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Feed energy utilization by hair sheep: does the 0.82 conversion factor of digestible to metabolizable energy need to be revised?

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Abstract

The objective was to evaluate energy partitioning and predict the relationship between metabolizable energy (ME) and digestible energy (DE) in hair sheep fed tropical diets at three feeding levels (maintenance, intermediate and high). To evaluate the energy partition, a database with 114 records (54 non-castrated males and 60 females) from comparative slaughter studies was used. To estimate the ratio ME:DE, 207 observations (74 non-castrated males and 133 females) were used from six studies in a multi-study approach, two indirect calorimetry studies ($n = 93$) and four comparative slaughter ($n = 114$), using a mixed model and study as random effect. A simple linear regression equation of the ME against DE was fitted to predict the efficiency of DE to ME conversion. Gas losses were greatest ($P < 0.05$) for animals fed at maintenance level (7.92% of gross energy intake). The variations of energy losses in the urine were 2.64, 2.06 and 2.08%; faecal losses were 34.37, 37.80 and 36.91% for maintenance, intermediary and high level of feeding, respectively. The regression analysis suggested a strong linear relationship between ME and DE, generating the model ME (MJ/day) = −0.1559 (±0.07525) + 0.8503 (±0.005864) × DE (MJ/day). This study highlights the importance of the relationship ME:DE. Equation/factor 0.85 presented herein is alternative that could be used for the calculation of ME from DE in feedlot diets tropical. In conclusion, we suggest that for hair sheep fed tropical diets the conversion factor 0.85 is more adequate to predict ME from DE.

Introduction

The correct supply of energy is essential to optimize livestock productivity and profitability (NRC, 1996) and estimates of the availability of energy in feeds are essential to systems for describing nutrient requirements (Galyean *et al*., 2016). Understanding inefficiencies in energy use and what proportion of digestible energy is metabolizable is needed to support recommendations.

In the conversion of feed energy to tissue synthesis several steps must occur that are associated with classic ways of considering feed energy values (VandeHaar and St-Pierre, 2006) and most Committees (NRC, 2001; BR-CORTE, 2016; NASEM, 2016) classify feed energy into four levels: gross energy (GE), digestible energy (DE), metabolizable energy (ME) and net energy (NE). GE is the chemical bonding energy measured by combustion (Kleiber, 1975). A portion of the GE of feeds is lost through faeces, and the remaining DE is absorbed. A portion of DE is further lost as urine and gaseous energy, while the remaining energy is termed ME (CSIRO, 2007). Net energy refers to ME minus the heat increment; thus, NE is the actual energy used for physiological processes (maintenance and gain). Thus, productive functions of domestic animals involve transformations of ingested energy (obeying the laws of thermodynamics), which is food (energy/matter), into desired products, such as milk, meat, etc. (Brody, 1945).

The ratio ME:DE of 0.82 has been widely used for cattle and sheep for many years, mainly because of the NE equations of Garrett (1980), and because it is convenient. The original factor of 0.82 was obtained from a study by Blaxter and Wainman (1961) with three cattle and three sheep fed high-forage diets with a maintenance level of dry matter intake. Subsequently, the 0.82 conversion factor was published by the ARC (1965) and adopted by the NRC (1976). The NRC (1985) reported that the conversion is possible with the factor 0.82, however, cautioned that for diets with a high grain content, high values were observed by Johnson (1972). The NASEM (2016) and BR-CORTE (2016) support that the relation ME = 0.82 × DE is variable, and this variation is between 0.82 and 0.93 in growing cattle. Hales (2019) conducted a meta-analysis and suggested that the factor can be as high as 0.94 (14.35 MJ/kg of ME to 15.27 MJ/kg of ME), varying from 0.82 to 0.95. Unfortunately, studies on the ME:DE ratio in sheep are scarce in the literature, which made the use of the 0.82 factor convenient.

Aware that we must understand the inefficiencies of energy use, as well as the proportion of digestible energy that is metabolizable, to support recommendations for hair sheep, we hypothesize that the DE to ME conversion factor may differ from the conventionally used 0.82 by the world Committees. In this context, the aim of this study was to comprehend energy partitioning and determine the proportion of digestible energy that is metabolizable in hair sheep fed tropical diets.

Materials and methods

Studies and inclusion criteria

Only studies that contained individual information from each animal of hair sheep fed tropical diets at three feeding levels (maintenance, intermediate and high) were included. In addition, studies containing at least one of the following quantitative information items were included: body weight (BW), dry matter intake (DMI), gross energy intake (GEI), digestible energy intake (DEI), metabolizable energy intake (MEI), gross energy of faeces (GEF), gross energy of urine (GEU), gross energy of gases (GEG), heat production (HP), retained energy (RE) and chemical composition of diets (crude protein, CP; ether extract, EE; and neutral detergent fibre, NDF).

For energy partitioning, a database with 114 individual records (Mendes *et al.*, 2021; Herbster, unpublished; Brito Neto, unpublished; Rocha, unpublished) was used, comprising 54 non-castrated males and 60 females from comparative slaughter studies. To establish the regression equation between DE and ME, a database consisting of 207 observations (74 non-castrated males and 133 females) was used in a multi-study approach, 114 from comparative slaughter studies (Mendes *et al.*, 2021; Herbster, unpublished; Brito Neto, unpublished; Rocha, unpublished) and 93 from indirect calorimetry (Macedo Junior, 2008; Santos, 2020), of sheep fed in a feedlot system (Table 1).

Collection of urine, faeces and gases

In all studies, the animals were fed on diets as total mixed rations twice daily (at 08.00 h and 04.00 h). Before feeding, the diet refusals of each animal were removed and weighed for control of daily DMI. The animals were weighed weekly to calculate average daily gain. In the study by Herbster (unpublished), BW ranged from 16.55 to 42.55 kg; in Brito Neto (unpublished), BW ranged from 13.56 to 42.06 kg; and in Rocha (unpublished), BW ranged from 12.60 to 56.70 kg. The trial period in these studies was 135, 180 and 202 days, respectively. The BW range and duration of the experimental period in the other studies can be found in Mendes *et al.* (2021), Santos (2020), Macedo Junior (2008).

In the studies by Santos (2020), Macedo Junior (2008), total faecal and urine collections were performed during 24 h for five consecutive days. In the study of Rocha (unpublished), total urine collections were performed for 24 h at 45, 105 and 200 days of the experimental period using collecting funnels, which were coupled to the animals by hoses leading to gallon urine containers containing 100 ml of 20% H_2SO_4 to reduce N losses. Total faeces collections were performed using collection bags for three consecutive days in each collection period, which occurred at 48, 108 and 203 days of the experimental period.

In the studies by Mendes *et al.* (2021), Herbster (unpublished) and (unpublished), the digestibility trial was carried out indirectly using indigestible neutral detergent fibre (iNDF) to estimate faecal DM excretion. Every 15 days, for three consecutive days and at specific times (08.00 h on the first day, 12.00 h on the second day and 04.00 h on the third day), faeces were collected from the animals' rectal ampulla, totalizing 15 collection days for the study by Mendes *et al.* (2021), 21 days for the study by C. J. L. Herbster (unpublished) and 30 days for the study by A. S. Brito Neto (unpublished). Faecal samples, refusals, concentrate and Tifton 85 hay were incubated *in situ* over a period of 240 h in the rumen of a cow receiving an experimental feed. After, the bags were washed in water until they became clear (Van Soest *et al.*, 1991), and the residue was weighed and considered to be the iNDF. Spot urine samples by spontaneous urination were collected every 15 days, approximately 4 h after the morning feeding, totalizing five collection days for the study by Mendes *et al.* (2021), 7 days for the study by Herbster (unpublished) and 10 days for the study by Brito Neto (unpublished). For the collection of urine from males, plastic collectors adapted to the animal's body were used. Disposable urethral catheters were used to collect urine from females. The concentration of creatinine in the urine was determined using a commercial kit (Labtest, Lagoa Santa, MG, Brazil) to estimate the urinary volume.

To estimate the production of gases, the animals from the studies by Santos (2020) and Macedo Junior (2008) were subjected to solid fasting for 48 h and, after this period, they were transferred to a respirometry chamber, still fasting, to measure the heat production for a period of 20 h. Twelve hours before being placed inside the respirometry chamber, the measurement of urine production was started, which was maintained until the end of the gas reading. The loss of energy in CH_4 production was quantified, assuming a value of 39.52 kJ/l of CH_4 produced (Brouwer, 1965).

In the comparative slaughter studies, GEG was estimated using the equation proposed by Blaxter and Clapperton (1965): $GEG\ (MJ/day) = GEI \times [4.28 + (0.059 \times GEDC)]$, where GEDC is the gross energy digestibility coefficient (%). The DEI was calculated as GEI minus GEF, and MEI was calculated by the difference between GEI and the losses of GEF, GEU and GEG.

Chemical analyses and determination of retained energy

Concentrate, roughage and refusal samples were dried in a forced-air oven at 55°C for 72 h and then ground in a knife mill with a 1-mm screen. The samples were analysed to determine levels of DM (AOAC, 1990; method 967.03), CP (AOAC, 1990; method 981.10), EE (AOAC, 1990; method 920.39) and the NDF was determined according to Van Soest *et al.* (1991). The body components were dried at 55°C for 72 h in forced-air circulation and analysed for fat DM content (AOAC, 1990; method 930.15). Subsequently in this procedure, the samples were defatted in a Soxhlet apparatus for 12 h (AOAC, 1990; method 920.39). After the fat extraction, the fat-free samples were ground in a ball mill and analysed for DM (AOAC, 1990; method number 930.15) and CP (AOAC, 1990; method 981.10) contents.

Table 1. Database used for evaluation of the relationship between metabolizable energy and digestible energy in hair sheep

							DM (g/kg)			Energy intake (MJ/day)			
Source	Level of feeding	Roughage	Breed	*n*	BW (kg)	DMI (kg/day)	CP	EE	NDF	GE	DE	ME	ME:DE ratio
Santos (2020)	Maintenance	Tifton 85 hay	DP × SI	4	20.0	0.394	110	20	533	18.4	10.3	8.5	0.82
		SUDBL hay	DP × SI	4	20.0	0.364	125	45	570	16.7	13.4	9.8	0.73
		SHDBL hay	DP × SI	4	20.0	0.365	125	40	500	18.6	10.0	8.5	0.85
		SUDBP hay	DP × SI	4	20.0	0.324	112	12	499	14.6	10.1	8.1	0.80
		SHDBP hay	DP × SI	4	20.0	0.320	102	11	474	18.5	10.1	8.5	0.84
Macedo Junior (2008)	Intermediary	Tifton 85 hay	SI	40	48.5	1.218	111	27	439	24.2	16.0	13.6	0.85
	Maintenance	Tifton 85 hay	SI	33	53.4	1.073	98	25	564	20.8	13.2	11.2	0.85
Mendes *et al.* (2021)	High	Tifton 85 hay	DP × SI	10	39.1	1.369	142	30	498	24.6	11.6	9.5	0.82
	Intermediary	Tifton 85 hay	DP × SI	10	36.2	0.972	142	30	498	17.5	9.3	7.8	0.84
	Maintenance	Tifton 85 hay	DP × SI	10	30.6	0.513	142	30	498	9.2	5.2	4.4	0.84
C.J.L. Herbster[a]	High	Tifton 85 hay	DP × SI	8	28.9	1.120	158	30	456	21.4	14.0	11.8	0.85
	Intermediary	Tifton 85 hay	DP × SI	8	26.2	0.754	158	30	456	14.3	9.9	8.4	0.85
	Maintenance	Tifton 85 hay	DP × SI	8	21.0	0.376	158	30	456	7.2	5.2	4.5	0.87
A.S. Brito Neto[a]	High	Tifton 85 hay	SI	12	22.6	0.818	139	31	430	14.9	9.6	8.2	0.85
	Intermediary	Tifton 85 hay	SI	12	22.4	0.815	134	25	565	15.2	9.0	7.5	0.83
	Maintenance	Tifton 85 hay	SI	12	16.0	0.297	134	25	565	5.5	3.7	3.1	0.84
A.C. Rocha[a]	High	Tifton 85 hay	SI/MN	6	32.2	1.151	126	24	514	22.9	16.6	13.8	0.83
	Intermediary	Tifton 85 hay	SI/MN	6	32.2	1.057	111	26	515	20.4	14.4	12.1	0.84
	Low	Tifton 85 hay	SI/MN	6	32.0	1.071	92	29	515	20.8	14.3	11.9	0.83
	Maintenance	Tifton 85 hay	SI/MN	6	19.5	0.347	126	24	514	6.9	4.7	3.6	0.77

DP × SI, Dorper × Santa Ines; SI, Santa Ines; MN, Morada Nova; BW, body weight; DMI, dry matter intake; DM, dry matter; CP, crude protein; NDF, neutral detergent fibre; EE, ether extract; GE, gross energy; DE, digestible energy; ME, metabolizable energy; SUDBL, sun-dried banana leaf; SHDBL, shade dried banana leaf; SUDBP, sun-dried banana pseudostem; SHDBP, shade-dried banana pseudostem.
[a]Unpublished studies.

The GE of feed, refusals, faeces and urine was determined using a bomb calorimeter metre (model Parr 208 for studies of Santos (2020) and Macedo Junior (2008), and the other studies using model Ika C 200). To measure the energy from urine, the samples were dried at 55°C for 72 h in forced-air circulation in a polyethylene capsule before combustion. The known heat of combustion per gram of polyethylene capsule minus the total heat observed (urine plus capsule) was considered as the energy of urine.

The RE was determined in studies by Mendes *et al.* (2021), Herbster (unpublished), Brito Neto (unpublished) and Rocha (unpublished) using the comparative slaughter method as described by Pereira *et al.* (2018). Daily energy retention was calculated as the difference between the total final energy contained in the empty body minus the initial total energy, estimated from the initial composition of the reference animals, divided by the number of days the animals spent in the experiment. The body energy content of the animals of each study was calculated by the equation recommended by the ARC (1980), being calculated according to the caloric coefficients of 23.599 and 39.299 MJ/g for protein and fat, respectively. The HP was estimated based on the difference between daily MEI (MJ/day) and RE (MJ/day).

Statistical analyses

The statistical analysis included the effects of levels of feeding on the variables of energy partition under the following model:

$$Y_{ij} = \mu + F_i + \varepsilon_{ij}$$

where Y_{ij} is the dependent or response variable, Y is measured in the jth animal or experimental unit, ith is the level of feeding; μ is the overall mean; F_i is the effect of level of feeding; and ϵ_{ij} is the random error term. The Tukey test with a significance level of 0.05 was used to compare means. The analysis was performed using the GLM procedure in SAS (version 9.2, SAS Institute Inc.).

The mixed model adopted was used to evaluate the relationship between dietary DE and ME concentration, the first as the dependent variable, and the latter variable as the independent variable in a simple linear regression. As the database was composed of different studies, a mixed model with the random effect of study (St-Pierre, 2001) was used. The random effect of the study was included and tested in the intercept and slope of all models, considering the possibility of covariance. Seventeen covariance matrices were tested, with the variance component being the selected matrix. The choice of the matrix was based on the Akaike information criterion. Residuals were evaluated for normality and dispersion of standardized residuals. Individual observations with studentized residuals greater than 2.5 or below −2.5 were considered 'outliers' (Pell, 2000; Tedeschi, 2006) and excluded from the database. In addition, when Cook's distance was greater than one, the study was considered an 'outlier' and removed from the data set for that specific analysis (Cook, 1977, 1979). A significant level of 0.05 was adopted for all statistical procedures for fixed and random effects. For mixed models, the MIXED procedure of SAS was used (version 9.2, SAS Institute Inc).

Validation of the DE:ME model

To validate the model, nine studies (Freitas *et al.*, 2003; Rogério *et al.*, 2007; Pereira, 2011; Silva *et al.*, 2011; Gomes *et al.*, 2012; Machado *et al.*, 2015; Ribeiro *et al.*, 2015; Lima, 2019; Castro *et al.*, 2021) were used totalizing 139 hair sheep. The experimental diets in these studies were composed of feeds commonly used in tropical feedlots (Tifton hay, *Pennisetum purpureum* grass hay, corn silage, sorghum silage, *Andropogon gayanus* grass silage, and agro-industrial residues). The database used to generate the equation differed from the data used to validate the equation.

The comparison between predicted and measured values was performed using the model evaluation system (MES) software, version 3.1.13 (Tedeschi, 2006). To validate the equation, the observed and predicted ME values were compared using the following regression model:

$$Y = \beta 0 + \beta 1 \times X \tag{1}$$

where X is the predicted values; Y is the observed values; β_0 is the intercept of equation; and β_1 is the slope of equation. Regression was evaluated with the following statistical hypotheses (Neter *et al.*, 1996): H_0: $\beta_0 = 0$ and $\beta_1 = 1$; H_a: not H_0. The slope and intercept of the curve were evaluated separately to identify possible errors in the equations. After validation, the model's prediction errors were determined using the estimated mean squared error of prediction (MSEP) and mean bias (MB), where the closer to zero the better (Bibby and Toutenburg, 1977). The root squares mean prediction error (RMSEP) was used to evaluate model precision, being that the smaller the RMSEP values the better the model precision. The coefficient of determination (R^2) was used as a precision predictor, and values closer to one were better. The concordance correlation coefficient (CCC) was used to assess the model's accuracy and precision (Deyo *et al.*, 1991; Nickerson, 1997; Liao, 2003), and values closer to +1 were better.

Results

Table 2 shows energy partitioning in hair sheep and Fig. 1 is a schematic representation of the typical influence of intake level on the partition of intake energy. GEI was higher ($P < 0.05$) with intermediary and high levels of feeding (16.59 and 20.39 MJ/day, respectively) compared to maintenance (7.14 MJ/day). The higher losses were through the faecal component, being significant for levels above maintenance ($P < 0.05$) recording values of 6.41 and 7.79 MJ/day for intermediary and high level of feeding, respectively. At both levels above maintenance, there were no differences ($P > 0.05$) for daily urine energy loss (MJ/day), with mean values of 0.39 MJ/day; however, it was lower ($P < 0.05$) in animals fed at maintenance level (0.19 MJ/day). Gas losses were greatest ($P < 0.05$) for animals fed at maintenance level (7.92% of GEI), followed by 7.73 and 7.65% for intermediary and high level of feeding, respectively. The variations of energy losses in the urine were 2.64, 2.06 and 2.08%; faecal losses were 34.37, 37.80 and 36.91% for maintenance, intermediary and high level of feeding, respectively.

The adjusted simple linear regression equation with dietary ME (MJ/day) concentration as the dependent variable and dietary DE (MJ/day) concentration as the independent variable is the follows:

$$ME = -0.1559(\pm 0.07525) + 0.8503(\pm 0.005864) \times DE \tag{2}$$

($R^2 = 0.998$; MSE = 0.027; AIC = −102.2; intercept $P = 0.0894$; slope $P < 0.0001$)

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Table 2. Partitioning of energy (MJ/day) in hair sheep fed at three levels of feeding (means and ± S.D.)

	Levels of feeding				
Item	Maintenance	Intermediary	High	S.E.M.	*P* value
GEI	7 ± 1.6	17 ± 2.8	20 ± 4.40	0.60	<0.001
GEF	2.5 ± 0.96	6 ± 1.5	8 ± 3.3	0.30	<0.001
DEI	4.6 ± 0.82	10 ± 2.3	13 ± 3.0	0.02	<0.001
GEU	0.2 ± 0.16	0.3 ± 0.23	0.4 ± 0.23	0.05	<0.001
GEG	0.6 ± 0.11	1.3 ± 0.25	1.6 ± 0.33	0.27	<0.001
MEI	3.9 ± 0.73	9 ± 1.9	11 ± 2.6	0.09	<0.001
HP	3.9 ± 0.86	8 ± 1.7	9 ± 2.4	0.38	<0.001
RE	0.1 ± 0.27	1.4 ± 0.32	2.1 ± 0.61	0.32	<0.001

GEI, gross energy intake; GEF, gross energy faeces; DEI, digestible energy intake gross; GEU, energy of urine gross; GEG, energy of gases; MEI, metabolizable energy intake; HP, heat production; RE, retained energy.

The ME:DE ratio is graphically presented in Fig. 2. Figure 3 shows the plot of the observed *v.* predicted dietary ME concentrations assuming a fixed ME:DE ratio of 0.82 (ARC, 1965) and based on Equation 2 proposed in this study. Considering the distance between the predicted and observed values, the residuals of the predictions were plotted as a function of the predicted ME and are shown in Fig. 4. The visual evaluation of residuals' behaviour reinforces the hypothesis of lack of adjustment of the factor 0.82 for hair sheep. It is also possible to observe that this model overestimates the prediction of the ME, which suggests that the 0.82 factor is more appropriate for lower-quality diets (ME < 15.0 MJ/day). On the other hand, residues were less dispersed with the equation in this study, which indicates a smaller possibility of error in the prediction and a better fit for better-quality diets.

The validation analysis showed that Eqn (2) adequately estimated the ME values, considering both the intercept ($P = 0.629$) and the slope ($P = 0.172$). Furthermore, R^2 (0.985) and CCC (0.989) were close to one (Table 3). In addition, Eqn (2) had a low value of MSEP (0.1622), and a low MB (0.2106), which indicates an accurate estimate of ME.

Discussion

In our study, the percentage of faecal energy losses in relation to GEI was high, and the DE values as a percentage of GE were lower compared to the findings by Jennings *et al.* (2018). However, the DE values from our current study closely resembled those reported by Reynolds *et al.* (1991) and Ferrell *et al.* (2001). The urinary energy losses, as a percentage of GEI, were lower (2.26%) than the values reported by Blaxter and Wainman (1961), which documented an average of approximately 4.21% for sheep. These losses come from urea produced during the

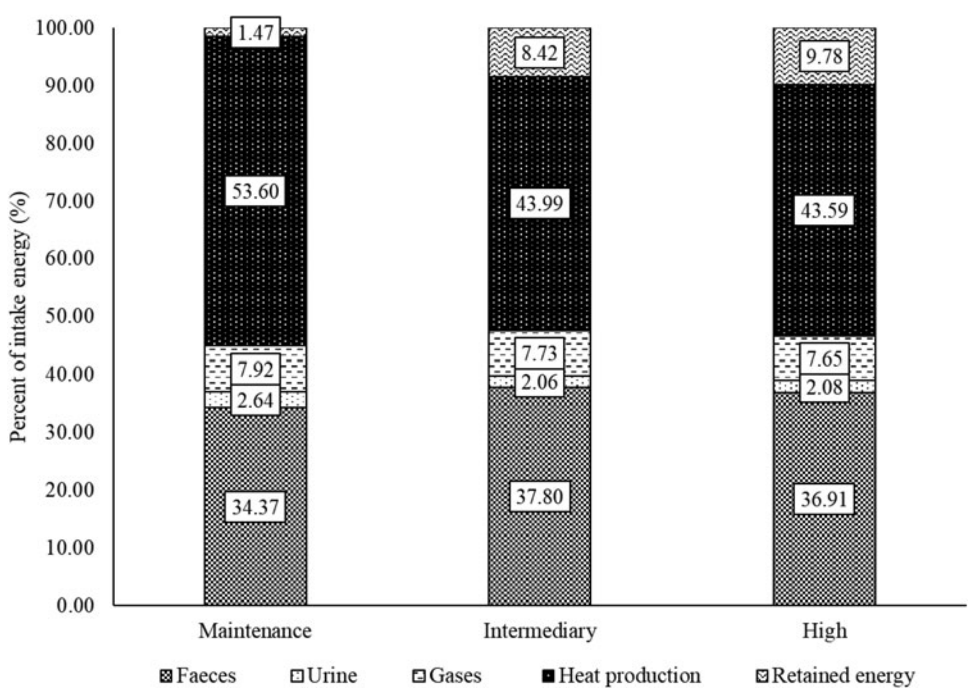

Figure 1. Energy partition between different levels of feeding.

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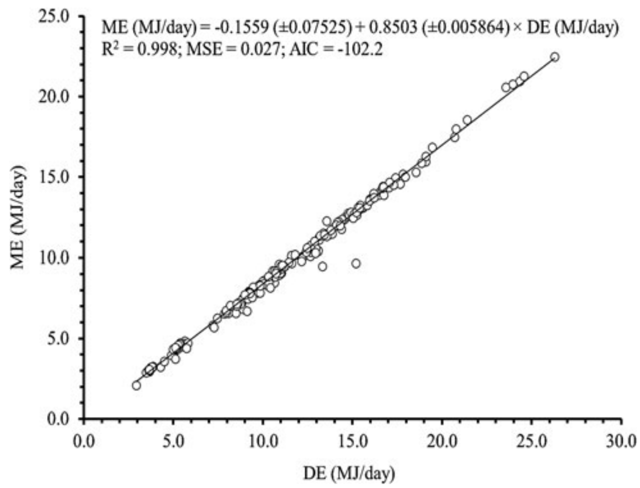

Figure 2. Relationship between digestible energy (DE) and metabolizable energy (ME) concentration for hair sheep.

catabolism of nitrogen-containing organic molecules. Animals very close to maintenance or below may have, in addition to urea, greater amounts of allantoin and hippuric acid, which occurs when protein is oxidized in the body, corresponding to greater energy losses through urine.

The variation in our study can be attributed to the fact that not all energy fuel is utilized by the animal; a portion of it remains undigested and is lost as faecal energy. Additionally, a fraction of the digestible energy is emitted in the form of gaseous energy, primarily methane produced during fermentation (NRC, 1981).

In the current study, the dietary pattern was of medium nutritional quality, with gaseous energy losses of around 7.8% of GEI. A mean methane emission value of 6.5% was recorded by Carvalho *et al.* (2018) with cattle raised in tropical areas, while Blaxter and Wainman (1961) found a value of 7.55% in sheep. The heat of fermentation within the gut (gaseous losses) can account for 6.2–10.8% of GE in ruminants.

Considering the first law of thermodynamics of conservation of energy, where energy is neither lost nor gained, it is transformed (Kleiber, 1975), the rest of the energy is known as NE or energy retained or recovered, which represents the tissues added to the body of a growing sheep and the chemical energy that is converted into heat to support the animal's domestic functions (NRC, 1981). In the current study, the variation in energy losses at the maintenance dietary and two levels above maintenance is notably explained by the classic law of diminishing returns, in which small increases in the dietary plan above maintenance considerably decrease urinary energy losses and by gases (VandeHaar and St-Pierre, 2006), resulting in a compression of HP which promotes a dilution of maintenance requirements and consequently, greater energy input for the addition of tissues. This fact confirms that an animal fed at maintenance level is inefficient, due to the increase in energy losses through faeces, urine and gases. However, at dietary levels far above maintenance, energy retention decreases with increasing food intake. The reason for the decline is largely because the digestion and fermentation of food slow down with increasing intake.

The information generated in our study regarding energy partitioning is useful for accurate estimates of ME and for understanding the relationship between ME and DE. However, over the past seven decades (ARC, 1965) the 0.82 factor has been used holistically for different species and feeding conditions. However, as elucidated by Garrett and Johnson (1983) there is a necessity to develop increasingly precise methods for evaluating foods in research involving energy metabolism. In our findings DE correlated well with the ME of the diets, resulting in a DE to ME conversion factor of 0.85 being more accurate and precise in predicting the ME in tropical diets than the 0.82. In the residual analysis, these were less dispersed with the

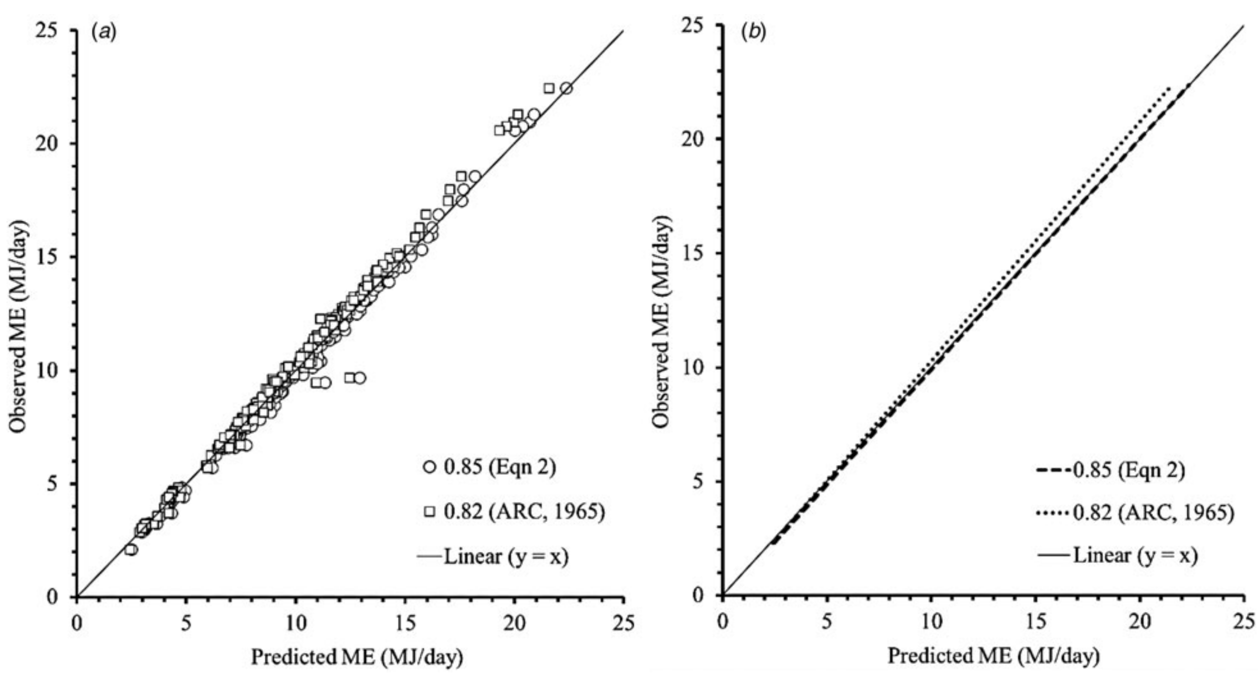

Figure 3. Relationship between observed metabolizable energy (ME) and predicted ME from digestible energy (DE) using 0.82 factor (ARC, 1965) and using factor 0.85 proposed in this study (a); in (b) the trend lines of the predictions are presented using the factor 0.82 and the factor 0.85, and for $y = x$.

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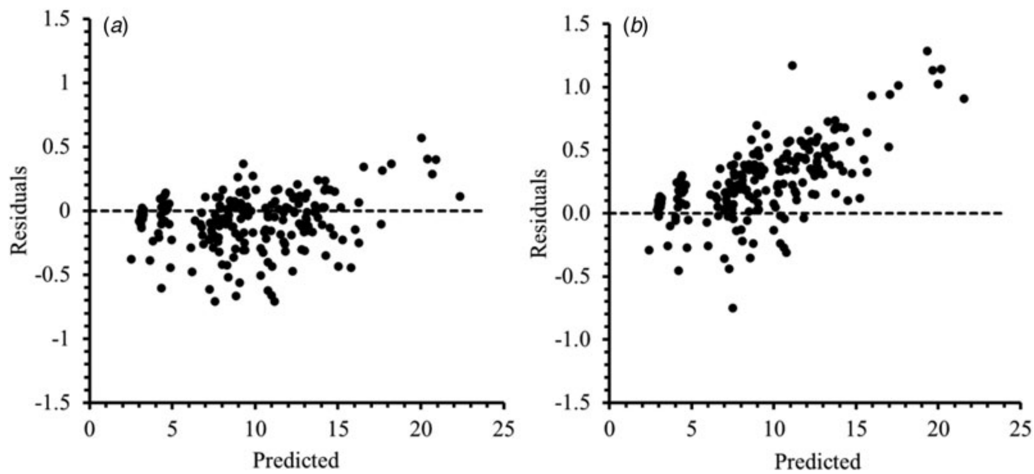

Figure 4. Distribution of prediction residuals using 0.85 factor proposed in this study (a) and using 0.82 factor (ARC, 1965; (b) in function of predicted metabolizable energy.

equation in this study, which indicates a smaller possibility of error in the prediction and a better fit for better-quality diets. These differences demonstrate that our factor is more suitable for hair sheep. Thus, reliable predictions of ME from DE are necessary to accurately prescribe the nutrient requirements of sheep. According to comparative analysis in MES, the equation in the current study has better accuracy and precision, as the CCC is closer to one and this parameter indicates the efficiency and reproducibility of the tested equation (Tedeschi, 2006). For example, if we consider an ME requirement of 11.573 MJ/day for a hair sheep weighing 30 kg with an average daily gain of 200 g, as recommended by the meta-analysis of Oliveira *et al.* (2017), and using the constant 0.82 (DE = ME/0.82) we would obtain a DE of 14.11 MJ/day or 0.765 kg/day TDN; on the other hand, if we calculate the DE using the factor proposed in this study (DE = ME/0.85), we will arrive at the value of 13.61 MJ day or 0.738 kg/day TDN. Therefore, the use of a factor of 0.82 overestimates the energy requirements of hair sheep by 4%. Furthermore, accurate TDN predictions are needed for better estimates of microbial protein synthesis (Santos *et al.*, 2021).

This study highlights the importance of the relationship ME: DE. Equation/factor 0.85 presented herein is an alternative that could be used for the calculation of ME from DE in feedlot diets tropical. In conclusion, we suggest that for hair sheep fed tropical diets the conversion factor 0.85 is more adequate to predict ME from DE.

Table 3. Observed values of metabolizable energy and parameters of regression and accuracy between the estimate of metabolizable energy by correction factor in this study and the 0.82 factor proposed by the ARC (1965) and adopted by most sheep world Committees

		Predicted	
Item	Observed	0.85 (Eqn (2))	0.82 (ARC, 1965)
Energy metabolizable, MJ/day	10.2	9.9	9.7
S.D.	2.8	2.7	2.6
Median, MJ/day	9	10	9
Intercept		−0.1186	−0.2858
S.D.		0.24	0.25
P value		0.629	0.257
Slope		1.0330	1.0720
S.D.		0.12	0.12
P value		0.172	< 0.001
R^2		0.985	0.985
CCC		0.989	0.978
MSEP		0.1622	0.3157
AICc		25.657	25.717
MB		0.2106	0.4152
CB		0.996	0.985
RMSEP		0.4028	0.5618

S.D., standard deviation; CCC, concordance correlation coefficient; MSEP, mean square error of prediction; AICc, corrected Akaike's Information Criterion; MB, mean bias; CB, model accuracy; RMSEP, root mean square error of prediction.

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