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Comparison of Alternative Models to Predict Lean Meat Percentage of Lamb Carcasses

Vasco A. P. Cadavez[1] and Fernando C. Monteiro[2]

***Abstract*—**The objective of this study was to develop and compare alternative prediction equations of lean meat proportion (LMP) of lamb carcasses. Forty (40) male lambs, 22 of Churra Galega Bragançana Portuguese local breed and 18 of Suffolk breed were used. Lambs were slaughtered, and carcasses weighed approximately 30 min later in order to obtain hot carcass weight (HCW). After cooling at 4º C for 24-h a set of seventeen carcass measurements was recorded. The left side of carcasses was dissected into muscle, subcutaneous fat, inter-muscular fat, bone, and remainder (major blood vessels, ligaments, tendons, and thick connective tissue sheets associated with muscles), and the LMP was evaluated as the dissected muscle percentage. Prediction equations of LMP were developed, and fitting quality was evaluated through the coefficient of determination of estimation ($\mathbf{R}^2_e$) and standard error of estimate (SEE). Models validation was performed by k-fold crossvalidation and the coefficient of determination of prediction ($\mathbf{R}^2_p$) and standard error of prediction (SEP) were computed. The BT2 measurement was the best single predictor and accounted for 37.8% of the LMP variation with a SEP of 2.30%. The prediction of LMP of lamb carcasses can be based simple models, using as predictors the HCW and one fat thickness measurement.

***Keywords*—**Bootstrap, Carcass, Lambs, Lean meat

I. Introduction

CLASSIFICATION describes the features of the carcasses that are important to define quality and composition classes for use in trade along the meat industry chain [1]. The set of descriptive terms used to describe the features of the carcasses must be easy to understand and must have commercial relevance for carcasses trading. A carcass with ideal composition should have the maximum price, and whenever the carcass composition moves away from the ideal, its price must suffer penalties. In longer term, classification could lead to better producer prices and quality, more in line with consumer demand by providing an objective basis for measuring performance and giving feedback to producers [2].

However, currently in the European Union (EU) the lamb carcasses classification is still being performed by trained inspectors, based on photographic standards [3], by visual appraisal of fatness and conformation, which is subjective, laborious, costly and inherently unreliable. Johansen [4] found that this classification system suffers of inconsistency among slaughter-houses and assessors. Thus, the change to an objective system of carcasses classification has been pursued by researchers and meat industry. The EU legislation, concerning the development of objective carcass classifications systems, imposes that they must be based on the prediction of lean meat percentage (LMP), and models must present a standard error of prediction (SEP) lower than 2.5% [5].

Clearly, the carcasses lean meat weight (LMW) and the LMP are related traits, but for classifications purposes they are not synonymous. The coefficients of determination are reportedly lower for models predicting the LMP than for models predicting the LMW [6]. This feature of models to predict the LMP comes from the low variation observed in this tissue [7]. Mathematically it is not possible to convert the predicted LMW into predicted LMP using a simple ratio between the predicted LMW with carcass weight. This direct calculation is possible only if all carcasses have equal weight as demonstrated here. Lets the absolute error of prediction of LMW be:

$$e_i = y_i - \hat{y}_i = y_i - (a + bx_i) \quad (1)$$

and the error of prediction, the regression coefficient, and the intercept, respectively, of the LMP be:

$$e_{i\%} = y_{i\%} - \hat{y}_{i\%} = y_{i\%} - (a_{\%} + b_{\%}x_{i\%}) \quad (2)$$

$$b_{\%} = \frac{\sum (x_i - \bar{x})(\frac{y_i}{w_i} - \frac{\sum \frac{y_i}{w_i}}{n})}{\sum (x_i - \bar{x})^2} \quad (3)$$

$$a_{\%} = \sum \frac{y_i}{w_i} - \frac{\sum (x_i - \bar{x})(\frac{y_i}{w_i} - \frac{\sum \frac{y_i}{w_i}}{n})}{\sum (x_i - \bar{x})^2}\bar{x} \quad (4)$$

If all carcasses has the same weight (constant weight) we have $w_i = w$, then replacing in equations 2, 3, and 4 we get:

$$e_{i\%} = \frac{y_i}{w} - (\frac{1}{w}a + \frac{1}{w}bx_i) = \frac{e_i}{w} \quad (5)$$

$$b_{i\%} = \frac{1}{w}b \quad (6)$$

$$a_{i\%} = \frac{1}{w}a \quad (7)$$

Replacing these values in equation 2 we get:

$$\frac{e_i}{w} = \frac{1}{w}\left[y_i - (a + bx_i)\right] \Rightarrow ei = ei \quad (8)$$

[1]Vasco Cadavez is with the Mountain Research Center (CIMO), ESA - Polytechnic Institute of Bragança, Campus Santa Apolónia, Apartado 1172, 5301-855 Bragança, Portugal. e-mail: vcadavez@ipb.pt.
[2]Fernando C. Monteiro is with the Polytechnic Institute of Bragança, Campus Santa Apolónia, Apartado 1134, 5301-857 Bragança, Portugal. e-mail: monteiro@ipb.pt.

The European sheep production systems are characterized by a high number of breeds, with different body size, raised under very different production systems, leading to a great market variety in lambs' age and live/carcass weight at slaughter. Thus, at slaughter-houses, carcasses weight is very diverse, and for on-line classification of carcasses, models must be developed to predict their LMP. The objective of this study was to develop and compare alternative prediction equations of LMP of lamb carcasses.

II. Material and methods

A. Animals

Forty male lambs of Churra Galega Bragançana (CGB; n = 22) and Suffolk (SU; n = 18) breeds, were selected to cover the carcass weight range (12.1±1.93 kg for CGB and 12.3±2.09 for SU) of lambs slaughtered in Portugal. The lambs were randomly selected from the experimental flock of the Escola Superior Agrária de Bragança. Lambs were raised with their mothers in natural suckling until slaughter, and had access to pasture, natural meadow hay, and to commercial concentrate mixture and mineral-vitamin supplementation.

B. Slaughter procedure and carcass measurements

Lambs were slaughtered after 24-h fast in the experimental slaughter-house at the Escola Superior Agrária de Bragança, and carcasses were weighted approximately 30 minutes after slaughter in order to obtain the HCW according to [8]. After chilling at 4ºC for 24-h, carcasses were suspended on a gamble with 21-cm distance between legs. The following carcass measurements were taken: 1) carcass length (K, cm) measured from the base of the tail to the base of the neck [9]; 2) leg length (F, cm), representing the smallest distance from the perineum to the interior face of the tarsal-metatarsal articular surface [9]; 3) buttocks width (G, cm) measured using the measuring caliper at the level of the proximal edge of the patellae [8]; 4) thorax circumference (U, cm) measured using a tape held horizontally around the thorax at the level of the caudal portion of the scapula; and, 5) buttock circumference (CB, cm) was measured using a tape held horizontally around the buttocks at the level of the tail insertion [8].

C. Carcasses quartering and dissection

Carcasses were halved through the centre of the vertebral column, and the kidney knob and channel fat was removed and weighed. The left side was divided into eight standardised commercial joints: leg, chump, loin, ribs, anterior ribs, shoulder, breast and neck according to the commercial jointing and cutting system of Estação Zootécnica Nacional. During quartering tissue measurements were performed with a caliper on maximum longissimus muscle depth (mm) and subcutaneous fat thickness (mm) between the 12th and 13th ribs (B12 and C12, respectively), 1st and 2nd lumbar vertebrae (B1 and C1, respectively), and 3rd and 4th lumbar vertebrae (B3 and C3, respectively). Additionally, longissimus muscle area ( ) between the 12th and 13th ribs (LEA12), 1st and 2nd lumbar vertebrae (LEA1), and 3rd and 4th lumbar vertebrae (LEA3) was traced on acetate sheet and longissimus muscle area was measured using a digital planimeter (Model KP-90; Koizumi Placom, Niigata, Japan). Finally, total breast bone tissue thickness (mm) was taken with a sharpened steel rule at middle of the 2nd (BT2), 3rd (BT3) and 4th (BT4) sternebrae as proposed by [10]. Each carcass joint was then dissected into muscle, subcutaneous fat, inter-muscular fat, bone, and remainder (major blood vessels, ligaments, tendons, and thick connective tissue sheets associated with muscles), and the carcasses LMP was evaluated as the dissected muscle percentage.

D. Statistical analysis

Data were analyzed using the [11] software. Simple and multiple linear models to predict LMP were developed through regression procedures under the MASS package [12]. Models fitting quality was evaluated through the coefficient of determination of estimation (R^2_e) and standard error e of estimate (SEE). Models validation was performed by k-fold crossvalidation using the cv.lm() function in the DAAG package [13], and the coefficient of determination of prediction (R^2_p) and standard error of prediction (SEP) were computed.

TABLE I

Mean, CV, minimum and maximum of HCW, carcass dimensions and tissues measurements

Variable	Mean	CV	Min	Max
HCW - Hot carcass weight, kg	12.2	16.7	8.0	15.0
Carcass measurements, cm				
F - Leg length	27.3	7.7	23.0	31.0
K - Carcass length	72.4	8.1	61.3	82.0
G - Buttocks width	20.9	6.0	18.3	23.0
U - Thorax circumference	61.9	5.7	55.0	67.5
CB - Buttocks circumference	54.6	5.9	47.4	60.5
Longissimus muscle depth, mm				
B12 - rib	24.9	15.7	17.3	32.7
B1 - lumbar vertebrae	26.6	15.4	19.8	35.0
B3 - lumbar vertebrae	24.0	12.1	17.5	32.6
Longissimus muscle area,				
LEA12 - rib	10.5	19.3	6.4	14.6
LEA1 - lumbar vertebrae	10.7	18.1	6.7	14.9
LEA3 - lumbar vertebrae	10.4	15.9	6.7	14.2
Subcutaneous fat thickness, mm				
C12 - rib	1.3	44.5	0.4	2.5
C1 - lumbar vertebrae	1.2	57.1	0.4	3.2
C3 - lumbar vertebrae	2.1	64.0	0.3	5.4

III. Results and Discussion

Table I shows the mean, CV, minimum and maximum of HCW, carcass dimensions and tissues measurements. In spite of the large variation observed in HCW, the carcass dimension measurements (F, K, G, U and CB) had the lowest CV (from 5.7 to 8.1%). Similar results have been presented by [14] in a study with several sheep breeds raised in France. Subcutaneous fat thickness measurements (C12, C1 and C3) had the highest CV (> 44.5%) of all the measurements recorded which agrees with the results from [6] and [15]. The BT measurements presented a magnitude higher (from 5.9 to

13.6 times) than the C measurements; therefore, BT measurements would present smaller measurement errors [16], especially in very young animals with low subcutaneous fat, which are typical in Mediterranean countries where light carcasses are mainly produced from local breeds.

Best five simple linear models for predicting LMP are presented in Table II. The HCW accounted for 1.2% of the variation in LMP (data not shown). These results are in concordance with the results from [17], [18] and [19] who found that HCW alone was not able to account for the LMP, presenting a small contribution to the explanation of LMP. On the contrary, several studies presented models dominated by live weight [20, 21] or carcass weight [6, 22].

However, these models were developed to predict muscle weight instead of muscle proportion. The R^2 is a function of weight range [1], thus models developed from samples with small variation on carcass weight (in the limit at constant weight) will present low R^2 while those developed from samples with large variation in carcass weight will present high. Thus, comparing the R^2 of models developed to predict

TABLE II
BEST FIVE SIMPLE LINEAR MODELS FOR PREDICTING LAMB CARCASSES LEAN MEAT PERCENTAGE

Model	Variables	Parameter	SE	T value	Pr(>|t|)
1	Intercept	69.7	1.77	39.353	< 2e-16***
	BT2	-0.508	-0.106	-0.4.804	2.44e-05***
	R^2_e = 0.387, SEE = 2.28, R^2_p = 0.317, SEP = 2.30				
2	Intercept	68.7	1.60	43.007	< 2e-16***
	BT3	-0.495	0.105	-4.704	3.33e-05***
	R^2_e = 0.368, SEE = 2.30, R^2_p = 0.311, SEP = 2.34				
3	Intercept	63.7	0.71	89.372	<2e-16***
	C3	-1.113	0.283	-3.929	0.000348***
	R^2_e = 0.289, SEE = 2.44, R^2_p = 0.216, SEP = 2.43				
4	Intercept	67.1	1.72	39.097	<2e-16***
	BT4	-0.436	0.127	-3.433	0.00145**
	R^2_e = 0.237, SEE = 2.53, R^2_p = 0.167, SEP = 2.62				
5	Intercept	76.2	5.17	14.74	<2e-16***
	BT4	-0.205	0.071	-2.88	0.0065**
	R^2_e = 0.179, SEE = 2.62, R^2_p = 0.082, SEP = 2.67				

LMW with models developed to predict LMP would not reflect their relative precision of estimation. In fact, when expressed as a proportion of carcass weight, the carcasses' LMP present small variation (CV = 4.6% in this study) and explain the lower of models predicting LMP when compared with models predicting LMW. The best simple predictor of LMP was the BT2 measurement, which accounted for 38.7% of the LMP variation with a SEE of 2.28% and a SEP of 2.3%.

The fat measurements (BT2, BT3, C3 and BT4) dominated the models, and in spite of R^2_p lower than 35%, Models 1, 2 and 3 yielded SEP lower than 2.5%, which is the superior limit for approval of prediction equations for objective carcass classifications systems by the EU [5]. It is important to notice that carcass dimension measurements were poor predictors of LMP, confirming the lack of relationship between carcasses conformation and composition [23]. The differences in the fitting quality observed among homologous predictors (measurements taken at different anatomical positions) would result from data noise coming from measurement errors. When developing regression models it is assumed that regressors are measured without errors and, obviously, that is not the case of tissue measurements which are subjected to several types of measurement errors. Thus, special attention should be given to the precision of measurements of the predictors. In fact, the Model 3 based on the C3 measurement presented lower predictability, which can be attributed to the higher susceptibility to measurement errors on this predictor resulting from its lower magnitude in contrast to the BT measurements.

The best six models with two predictors, best model with three predictors and the model with three predictors of carcasses LMP are shown in Table III. The best six models with two predictors presented similar fitting quality among them as can be observed by the confidence interval of R^2_e. However, Model 6 presented the higher fitting quality, and the LEA12 and BT2 measurements accounted for 49.2% of the LMP variation, with a SEE of 2.09% and a SEP of 2.87%.

The usefulness of the loin eye area (LEA) for predicting the lean meat yield was also reported by [24]. However, Model 11 (based on BT2 and HCW) presented only slightly better fitting quality than Model 6, yet the former had lower predictability as attested by its lower SEP (2.87% for Model 6 and 2.65% for Model 11).

Models 6 to 11 (with two predictors) presented higher fitting quality (lower and higher SEE) than Models 1 to 5, however the predictability of the first ones was lower as can be observed by the higher SEP (varying from 2.65% to 3.18%).

These results show that the inclusion of a second predictor

TABLE III
BEST SIX MODELS WITH TWO PREDICTORS AND BEST MODEL WITH THREE PREDICTORS OF CARCASSES LMP

Model	Variables	Parameter	SE	T value	Pr(>|t|)
6	Intercept	65.6	2.15	30.529	< 2e-16***
	LEA12	0.479	0.166	2.890	0.00641 **
	BT2	-0.508	-0.106	-0.4.804	2.44e-05***
	R^2_e = 0.492, SEE = 2.09, R^2_p = 0.415, SEP = 2.87				
7	Intercept	65.4	2.27	28.778	< 2e-16***
	LEA1	0.506	0.186	2.715	0.01*
	BT2	-0.576	0.101	-5.706	1.57e-06***
	R^2_e = 0.481, SEE = 2.11, R^2_p = 0.397, SEP = 3.18				
8	Intercept	65.8	2.32	28.301	< 2e-16***
	LEA3	0.528	0.219	2.414	0.0208*
	BT2	-0.604	0.107	-5.632	1.98e-06***
	R^2_e = 0.463, SEE = 2.15, R^2_p = 0.374, SEP = 2.91				
9	Intercept	56.2	6.08	9.250	3.67e-11***
	G	0.653	0.282	2.314	0.0263*
	BT2	-0.516	0.100	-5.150	8.87e-06***
	R^2_e = 0.392, SEE = 2.16, R^2_p = 0.392, SEP = 2.79				
10	Intercept	58.4	6.23	9.384	2.52e-11***
	CB	0.234	0.124	1.886	0.0672.
	BT4	-0.600	0.113	-5.291	5.72e-06***
	R^2_e = 0.432, SEE = 2.21, R^2_p = 0.367, SEP = 3.01				
11	Intercept	67.0	2.31	29.003	<2e-16***
	HCW	0.368	0.211	1.747	0.0889.
	BT2	-0.618	0.121	-5.120	9.74e-06***
	R^2_e = 0.425, SEE = 2.22, R^2_p = 0.345, SEP = 2.65				
12	Intercept	64.3	2.36	27.195	<2e-16***
	BT2	-0.610	0.103	-5.906	9.28e-07***
	LEA3	0.309	0.238	1.299	0.2021
	LEA12	-0.367	0.185	1.977	0.0558
	R^2_e = 0.515, SEE = 2.10, R^2_p = 0.394, SEP = 2.26				

increases the models fitting quality evaluated by the R^2_e and SEE. Nevertheless, the predictability of the models decreases as can be observed by the lower R^2_p and higher SEP in Models

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6 to 11. MacNeil [25] showed that the equation with the higher R^2_e does not necessarily ensure that we are in presence of the best equation, and the equation with maximum R^2_e may present higher prediction error variance than other equations. These findings of MacNeil [25] were confirmed in this study, and equations with higher R^2_e did not present the best predictability. Only equations with stable relationships between dependent and independent variables will be useful, because no amount of replication can overcome bias [25].

In fact, the inclusion of a second predictor leads to model instability, which can be observed by the variations in the parameters estimates as well as by the increase in the standard errors of the parameters estimates. The reduction of the predictive ability of models with two predictors results from the correlations between predictors which leads to instability in the estimation of the regression coefficients as stated by [26].

Model 1 presented higher predictive ability than Model 11 (which is Model 1 plus HCW), thus HCW did not contribute to explain the carcasses LMP. Contrarily, [27] found that models predicting LMP were more accurate when fat measurements were combined with HCW. However, in that study the carcasses had higher range in HCW (13.6 to 34.0 kg) than the carcasses of our study (8.0 to 15.0 kg), and the increase in HCW variation leads to an increase of R^2 of models as described above.

Model 11, which is Model 1 plus the HCW as second predictor, presented a marginal improvement in fitting quality when compared with Model 1. However, the predictive quality of Model 11 was lower than that observed for Model 1 (SEP=2.65 for Model 11 and SEP=2.30 for Model 1). Thus, the improvement obtained in the model fitting quality by the inclusion of HCW is not sufficient as to justify its inclusion since it leads to a lower predictive quality.

Therefore, the sample of carcasses used to develop prediction models should be of adequate size and representative of the population in the region where the trade is made [28]. Thus, for populations with characteristics different from those used in this study, other specific studies should be undertaken in order to define the best model.

Model 12 (Model 6 plus LEA3) was model with three predictors that presented the best fitting quality (R^2_e =51.5 and SEE=2.10) than Models with one (Models 1 to 5) and two (Models 6 to 11) predictors.

The prediction of LMP can be based on one single fat measurement like BT2, but since the HCW is commonly known along the commercial chain, models can include also the HCW (like Model 11). However, the regression models can be sensitive to changes in samples: genotype, treatment and their proportion in the population [1]; and to obtain robust models to predict LMP, special attention must be taken in the selection of a representative sample of the population where the models should be applied.

Light carcasses (carcass weight lower than 13 kg), which are very common in Mediterranean countries [29], usually present low development of subcutaneous fat (small magnitude) leading to low accuracy of the C measurements as demonstrated by [16]. Thus, for light carcasses the subcutaneous fat measurements can be replaced by breast bone tissues thickness measurements (like BT2), since the higher magnitude of this tissue makes the measurement easier to take and consequently more stable to measurement errors [16].

IV. Conclusion

The prediction of LMP of lamb carcasses can be based on simple models, using as predictors the HCW and one fat thickness measurement. For light carcasses, very common on Mediterranean countries, the breast bone tissue thickness measurement (like BT2), being easier to record and more stable to measurement errors than the C measurement, should be preferred as predictor of LMP.

References

[1] Y. Gu, A. P. Schinckel, T. G. Martin, J. C. Forrest, C. H. Kuei, and L. E. Watkins, “Genotype and treatment biases in estimation os carcass lean of swine,” Journal of Animal Science, vol. 70, pp. 1708–1718, 1992.
[2] Commission of the European Communities, “Report from the commission to the council on the implementation of council regulation (eec) no 2137/92 concerning the community scale for the classification of carcasses of ovine animals,” Tech. Rep., 2002.
[3] Commission Regulation (EC) No 22/2008, “Commission regulation (ec) no 22/2008 of 11 january 2008 laying down detailed rules for the community scale for the classification of carcases of ovine animals,” Official Journal of the European Union, pp. L9/6–L9/11, 2008.
[4] J. Johansen, A. H. Aastveit, B. Egelandsdal, K. Kvaal, and M. Roe, “Validation of the europ system for lamb classification in norway; repeatability and accuracy of visual assessment and prediction of lamb carcass composition,” Meat Science, vol. 67, pp. 497–509, 2006.
[5] Commission Regulation (EC) No 1249/2008, “Commission regulation (ec) no 1249/2008 of 10 december 2008 laying down detailed rules on the implementation of the community scales for the classification of beef, pig and sheep carcases and the reporting of prices thereof,” Official Journal of the European Union, pp. L337/3–L337/30, 2008.
[6] M. T. Díaz, V. C. Cañeque, S. Lauzurica, S. Velasco, F. R. de Huidobro, and C. Perez, “Prediction of suckling lamb carcass composition from objective and subjective carcass measurements,” Meat Science, vol. 66, pp. 895–902, 2004.
[7] A. Fortin and J. N. B. Sherestha, “In vivo estimation of carcass meat by ultrasound in ram lambs slaughtered at an live weight of 37 kg,” Animal Production, vol. 43, pp. 469–475, 1986.
[8] A. V. Fisher and H. Boer, “The EAAP standard method of sheep carcass assessment. carcass measurements and dissection procedures. report of the EAAP working group on carcass evaluation, in cooperation with the CIHEAM instituto agronomico mediterraneo of zaragoza and the CEC directorate general for agriculture in brussels,” Livestock Production Science, vol. 38, pp. 149–159, 1994.
[9] H. Pálsson, “Meat qualities in the sheep with special reference to scottish breeds and crosses,” J. Agric. Sci. (Camb.), vol. 29, pp. 544–626, 1939.
[10] R. Delfa, C. Gonzalez, and A. Teixeira, “Use of cold carcass weight and fat depth measurements to predict carcass composition of rasa aragonesa lambs,” Small Ruminant Research, vol. 20, pp. 267–274, 1996.
[11] Development Core Team, R: A Language and Environment for Statistical Computing, R Foundation for Statistical Computing, Vienna, Austria, 2008, ISBN 3-900051-07-0. [Online]. Available: http://www.R-project.org =0pt
[12] W. N. Venables and B. D. Ripley, Modern applied statistics with S.1em plus 0.5em minus 0.4emNew York: Springer, 2002. [Online]. Available: http://www.stats.ox.ac.uk/pub/MASS4 =0pt

[13] J. Maindonald and W. J. Braun, DAAG: Data Analysis And Graphics, 2008. [Online]. Available: URL http://www.stats.uwo.ca/DAAG =0pt
[14] M. R. Anous, "Interrelations entre les principaux composants natomiques, conformation et longueur des os du gigot des ovins," Annales de Zootechnie, vol. 32, pp. 185–200, 1986.
[15] A. Teixeira, S. Batista, R. Delfa, and V. Cadavez, "Lamb meat quality of two breeds with protected origin desig- nation. influence of breed, sex and live weight," Meat Science, vol. 71, p. 530–536, 2005.
[16] V. Cadavez, R. Amaro, and A. Fonseca, "Subcutaneous fat depth magnitude influences its measurement errors: a simulation study," in FOODSIM'2010 In 6th International Conference on Simulation and Modelling in the Food and Bio-Industry. Bragança: CIMO, 2010, pp. 118–121.
[17] R. P. Garrett, J. W. Savell, J. W. Edwards, and J. D. Tatum, "Evaluation of the hennessy grading probe to predict yields of lamb carcasses fabricated to multiple end points," Journal of Animal Science, vol. 70, pp. 1146–1152, 1992.
[18] A. H. Kirton, G. L. Bennett, J. L. Dobbie, G. J. K. Mercer, and D. M. Duganzich, "Effect of sire breed (southdown, suffolk), sex, and growth path on carcass composition of crossbred lambs," New Zealand Journal of Agricultural Research, vol. 38, no. 1, pp. 105–114, 1995.
[19] D. L. Hopkins, E. N. Ponnampalam, and R. D. Warner, "Predicting the composition of lamb carcasses using alternative fat and muscle depth measures," Meat Science, vol. 78, pp. 400–405, 2008.
[20] E. Sehested, "In-vivo prediction of lamb carcass composition by computer tomography," Master, Agricultural University of Norway, As-NLH, Norway, 1986.
[21] A. Teixeira, S. Matos, S. Rodrigues, R. Delfa, and V. Cadavez, "In vivo estimation of lamb carcass composition by real-time ultrasonography," Meat Science, vol. 74, pp. 289–295, 2006.
[22] E. Migueléz, J. M. Zumalacarregui, M. T. Osorio, O. Beteta, and J. Mateo, "Carcass characteristics of suckling lambs protected by the pgi "lechazo de castilla y leon" european quality label: Effect of breed, sex and carcass weight," Meat Science, vol. 73, pp. 82–89, 2006.
[23] E. Laville, J. Bouix, T. Sayd, F. Eychenne, F. Marcq, P. L. Leroy, J. M. Elsen, and B. Bibé, "La conformation bouchére des agneaux. etude d'aprés la variabilité génétique entre races," INRA Productions Animales, vol. 15, no. 1, pp. 53–66, 2002.
[24] D. L. Hopkins, "An industry applicable model for predicting lean meat yield in lamb carcasses," Australian Journal of Experimental Agriculture, vol. 48, pp. 757–761, 2008.
[25] M. D. MacNeil, "Choice of a prediction equation and the use of the selected equation in subsequent experimentation," Journal of Animal Science, vol. 57, no. 5, pp. 1328–1336, 1983.
[26] S. Chatterjee, A. S. Hadi, and B. Price, Regression analysis by a example.1em plus 0.5em minus 0.4emNew York: John Willey & Sons, Inc., 2000.
[27] D. L. Hopkins, E. Safari, J. M. Thompson, and C. R. Smith, "Video image analysis in the australian meat industry - precision and accuracy of predicting lean meat yield in lamb carcasses," Meat Science, vol. 67, pp. 269–274, 2004.
[28] A. J. Kempster and G. L. Cook, "Errors in carcass lean prediction with special reference to the EC grading scheme," in New Techniques in Pig Carcass Evaluation, ser. Proc. of the EAAP-Symposium of the commission on pig Production, 1988.
[29] C. Russo, G. Breziuso, and P. Veritá, "Eu carcass classification system: carcass and meat quality in light lambs," Meat Science, vol. 64, no. 4, pp. 411–416, 2003.