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In vivo estimation of lamb carcass composition by real-time ultrasonography

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Abstract

The objective of this study was to evaluate the accuracy of ultrasonography to measure fat thickness in live lambs and predict carcass composition to find a system that can assess carcass composition easily and accurately, without damage to the product and can improve carcass classification.

Fat thickness (FTh) between the 12th and 13th ribs and between the 3rd and 4th lumbar vertebrae, was measured in vivo using real-time ultrasound, in 67 Churra Galega Bragançana males (mean weight 36.0 kg, range 21.5–47.0 kg), using an ALOKA SSD-500V equipped with two probes (5 and 7.5 MHz) in order to predict carcass composition. The most satisfactory correlation between carcass and ultrasound measurements was between the 3rd and 4th lumbar vertebrae fat thickness (FTh). The first variable admitted in the models to predict carcass composition (live weight, LW) explained between 63% and 96% of the total variation of the weight of the components of the carcass. In fact, 96% of the variation in total amount of muscle was accounted for by live weight. The inclusion of the ultrasound measures with the 7.5 MHz probe improved, in all prediction equations, the coefficient of determination (R^2) with a substantial reduction in the residual standard deviation (RSD). In relation to the subcutaneous fat of the carcass, 85% of the variation was explained by live weight and the FTh 12–13 7.5 measurement. In the prediction model for total carcass fat weight, live weight and ultrasound fat thickness measurement explained 88% of the variation. The results indicate that in vivo ultrasound fat thickness measures in association with live weight can be used to predict carcass composition in Churra Galega Bragançana lambs.

Keywords: Lamb; Fat thickness; Carcass composition; Ultrasound

1. Introduction

The Bragançano breed belongs to the Portuguese Churro group. It is a local breed reared in the NE part of Portugal mainly in Montesinho's Natural Park, which is one of the largest protected areas in Portugal covering 75,000 ha at an altitude varying from 438 to 1481 m, in a succession of uplands and deep valleys. There are extensive areas of hill grazing, the weather is often harsh, there are wide variations in food supply, and animals are submitted to a wide variation of fat body reserves. So, the knowledge of carcass composition and the attempts to estimate the body composition in live animals is essential for producers to programme the food supply needs and produce lambs according to consumer requests.

On the other hand, lamb consumers in Mediterranean area and particularly in Portugal require lightweight carcasses (6–10 kg) with more lean and less fat. In order to correspond to consumer demand it becomes more and more important to provide adequate information about carcass composition such as saleable meat or fat, muscle, and bone contents. Therefore, and not different from other species the need for a more accurate method to assess carcass composition is increasing. Producers, slaughterhouses, processing industries and consumers require an

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accurate and practical model to predict carcass composition which can be useful in a classification and grading system of sheep.

The use of ultrasound technology to estimate carcass composition in sheep saw the early studies with several authors (Edwards et al., 1989; Fortin & Shrestha, 1986; Hamby, Stouffer, & Smith, 1986; Jones, Walton, Wilton, & Szkotnicki, 1982 & McLaren et al., 1991) with little expectation. The initial cost-effective of the equipment, the small size of fat thickness comparing with other species, the lack of variation in subcutaneous tissue, and the presence of wool were the main limitations of the utility of ultrasound in sheep. In spite of that, subcutaneous fat thickness measured between the 3rd and 4th lumbar vertebrae is a useful predictor of lamb and mutton carcass composition in a study conducted by Bruwer, Naudé, Toit, Cloete, and Vosloo (1987). Also Young, Nsoso, and Beatson (1996) studying the factors that affected the repeatability of tissue depth determination by real-time ultrasound in sheep concluded that the measurements could be accurately assessed from one ultrasound measurement. Analysing the subcutaneous fat distribution assessed by ultrasound in Border Leicester and Dorset Down ewe hoggets, Deaker and Young (1992) reported that their findings had implications for carcass classification, breeding programmes, lean growth and comparison of fatness of different genotypes. Just as Clarke, Dobbie, Uljee, and Wrigglesworth (1997) used the ultrasonic fat and eye muscle dimensions to compare weight-selected Romney hoggets for growth. Stanford, Clark, and Jones (1995) found a good prediction of saleable meat yield using an ultrasound measurement of subcutaneous fat depth taken at the first lumbar vertebrae ($R^2 = 0.64$; RSD = 1.2). Subsequently, Stanford, Jones, and Price (1998) published a review of methods for predicting lamb carcass composition with reference to the use of ultrasound for predicting body/carcass composition in sheep. Simm, Lewis, Grundy, and Dingwall (2002) referred that in vivo measurements most widely used have been ultrasonic measures of fat and muscle depth or areas and found from their experimental results that substantial responses can be achieved by selecting sheep on an index of live weight and ultrasonic measurements of fat and muscle (Simm, 1992; Simm, Dingwall, & Lewis, 1993).

Previous studies with some sheep breeds from Spain have shown the usefulness of ultrasound to predict carcass composition and suggest that ultrasound fat thickness measurements with the live weight, can be good predictors of carcass composition (Delfa et al., 1996; Fernández, García, Vergara, & Gallego, 1998; Mendizabal et al., 2003 & Teixeira & Delfa, 1997). Recently, working with the same breed of the present study Cadavez, Teixeira, Delfa, and Rodrigues (2000) and Cadavez et al. (2001) have been evaluating of ultrasonic measurements of fat thickness to estimate the carcass composition. Silva, Gomes, Dias-da-Silva, Gil, and Azevedo (2005) working with Île de France and the native Portuguese breed Churra da Terra Quente found that body chemical composition of growing lambs can be predicted by the body weight and real time ultrasonography measurements associated with the image analysis. So the objective of this study was to evaluate the accuracy of the ultrasound to measure fat thickness in live lambs and predict the carcass composition and to contribute as to find a system that can assess the carcass composition easily and accurately, without depreciation of the product and improve the carcass classification giving more information to consumers.

2. Material and methods

A total of 67 Churra Galega Bragançana males weighing 21.5–47.0 kg, were selected from the research herd of the Bragança's School of Agriculture (Escola Superior Agrária de Bragança). Sheep were fed on pasture, supplemented with hay from natural grassland (ad libitum) and a supplement of commercial concentrates (250 g/animal). All animals had free access to fresh water.

To obtain the measurements, the animals were immobilized and an acoustic gel was used to allow a better contact between the probe and the skin of the animal. Animals were held manually while the operator scanned the lumbar region. All procedures were made indoors at the slaughterhouse at 15–18 °C.

The measures were taken with the two probes in a perpendicular position to the dorsal medium line, at the level of the largest depth of the muscle *longissimus thoracis et lumborum* (LTL).

Twenty-four hours before slaughter, real time ultrasound measurements of fat thickness over the *longissimus thoracis et lumborum* muscle between the 12th and 13th rib (FTh 12–13 5 and FTh 12–13 7.5, with the 5 and 7.5 MHz probes, respectively) and between the 3rd and 4th lumbar vertebrae (FTh 3–4 5 and FTh 3–4 7.5, with the 5 and 7.5 MHz probes, respectively) were collected as shown in Fig. 1. An ALOKA SSD-500V Real-Time Ultrasound Scanner, with a 5 and 7.5 MHz probes, was used for all ultrasound measurements. The probes were placed perpendicular to the backbone, using a gel as coupling medium. The fat depth was measured with skin. When an acceptable image of the anatomical points was obtained, it was recorded and video printed and the digitized (Fig. 2). After that the measurements were performed by image analysis with National Institute of Health 1.57 software (http://rsb.info.nih.gov/njh-image/) to help the operator interpret the image and identify the anatomical points to take the measurements with the same technique in all scanned animals.

All lambs were slaughtered, under the same conditions and in accordance with the laws of ethics and welfare of animals, after 24 h fasting in the experimental slaughterhouse at the Bragança's School of Agriculture. After slaughter, carcasses were cooled at 4 °C for 24 h. Carcasses were halved carefully. The kidney and pelvic fat were removed and weighed. On the left side, the fat thickness measurement C, as defined by Pálsson (1939), was made

with measuring calipers, between the 12th and 13th rib (C12–13) and between the 3rd and 4th lumbar vertebrae (C3–4).

The left side of each carcass was divided into eight standardized commercial joints: leg, chump, loin, ribs, anterior ribs, shoulder, breast, and neck. The joint procedure was outlined by Teixeira (1984) according to the Zootechnique National Station cut (Estação Zootécnica Nacional - EZN cut) (Calheiros & Neves, 1968). Each joint was then dissected into muscle, subcutaneous fat, intermuscular fat, bone, and remainder (major blood vessels, ligaments, tendons, and thick connective tissue sheets associated with muscles). In all 67, carcasses were evaluated and completely dissected.

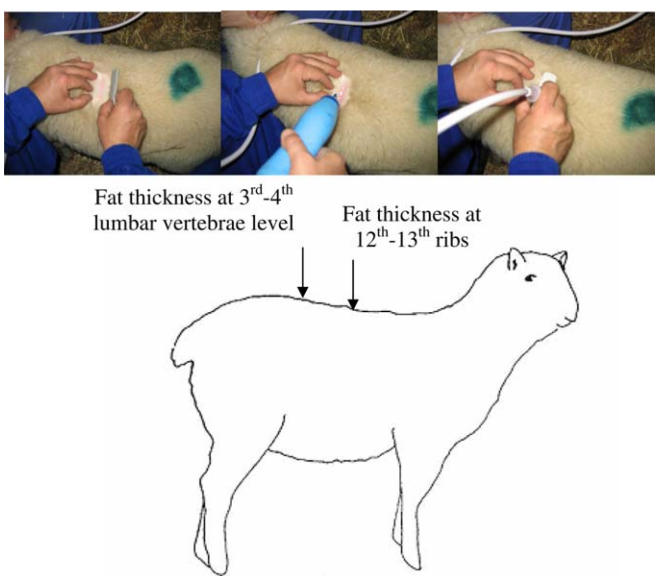

Fig. 1. Ultrasound image collect procedure.

The relationship between in vivo measurements of fat thickness and the same carcass measurements was analysed by linear correlation (Steel & Torrie, 1980). To estimate carcass composition, the data was analysed (SAS, 1998) by stepwise regression (Ott, 1993) using as independent variables live weight and the ultrasound fat thickness measurements in the sequence: untransformed variables; dependent variables on a logarithmic scale and independent variables on a logarithmic scale. The accuracy of the estimates was evaluated by the determination coefficient (R^2) and by the residual standard deviation (RSD).

3. Results and discussion

The means, standard deviation, maximum, and minimum of the live weight, ultrasound measurements, and carcass components are shown in Table 1. All characteristics have a substantial variation suggesting that we have worked with a large range of live weight, fat measurements, and carcass fat depots representative of Bragançano lamb carcasses as normally slaughtered and marketed.

Simple correlation coefficients between ultrasound and carcass measurements, shown in Table 2 indicate that ultrasound and actual fat thickness were moderately correlated ($r = 0.31–0.42$). The best correlation was obtained at the level of the 3rd–4th lumbar vertebrae ($r = 0.42$; $P < 0.01$, with the 5 MHz probe). This confirms the results of Bruwer et al. (1987) that the fat thickness measured between the 3rd and 4th lumbar vertebrae is a useful predictor of carcass composition as well as the results of Delfa, Teixeira, Blasco, and Colomer-Rocher (1991). The correlation coefficients found, for both probes, were also inferior to those obtained by Cadavez, Teixeira, Delfa, and Pereira

Fig. 2. Example of a real time ultrasound measurement of fat thickness over the *longissimus thoracis et lumborum muscle* between 12th and 13th rib with 7.5 MHz probe.

Table 1
Means, maximum, minimum and standard deviation of the live weight, ultrasound measurements and carcass components

	Mean	Maximum	Minimum	Standard deviation
Live weight (kg)	36.0	47.0	21.5	8.3
Muscle (kg)	9.2	13.0	4.8	2.3
Subcutaneous fat (kg)	1.6	3.1	0.4	0.8
Intermuscular fat (kg)	2.4	4.2	1.0	0.9
Kidney and pelvic fat (kg)	0.6	3.4	0.1	0.3
Bone (kg)	2.7	3.8	1.6	0.6
Total carcass fat (kg)	4.6	8.6	1.6	1.8
FTh 12–13 5 (mm)	0.41	0.7	0.2	0.12
FTh 12–13 7.5 (mm)	0.36	0.6	0.2	0.11
FTh 3–4 5 (mm)	0.46	0.8	0.2	0.15
FTh 3–4 7.5 (mm)	0.42	0.7	0.1	0.13
C 12–13 (mm)	0.35	1.6	0.13	0.21
C 3–4 (mm)	0.56	1.5	0.2	0.25

FTh 12–13 5 – fat thickness over the *longissimus thoracis et lumborum* muscle between the 12th and 13th rib with the 5 MHz probe.
FTh 12–13 7.5 – fat thickness over the *longissimus thoracis et lumborum* muscle between the 12th and 13th rib with the 7.5 MHz probe.
FTh 3–4 5 – fat thickness over the *longissimus thoracis et lumborum* muscle between the 3rd and 4th lumbar vertebrae with the 5 MHz probe.
FTh 3–4 7.5 – fat thickness over the *longissimus thoracis et lumborum* muscle between the 3rd and 4th lumbar vertebrae with the 7.5 MHz probe.
C 12–13 – carcass fat thickness measurement C between the 12th and 13th rib.
C 3–4 – carcass fat thickness measurement C between the 3rd and 4th lumbar vertebrae.

Table 2
Correlation coefficients (r) between ultrasound and carcass fat thickness

	Carcass measures	
	C12–13	C3–4
FTh 12–13 5	0.32*	
FTh 3–4 5		0.42**
FTh 12–13 7.5	0.31*	
FTh 3–4 7.5		0.35**

FTh 12–13 5 – fat thickness over the *longissimus thoracis et lumborum* muscle between the 12th and 13th rib with the 5 MHz probe.
FTh 12–13 7.5 – fat thickness over the *longissimus thoracis et lumborum* muscle between the 12th and 13th rib with the 7.5 MHz probe.
FTh 3–4 5 – fat thickness over the *longissimus thoracis et lumborum* muscle between the 3rd and 4ptth lumbar vertebrae with the 5 MHz probe.
FTh 3–4 7.5 – fat thickness over the *longissimus thoracis et lumborum* muscle between the 3rd and 4th lumbar vertebrae with the 7.5 MHz probe.
C 12–13 – carcass fat thickness measurement C between the 12th and 13th rib.
C 3–4 – carcass fat thickness measurement C between the 3rd and 4th lumbar vertebrae.
* $P < 0.05$.
** $P < 0.01$.

(1999a) ($r = 0.70$ and 0.71 for the 5 and 7.5 MHz probes, respectively) and for Cadavez, Teixeira, and Delfa (1999b) ($r = 0.68$ and 0.57 for the 5 and 7.5 MHz probes, respectively). Nevertheless, Fernández et al. (1998) obtained lower correlation coefficients (r between 0.04 and 0.38 with no significance). The correlation coefficients between ultrasound and actual fat thickness measured between the 12th and 13th ribs were very similar ($r = 0.32$ and 0.31, for 5 and 7.5 MHz probes, respectively; $P < 0.05$). Cadavez et al. (1999a) found, for both probes, correlations of $r = 0.73$ and 0.81 and Cadavez et al. (1999b) also found significant correlations for both probes ($r = 0.58$ and 0.66, for the 5 and 7.5 MHz probes, respectively). The differences among the correlation coefficients observed in the articles can be due to the different experimental conditions, namely the type of animal and the live weight used, and if the animals were shorn or not.

Although the correlation coefficients obtained in this work were all significant, they were lower than expected. This can be due to the fact that we used a group of animals with a large range of live weight,in order to develop prediction models of carcass composition that are as general as possible, and similar to the live weight variations found in practice. However, the dressing procedures, namely the skinning and the cutting, can lead to alterations of the tissues which can be responsible for the lower correlation coefficients observed in this work. The low correlations found can be explained by the light lambs we have worked with which have a very low subcutaneous fat layer and this limits the potential of ultrasound to provide accurate measures as well as the high range in fat depths on the carcass (C 12–13 and C 3–4 measurements) than the ultrasonic fat measurements taken on the live animal (Table 1). Our coefficients are lower than those found by Silva et al. (2005) and this can be explained by the different ultrasonic measurement procedures. We did not shear and clip the wool as this not possible in a commercial slaughter house.

However, ultrasonic measurements could predict carcass fat thickness as we can see from Table 3, where the best regression equations for predicting carcass composition are shown. These equations were developed by multiple linear regression using live weight and the ultrasound fat thickness measurements as independent variables. With the exception of muscle estimation all the other carcass component estimations were computed on logarithmic scales. This suggests that the fat depots have a logarithmic relationship with live weight as previously shown by Teixeira, Delfa, and Colomer-Rocher (1989) Teixeira, Delfa, Gonzalez, Gosalvez, and Tor (1995) working with sheep and goats, respectively. The R^2 values were generally high and the results reported were all significant at the $P < 0.001$ level.

Live weight was the first variable admitted in the models. This variable accounted for 63–96% of the variation in carcass tissue weights. These results agree with those found by Delfa et al. (1996), Fernández et al. (1998), Hopkins (1990), Mendizabal et al. (2003) and Silva et al. (2005) and Teixeira and Delfa (1997). On the other hand, Ramsey, Kirton, Hogg, and Dobbie (1991) were of the opinion that the improvements in accuracy of prediction due to live weight were not sufficient to warrant the use of this variable in multiple regression equations, which is not in agreement with the results obtained in the present work.

The better equations were obtained by the utilization of a high-frequency probe (7.5 MHz) as was reported by Silva

Table 3
Multiple regression equations using live weight and ultrasound fat thickness measurements for predicting carcass composition (g)

Dependent variables	Independent variables	*a*	*b*	sb	R^2	RSD
Muscle	LW	−296.85	135.92	3.47	0.96***	214.6
Log SF	Log LW	0.54	1.64	0.16	0.81	0.10
	Log FTh 12–13 7.5		0.45	0.12	0.85***	0.09
Log IF	Log LW	1.34	1.18	0.11	0.82	0.069
	Log FTh 12–13 7.5		0.24	0.08	0.84***	0.066
Log KP	Log LW	−0.52	1.75	0.26	0.63	0.17
	Log FTh 12–13 7.5		0.54	0.25	0.66***	0.16
Log TF	Log LW	1.35	1.38	0.10	0.85	0.08
	Log FTh 12–13 7.5		0.33	0.09	0.88***	0.07
Log B	Log LW	1.68	0.93	0.04	0.92***	0.03

$\log_{10}(\text{fat depots}) = b\log_{10}(\text{independent variable}) + a$.
a = intercept; b = regression coefficient; sb = standard deviation of b.
SF – subcutaneous fat; IF – intermuscular fat; KP - kidney and pelvic fat; TF – total carcass fat; B – bone.
LW – live weight.
FTh 12–13 5 – fat thickness over the *longissimus thoracis et lumborum* muscle between the 12th and 13th rib with the 5 MHz probe.
FTh 12–13 7.5 – fat thickness over the *longissimus thoracis et lumborum* muscle between the 12th and 13th rib with the 7.5 MHz probe.
FTh 3–4 5 – fat thickness over the *longissimus thoracis et lumborum* muscle between the 3rd and 4th lumbar vertebrae with the 5 MHz probe.
FTh 3–4 7.5 – fat thickness over the *longissimus thoracis et lumborum* muscle between the 3rd and 4th lumbar vertebrae with the 7.5 MHz probe.

et al. (2005). The FTh 12–13 7.5 measurement was included in the prediction models for subcutaneous, intermuscular, kidney and pelvic fat and total carcass fat. The inclusion of this measurement increased the determination coefficient between 2% and 4%, but more important, was the decrease in RSD of between 6% and 13%, increasing the accuracy of the estimation.

Although some authors have shown that the inclusion of ultrasound measurements in the multiple regression equations for predicting carcass composition provided only a small improvement in the accuracy of the prediction (Cuthbertson, Croston, & Jones, 1984; Leymaster, Mersmann, & Jenkins,1985; Yates, Cuthbertson, & Owen, 1985; Yates et al., 1993) and expressed doubts about the usefulness of these measurements as predictors of carcass composition, in the present work we found the opposite as can seen from the results in Table 3. Nevertheless, the potential use of this technique to predict the weight of the different tissues of the carcass has been demonstrated by several authors (Delfa, Teixeira, Gonzalez, & Blasco, 1995, 1996; Fernández et al., 1998; Hopkins, 1990; Kempster, Arnall, Alliston, & Barker, 1982; Mendizabal et al., 2003; Teixeira & Delfa, 1997).

All relationships are highly significant as we can see in Table 3. In fact, 96% of the variation in the total amount of muscle was accounted for by live weight, and none of the ultrasound measurements admitted as independent variables in the model, as previously found by Teixeira and Delfa (1997) ($R^2 = 0.94$). Also, Delfa et al. (1995) found similar results for muscle prediction, however, they obtained smaller determination coefficients ($R^2 = 0.21$; $P < 0.01$). For muscle content live weight alone accounted for 92% of the variation of total weight of carcass bone. Nevertheless, Delfa et al. (1995) found that live weight only accounted for 19% of the variation of the bone weight. The inclusion of ultrasound fat thickness measurement at the 4th lumbar vertebra allowed a significant ($P < 0.05$) improvement in the accuracy of the prediction, providing an increase in the determination coefficient of 31% and a decrease in RSD of 20.4%. On the other hand, Delfa et al. (1996) found that none of the ultrasound fat thickness measurements was admitted in the model as a predictor of the weight of the bone, but Teixeira and Delfa (1997) working with two probes and using live weight and the ultrasound fat thickness measurement as independent variables in a multiple regression equation, found that these two variables explained 84% of the variation of the weight of the bone in agreement with our findings.

In relation to the subcutaneous fat of the carcass we observed that 85% of the variation was explained ($P < 0.001$) by live weight and the FTh 12–13 7.5 measurement. The inclusion of the ultrasound measurement in the multiple regression equation increased by 4% the precision of the prediction, allowing a decrease in RSD of 10%. Similarly, Cadavez et al. (2000) used the same measure and explained 59.5% of the variation of the weight of this tissue. They found an improvement in the precision of the prediction when they used live weight in a multiple regression with the fat thickness measurement, using a 5 MHz probe, agreeing with the work of Fernández et al. (1998). In the work of Delfa et al. (1995), live weight accounts for only 18% of the total variation of the carcass subcutaneous fat weight. When fat thickness measured at the 4th lumbar vertebra was included in the model the variation explained was higher ($R^2 = 0.54$), however, this value is less than the value obtained in the present work.

Taking into account our results, it was also possible to predict the intermuscular fat of the carcass accurately. Live weight and fat thickness measurement explained 84% of the variation of the weight of this tissue. Live weight was again

the first variable used in the regression model, explaining, by itself, 82% of the variation of the weight of intermuscular fat, a value higher than that obtained by Delfa et al. (1995) ($R^2 = 0.47$), Delfa et al. (1996) ($R^2 = 0.47$) and Teixeira and Delfa (1997) ($R^2 = 0.50$). The values obtained in our work were more accurate than those observed by Teixeira and Delfa (1997) ($R^2 = 0.70$) and Delfa et al. (1995) ($R^2 = 0.60$), although in this last paper, the predictor used was the fat thickness measured at the 4th lumbar vertebra.

The weight of the kidney and pelvic fat of the carcass was predicted with high significance ($P < 0.001$). Live weight was, once again, the first variable admitted in the prediction model, accounting for 63% of the variation of the weight of this tissue. These results are more accurate than the values found by Delfa et al. (1996) ($R^2 = 0.48$) and are not in agreement with the results of Delfa et al. (1995), who found that live weight was not a good predictor of the weight of this tissue. The inclusion of the FTh 12–13 7.5 measurement improved the accuracy of the prediction model of 3% and led to a decrease in RSD of 5.9%. These results are not in agreement with Delfa et al. (1995), which found that the inclusion of the ultrasound fat thickness measurements in the models did not improve the accuracy of the prediction. The different accuracy for the kidney and pelvic fat prediction found in several studies could be explained by the development of this tissue. In fact, Butler-Hogg (1982) reported that kidney and pelvic fat had a biphasic development and can vary between breeds.

In the prediction model for total carcass fat weight, live weight and the ultrasound fat thickness measurement explained 88% of the variation. Live weight, by itself, explained 85% of the variation. These results differ from those obtained by Delfa et al. (1995, 1996) in which live weight only accounted for 26% and 44%, respectively, of the total carcass fat weight. The differences between the studies are the results of the different experimental conditions. So, prediction equations should be determined for each breed, according to the production system and not generalized.

4. Conclusion

Ultrasound measurements allowed us to obtain, in vivo, good predictions of the fat thickness of the carcass. Although the correlation coefficients obtained in this work were all significant they were lower than expected, however, from our point of view, ultrasound is an effective technique to measure subcutaneous fat thickness. Under our experimental conditions with unshaven animals, using portable equipment as our Real-Time Ultrasound Scanner, it is possible to do the work at the slaughterhouse or in the field. Live weight was an important variable, since it explained the largest variance percentage in the models and was the first variable admitted in the models for carcass composition. The in vivo ultrasound fat thickness measurements when they were admitted in the models improved the determination coefficient, but more importantly, they allowed a considerable reduction in the residual standard deviation of the prediction, the ultrasound fat thickness measurement being taken between the 12th and 13th rib with the 7.5 MHz probe.

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