.2
5	44.7^{c} (0.45)	8.56^{C} (0.130)	61.9	70.4	79.0	3.4

$^{a, b, c}$ or $^{A, B, C}$: Values with different superscripts within a column are statistically different, $p<0.05$.

RMSE = root-mean-squared error

Table 5. Comparison of two different estimates of LW at BCS=3 for individual animals at various ages by linear regressions Y= **a** + **b** x X. The dependent variable Y is the value estimated by eq. 1 and the independent variable X is the value estimated by the regressions in Table 4.

Year	**a** (SE)	**b** (SE)	R^2	RMSE
2	5.1^{a} (0.77)	0.89^{ab} (0.013)	0.79	2.34
3	3.9^{a} (0.66)	0.93^{b} (0.010)	0.87	1.86
4	6.6^{a} (0.63)	0.90^{b} (0.009)	0.88	1.75
5	10.9^{b} (0.59)	0.85^{a} (0.008)	0.89	1.68

$^{a, b, c}$: Values with different superscripts within a column are statistically different, $p<0.05$.

RMSE = root-mean-squared error

model analysis in Table 4 were then compared to predictions of LW at BCS=3 for the same 1266 ewes at specific ages by Equation 1. As reported in Table 5, the agreement between the two methods is good, although poorer for ewes in their 2nd year than for the older ewes.

Some of the variation in the development of LW adjusted to BCS=3 in 2nd to 5th year, as reported in Tables 3 and 4, can be related to birth years and whether the ewes did or did not rear lambs in their 1st year (Table 6).

There is a considerable distribution in mature weights (SRW@BCS3) of individual animals (Table 7), slightly greater when estimated by the mixed model than by Equation 1.

Table 6. LW at BCS=3 reached in 2nd, 3rd and 4th year of age as a proportion of LW at BCS=3 at 5th year of age, depending on whether ewes reared 0 or 1 lamb in their 1st year of age. Average, max and min values for birth years 1999 to 2017.

Rearing in 1st year	2nd year		3rd year		4th year	
	0	1	0	1	0	1
Average	0.87	0.84	0.92	0.91	0.97	0.97
max	0.90	0.87	0.97	0.96	1.01	1.01
min	0.81	0.78	0.84	0.82	0.92	0.92

Table 7. Estimated standard reference weight (SRW@BCS3) for 1266 ewes, by the mixed model (Table 5) and Equation 1, frequency in different weight (SRW) categories.

SRW, kg	Mixed model	Equation 1
≤60.0	2.9%	0.6%
60.1-65.0	15.1%	12.5%
65.1-68.0	15.7%	16.7%
68.1-72.0	28.4%	29.9%
72.1-75.0	16.9%	19.0%
75.1-80.0	15.4%	16.9%
≥80.1	5.6%	4.4%

DISCUSSION

The main purpose of this study is to define the mature weight, or more exactly the standard reference weight (SRW), at body condition score 3 (SRW@BCS3) of ewes of the Icelandic sheep breed, for a more exact determination of energy and protein requirements. Our study was inspired by earlier work, such as Zygoyiannis et al. (1997b) who proposed a method to estimate mature weight of different breeds of sheep by accounting for data on ewe age and body condition, as well as live weight records, which was analyzed to fit the linear relationship LW = **a** + **b** x BCS for ewes in different age categories. The mature weight is then found as LW calculated from this formula based on a certain BCS and **a** and **b** coefficients found for an age group that has reached maturity. Estimating the **b** slope in the regression formula accurately is particularly important, as it expresses how many kg LW can be expected to follow each unit of BCS. If this is known, each BCS mobilized or deposited through the annual production cycle can be translated into energy, which is very important in feed planning. This has been the focus of many studies on the relationships between live weights and body condition scores in ewes, e.g. Cannas and Boe (2003), Macé et al. (2019); McHugh et al. (2019) and Semakula et al. (2020).

An important question in this context is: when is full maturity achieved? Zygoyiannis et al. (1997b) analyzed data for ewes of three Greek breeds and assumed that full maturity was reached at 3.5 years of age, since with higher ages there was no significant increase in LW adjusted to a certain level of BCS. In the current study, analysis of ewes with complete records up to 6 years of age (Figure 1) found that, although the ewes did not gain weight after their 5th year, they continued to loose condition. LW adjusted to BCS 3 increased significantly from 5th to 6th year, although this was due to lower BCS at the 6th year, not a higher LW. Therefore, it was assumed that full maturity was reached at 5 years of age, and all subsequent analysis were based on that assumption. Available evidence suggested that the Icelandic sheep breed deposits relatively more fat internally and less fat in carcass than the more specialized mutton breeds and particularly deposits a low proportion of subcutaneous fat relative to the rest of the fatty tissue, which was more pronounced with increasing age (Thorgeirsson & Thorsteinsson, 1989).

Live weight in pregnancy was corrected for the estimated weight of the conceptus, as per McHugh et al. (2019) and Semakula et al. (2021). Using the pregnancy-free live weight (PFLW) allowed for additional LW and BCS during pregnancy to be used to increase data points from three to six per year. For the analysis to define the average SRW@BCS3 for ewes of the Icelandic sheep breed, records for 1266 ewes were used. Although other studies have used repeated measurements on the same ewes, to our knowledge no studies have utilized only complete records for the same animals over many years of age. This created an opportunity to isolate individual variation from the residual error. The results presented in Table 4 allow us to define the SRW@BCS3 for ewes of the Icelandic sheep breed as 70.4 ± 3.4 kg. Each unit of BCS for mature Icelandic ewes was approximately 8.5 kg LW.

Adult weight of three Greek breeds was estimated to be 41.6, 52.3 and 61.4 kg when standardized at condition score 3 and 56.3, 69.8 and 80.0 at condition score 5, for the Boutsko, Serres and Karagouniko breeds, respectively (Zygoyiannis et al. 1997b), using a similar method as our study. The SRW@BCS3 for female sheep of breeds of different sizes in Australia according to CSIRO (1990) was between 40-60 kg. These estimates were low compared to mature sizes of ewes of common breeds in the UK (AFRC 1993) and USA (NRC 2007). Icelandic sheep would be classified as medium-sized breed according to our estimate of approximately 70 kg for the mature weight of ewes. The lack of systematic determination of adult weight of different sheep breeds, however, makes it difficult to compare breeds with respect to adult weight. The method used in our study is applicable for different breeds, as it is based on physiological principles that translate into nutrient requirements and feed planning. The statistical relationships that are utilized are simple and reproducible. The completeness of the dataset is important but should not be difficult to attain with modern techniques.

As seen in the three Greek breeds (Zygoyiannis et al. 1997b), the choice of level of body condition at which the mature live weight is standardized is critical and should be a part of the information reported. For mature sheep of different breeds, it would be most efficient to report both **a** and **b** coefficients for the simple linear relationship LW = **a** + **b** x BCS, assuming the relationship between LW and BCS is linear. Most studies reviewed by Kenyon et al. (2014) found this to be the case. An exception was a study by Teixeira et al. (1989) where among 52 animals, evenly distributed over the BCS scale from 1.25 to 4.50, there were greater increases in LW required to gain one BCS unit at the higher end of the BCS scale. They also demonstrated that total body fat increased at a greater rate at the higher end of the BCS scale, which was later also found by Morel et al. (2016). However, when the method of body condition scoring was originally established for sheep, a linearity of the ratio of body fat to BCS and LW to BCS was reported (Russel et al. 1969), for 276 ewes between BCS 1.00 and 3.5. Based on available information, it seems safe to assume that the relationship between LW and BCS is linear in the practical ranges of BCS, most often worked with in sheep management and feed planning. However, although the repeatability of the BCS technique by experienced assessors is good (Kenyon et al. 2014), it should always be kept in mind that it is a subjective method.

Experiments reviewed by Kenyon et al. (2014), as well as later studies by McHugh et al. (2019) and Semakula et al. (2020), showed considerable differences in kg LW required to increase BCS by one unit, although most results were between 5 and 10 kg, with differences between sexes, sheep breeds, and individuals within the same breed and sex. These differences may be due to variation in body frame size, SRW and fat distribution throughout the body. Kenyon et al. (2014) reported that most studies on the relationship between LW and BCS were based on between-animal variation. Controlled studies investigating the relationship between LW and BCS frequently involved dissection of animals to determine body tissue composition (Russel et al. 1969, Teixeira et al. 1989, Morel et al. 2016), resulting in limited opportunity to analyze the within-animal relationship using repeated measures. For this purpose, it is possible to carry out studies where fully mature animals would be fed to create within-animal variability in LW and BCS. A more practical method is to use herd-databases with repeated measures of pregnancy-free live weight on the same animals, as in our study and that of McHugh et al. (2019). In both studies, there were considerable differences in the estimated slope (**b** coefficient), depending on stage of the production cycle (Table 2). A more robust estimate was achieved in our study when data was combined for different stages of the production cycle (Table 3) and with lower prediction error if the individual variation was isolated (Table 4).

Our estimate of the slope **b**, (8.56 kg, Table 4), or the kg LW change per unit BCS in mature Icelandic ewes, is in the higher range compared to estimates for other breeds. The estimate would have been lower (6.57-7.31; Table 2) if only some of the regressions for periods outside pregnancy for the mature ewes (5^{th} year) were used. The estimate of the slope **b** for ewes on their 5^{th} year differed slightly (8.56 vs 8.90; Tables 4 vs 3) if the individual variation was isolated using a mixed rather than linear regression analysis. The same applies to the final estimate of the SRW@BCS3, which was similar using both methods, but using the mixed model lowered the prediction error by approximately half. For the youngest and least mature (2^{nd} year) ewes, the linear model predicts similar slopes (**b**) as for older ewes, but the mixed model had lower predictions for younger ewes, which makes more sense. For future studies with similar aims, this is worth consideration.

The estimated slope **b** (8.56 kg) divided by the SRW@BCS3 (70.4 kg; Table 4) yielded the ratio 0.122, which was similar to the general ratio reported for diverse breeds of sheep (0.129) or sheep and cattle (0.1285) by Zygoyiannis et al. (1997b). For Churra ewes, Frutos et al. (1997) reported a ratio of 0.13. However, van Burgel et al. (2011) reported that Merino ewes had a 9.2 kg LW change per unit BCS, which was 0.19 times the SRW. The ewes in that study were in late pregnancy, and their live weights were not corrected for the weight of the conceptus, which could partly explain the high values.

The between-animal differences in mature weight are interesting, not only for improving the accuracy of estimates of SRW and LW per BCS for a breed in general, but also with respect to breeding targets. Larger animals have higher maintenance requirements, but also higher feed intake, which might override the increased maintenance requirements with respect to producivity and feed efficiency (Cannas et al. 2019). According to the physiological principles and genetic scaling rules addressed in the introduction, individuals with high mature weight should be leaner and have a lower degree of maturity at a certain LW, compared to animals with lower mature weight. Among Icelandic sheep, there has been a considerable genetic trend towards lower fat grade in carcasses (Eiríksson and Sigurðsson, 2017), meaning that carcasses can be heavier at the same fat grade. By breeding for leaner carcasses, it would be logical to assume that there will also be a genetic trend towards higher mature live weights. By estimating the mature weight of individual animals as in our study, it will be possible to calculate genetic correlations between mature weight and other important traits, based on data from Hestur farm.

Previously, multilevel models were used to analyze the effects of different explanatory variables, including ewe age, LW and BCS, on lamb birth weights and growth rates from Hestur farm data (Sveinbjörnsson et al. 2021). These three explanatory variables are partly related, as can be seen from the results presented in our study (Table 4). At a younger age, live weights are lower and fewer kg LW are required to increase BCS by one unit. From the analysis presented in Table 4, also accounting for the random intercept for individual ewes, it is possible to define the LW at BCS 3 of each animal in each year of age. Dividing that value with the LW at BCS 3 in the 5th year of age (Table 6), we can determine the animal's estimated degree of maturity at each year of age. This allows the analysis of the independent effects of individual SRW, degree of maturity, and BCS at particular stages in the production cycle and changes in BCS on production parameters such as ewe fertility, lamb birth weight and growth rates. For these types of studies, it seems logical to use data only for ewes that have full records until their 5th year of age. For studies of genetic parameters, it might be possible to also use data for ewes that do not have full records, by means of relationships like the one presented by Equation 1 above. The distribution in mature weights (SRW@BCS3) of individual animals was considerable in our study (Table 7), indicating possibilities for including that trait in a breeding program.

CONCLUSIONS

The standard reference weight (SRW) for ewes was estimated to be 70.4 ± 3.4 kg, for the Icelandic sheep breed. For a fully mature ewe, approximately 8.5 kg live weight was needed to raise body condition score by one unit. SRWs for individual animals were also determined, which creates opportunities for follow-up genetic and management studies.

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