Statistical models for estimating lamb birth weight using body measurements

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Abstract

The objective of this study was to estimate lamb birth weight based on body dimensions. We monitored 101 lambs (61 Charollais lambs, 27 Kent lambs, and 13 their crossbreds) at a selected commercial flock. Birth weight, chest circumference (CC), head circumference (HC), and shin circumference (SC) were measured immediately after birth using a tape measure. Correlation analysis indicated the promising use of CC \( r = 0.795; p < 0.001 \) or HC \( r = 0.679; p < 0.001 \) for estimating body weight. Statistical models with one body measurement indicated that a model with CC as a covariate had the highest coefficient of determination and the lowest Akaike's information criterion, corrected Akaike's information criterion, and Bayesian information criterion. The defined criteria generally identified that models with SC, HC, and CC and models with HC and CC as covariates were the best. Residual analyses verified our results, but more extensive analyses of other breeds under different breeding conditions should be conducted to confirm and generalise our results.

Highlights

- Statistical models have been proposed to predict the birth weight of lambs.
- Tape measure can be successfully used for birth weight estimation.
- Model with chest, head, shin circumferences as covariates were suggested.

Introduction

Body measurements are used to estimate live weights for many farm animals (Çelikeloğlu and Tekerli 2018; Canul-Solis et al. 2020). Studies have thus focussed on the determination of body live weight using defined body dimensions and have identified the optimal slaughter weights of mature animals (Ravimurugan et al. 2013; Shirzeyli et al. 2013; Boujenane and Halhaly 2015; Bautista-Díaz et al. 2020). Getachew et al. (2009) and Musa et al. (2012) reported that measuring chest circumference (CC) and the subsequent prediction of body weight for each animal could ensure the correct dosage of medication or adjustment of feed dose. Similarly, Tyagi et al. (2013) recommended using linear body measurements over three months to estimate body weights of growing kids. The utility of this method was confirmed by Sabbioni et al. (2020) in Cornigliese sheep and is very promising for estimating the birth weights (BWs) of newborns (Thiruvenkadan 2005; Iqbal et al. 2014).

These studies have indicated that body measurements could be recommended as an alternative way of estimating body weight, eliminating the use of scales for weighing animals. The use of scales limits the accurate determination of BW in lambs born under extensive sheep management condition. Information about BW in these breeding systems is important for managing flocks, because BW is closely associated with the ease of lambing (Dwyer and Bünger 2012; Horton et al. 2018), lamb survivability (Knight et al. 1988; Everett-Hincks and Dodds 2008), or subsequent growth traits (Sušič et al. 2005; Ptáček et al. 2017). Estimation of lamb BW using measurements would
therefore reduce the workload (without the need of digital scales) and could be easily applied under extensive breeding conditions of sheep management. Cattle breeding has provided some evidence for this prediction, where measuring tapes have successfully been used to determine the BWs of newborn calves (Ruble 1987; Salman et al. 2017).

Measurements of CC on newborn calves, mature animals, or kids is a promising indicator of body weight or body-condition score. CC tends to be positively correlated with the percentage of tissue coverage but cannot be used to determine the exact amount of muscle or fat (Jeffery and Berg 1972). Various metrics such as rump height, wither height, pelvic width, and body length have also been positively correlated with body weight (Cam et al. 2010; Ravimurugan et al. 2013; Shirzeyli et al. 2013; Tekle 2014). Specific body dimensions can thus be successfully used for estimating BW in newborn lambs.

The aim of this study was to design statistical models for estimating lamb BW based on defined body measurements to provide a fast, easy, and accurate method for determining BW in management systems when the normal use of scales is limited.

**Materials and methods**

All procedures performed with animals were in accordance with the Ethics Committee of Central Commission for Animal Welfare at the Ministry of Agriculture of the Czech Republic (Prague, Czech Republic) and were carried out in accordance with Directive 2010/63/EU for animal experiments. All investigations and handling used normal breeder practices, in accordance with official laws in the Czech Republic (Animal Protection Against Cruelty Act; Act No. 246/1992 Sb.).

**Data collection**

Lambs were monitored at a commercial flock at the Pilsen district, Czech Republic (49.975360°N, 13.157135°E). Lambing occurs from March to the first half of May in the sheepfold. The sheep after birth were separated into lambing pens (1–2 days). Lambs were identified with ear tags and transferred to nurseries with their mothers (about 10–12 ewes per pen). They were released to grazing pasture after 7–14 days when climatic conditions were favourable.

This study covered the lambing period in 2019, investigating a total of 101 lambs (61 Charollais lambs, 27 Kent lambs, and 13 their crossbreds). Each lamb was weighed using a digiScale 50 hanging digital scale immediately after birth, (Kerbl, Buchbach, Germany). CC, head circumference (HC), and shin circumference (SC) were measured (in cm) using a tape measure. CC was measured at the back of the shoulder blade immediately behind the forelimbs (Afolayan et al. 2011; Çelikelöglu and Tekerli 2018). HC was measured in the region of the superciliary arches, with the measuring tape passing under the lower jaw (Knight et al., 1988), and SC was measured around the metacarpals of one of the forelegs (Çelikelöglu and Tekerli 2018). Additional information about breed, mother age, sex, and litter size were recorded for further statistical analyses.

**Statistical evaluation**

All statistical evaluations were performed using SAS 9.3 (SAS 2011). Partial correlations between the body dimensions after birth (SC, CC, and HC) were expressed after adjusting the data for the effects of breed, category of mother age, litter size, and sex of the lambs. Generalised linear models and MIXED procedures were used for estimating BW with the models and for the comparison of these models. Significance was estimated at \( p < .05, .01, \) and \( .001 \). The following models were designed for the determination of lamb BW:

\[
\text{BW}_{ijklm} = \mu + \text{BREED}_i + \text{AGE}_j + \text{LS}_k + \text{SEX}_l + b_1(\text{SC}) + e_{ijklm}
\]

\[
\text{BW}_{ijklm} = \mu + \text{BREED}_i + \text{AGE}_j + \text{LS}_k + \text{SEX}_l + b_2(\text{HC}) + e_{ijklm}
\]

\[
\text{BW}_{ijklm} = \mu + \text{BREED}_i + \text{AGE}_j + \text{LS}_k + \text{SEX}_l + b_3(\text{CC}) + e_{ijklm}
\]

where \( \mu \) is the mean of the trait evaluated, \( \text{BREED}_i \) is the \( i^{th} \) fixed effect of breed \( (i = \text{Charollais}, n = 61; i = \text{Kent}, n = 27; i = \text{crossbred lambs}, n = 13) \), \( \text{AGE}_j \) is the fixed effect of \( j^{th} \) ewe age category \( (j = \text{two-year-old ewes}, n = 28; j = \text{three-year-old ewes}, n = 25; \)
Table 1. General data of birth weight and measurement lambs.

| Variable | N  | Mean  | Std Dev | Min. | Max. |
|----------|----|-------|---------|------|------|
| BW (kg)  | 101| 4.58  | 0.889   | 2.5  | 6.5  |
| SC (cm)  | 101| 7.23  | 0.773   | 5.0  | 9.0  |
| HC (cm)  | 101| 27.22 | 1.527   | 23.0 | 32.0 |
| CC (cm)  | 101| 38.32 | 2.661   | 30.0 | 43.0 |

N: number of observations; Std Dev: standard deviation; Min.: minimal value; Max.: maximal value; BW: birth weight; CC: chest circumference; SC: shin circumference; HC: head circumference.

Table 2. Partial correlation coefficients of birth weight dependence on body measurements.

| Variables | BW | SC | HC |
|-----------|----|----|----|
| SC        | 0.345** |
| HC        | 0.679*** | 0.514*** |
| CC        | 0.795*** | 0.290** | 0.658*** |

BW: birth weight; CC: chest circumference; SC: shin circumference; HC: head circumference; **p < .01; ***p < .001.

correlations indicate the promising use of CC (r = 0.795; p < .001) or HC (r = 0.679; p < .001) for determining BW.

All models used for estimating BW were significant. For the models with one only covariate (A, B, and C), the model using CC as the covariate (model C in Table 2) predicted BW the best. This model explained 78.1% of the variability of BW and had the lowest AIC, AICC, and BIC. An increase in CC of one centimetre increased BW by 225 g. Topai and Macit (2004), Musa et al. (2012), and Çelikeloğlu and Tekerli (2018) also suggested using tape measurements of CC for estimating body weight.

Model B using HC as the covariate explained 74.1% of the variability of BW. R² for HC was interesting. AIC, AICC, and BIC were lower for model B than model A but higher than for model C. HC is usually not studied as often as CC, body length, or other measurements, but Knight et al. (1988) investigated the effect of HC on lamb survival immediately after birth. HC is easily measurable and it is not affected by the physical condition of the animal (Berge 1977; Thiruvenkadad 2005; Shirzeyli et al. 2013). The muscle coverage of the head, chest, and limbs is low in lambs (Wallace 1948) but increases with gradual growth, so HC may not correctly estimate the body weights of older animals (Waldron et al. 1992; Jones et al. 2002). To the best of our knowledge, no previous study has investigated the correlation between HC and BW. Our results demonstrate that HC is a useful trait for determining BW for newborn lambs.

In general, the more variables included in a model, the higher the accuracy of estimates of live weight (Thiruvenkadad 2005; Ravimurugan et al. 2013; Iqbal et al. 2014). Sabbioni et al. (2020) demonstrated that the use of multiple body measurements led to much more accurate predictions of body weights for growing and mature Cornigliese sheep. These results are in full accordance with ours for newborn lambs (Table 2). Models containing three covariates (SC, HC, and CC; model F) and two covariates (HC and CC; model G) had the highest R² and the lowest AIC, AICC, and BIC. These two models should thus be used for estimating BW, as our results suggest. Our results suggest that at
least CC should be used for estimating BW when multiple measurements are difficult, but only for practical use.

The models were verified by comparing estimated and measured BWs (Table 4). The differences between these BWs (supplemented by standard deviations, minimal and maximal differences, and Partial correlation coefficients) were calculated for a residual analysis. This analysis confirmed that CC, HC, or SC should be measured, or that CC at the least should be measured, for the effective determination of BW. Ongoing analyses found that body measurements, especially CC, were major driving factors in the models, which even decreased the conclusiveness of other factors in the model and also showed the lowest average residual (Table 4). The particular factors in the models, however, were detected for significant evidence as well. Our results were estimated and verified using sheep for meat production (Charollais, Kent, and their crossbreds). Supporting analyses involving these breeds separately are therefore reported in Tables S1, S2, S3, and S4 in the Supplementary file. Other studies involving animals of other breeds or under different breeding conditions should be, however, performed to confirm and generalise our results.

Conclusion

This study found that BW was strongly correlated with body measurements of lambs. Statistical models for BW were subsequently designed for estimating lamb weight. For models with one body measurement, $R^2$ was highest when CC was the covariate. This measurement should be used as an absolute base for determining BW under field conditions when multiple measurements are not possible. BW prediction, however, improved using multiple body measurements. Information about the circumferences of the head and shin should therefore be included. Residual analyses verified our results, but more extensive analyses of other breeds under different breeding conditions should be conducted to confirm and generalise our results.

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Ethical approval

All authors declare that they followed the rules of the Declaration of Helsinki.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Table 3. Statistical models for estimation birth weight of lambs from body measurements.

| MODEL | GLM procedure | MIXED procedure | Significance of fixed effects |
|-------|--------------|----------------|-----------------------------|
|       | $R^2$ | p-Model | AIC | AICC | BIC | Breed | Age | Sex | LS |
| A    | 0.608 | ***   | 190.9 | 191.0 | 193.4 | *** | * | n.s. | *** |
| B    | 0.741 | ***   | 154.3 | 154.4 | 156.8 | *** | * | n.s. | *** |
| C    | 0.781 | ***   | 139.8 | 139.8 | 142.3 | n.s. | n.s. | n.s. | *** |
| D    | 0.751 | ***   | 153.7 | 153.8 | 156.2 | *** | n.s. | n.s. | *** |
| E    | 0.804 | ***   | 132.8 | 132.9 | 135.4 | ** | n.s. | n.s. | *** |
| F    | 0.818 | ***   | 127.2 | 127.3 | 129.8 | ** | n.s. | n.s. | *** |
| G    | 0.825 | ***   | 127.1 | 127.1 | 129.6 | ** | n.s. | n.s. | *** |

BW: birth weight; CC: chest circumference; SC: shin circumference; HC: head circumference; $R^2$: coefficient of determination; p-Model: p value of model; LS: litter size, Age: ewes’ age category; Sex: sex of lambs; n.s.: non-significant; *p < .05; **p < .01; ***p < .001

Table 4. Comparison of real vs. estimated birth weight.

| MODEL | RBW ± Sd | EBW ± Sd | RBW vs. EBW ± Sd | MinD | MaxD | CORR |
|-------|----------|----------|------------------|------|------|------|
| A     | 4.58 ± 0.89 | 4.93 ± 0.405 | −0.353 ± 0.773 | −2.334 | 1.691 | 0.498*** |
| B     | 4.58 ± 0.89 | 4.89 ± 0.524 | −0.313 ± 0.603 | −1.814 | 1.686 | 0.753*** |
| C     | 4.58 ± 0.89 | 4.63 ± 0.599 | −0.054 ± 0.500 | −1.333 | 0.991 | 0.845*** |
| D     | 4.58 ± 0.89 | 4.90 ± 0.552 | −0.325 ± 0.602 | −1.796 | 1.704 | 0.747*** |
| E     | 4.58 ± 0.89 | 4.68 ± 0.632 | −0.102 ± 0.481 | −1.362 | 0.950 | 0.854*** |
| F     | 4.58 ± 0.89 | 4.71 ± 0.630 | −0.135 ± 0.465 | −1.471 | 1.607 | 0.867*** |
| G     | 4.58 ± 0.89 | 4.72 ± 0.645 | −0.148 ± 0.463 | −1.462 | 1.132 | 0.865*** |

RBW: averaged real birth weight (kg); EBW: averaged estimated birth weight (kg); RBW vs. EBW: averaged difference between real birth weight and estimated birth weight (kg); MinD: minimal difference between real birth weight and estimated birth weight; MaxD: maximal difference between real birth weight and estimated birth weight; CORR: Pearson correlation coefficients between real birth weight and estimated birth weight; ***p < .001.
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Data availability statement

The data that support the findings of this study are available on request from the corresponding author, A. M. The data are not publicly available due to their containing information that could compromise the privacy of research participants.

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