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Models predict the proportion of bone, muscle, and fat in ewe lamb carcasses from *in vivo* measurements of the 9th to 11th rib section and of the 12th rib

Modelos para predição das proporções de ossos, músculos e gordura da carcaça de borregas por medidas obtidas *in vivo,* na seção entre a 9ª e 11ª costelas e 12ªcostela

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Abstract

The present work aimed at evaluating models that predict the proportion of bone, muscle, and fat in ewe lamb carcasses using *in vivo* data obtained from the 9th to 11th rib section and from the 12th rib. A study population of 30 wooled ewe lambs, derived from Texel breed crosses, were fed with different concentrate levels (0%, 20%, 40%, 60%, and 80%) and slaughtered at a weight of 37.70 ± 10.23 kg. Carcass fat content (FC%) and muscle content (MC%) were estimated from models using the proportion of muscle and fat in the 9th to 11th rib section or in the 12th rib, with or without additional data regarding subcutaneous fat thickness (SFT mm) or carcass ribeye area (RA cm^2). Carcass bone content (BC%) was predicted based on the proportion of bones in the 9th to 11th rib section or in the 12th rib. Modeling with *in vivo* data included fasting body weight (FBW), withers height (WH), and ultrasound measurements of SFT and RA. The FC% could be estimated from the carcass SFT and fat content in the 12th rib. The MC% was more accurately predicted from the proportion of muscles in the 9th to 11th rib section and from carcass RA. The 9th to 11th rib section provided the most accurate data for the prediction of BC%. To determine FC% and MC% from *in vivo* inputs, the model must include FBW and WH. *In vivo* FBW measurements alone allow for the estimation of BC%. We recommend the use of 12th rib composition for the accurate estimation of carcass fat content, and the use of the 9th and 11th rib section for the prediction of carcass muscle and bone content. Models using *in vivo* data for the prediction of fat, muscle, and bone in ewe lambs should incorporate FBW and WH.

Key words: Ribeye area. Body composition. Fat thickness. Ovine**.**

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Resumo

Objetivou-se ajustar e avaliar modelos para predição das proporções de ossos, músculos e gordura da carcaça de borregas a partir de medidas obtidas *in vivo,* na seção HH e 12ª costela. As 30 borregas lanadas, oriundas de cruzamentos com ovinos da raça Texel, foram confinadas, alimentadas com níveis crescentes de concentrado (20; 40; 60 e 80%) e abatidas com 37,70 ± 10,23 kg. Para estimativa da proporção de gordura (GC%) e músculo (MC%) na carcaça foram ajustados modelos com os percentuais de gordura e músculo da 9ª a 11ª costela (seção HH) ou da 12ª costela, acompanhados ou não da espessura de gordura (EGS mm) ou da área de olho de lombo da carcaça (AOL cm^2), respectivamente. A proporção de ossos da carcaça (OC%) foi predito pelo percentual de ossos na seção HH ou da 12ª costela. Para predição *in vivo,* foram ajustadas equações com peso corporal em jejum (PCJ), altura de cernelha (AC), EGS e AOL medidas por ultrassom. A GC% pode ser estimada pela EGS obtida na carcaça e o teor de gordura na 12ª costela. O MC% pode ser predito de forma mais acurada considerando o teor de músculo na seção HH e a AOL da carcaça. A seção HH foi o modelo mais acurado para predição da OC%. Para obtenção da GC% e MC% *in vivo* os modelos devem incluir PCJ e AC. O OC% *in vivo* pode ser estimado a partir do PCJ. Recomenda-se a utilização da composição física da 12ª costela para estimativa acurada da proporção de gordura na carcaça e o uso da seção HH para predição das proporções de músculo e ossos na carcaça. Para predição acurada das proporções de gordura, músculo e ossos de borregas *in vivo,* o modelo deve apresentar peso corporal em jejum e medidas de altura de cernelha.

Palavras-chave: Área de olho de lombo. Componentes corporais. Espessura de gordura. Ovinos.

Introduction

The development of models that accurately predict the proportion of bone, muscle, and fat in ewe lambs may contribute to the efficiency of meat production systems in Brazil. Such models provide information that allows producers to explore growth potential and feed efficiency to a maximum, to gain insight into weight gain composition and breed differences, to define nutritional demands, and finally, to evaluate animals for the production of ideal carcasses.

In this sense, the development of models that accurately predict animal body composition from the correlation of *in vivo* and carcass data will strongly contribute to reduce the demand for labor and laboratorial analyses, in particular as they relate to ovine nutritional requirements and carcass tissue components. Ovine weight gain requirements, regardless of sex and breed, are often estimated from the body composition of animals slaughtered at the beginning and end of experiments, which allow for the calculation of carcass energy retention (NRC, 2007). If body composition estimates can be derived from *in vivo* models based, for example, on ultrasound and biometric measurements, pre-experimental slaughter would become unnecessary in studies regarding weight gain requirements, which would reduce costs and number of animals needed.

Body composition models based on *in vivo* data would also provide estimates of muscle, fat and bone in the carcass; these proportions are associated with the yield of different cuts and with meat quality (SOUSA et al., 2008). The use of ultrasound in determining subcutaneous fat thickness and ribeye area would represent an excellent tool for the generation of models that estimate muscle-to-fat ratios prior to slaughter, which would allow producers to sell animals with pre-defined carcass profiles (SILVA et al., 2007).

Models that have carcass data as inputs usually rely on data generated from the 9th to 11th rib section to predict body composition (FERNANDES et al., 2008). Albeit accurate, this method affects the commercial use of the loin. Thus, the use of the 12th rib for input data generation may represent a better option that does not completely damage the cut, allows for rapid sample processing, and assesses the same characteristics of body composition as the 9th to 11th section (MENEZES et al., 2008). However,

little data exist on the accuracy of the equations generated from this method in ewe lambs.

Several equations for biological interpretation have been published, however they often only apply to specific populations, gender, breeds, and genetic groups (AZEREDO et al., 2006). Despite the existing body of work, no previous study has focused on the correlation of data obtained *in vivo* and from carcasses, from the 9th to 11th or from the 12th rib section, for the generation of accurate prediction models targeting ewes raised under tropical conditions. Thus, the present study aimed at evaluating models that predict the proportion of bone, muscle, and fat in the carcasses of ewe lambs, from data obtained *in vivo*, from the 9th to 11th rib section and from the 12th rib.

Materials and Methods

Experiments were conducted at the School of Veterinary Medicine and Zootechny of the Universidade Federal de Mato Grosso do Sul (UFMS), Campo Grande, MS, Brazil, from August to December of 2009, after approval by the Committee for the Ethics of Animal Use at the university (process number 235/2009). Treatment of ewe lambs followed approved procedures for the use of animals in research.

We used 30 wooled ewe lambs derived from crosses between Texel animals, with an initial body weight of 24.55 ± 3.26 kg and 3 ± 1 months of age. Animals were randomly distributed into five treatments including 0%, 20%, 40%, 60%, and 80% feed concentrate. Dietary variations were used to increase databank variability, increasing its reach and applicability to different production systems. Diets (Table 1) were formulated according to the NRC (2007) for ovines with weight gain of 100, 150, 200, and 250 g/day. The forage used was Tifton 85 Bermuda grass (*Cynodon spp.*) ground and sieved through an 18 mesh (1 mm).

Table 1. Chemical composition of the experimental diets, based on dry matter.

Chemical composition	Concentrate levels			
	20%	40%	60%	80%
Dry matter (%)	91.98	91.58	91.18	90.78
Organic matter (%)	93.83	93.88	93.94	93.99
Crude Protein (%)	20.76	21.98	23.21	24.44
Ether extract (%)	2.44	2.54	2.65	2.76
Neutral detergente fiber (%)	67.66	58.35	49.04	39.73
Acid detergent fiber (%)	34.40	27.21	20.02	12.84
Neutral detergente insoluble N (%)	0.84	0.80	0.77	0.74
Acid detergent insoluble N (%)	0.22	0.21	0.20	0.19
Lignin (%)	4.25	3.30	2.36	1.41
Non-fiber carbohydrate[1] (%)	10.06	16.43	22.80	29.17
Total digestible nutrientes (%)	65.38	72.52	76.81	77.28

[1]Estimated by equation of Hall (2000): NFC = 100 – [($CP_{\%}$ - CP derived from $urea_{\%}$ + $urea_{\%}$) + $NDFp_{\%}$ + $EE_{\%}$ + $ash_{\%}$]; $NFC_{\%}$ = non-fiber carbohydrate, %; $CP_{\%}$ = crude protein, %; $NDFp_{\%}$ = neutral detergent fiber corrected for protein, %; $EE_{\%}$ = ether extract, %.

At the end of the experimental period, body weights at slaughter were obtained by weighing animals after 18 h of solid feed fasting. The end of the experiment, when all animals were slaughtered, was defined as the time when animals in the 80% group reached a fasting body weight of 48.0 kg.

During pre-slaughter weightings, we used a tape measure to record withers height (WH), which corresponded to the vertical distance between animal withers and the ground. After WH measurements, we used ultrasound to assess subcutaneous fat thickness (SFT) and ribeye area (RA) in the region between the 12th and 13th ribs on the right side of the animal. The ultrasound equipment was an Áquila Veterinário, Pie Medical® (Nutricell, Campinas, São Paulo, Brazil), with linear transductor with a frequency of 6.0/8.0 MHz and 7 cm in length.

Animals were slaughtered at the Carcass Evaluation Laboratory of Embrapa Beef Cattle, located in Campo Grande, MS, Brazil. Animals were stunned with a stun bolt gun, and bled through a cut to the carotid artery and jugular vein, after which they were skinned and eviscerated. Head and legs were separately weighed. Carcasses were divided into two halves, warm carcass weights (WCW) were measured immediately and cold carcass weights (CCW) obtained after carcasses had been kept in the cold chamber at -4 ºC for 24 h.

Right half-carcasses were completely dissected into muscle, fat, and bone, and each tissue type was weighed separately. Afterwards, muscle and fat were ground in meat grinders, identified, and frozen separately for posterior analyses. Carcass bones, the head and legs were sawn into small pieces with a tape saw (all tissues were sawn with attached soft tissues), sampled, identified, weighed, and stored.

Left half-carcasses were cut transversally between the 12th and 13th thoracic vertebrae for the exposure of the *longissimus dorsi* muscle and determination of the RA perimeter on parchment paper. RA was determined from the perimeter using the LI 3100 Area Meter (LICOR®, Lincoln, Nebraska, USA). The *longissimus dorsi* SFT was measured with a digital caliper at the point corresponding to 2/3 of the muscle longitudinal section (CÉZAR; SOUSA, 2007).

The 9th to 11th rib section was collected from the left half-carcasses following the procedure described by Hankins and Howe (1946). The 12th rib was also collected. In both methods, samples were dissected before components (muscle, fat, and bone) were separately weighed and percentage compositions determined. For the prediction of body components (muscle, fat, and bone) four models were applied, three of which used carcass data (models 1, 2, and 3) and one used *in vivo* data (model 4).

Model 1 was elaborated to estimate carcass fat content, using as input variables the proportions of fat in the 9th to 11th rib section or in the 12th rib, with or without SFT data, measured directly from the carcass. Model 2 was elaborated for the prediction of carcass muscle content, using as input variables the proportion of muscle tissue in the same sections, again with or without SFT data, measured from the carcass. Similarly, model 3 was elaborated for the prediction of bone content, using as input variables the proportion of bones in the same sections described above. Finally, model 4 was elaborated for the prediction of all body components evaluated, using as input variables assessed *in vivo* including fasting body weight, WH, as well as the SFT and RA data obtained by ultrasound.

Model adjustments and variable selection were performed using the procedure (PROC) REG, and the correlation study among variables was performed using PROC CORR of SAS v 9.3 (SAS Inst. Inc.®, Cary, North Carolina, USA). The outliers were tested by the evaluation of studentized residuals in relation to values predicted by the models. Residuals that fell outside the range of -2.5 to 2.5 were removed. Model adequacy was evaluated as proposed by Tedeschi (2006). Linear regressions were calculated for observed data against the predictions from each model, coefficients of determination (R^2) was calculated, and the simultaneous F test was performed for parameter identity ($\beta 0 = 0$ e $\beta 1 = 1$). Other criteria used include the coefficient of correlation and concordance (CCC), the square root of the mean square error (SRMSE), and the partition of the mean square error into mean bias, systemic bias, and random error.

For the comparison of models regarding the accuracy of their predictions, we analyzed the mean square error of paired predictions (WALLACH; GOFFINET, 1989), and for the comparison regarding precision, we used Akaike Information Criterion Delta (BURNHAM; ANDERSON, 2002). Statistical calculations for model evaluation and comparison were performed using the MES – Model Evaluation System (http.//nutritionmodels.tamu.edu/mes.htm, College Station, TX, USA) (TEDESCHI, 2006). A significance level of 10% was adopted in all statistical procedures.

Results and Discussion

The observed body measures were characteristic of growing ewes nearing adult weight, and able to reproduce (Table 2). Standard deviation values for each characteristic were elevated, in particular the CCW and fasting body weight, tissue proportions obtained from dissected carcasses, ultrasound measurements of SFT and RA, WH, and the percentage tissue proportions from the two evaluated rib sections. This result was expected, because the different dietary concentrate levels (0%, 20%, 40%, 60%, and 80%) resulted in different performances and slaughter weights (RIBEIRO, 2011), and formed the basis for a robust and diversified databank. The observed variation in fasting body weight may have contributed to the high standard deviation values recorded for carcass composition characteristics. According to the NRC (2007), heavier animals have a higher proportion of muscles and fat in their carcasses in comparison with smaller ones, because tissue deposition continues until animals reach their adult weight. Thus, the closer an animal is to its adult weight at slaughter, the greater will be the proportion of muscle and fat in its carcass, as observed by different authors (MEDEIROS et al., 2008; PIOLA JÚNIOR et al., 2009; OSÓRIO et al., 2012).

Table 2. Mean values and standard deviations for the variables used as inputs in different body composition models.

Variables	N	Mean	Standard Deviation
Fasting body weight, kg	30	37.705	9.886
Cold carcass weight, kg	30	17.763	6.026
Carcass muscle, kg	30	8.646	2.459
Carcass fat, kg	30	5.478	3.112
Carcass bone, kg	30	2.355	0.541
Carcass loin ribeye area, cm^2	30	10.418	3.012
Ultrasound loin ribeye area, cm^2	30	10.602	2.689
Carcass subcutaneous fat thickness, mm	30	3.796	3.141
Ultrasound subcutaneous fat thickness, mm	30	2.697	1.285
Withers height, cm	30	64.067	6.221
Muscle in the 9^{th} to 11^{th} rib section, %	30	45.293	8.459
Fat in the 9^{th} to 11^{th} rib section, %	30	38.783	12.824
Bone in the 9^{th} to 11^{th} rib section, %	30	15.92	5.939
Muscle in the 12^{th} rib, %	30	38.089	10.739
Fat in the 12^{th} rib, %	30	43.373	14.487
Bone in the 12^{th} rib, %	30	18.53	13.545

N: number of observations.

Model 1 (Table 3) was adjusted for predicting the proportion of fat in carcasses, using the percentage of fat in the 9th to 11th rib section (Fsec%) and the percentage of fat in the 12th rib (F12%), associated (Eq. [1] and [3]) or not (Eq. [2] and [4]) to the SFT measured from the carcasses (Table 3). Comparison of these equations indicated a greater accuracy (P<0.10) for those using F12% with or without SFT (Eq. [3] and Eq.[4], Table 3) in comparison to models using Fsec% (Eq. [1] and [2], Table 3).

Table 3. Statistical[1] evaluation of models for the prediction of carcass fat content based on data from the 9th to 11th rib section or from the 12th rib.

Models[2,3]	N	R^2	P	CCC	SRMSE	SME partitioning (%)		
						MB	SB	RE
1) $FC_{\%} = 0.097^{***}(\pm 0.017) + 0.010^{***}(\pm 2.47 \times 10^{-3}) \times FT_{mm} + 4.39 \times 10^{-3***} (\pm 6.05 \times 10^{-4}) \times G_{sec\%}$	29	89.4	0.999	0.96	0.00057	0.0	0.0	100
2) $FC_{\%} = 0.056^{***}(\pm 0.019) + 6.45 \times 10^{-3***}(\pm 4.66 \times 10^{-4}) \times G_{sec\%}$	29	84.5	0.999	0.94	0.00096	0.0	0.0	100
3) $FC_{\%} = 0.072^{***}(\pm 0.014) + 5.17 \times 10^{-3**}(\pm 2.10 \times 10^{-3}) \times FT_{mm} + 4.98 \times 10^{-3***} (\pm 4.55 \times 10^{-4}) \times G12_{\%}$	29	96.9	0.999	0.98	0.00031	0.0	0.0	100
4) $FC_{\%} = 0.050^{***}(\pm 0.012) + 5.94 \times 10^{-3***}(\pm 2.58 \times 10^{-4}) \times G12_{\%}$	29	92.9	0.999	0.98	0.00038	0.0	0.0	100

[1] Statistics: R^2= coefficient of determination. P = F Test probability for parameter identity from the regression of observed versus predicted data. CCC = concordance correlation coefficient. SRMSE = square root of the mean square error. MSE = mean square error. MB = mean bias. SB = systemic bias. RE = random error.
[2] Models: FC = carcass fat content, %; FT = fat thickness on the 13th rib, mm; Fsec fat content in the 9th to 11th rib section, %; and G12 = fat content on the 12th rib, %.
[3]***(p<0.001); **(p<0.01).

Hopkins et al. (2008), while attempting to establish similar predictive models based on SFT and RA of the 12th rib, concluded that the inclusion of all variables did not generate more accurate predictions, because the R^2 for fat content (FC%) remained between 0.293 and 0.571, always below 0.85 and below the values observed in the present work.

While further evaluating the equations for the prediction of FC%, we found that the p-value for all equations was close to 1.0, that is, predicted values were similar to observed values. Partition of the mean square error indicated that most of the errors in these equations were of random origin, and the CCC and SRMSE were similar, indicating that all of the equations were equally good at predicting FC%. In spite of these similarities, results obtained point to the greater accuracy and precision (P<0.05) of the equation that had F12% and SFT as inputs (Eq. [3], Table 3).

Model 2 equations for the prediction of carcass muscle content (MC%) also had p-values near 1 (Table 4). Furthermore, partitioning of the mean square error showed that most of the error in these equations had a random origin. These findings, in combination with R^2 values near 80% and CCC near 0.80, indicate that the equations had similar predictive strengths. These equations did not differ in accuracy (P>0.10). On the other hand, the equation 1, which had as input the muscle content in the 9th to 11th rib section (Msec%) and RA measured from the carcass (Table 4), was more precise (P<0.10) than Eqs. [2], [3] and [4], which did not differ among them (P>0.10).

Table 4. Statistical[1] evaluation of models for the prediction of carcass muscle content based on data from the 9th to 11th rib section or from the 12th rib.

Models[2,3]	N	R^2	P	CCC	SRMSE	SME partitioning (%)		
						MB	SB	RE
1) $MC_{\%} = 0.406^{***}(\pm 0.050) - 5.85 \times 10^{-3**}(\pm 2.11 \times 10^{-3}) \times LEA_{cm2} + 4.34 \times 10^{-3***}(\pm 7.78 \times 10^{-4}) \times Msec_{\%}$	28	88.6	0.999	0.84	0.00070	0.00	0.00	100
2) $MC_{\%} = 0.298^{***}(\pm 0.035) + 5.36 \times 10^{-3**}(\pm 7{,}68 \times 10^{-4}) \times Msec_{\%}$	28	73.8	0.999	0.79	0.00092	0.00	0.00	100
3) $MC_{\%} = 0.473^{***}(\pm 0.047) - 5.75 \times 10^{-3**}(\pm 2.41 \times 10^{-3}) \times LEA_{cm2} + 3.16 \times 10^{-3***}(\pm 6.93 \times 10^{-4}) \times M12_{\%}$	28	79.3	0.999	0.81	0.00086	0.00	0.00	100
4) $MC_{\%} = 0.378^{***}(\pm 0.026) + 4.02 \times 10^{-3***}(\pm 6.44 \times 10^{-4}) \times M12_{\%}$	28	76.0	0.999	0.75	0.00106	0.00	0.00	100

[1]Statistics: R^2= coefficient of determination. P = F Test probability for parameter identity from the regression of observed versus predicted data. CCC = concordance correlation coefficient. SRMSE = square root of the mean square error. MSE = mean square error. MB = mean bias. SB = systemic bias. RE = random error.
[2] Models: MC = carcass muscle content, %; LEA = loin eye muscle on the 13th rib, $_{cm}^2$; Msec muscle content in the 9th to 11th rib section, %; and M12 = muscle content on the 12th rib, %.
[3]***(p<0.001); **(p<0.01).

Our results support those obtained by Cadavez (2009), who observed a positive correlation between conformation, which is associated to RA, and MC% in ovines. According to this author, variables such as RA improve the predictive strength of models regarding MC%. Lambe et al. (2009) observed that *post mortem* measurements of RA and SFT improved model predictions of MC% and meat quality.

In addition to carcass composition, RA has a relevant correlation with the yield of meat cuts. However, when using this variable one must take into account the factors that might lead to under- or overestimates. Factors such as poorly performed skinning, excessive fat removal, altered position of tissues in the carcass, and incorrect cutting of the measured section may alter the accuracy and precision of models (PINHEIRO et al., 2010).

For the prediction of carcass bone content (BC%), model 3 equations took into account the proportion of bone in the 9th to 11th rib section (Bsec%) and in the 12th rib (B12%) (Table 5). Other equations were not evaluated as a result of the lack of significance of input variables. Both bone equations displayed P-values near 1.0 (Table 5), again pointing to the similarity between predicted and observed values. Partitioning of the mean square error showed that almost all the error built into model predictions had a random origin. On the other hand, BC% prediction by the equation that included Bsec% (Eq. [1], Table 5) had higher R^2 and lower SRMSE, in addition to greater accuracy and precision (P<0.05).

Published data on bone proportion are scant, probably reflecting the smaller variation in bone tissue among animals in a given age range and genetic group, when compared to the variations in muscle and fat. Nevertheless, bone represents the main inedible component of carcasses, and predicting its proportions is crucial to determining final yield of meat cuts.

Table 5. Statistical[1] evaluation of models for the prediction of carcass bone content based on data from the 9th to 11th rib section or from the 12th rib.

Models[2,3]	N	R^2	P	CCC	SRMSE	SME partitioning (%)		
						MB	SB	RE
1) $BC_{\%}$ = 0.059***(±0.008) + 5.81 × 10^{-3}***(±4.73 × 10^{-4}) × Bsec%	29	78.3	0.999	0.92	0.00021	0.00	0.00	100
2) $BC_{\%}$ = 0.116***(±0.009) + 1.83 × 10^{-3}***(±3.97 × 10^{-4}) × B12%	29	63.7	0.999	0.61	0.00078	0.00	0.00	100

[1]Statistics: R^2= coefficient of determination. P = F Test probability for parameter identity from the regression of observed versus predicted data. CCC = concordance correlation coefficient. SRMSE = square root of the mean square error. MSE = mean square error. MB = mean bias. SB = systemic bias. RE = random error.
[2]Models: BC = carcass bone content, %; Bsec = bone content in the 9th to 11th rib section, %; and B12 = bone content on the 12th rib, %.
[3]***(p<0.001); **(p<0.01).

Model 4, for the prediction of body components based on *in vivo* variables, took into account fasting body weight and WH (Eq. [1] and Eq. [2], Table 6). Other equations, which had as inputs RA and SFT, were not evaluated because of the lack of significance of tested variables. Fasting body weight was the only significant variable for the estimation of BC% (Eq. [3], Table 6). P-values were non-significant for all equations, indicating that all of the equations could predict observed values (P>0.10). Partitioning of the mean square error indicated that model errors were mostly random. In addition, high R^2 and CCC values associated with low SRMSE further support the good adjustment of these equations.

Table 6. Statistical[1] evaluation of models for the prediction of carcass fat, muscle and bone content based on data from the measured *in vivo*.

Models[2,3]	N	R^2	P	CCC	SRMSE	SME partitioning (%)		
						MB	SB	RE
1) $FC_{\%}$ = – 0.192***(±0.068) + 6.38 × 10^{-3}*** (±9.09 × 10^{-4}) × BWF_{kg} +4.02 × 10^{-3}***(±1.43 × 10^{-3}) × WH_{cm}	29	84.6	0.248	0.95	0.00076	0.00	9.79	90.2
2) $MC_{\%}$ = – 0.934***(±0.052) – 2.52 × 10^{-3}*** (±6.93 × 10^{-4}) × BWF_{kg} – 4.63 × 10^{-3}**(±1.09 × 10^{-3}) × WH_{cm}	29	86.8	0.999	0.92	0.00044	0.00	0.00	100
3) $BC_{\%}$ = 0.285***(±0.011) – 3.54 × 10^{-3}*** (±2.69 × 10^{-4}) × BWF_{kg}	29	85.1	0.999	0.93	0.00019	0.00	0.00	100

[1] Statistics: R^2= coefficient of determination. P = F Test probability for parameter identity from the regression of observed versus predicted data. CCC = concordance correlation coefficient. SRMSE = square root of the mean square error. MSE = mean square error. MB = mean bias. SB = systemic bias. RE = random error.
[2] Models: FC = carcass fat content, %; MC = carcass muscle content, %; BC = carcass bone content, %; BWF = body weight fasting, kg; WH = withers height, cm.
[3]***(p<0.001); **(p<0.01).

In predicting FC% and MC%, fasting body weight and WH were the variables with the best results, whereas the ultrasound data had little applicability for the prediction of body components. Fasting body

weight and WH can be easily obtained in the field, at a low cost when compared to ultrasound imaging. When using biometric measurements associated to weight to estimate body components, Fernandes et al. (2010) also observed high model accuracy and precision.

Predicting animal body fat *in vivo* provides crucial information for the estimation of total fat composition, especially for the evaluation of tissue deposition during the growth and finishing phases of animal production, and to help prepare uniform groups for slaughter. Predicting carcass muscle content *in vivo* would represent a tool for the estimation of animal nutritional demands, especially during the growth phase when more dietary protein is required. Finally, estimating carcass bone content from *in vivo* data was only accurate with the use of fasting body weight, indicating that periodic animal weighting would allow for the estimation of bone development, dietary mineral requirements, and carcass yield.

Conclusions

Based on our results, we recommend the use of 12th rib data for estimating FC%, and the use of data from the 9th to 11th rib section for estimating MC% and BC%. For the accurate prediction of FC% and MC% from *in vivo* data, the models should incorporate fasting body weight and WH, whereas BC% can be estimated from fasting body weight.

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