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Institute of Genetics and Animal Breeding, Jastrzębiec, Poland

In vivo fat and muscle weight prediction for lambs from fat- and thin-tailed breeds by real-time ultrasonography

Hadhami Hajji[1,2] Naziha Atti[1]*, Mohamed Ben Hamouda[3]

[1] INRA-Tunisie, Laboratoire de Productions Animales et Fourragčres, rue Hédi Karray, 2049 Ariana, Tunisia

[2] INAT-43 avenue Charles Nicoles, Tunis, Tunisia

[3] Institution de la Recherche et de l'Enseignement Supérieur Agricoles, 30 Rue Alain Savary, 1002 Tunis-Belvédčre Tunisia

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The aim of this study was to predict *in vivo* fat and muscle contents of lambs from a fat-tailed Barbarine and a thin-tailed Noire de Thibar (NT) breeds. The prediction was performed using body weight (BW), carcass weight (CW) and ultrasonic measurements. Ultrasonic measurements included subcutaneous fat thickness (FTh), longissimus dorsi muscle depth (MTh), muscle area (MAr) and circumference (MCir), taken on live animals and on carcasses using a real time ultrasound machine equipped with a 3.5 MHz linear probe. Dissected carcass muscle and fat tissues were weighted and then estimated by developing regression equations.
BW was the most important estimator for carcass components for both types of breeds. For the fat-tailed breed, muscle content was better predicted by FTh and fat by MAr. The last with BW the latter explained 77 % of fat variation. For the thin-tailed breed BW and *in vivo* ultrasonic measurements explained 90 and 88 % of variation for fat and muscle contents, respectively. Using carcass ultrasonic measurements with CW mildly improved accuracy relative to BW and in vivo measurements.

KEY WORDS: estimation / fat / *in vivo* / lambs / muscle / ultrasonic

Nowadays, lamb consumers in almost all areas of the world require carcasses with more lean and less fat contents. In order to satisfy the consumer demand, it

*Corresponding author: nazihaatti@gmail.com

is interesting to provide adequate information about carcass composition, such as saleable meat or fat contents. The sheep population in the world is composed, among others, by thin-tailed and fat-tailed breeds. To compare carcass composition in both types of breeds, many studies were undertaken [Shelton *et al*. 1991; Atti and Mahouachi 2011]. In these investigations the direct method based on dissection was applied. Nevertheless, there are *in vivo* estimation methods based on body weight (BW) and some measurements that may be useful in this respect. The technique referring to the dilution space of deuterium oxide to determine carcass composition was tested by many authors [Robelin 1973, Atti *et al*. 2000]. This technique leads to high prediction accuracy, but it is as heavy technique as the direct method. For the fat-tailed breeds, using only tail measurements or those associated with body condition scores, many authors advanced carcass composition prediction with high accuracy [Atti 1992, Zamiri and Izadifard 1997]. As other *in vivo* methods, the ultrasonic technique was used by several authors [Edwards *et al.* 1989, McLaren *et al*. 1991]. It may be used in experimental work and can also have a genetic goal [Kvame and Vangen 2007]. Very few studies have been conducted on fat-tailed breeds to determine longissimus muscle dimensions and fat thickness using ultrasonography.

The aim of this study was to establish a prediction equation for carcass composition in lambs from thin-tailed and fat-tailed breeds by the ultrasonic technique with the intention to provide information for use in experimental situations and genetic purposes.

Material and methods

Animals and experimental equipment

The study was carried out on the experimental flocks of the National Institute of Agricultural Research of Tunisia (INRAT) on a total of 35 male lambs from two breeds of identical adult weight (75 kg). At the beginning of the experiment, they were 10 months old and had 30.1±3.59 kg body weight (BW). There were 21 lambs from the fat-tailed Barbarine breed and 14 lambs from a thin-tailed breed (Noire de Thibar (NT). Animals of each breed were housed in a separate pen with a mean area of 1.8 m^2/lamb. They received 0.5 kg of oat hay/lamb/day and had free access to water and concentrate. At the end of the fattening time the lambs were 13 months old, age required for slaughtering, and had 51 kg average BW.

The ultrasound measurements were performed using a portable real-time ultrasound "falco vet", which is a version of B-mode, producing images almost instantaneously using a 3.5 MHz and 12 cm linear transducer. Scanner maximum penetration depth was 5 cm with a 3.5 MHz probe. Ultrasonic measurements and BW of lambs were recorded one day before slaughter. According to several authors [Young and Deaker 1994, Silva *et al*. 2005], ultrasonic images were defined between the 12th and the 13th ribs and at 10 mm from the dorsal medium line. Light conditions during the measurements were identical and all animals were ultrasound scanned by the same operator. The animals were immobilized, wool was spread and an acoustic gel "gelco" (10°C<T<40°C) was deposited in the free wool line to allow a better contact between the probe and the skin of the animal. The measures were taken with the linear probe in the perpendicular position to the dorsal medium line [Teixeira *et al*. 2006]. Real time ultrasound measurements of fat thickness (FTh), muscle depth (MTh), circumference (MCir) and area (MAr) of the longissimus dorsi were collected. The depth measurements were taken with skin. When an accepted image of the anatomical point was obtained, it was recorded and video printed, then measures were determined using the Cursor over the "falco vet" screen.

Measurements and carcass composition

Cold carcass weight (CW) was recorded 24 h post-mortem after storage at 4°C. After tail had been removed, the carcasses were split longitudinally into two halves. All ultrasonic measurements were taken the second time on the left halves of carcasses at the same anatomical point, then these half-carcasses were cut each into six joints (leg, ribs, loin, shoulder, breast and neck), which were dissected into fat, muscle and bone. Tissues were weighed individually; the sum of the weights of each tissue in all joints represents the weight of tissue in the half carcass and was used to calculate the amounts and proportions of tissues in the carcasses.

Statistical analysis

A one-way analysis of variance for the breed effect on carcass components and ultrasound measurements was applied. The Pearson correlation coeffcients between *in vivo* ultrasonic measurements and the carcass components reported in absolute and relative values were established by breed. The relationships were further estimated between carcass muscle and fat on ultrasound measurements taken on live animals as well as CW on the basis of linear regression equations. The stepwise multiple regression analyses were performed to determine the most accurately predicted equation of amounts and proportions of tissues in the carcass, using in vivo ultrasound measurements and BW or carcass ultrasound measurements and CW. Only the most efficient equations were retained. The inclusion or exclusion of a predictor variable is based on the additive or lack of accuracy for the equation. Coefficients of determination (R^2) and the residual standard deviations (RSD) were used to appreciate the fit accuracy of the model. Statistical analyses were performed with the SAS software (1989) .

Results and discussion

Carcass composition

The BW of lambs from both breeds ranged between 37 and 68 kg; these values correspond to the range of the lambs' live weight in North Africa and central Europe. The breed had no significant effect on the weight of the total muscle, which averaged 11 kg (Tab. 1). In other studies comparing younger and lighter lambs, the NT breed

Table 1. Effect of breed on body weight (BW) and carcass weight (CW) and composition

Variable	Barbarine				Noire de Thibar				Breed effect
	mean	SD	min	max	mean	SD	min	max	(*P*-value)
Body weight (kg)	51.3	4.98	40	68	49.3	7.37	37	68	ns
Carcass weight (kg)	23.1	2.99	16.67	30.39	21.8	3.81	15.33	30.01	ns
Carcass components (kg)									
muscle	11.13	1.26	8.58	14.07	11.32	2.08	8.30	15.07	ns
fat	8.58	2.23	4.64	12.88	5.89	1.45	3.60	9.78	0.001
fat-tail	2.55	0.70	0.89	3.63	-	-	-	-	
bone	3.64	0.63	2.80	5.70	4.33	0.57	3.03	5.34	0.006
Carcass components (%)									
muscle	50.14	4.70	40.73	59.37	56.48	4.89	48.88	63.99	0.001
fat	32.42	6.93	19.34	45.51	21.62	5.60	12.94	32.58	0.001
fat-tailed (% fat)	35.67	9.50	17.27	60.22	-	-	-	-	
bone	17.36	2.78	10.31	22.75	21.38	2.12	17.05	25.31	0.001

SD – standard deviation.

accumulated more muscle than the Barbarine [Atti and Mahouachi 2011]. Thus, at a high BW and advanced age, thin-tailed and fat-tailed breeds tend to accumulate the same amounts of muscle, since the muscular tissue has an isomeric development. However, the muscle proportion was significantly affected by the breed and the fat-tailed breed had a relatively lower muscle proportion than the thin-tailed breed (50.1 vs. 56.5%). The NT breed had a lower weight (5. 9 kg) and proportion (21.6%) of fat content. The fat-tailed Barbarine breed had 8.6 kg of fat (35.7 %), of which the fat of the tail accounted for 2.55 kg. The thin-tailed breed had significantly more bone tissue (4.3 kg) than the fat-tailed breed with only 3.6 kg (Tab. 1).

Ultrasonic measurements

The average values of FTh for both breeds were 0.7 and 0.4 cm for *in vivo* and on carcass measurements, respectively. These parameters were significantly higher for the fat-tailed Barbarine lambs than the thin-tailed breed (Tab. 2). This difference in subcutaneous fat thickness recorded for the Barbarine breed is related to the important development of this fat depot for this breed when compared with the thin-tailed breed [Atti and Mahouachi 2011]. Furthermore, the Barbarine, being a fat-tailed breed, is characterized by the considerable fat cover [Kashan *et al*. 2005]. The *in vivo* FTh for these animals was higher than that of other breeds slaughtered at the same range of weight, in which fat thickness did not exceed 0.33 cm for thin-tailed lambs [Hopkins et al. 2008] and 0.41 cm for Awassi, a fat-tailed breed [Omran *et al*. 2008].

Muscle thickness (MTh) was similar for both breed types (Tab. 2). This result is a consequence of the similarity in muscle content for both breeds (Tab. 1). The same range of MTh (3.32 cm) was reported for crossbred lambs (Poll Dorset x Merino) with a mean BW of 47 kg [Hopkins *et al*. 2008], while it did not exceed 1.75 cm for light (22 kg) Aragon lambs [Delfa *et al.* 1995]. However, the MAr and MCir were significantly higher for the fat-tailed than the thin-tailed breeds (Tab. 2). This fact may be explained by the conformation roundness of the fat-tailed Barbarine lambs,

Table 2. Effect of breed on *in vivo* and carcass ultrasound measurements

Variable	Barbarine				Noire de Thibar				Breed effect (*P*-value)
	mean	SD	min	max	mean	SD	min	max	
In vivo									
FTh (cm)	0.88	0.25	0.46	1.28	0.55	0.12	0.37	0.82	0.006
MTh (cm)	3.20	0.45	2.37	4.02	2.90	0.37	2.28	3.56	0.25
MAr (cm²)	18.32	3.04	12.13	24.54	16.03	3.22	11.10	20.90	0.02
MCir (cm)	23.38	2.79	19.58	28.97	21.10	3.17	16.65	26.82	0.02
On carcass									
FTh (cm)	0.42	0.14	0.18	0.74	0.38	0.10	0.18	0.64	0.5
MTh (cm)	3.20	0.29	2.74	3.93	3.19	0.65	2.19	4.02	0.5
MAr (cm²)	18.26	3.10	13.15	25.13	17.53	3.99	11,99	24.53	0.5
MCir (cm)	21.90	1.73	18.66	25.87	21.06	3.11	17.19	28.19	0.3

SD – standard deviation.
FTh – fat thickness (cm); MTh – muscle depth (cm); MAr – muscle area (cm²); Mcir – muscle circumference (cm) of the *longissimus dorsi* between the 12th and 13th ribs.

whereas the thin tailed breed has a more lengthened form. Ultrasonic measurements of the muscle tissue taken on carcasses were comparable for both thin- and fat-tailed breeds (Tab. 2).

Carcass muscle and fat prediction by simple regression on body weight and carcass weight

The BW alone accounted for 54% of Barbarine muscle variation. This value was in the same range as that of 59% shown by Nicol and Parrat [1984]. Muscle accuracy prediction from BW increased for the NT thin tailed breed to reach 83% of total variation. As shown by several authors [Shelton et al. 1977, Jones *et al*. 1982], BW was the most important indicator for prediction of carcass components. The fat estimation accuracies based on BW were 70 and 87% for Barbarine and NT lambs, respectively. These values were higher than those recorded (60%) by other authors [Jones *et al.* 1982]. Using CW as a single variable in prediction of carcass composition did not improve the accuracy of muscle prediction for the Barbarine breed in comparison to the accuracy attained when using BW. However, for the NT breed the replacement of BW with CW increased muscle prediction accuracy by about 10%. An opposite observation was made for fat prediction. In fact, CW did not improve fat prediction for the NT breed. In contrast, CW improved fat accuracy in the Barbarine breed by 8%. Hopkins *et al*. [2008] found that CW explained only 26 % and 29% of muscle and fat content variation, respectively.

Relations between muscle and fat amounts and ultrasonic measurements

For the fat-tailed breed, the fat content was significantly correlated to all *in vivo* ultrasound muscle measurements. The highest correlation was between fat content and *in vivo* MAr ($r = 0.69$, $P<0.001$). Moreover, these measurements used individually better explain the variation of muscle and fat quantity than the FTh measurement (Tab. 3). However, there was any significant correlation between muscle content and these parameters, the highest correlation was with in vivo MTh ($r = 0.42$, $P<0.06$). Also,

Table 3. Coefficients of determination (R^2) and the residual standard deviation (RSD, g) of prediction models for muscle and fat contents from ultrasound measurements

Variable	Barbarine (n=21)				Noire de Thibar (n=14)			
	fat		muscle		fat		muscle	
	R^2	RSD	R^2	RSD	R^2	RSD	R^2	RSD
In vivo								
FTh	0.16	435	0.00	283	0.32	335	0.30	488
MTh	0.41	364	0.17	257	0.57	265	0.54	396
MAr	0.47	345	0.11	267	0.49	291	0.58	374
Mcir	0.35	383	0.03	279	0.65	240	0.59	371
On carcass								
FTh	0.04	445	0.12	228	0.16	372	003	574
MTh	0.05	442	0.01	242	0.40	314	0.52	405
MAr	0.07	438	0.02	240	0.45	302	0.33	476
MCir	0.00	453	0.07	234	0.61	255	0.46	425

FTh – fat thickness (cm); MTh – muscle depth (cm); Mar – muscle area (cm²); Mcir – muscle circumference (cm) of the *longissimus dorsi* between the 12th and 13th ribs.

fat and muscle prediction equations were weakly explained by carcass measurements (Tab. 3). Higher correlation coefficients and more accurate prediction equations were reported between fat content and linear fat-tailed measurements [Zamiri and Izadifard 1997, Atti and Ben Hamouda 2004]. For the thin-tailed breed (NT), the content of fat and muscle was significantly correlated to all *in vivo* ultrasound fat and muscle measurements. The highest correlations were between MCir and both fat ($r = 0.81$; $P<0.001$) and muscle contents ($r = 0.77$, 0.001). Tissues were also significantly correlated with carcass ultrasound muscle measurements. The highest correlations were also found between MCir and both fat and muscle contents ($r = 0.78$ (0.001), $r = 0.68$ (0.001), respectively). These results were close to those around 0.8 reported for the correlation between in vivo ultrasound and muscle thickness [Sahin *et al*. 2007, Omran *et al*. 2008]. In turn, Edwards *et al.* [1989] reported no significant correlation between the same parameters, with the value of 0.36. All *in vivo* ultrasound muscle measurements, used each as a unique independent variable, significantly explain the variation of muscle and fat quantity for the thin-tailed breed (Tab. 3). For this breed the MCir measurement explained 65 and 59% of fat and muscle variation, respectively. The ultrasound fat and muscle measurements taken on the carcass better explained the variations for the thin-tailed than fat-tailed breed. For this reason this technique, valuable for this breed type, needs to be more thoroughly investigated for fat-tailed breeds. For both breed types, the *in vivo* and carcass FTh had the lowest correlation coefficient with fat and muscle contents. A higher value was recorded between in vivo FTh and fat content for the NT breed ($r = 0.57$, $P<0.03$). In the opinion of other authors this measurement reflects convincingly the variation of chemical body fat and protein levels [Silva *et al.* 2005]; their prediction accuracy was higher than 0.8. Those authors used equipment with a 7.5-MHz probe (high frequency); the use of a 3.5 MHz probe in the current study could have caused this low accuracy close to that reported by authors using equipment with 2-MHz [Leymaster et al. 1985], 3-MHz [McEwan *et al.* 1989] and 5-MHz probes [Young and Deaker 1994].

Muscle prediction by multiple regressions on BW, CW and ultrasonic measurements

The FTh measurement used with BW accounted for a further 5% of muscle content variation for Barbarine lambs (not mentioned). Indeed, Delfa *et al*. [1991] found that the best muscle content predictor is the carcass weight with fat thickness (R = 0.91). For this breed, a higher accuracy was obtained with FTh, MAr and MCir in addition to BW (R = 0.65, RSD = 187, Tab. 4). This leads to a further 11 % accuracy improvement when compared to BW alone. Conversely, FTh did not improve prediction accuracy of muscle content for the thin-tailed breed, for which accuracy improvement (5%) regarding the BW alone was obtained by the addition of all in vivo ultrasound measurements (Tab. 4). Lower accuracy improvements (2%) were reported by Sahin *et al*. [2007], when they added ultrasound measurements as independent variables to BW. Muscle content prediction accuracy was higher at the application of carcass ultrasonic measurements and CW than that based on BW and *in vivo* measurements (Tab. 4) particularly for the thin-tailed breed (R^2 = 0.97). This improvement could be related to the type of breed, given the NT is a selected breed for meat production.

Table 4. Predicting models for carcass muscle and fat weights (g) with the highest improvement using body weight (BW) and *in vivo* ultrasound measurements or carcass weight (CW) and carcass ultrasound measurements

Item	BW	CW	FTh	MTh	MAr	MCir	Constant	R^2	RSD
BW and *in vivo* ultrasound measurements									
muscle for Barbarine	192	-	1089		-14	+147	2331	0.65	187
muscle for Noire de Thibar	205	-	+635	-339	+267	-60	-1172	0.88	238
fat for Barbarine	278	-			+226		-9802	0.77	233
fat for Noire de Thibar	143	-	-22	+393	-70	+149	-4328	0.90	151
CW and carcass ultrasound measurements									
muscle for Barbarine	-	0.29	+507	+669	-164	-36	+2134	0.68	191
muscle for Noire de Thibar	-	0.56	-605	+117	-79	-199	1063	0.97	116
fat for Barbarine	-	0.54	-1108	-2092	+261	+58	-2806	0.88	173
fat for Noire de Thibar	-	0.33	+2551	-644	+41	+87	-2824	0.92	142

FTh – fat thickness (cm); MTh – muscle depth (cm); Mar – muscle area (cm²); Mcir – muscle circumference (cm) of the *longissimus dorsi* between the 12th and 13th ribs.

Fat prediction by multiple regressions based on BW, CW and ultrasonic measurements

For the fat-tailed Barbarine breed, the highest fat content estimation accuracy was achieved using BW and MAr measurement only, R^2 = 0.77 and RSD = 233 g (Tab. 4). The addition of any other ultrasonic measurement or all the ultrasonic measurements did not improve this accuracy. For the same breed, regression of fat tissue on BW and linear tail measurements in young lambs [Atti and Ben Hamouda 2004] or these measurements and body condition score in adult ewes [Atti 1992] resulted in higher accuracy (R^2 = 0.83 and 0.93, respectively). For the Akkaraman fat-tailed breed, the FTh added to BW explained 84% of the fat variation [Sahin *et al.* 2007]. The addition of FTh has not improved fat content prediction accuracy of the NT breed. For other thin-tailed breeds, BW and FTh explained 86 to 88% of carcass fat variation [Silva *et al*. 2005, Teixeira *et al*. 2006]. The multiple regression using BW and all *in vivo* ultrasonic measurements resulted in 3 and 7% accuracy difference in fat content prediction for the NT thin-tailed and Barbarine fat-tailed breeds, respectively. This small increase in prediction accuracy is in agreement with the results reported by Shelton *et al*. [1977], showing that BW was the dominant variable in the prediction of carcass composition. The highest prediction accuracy was obtained by regression of fat content on CW and carcass ultrasonic measurements. In fact, the fat content prediction accuracy reached 88 and 92% for the Barbarine and NT breeds, respectively (Tab. 4). This result may be explained by the fact that CW is closer to total fat content than the whole BW.

The current study has improved the practical aspect of the ultrasonic technique by asserting the difference between both sheep breed types in terms of the technique accuracy and by focusing the appropriate variable to be taken into consideration when predicting each type of carcass component in each breed type. Even if the ultrasonic method is less precise than other *in vivo* prediction techniques, such as linear measurements for fat-tailed breeds, this technique may be more practical because of its adaptation to both breed types.

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