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RELATIONSHIPS BETWEEN BODY MASS INDEX, ULTRASOUND MEASUREMENTS AND, INTERNAL BODY FAT DEPOTS IN PELIBUEY SHEEP

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Abstract
The objective of this study was to evaluate the relationship between body mass index (BMI), ultrasound measurements (USM), and internal fat (IF) in hair sheep. The BMI and USM were determined 24 hours before laughter in 35 animals finished in intensive fattening. At slaughter, the IF (inner adipose tissue) was dissected, weighed, and grouped as mesenteric, omental, or perirenal fat; these three depots were summed to obtain their total weight. The relationship of the variables was evaluated through Pearson's correlation coefficient (r) using the CORR procedure and by regression models using the REG procedure of SAS ver. 9.3. The IF and BMI presented r= 0.75 (P <.0001), while the IF and USM presented an r that varied from 0.70 to 0.80 (P <.0001). Among the internal fat deposits, the perirenal was the one that presented minor correlation coefficients with BMI (r = 0.55), subcutaneous fat thickness (0.55), and thoracic *Longissimus dorsi* area) (r = 0.33), and for this, the last correlation was not significant (P>0.05). The regression equation between IF and BMI had a coefficient of determination (r^2) of 0.67 (P <.0001). The inclusion of the subcutaneous fat thickness together with the BMI improved the r^2 with a range of 0.77. The BMI and the subcutaneous fat thickness could be used to predict the weight of the internal fat in hair sheep.

Keywords: Body mass index. Body fat. Energy reserves. Ultrasound measurements.

1. Introduction

The determination of the size and distribution of body energy reserves, mainly fat deposits, is necessary to calculate the nutritional needs of animals (Oliveira et al. 2017; Morales-Martínez et al. 2019). Internal body fat (IF) is positively related to total body energy, which is often used in energy balance experiments and calculations (Chay-Canul et al. 2019; Morales-Martínez et al. 2019). In addition, due to the large amount of energy stored by farm animals in the IF, it is crucial that non-invasive methods that allow the estimation of these fat deposits during different physiological states are developed (Härter et al. 2014; Morales-Martínez et al. 2019).

The body mass index (BMI) is a tool that associates body weight with measures such as body compression and hip height (Vaz et al. 2022), allowing a better understanding of the dynamics of tissue deposition in the empty body of animals. In this sense, the BMI has recently been related to body condition, body energy reserves, and body composition in adult Pelibuey ewes and growing lambs, showing a moderate potential for the estimation of these variables (Chavarría-Aguilar et al. 2016; Salazar-Cuytun et al. 2020a; Salazar-Cuytun et al. 2020b; Salazar-Cuytun et al. 2022).

The use of ultrasound measurements (USM) seems to be a viable option (Morales-Martínez et al. 2019) to complement and improve the prediction of internal fat deposits through BMI. Real-time ultrasound images have a high correlation with carcass muscle and fat composition, which is easily measured in the *Longissimus lumborum* muscle between the 12th and 13th thoracic vertebrae (Gomes et al. 2021). As observed by Morais et al. (2016), the association of *in vivo* measurement and fasting body weight provides accurate estimates of body fat in feedlot-finished Texel sheep. However, under field conditions, it is not known how BMI, MUS, and FI are related to each other.

We hypothesised that combining ultrasonic measurements with BMI could generate accurate models to predict internal fat deposits in sheep. Finally, the objective of the present study determines the relationship between BMI, MUS, and IF depots in Pelibuey sheep.

2. Material and Methods

Experimental site and animals

The animals included in the present study were managed in compliance with the ethical guidelines and regulations for animal experimentation of División Académica de Ciencias Agropecuarias at Universidad Juárez Autónoma de Tabasco (approval code: UJAT- DACA-2015-IA-02). All methods were performed according to in vivo animal research guidelines: ARRIVE 2.0 (Sert et al. 2020).

The experiment was carried out at the Southeastern Centre for Ovine Integration (*Centro de Integración Ovina del Sureste* [CIOS]; 17° 78" N, 92° 96" W; 10 masl) located at 25 + 3 km of the Villahermosa-Teapa road in the town of Alvarado Santa Irene 2nd Section in the state of Tabasco, Mexico. Twenty-eight male fattening Pelibuey sheep at six months of age with an average (± SD) body weight (BW) of 39.36 ± 5.14 kg and BCS of 3.5 ± 0.5 points were used.

The sheep were finished in a raised-slatted floor cage system. The diet consisted of 80% concentrate and 20% forage, with an estimated 15% of crude protein (AFRC 1993). The dietary ingredients were cereal grains (maize or sorghum), soybean meal, tropical grass hay, vitamins, and minerals.

Ultrasound measurements

The USM were taken 24 h before slaughter. The subcutaneous fat thickness (SFT) and thoracic *Longissimus dorsi* area (LDMA) were determined using Chison® B-mode real-time ultrasound equipment (Medical Imaging Co., Ltd.; Wuxi, Jiangsu, China) with a 5-MHz linear probe. Previously, the sheep had been shaved between the 12th and 13th thoracic vertebrae and the 3rd and 4th lumbar vertebrae as described by Aguilar-Hernández et al. (2016) and Chay-Canul et al. (2016). Additionally, the maximum length of the *Longissimus* muscle (A) and the maximum depth of the *Longissimus* muscle (B) were measured as described by Härter et al. (2014). The LDMA was then calculated using the equation LMA $cm^2 = ([A/2 \times B/2] \times \pi)$, according to Costa et al. (2012). The sheep were manually immobilised and an acoustic gel was used to create good contact between the probe and the skin of the animals. The pressure over the transducer head was kept to a minimum to avoid compression of the subcutaneous fat (Chay-Canul et al. 2019). All measurements were taken on the right side of the sheep. The USM was recorded for all animals by the same operator, as previously described (Chay-Canul et al. 2019).

After the USM, the animals were weighed and body width and height at the cross were measured, considering the anatomical references described by Bautista-Diaz et al. (2020). The BMI was calculated using the formula presented by Tanaka et al. (2012): BMI = (BW (kg)/ height at the cross (m)/ body width (m))/10.

Slaughter of animals and body fat depot measurements

Twenty hours before slaughter, feed and water were withdrawn. The animals were slaughtered according to the Mexican Official Standard NOM-033-SAG/ZOO-2014 for the humane slaughter of animals. Data recorded at slaughter included carcass and non-carcass components (viscera). The IF (inner adipose tissue) was dissected, weighed, and grouped as mesenteric (MF), omental (OF), or perirenal fat (PF); these three depots were summed to obtain their total weight (TIF).

Data analyses

A descriptive statistical analysis was performed using the PROC MEANS procedure in SAS (SAS Inst. Inc., Cary, NC, 2010). In the same software, correlation coefficients among variables were also estimated using the PROC CORR procedure (SAS Ver. 9.3, 2010), and regressions were carried out using the PROC REG procedure (SAS Ver. 9.3, 2010). The STEPWISE and Mallow's Cp options were used in the SELECTION statement to select the variables included in the model.

3. Results

The descriptive statistics of measurements performed, BMI, ultrasound, and IF deposits resulted in means, data amplitude, and variability represented by the standard deviation being obtained (Table 1).

Table 1. Descriptive analyses of the data measured in live fattening Pelibuey sheep (n = 35).

Variable	Description	Mean ± SD	Maximum	Minimum
BMI	Body mass index (kg/cm^2)	12.62 ± 1.63	15.49	8.87
SFT	Subcutaneous fat thickness (cm)	0.25 ± 0.07	0.39	0.10
LDMA	Thoracic *L. dorsi* area (cm^2)	7.20 ± 1.26	9.73	4.40
MF	Mesenteric fat (kg)	0.64 ± 0.24	0.99	0.16
OF	Omental fat (kg)	1.21 ± 0.58	2.10	0.12
PF	Perirenal fat (kg)	0.74 ± 0.43	1.50	0.03
TIF	Total internal fat (kg)	2.61 ± 1.16	4.30	0.30

SD = Standard deviation.

Positive correlations were observed between the internal OF deposit with the BMI (r=0.77), SFT (r=0.77), and LDMA (r=0.76) (Table 2). Three equations were obtained to predict the OF (Table 3). The BMI explained 66% of the variation in the OF. However, USM (SFT and LDMA) provided an increase in r^2 and a reduction in RMSE (Equation 3).

Table 2. Pearson's correlations between BMI, USM, and IF in Pelibuey sheep.

	SFT	LDMA	OF	MF	PF	TIF
BMI	0.72*	0.71*	0.77*	0.70*	0.55*	0.81*
SFT		0.57*	0.77*	0.69*	0.55*	0.81*
LDMA			0.76*	0.64*	0.33^{ns}	0.70*

BMI: body mass index; OF: omental fat; MF: mesenteric fat; PF: pelvic fat; TIF: total internal fat; SFT: subcutaneous fat thickness; (cm); LDMA: *Longissimus dorsi muscle area* (cm^2) *: P<0.05; ns: non-significative.

The MF is positively correlated with the BMI (r = 0.70), SFT (r = 0.69) and LDMA (r = 0.64). The BMI was responsible for 49% of the FM variation. The inclusion of the SFT in the second step of the stepwise procedure to estimate the amount of MF provided an increase in the coefficient of determination from 0.49 to 0.56. In addition, the LDMA did not reach a level of significance to be inserted into the equation (Table 3).

Among the internal fat deposits, the PF was the one that presented minor correlation coefficients with the BMI (r = 0.55), SFT (0.55), and LDMA (r = 0.33), and for this, the last correlation was not significant (Table 2). For the PF, an equation was generated in which SFT was the only significant measure; it explained 30% of the variation of PF (Table 3).

4. Discussion

The measures evaluated in this research were influenced by environmental factors such as race, sexual status, age, and nutritional management (Oliveira et al. 2017; Gurgel et al. 2020; Vaz et al. 2022), which justifies the variability observed in the data from this study. It should be noted that a diversified database is desirable to improve the predictive capacity and comprehensiveness of the generated equations (Menezes et al. 2015; Gomes et al. 2021; Gurgel et al. 2021).

Table 3. Regression equations between BMI, USM and IF in Pelibuey.

No.	Equation	r^2	MSE	RMSE	P
	Omental fat (OF)				
1	OF (kg) = -1.71 (±0.46**) + 0.23 (±0.03***) × BMI	0.60	0.09	0.30	<.0001
2	OF (kg) = -1.26 (±0.44*) + 0.13 (±0.04**) × BMI+ 2.97 (±1.05**) × SFT	0.70	0.07	0.26	<.0001
3	OF (kg) = -1.33 (±0.40*) + 0.06 (±0.05**) × BMI+ 2.70 (±0.95**) × SFT+ 0.14 (±0.05**) × LDMA	0.76	0.06	0.24	<.0001
	Mesenteric fat (MF)				
4	MF (kg) = -0.36 (±0.20*) + 0.08 (±0.01***) × BMI	0.49	0.019	0.14	<.0001
5	(MF kg) = -0.21 (±0.20*) + 0.04 (±0.02*) × BMI+ 1.01 (±0.49*) × SFT	0.56	0.017	0.13	<.0001
	Perirenal fat (PF)				
6	PF (kg) = 0.19 (±0.19 *) + 2.42 (±0.71***) × SFT	0.30	0.07	0.26	0.0021
	Total internal fat (TIF)				
7	TIF (kg) = -2.60 (±0.73***) + 0.42 (±0.05***) × BMI	0.67	0.24	0.49	<.0001
8	TIF (kg) = -1.80 (±0.66*) + 0.25 (±0.07***) × BMI + 5.23 (±1.58***) × SFT	0.77	0.17	0.41	<.0001

BMI: body mass index; SFT: subcutaneous fat thickness; (cm); LDMA: *Longissimus dorsi muscle area* (cm^2); P-value: ***P<0.001; ** P<0.01; * P<0.05; MSE: mean square error; RMSE: Root MSE.

The BMI has been widely used to estimate the percentage of fat in production animals and helps in the development of nutritional strategies to increase their productive and reproductive rates (Morley and Murray 2014; Urrutia-Morales et al. 2016; Vaz et al. 2022). In sheep, USM are also used to estimate carcass characteristics (Aguilar-Hernández et al. 2016; Chay-Canul et al. 2019) and body fat deposits (Chay-Canul et al. 2016; Morales -Martínez et al. 2019). However, with this study, we propose the association of BMI with USM, aiming at more precise and accurate estimates of internal fat deposits. To the best of our knowledge, the present study is the first to report the use of USM associated with BMI as a tool to predict fat deposits in sheep. Accordingly, Morales-Martínez et al. (2019) observed that about 61% of the variation in OF was explained by BW. In addition, when empty BW was associated with the thickness of renal fat measured by ultrasound, there was an increase of 17% in r^2 of the equation.

To predict the pelvic fat of Pelibuey sheep, Morales-Martínez et al. (2019) used only the measure of the thickness of renal fat measured via ultrasound, The authors reported weak correlations between the LDMA and PF (R = 0.41). The low correlation between the amount of PF with USM and BMI is partially due to the dynamics of fat deposition in sheep, which follows a sequence: first internal fat, followed by intermuscular, subsequently by subcutaneous and finally intramuscular fat (Pethick et al. 2004; Chay-Canul et al. 2011). Furthermore, the first place where fat reaches maturity is around the kidneys (perirenal), followed by the intermuscular, subcutaneous, and, finally, intramuscular fat (Burin 2016). Therefore, it is possible to have greater PF deposits even in animals with low BMI and with early-stage subcutaneous fat deposits. Thus, measures such as the thickness of renal fat measured by ultrasound, and more, provide more accurate estimates of PF. Similarly, LDMA has not been used to estimate MF in sheep (Morales-Martínez et al., 2019), goats (Härter et al. 2014) or cattle (Ribeiro and Tedeschi 2012).

TIF and BMI presented a correlation coefficient of 0.75 (P<.0001), similar to that reported by Chavarría-Aguilar et al. (2016) (r = 0.73); These same authors indicate that this type of study enables the study of BMI and its relationship with body composition and health and reproduction parameters in small ruminants. Here, the IF and the USM presented an r that varied from 0.7 to 0.8 (P<.0001) (Table 2). The regression equation between TIF and BMI had a coefficient of determination of 0.54 (P <.0001). The inclusion of SFT along with BMI improved r^2 from 0.56 to 0.74. This indicates that the thickness of the subcutaneous fat and the BMI could explain the variation in the internal fat of Pelibuey sheep. In past studies, the use of USM has been reported as an accurate and non-invasive method to monitor different fat deposits (Ribeiro and Tedeschi 2012; Härter et al. 2014; Raschka et al. 2016; Morales-Martínez et al. 2019). However, in the present study, the SFT was used as the only predictor of inaccurate TIF. This confirms our hypothesis that the combination of USM with BMI could generate accurate models to predict internal fat deposits in sheep.

5. Conclusions

The BMI and USM presented a good relationship with the IF. The BMI and the thickness of subcutaneous fat in the thoracic region could be used to predict the weight of the internal fat in hair sheep.

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References

AFRC, 1993. Technical Committee on Responses to Nutrients. Energy and Protein Requirements of Ruminants. CAB International, Wallingford, UK.

AGUILAR-HERNÁNDEZ, E., et al. Relationship of ultrasound measurements and carcass traits in Pelibuey ewes. *Journal of Animal and Plant Sciences*. 2016, **26**(2), 325–330. Available from: https://www.thejaps.org.pk/docs/v-26-02/04.pdf

BAUTISTA-DÍAZ, E., et al. Prediction of carcass traits of hair sheep lambs using body measurements. *Animals.* 2020, **10**(8), e1276. https://doi.org/10.3390/ani10081276

BURIN, P.C. Quality of fat sheep: characteristics and influence factors. *Revista Electrónica de Veterinaria.* 2016, **17**(10), 1–28. Available from: http://www.veterinaria.org/revistas/redvet/n101016.html

CHAVARRÍA-AGUILAR, L.M., et al. Relationship between body fat depots and body mass index in Pelibuey. *Small Ruminant Research.* 2016, **141**(2016), 124–126. https://doi.org/10.1016/j.smallrumres.2016.07.014

CHAY-CANUL, A.J., et al. The effects of metabolizable energy intake on body fat depots of adult Pelibuey ewes fed roughage diets under tropical conditions. *Tropical Animal Health and Production.* 2011, **43**(5), 929–936. https://doi.org/10.1007/s11250-011-9785-5

CHAY-CANUL, A.J., et al. Body fat reserves and their relationship to ultrasound back fat measurements in Pelibuey ewes. *Ecosistemas y Recursos Agropecuarios.* 2016, **3**(9), 407–413.

CHAY-CANUL, A.J., et al. Development and evaluation of equations to predict body weight of Pelibuey ewes using heart girth. *Revista Mexicana de Ciencias Pecuarias*. 2019, **10**(3), 767-777. https://doi.org/10.22319/rmcp.v10i3.4911

COSTA, R.G., et al. Using different methodologies to determination the loin eye area in sheep. *Archivos de zootecnia.* 2012, **61**(236), 615–618. https://doi.org/10.4321/S0004-05922012000400014

GOMES, M.B., et al. Prediction of carcass composition through measurements *in vivo* and measurements of the carcass of growing Santa Inês sheep. *Plos One.* 2021, **16**(3), e0247950. https://doi.org/10.1371/journal.pone.0247950

GURGEL, A.L.C., et al. Visual scores are an efficient tool for identifying precocious cattle. *Boletim de Indústria Animal.* 2020, **77**(2020), 1–10. https://doi.org/10.17523/bia.2020.v77.e1467

GURGEL, A.L.C., et al. Prediction of dry matter intake by meat sheep on tropical pastures. *Tropical Animal Health and Production.* 2021, **53**(5), 479. https://doi.org/10.1007/s11250-021-02916-8

HÄRTER, C.J., et al. Ultrasonographic measurements of kidney fat thickness and Longissimus muscle area in predicting body composition of pregnant goats. *Animal Production Science.* 2014, **54**(9), 1481–1485. Available from: http://dx.doi.org/10.1071/AN14282

MENEZES, B.B., et al. Prediction of physical and chemical composition carcass of ewe lambs by 9-11th ribs section or 12th rib. *Revista Brasileira de Saúde e Produção Animal.* 2015, **16**(4), 874–884. https://doi.org/10.1590/S1519-99402015000400011

MORAIS, M.G., et al. 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. *Semina: Ciências Agrárias.* 2016, **37**(2), 1081–1090. https://doi.org/10.5433/1679-0359.2016v37n2p1081

MORALES-MARTÍNEZ, M.A., et al. Developing equations for predicting internal body fat in Pelibuey sheep using ultrasound measurements. *Small Ruminant Research.* 2019, **183**(1), 106031. https://doi.org/10.1016/j.smallrumres.2019.106031

MORLEY, S.A. and MURRAY, J.A. Efects of body condition score on the reproductive physiology of the broodmare: a review. *Journal of Equine Veterinary Science.* 2014, **34**(7), 84–853. https://doi.org/10.1016/j.jevs.2014.04.001

OLIVEIRA, L.B., et al. Allometric growth of body components in crossbred ewe lambs fed increasing dietary concentrate levels. *Semina: Ciências Agrárias.* 2017, **38**(1), 391–400. https://doi.org/10.5433/1679-0359.2017v38n1p391

PETHICK, D.W., HARPER, G.S. and ODDY, V.H. Growth, development and nutritional manipulation of marbling in cattle: A review. *Australian Journal of Experimental Agriculture.* 2004, **44**(7), 705–715. https://doi.org/10.1071/EA02165

RASCHKA, C., et al. *In vivo* determination of subcutaneous and abdominal adipose tissue depots in German Holstein dairy cattle. *Journal of Animal Science.* 2016, **94**(), 2821–2834. https://doi.org/10.2527/jas2015-0103

RIBEIRO, F.R.B. and TEDESCHI, L.O. Using real-time ultrasound and carcass measurements to estimate total internal fat in beef cattle over different breed types and managements. *Journal of Animal Science.* 2012, **90**(7), 3259–3265. https://doi.org/10.2527/jas.2011-4697

SALAZAR-CUYTUN, E.R., et al. Relationship between body mass index and body condition score in Pelibuey ewes. *Ecosistemas y Recursos Agropecuarios.* 2020a, **7**(2), e2474. https://doi.org/10.19136/era.a7n2.2474

SALAZAR-CUYTUN, E.R., et al. Body mass index and body chemical components in Pelibuey ewes. *Ecosistemas y Recursos Agropecuarios.* 2020b, **7**(2), 2515. https://doi.org/10.19136/era.a7n2.2515

SALAZAR-CUYTUN, E. R., et al Predicting body composition of hair-lambs based on body mass index. *Journal of Animal and Feed Sciences.* 2022, **31**(3), 283-291. https://doi.org/10.22358/jafs/150005/2022

SERT, N.P., et al. The ARRIVE guidelines 2.0: Updated guidelines for reporting animal research. *Plos Biology.* 2020, **18**(7), e3000410. https://doi.org/10.1371/journal.pbio.3000410

TANAKA, T., et al. Corrigendum to "Fasting-induced suppression of pulsatile luteinizing hormone secretion is related to body energy status in ovariectomized goats. *Animal Reproduction Science.* 2012, **72**(3-4), 185–196. https://doi.org/10.1016/s0378-4320(02)00091-x

URRUTIA-MORALES, J., et al. Resumption of ovarian activity is modifed by non-photoperiodic environmental cues in Criollo goats in tropical latitudes. *Small Ruminant Research.* 2016, **137**(2016), 9–16. https://doi.org/10.1016/j.smallrumres.2016.02.016

VAZ, R.Z., et al. Body mass index at calving on performance and efciency of Charolais cow herds. *Tropical Animal Health and Production.* 2022, **54**(3), 168. https://doi.org/10.1007/s11250-022-03108-8

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