ITALIAN JOURNAL OF ANIMAL SCIENCE
2023, VOL. 22, NO. 1, 1067–1072
https://doi.org/10.1080/1828051X.2023.2264879

SHORT COMMUNICATION

Estimation of the metabolisable energy requirements of feedlot light lambs and comparison with the U. S. National Research Council predictions

Andrés L. Martínez Marín, Manuela Renna, Claudio Forte, Emanuela Valle and Achille Schiavone

Dipartimento di Scienze Veterinarie, Università degli Studi di Torino, Grugliasco, TO, Italy

ABSTRACT

The aim of the present work was to compare the estimated metabolisable energy requirements (MER) of fattening light lambs raised in feedlot with the U. S. National Research Council (NRC) predictions. Body weight (BW) gain and feed intake were collected from 15 pens (7 lambs/pen) of Manchega male lambs under on-farm conditions over six weeks. The pens were randomly assigned to three dietary treatments (5 pens/treatment) consisting of three concentrates of different composition and barley straw. Feeds were offered for ad libitum consumption throughout the experimental period. Average daily metabolisable energy intake (MEI) was calculated on a weekly basis for each pen from the average daily consumption of concentrate and barley straw and their respective ME contents. Following, the average daily MER was predicted for each pen from the weekly average of both BW and BW gain, according to two models: One including the adjustment of ME for body maintenance (MEm) for the effect of level of MEI on visceral organ tissue energy use as described by NRC (Model 1), and the other excluding such adjustment (Model 2). Model 1 had no mean bias, and exhibited a higher concordance correlation coefficient and a lower underprediction, supporting the need for the upward adjustment of MEm in accordance with MEI to enhance the precision and accuracy of predicted MER. It was concluded that the NRC method was precise and accurate enough to support its application for calculating the MER of feedlot light lambs.

HIGHLIGHTS

- A dataset comprising metabolisable energy (ME) intake and growth performance data of Manchega male lambs was utilised.
- The lambs' ME requirements were predicted according to the U.S. National Research Council (NRC) methods.
- Our data agree with NRC predictions, supporting its use in feedlot Manchega lambs.

ARTICLE HISTORY
Received 21 August 2023
Accepted 25 September 2023

KEYWORDS
Lambs; fattening; metabolisable energy; NRC

Introduction

In the European Union, Greece, Italy, Portugal, and Spain collectively account for over 40% of sheep meat production (EC 2023). Traditionally, lambs in these countries are slaughtered at a very young age (1–4 months). In some systems, lambs are slaughtered while still unweaned, typically when they are less than two months old and weigh up to 15 kg body weight (BW). In other systems, lambs are weaned, raised in feedlots and slaughtered when they are typically less than three months of age and under 30 kg BW (Alfonso et al. 2001; Sañudo et al. 2007). In the latter system, lambs are typically fed high concentrate diets indoors to promote accelerated growth rates (Blanco et al. 2014; Armero and Falagán 2015; Valenti et al. 2018).

Understanding the metabolisable energy requirements (MER) of fattening lambs is crucial for designing effective diets aimed at enhancing animal performance and reducing feed costs. The U.S. National Research Council method for predicting the MER of fattening lambs is based on the model developed by Cannas et al. (2004) and it is detailed in its latest publication dedicated to the nutrient requirements of small ruminants (NRC 2007). A close examination of

CONTACT Andrés L. Martínez Marín pa1martm@uco.es

the database constructed in NRC (2007) to evaluate the model of Cannas et al. (2004) reveals that (1) none of the Southern European genotypes was represented (e.g. Merino Branco, Manchega, Rasa Aragonesa, Segureña, Comisana, Bergamasca, Karagouniko, etc.); and (2) more than 90% of the data showed average BW values higher than the typical average BW for fattening light lambs raised in feedlot (33.2 ± 8.24 kg vs. 18.9 ± 2.19 kg), while over 70% fell below the expected average daily gain (ADG) for such animals (189 ± 103.7 g/d vs. 249 ± 42.8 g/d) (Zygoyiannis et al. 1999; Santos-Silva et al. 2002; Bodas et al. 2007; Tufarelli et al. 2011; Aguayo-Ulloa et al. 2013; Facciolongo et al. 2014, Armero and Falagán 2015; Valenti et al. 2018; Avilés Ramírez et al. 2019; Scarpa et al. 2021).

After a careful evaluation, Costa et al. (2013) recommended the NRC (2007) method for formulating lamb diets under tropical conditions. However, to the authors' knowledge the application of NRC (2007) methodology to the MER calculation of fattening light lambs has not been evaluated. Therefore, the aim of the present work was to compare the estimated MER of fattening light lambs raised in feedlot with the U. S. National Research Council (NRC) predictions.

Materials and methods

The experimental design was developed in compliance with European Directive 2010/63/EU on the protection of animals used for scientific purposes (EU 2010), and Council Directive 98/58/EC setting minimum standards for the protection of farmed animals (EU 1998).

The present work was carried out with data collected in a study which main results have been presented elsewhere (Avilés Ramírez et al. 2019). Briefly, a total of 105 intact male lambs of the Manchega breed, with an initial BW of 13.9 ± 0.61 kg and 35 ± 7 days old, were randomly allocated to 15 straw-bedded pens in a commercial farm. Each pen was equipped with its own water and feed troughs, as well as a straw rack. Concentrate feed troughs had a rough capacity of 40 kg, were designed against feed scattering and waste, and were replenished as frequently as needed. The animals had free access to clean and fresh water, concentrate feed and barley straw throughout the entire experimental period (6 weeks). The pens were assigned at random to one of three concentrates of different ingredient composition, namely CON, CAM and FIB, to study their effects on growth performance and meat quality traits (Table 1). The CON concentrate contained the following ingredients (g/kg as fed): barley, 400; maize, 200; soybean meal, 200; wheat, 100; wheat bran, 42; mineral and vitamins, 38; calcium salts of palm oil, 20. The composition of the CAM concentrate was the same as that of the CON one, except for the inclusion of 120 g/kg as fed of camelina meal that replaced 99 and 21 g/kg of soybean meal and wheat bran, respectively. The ingredients of the FIB concentrate were (g/kg as fed): soybean hulls, 140; wheat bran, 120; corn gluten feed, 107; maize hominy feed, 100; bitter vetch, 100; maize dried distillers grains with solubles, 80; dehydrated barley sprouts, 60; camelina meal, 60; NaOH-treated straw, 50; grape seed meal extract, 50; camelina husks, 48; minerals and vitamins, 42; rice bran, 23; cane molasses, 20. The weekly concentrate intake in each pen was calculated as the difference between the total feed offered in the through during the week and the remaining feed at the end of the week. The lambs from each pen were weighed individually once a week. Following, average daily intake of concentrate and average daily gain (ADG) during the week were calculated for each pen. The straw racks of the farm did not allow straw consumption to be measured. Therefore, it was assumed that barley straw represented 5% of total dry matter intake as previously observed in similar experimental conditions (Mungói et al. 2012; Blanco et al. 2014). The procedures described by de Boever et al. (1986) were used to determine the organic matter digestibility of the concentrates with the pepsin-cellulase technique and to derive their metabolisable energy (ME) contents (Table 1). Due to the large prediction errors of ME in straws when predicted from the vitro organic matter digestibility determined with the pepsin-cellulase technique (de Boever et al. 1988), the ME content of barley straw was assumed the same as in NRC (2007). The weekly average daily ME intake (MEI) for each pen was derived from the ME contents of the concentrates and barley straw and their respective average daily intakes. In each week, the average daily MER for each pen were predicted from the average BW and ADG in that week, including the adjustment

Table 1. Chemical and biological characteristics of the concentrates (dry matter basis).

	Concentrate		
	CON	CAM	FIB
Organic matter, %	92.6	91.2	89.8
Crude protein, %	17.6	17.5	17.8
Crude fat, %	4.8	4.6	4.4
In vitro organic matter digestibility, %	83.2	82.9	74.1
Metabolisable energy (ME), MJ/kg	11.7	11.5	10.1
Diet ME[1], MJ/kg	11.5	11.3	9.9
Efficiency of ME use for gain	0.43	0.43	0.38

[1]Assuming that the diet was comprised of 95% concentrate and 5% barley straw on a dry matter basis. See the text for details.

of ME for body maintenance (MEm) for the effect of level of MEI on visceral organ tissue energy use as described by NRC (2007), and without such adjustment (hereafter referred to as Model 1 and Model 2, respectively). The maturity index calculation used a full BW at a body condition score of 3.0 set at 100 kg (MAPA 2023).

Data on feed intake, growth performance and MEI were analysed with the GLM procedure of SAS OnDemand for Academics (SAS Institute, Cary, NC, USA). The experimental unit was the pen, and the statistical model included the week on fattening as a fixed effect. When the model was significant, the differences between the least squares means were established by the Tukey test. Statistical significance was declared at $p < 0.05$. The models' performance was assessed by the coefficient of determination (R^2), the root of the mean square of prediction error (RMSPE), the RMSPE expressed as proportion of the observed mean (%RMSPE), the standardised RMSEP (RSR), and the concordance correlation coefficient (CCC) computed from the bias correction factor and the Pearson correlation coefficient (Lin 1989). The higher the values of R^2 and CCC and the lower the values of RMSEP and RSR, the better the precision and accuracy of the models. The mean square of prediction error (MSPE) was decomposed into mean bias (a measure of accuracy), slope bias (a measure of precision), and random error due to disturbances (Tedeschi 2006). Mean and linear bias significances were assessed by regression of the residuals on the predicted values centred on the predicted mean (St-Pierre 2003).

Results and discussion

The data collected on feed intake, growth performance and MEI are shown in Table 2. Avilés Ramírez et al. (2019) reported that final BW and ADG did not differ between treatments, but concentrate FIB intake was significantly higher. As expected, BW exhibited an increasing linear trend ($p < 0.05$) (Álvarez-Rodríguez et al. 2008; Lupi et al. 2015), whereas ADG remained constant from the second week on fattening onward ($p > 0.05$), exhibiting an average value in agreement with previous findings for the same breed and gender under intensive feeding conditions (Vergara and Gallego 1999; Mungói et al. 2012).

Results of previous studies suggest that the feed intake in light fattening lambs under intensive feeding conditions is driven by the energy required to express their growth potential and to meet the energy needs for body maintenance (Blanco et al. 2014; Avilés Ramírez et al. 2019), thus MEI equals MER for a given BW and ADG (Al Jassim et al. 1996). Barley straw intake could not be measured in the present study. Nevertheless, it should have a very small impact on our MEI calculations (Table 1), because its consumption is usually lower than 10% in feedlot light lambs (Mungói et al. 2012; Blanco et al. 2014) and its ME content is typically low (Haddad 2000).

All data ($n = 90$) were used to evaluate the MER prediction. Models 1 and 2 underpredicted MEI, but

Table 3. Performance of the U. S. National Research Council method for predicting the metabolisable energy requirements of fattening light lambs.

	Models[a]	
Statistics	Model 1	Model 2
R^2	0.66	0.66
RMSEP, MJ/d	1.45	1.63
RMSEP, % mean	15.96	17.93
RSR, % standard deviation	32.52	36.55
CCC	0.80	0.74
Central tendency error, % total error	1.57	31.66
Linear error, % total error	22.52	10.62
Random error, % total error	72.91	57.72

[a]Model 1 includes an adjustment of the metabolisable energy required for maintenance for the effect of the level of metabolisable energy intake on visceral organ tissue energy use, while such adjustment is not included in Model 2. R^2: coefficient of determination. RMSEP: root mean square error of prediction. RSR: standardised RMSEP. CCC: concordance correlation coefficient.

Table 2. Least squares means of growth performance, feed intake and metabolisable energy intake (MEI) of Manchega male lambs from the first week of fattening until slaughter and metabolisable energy requirements (MER) predicted by the U. S. National Research Council (NRC).

	Weeks on fattening							
Measured parameters	1	2	3	4	5	6	SEM	*P*
Body weight, kg	14.4^{f}	16.0^{e}	18.2^{d}	20.5^{c}	22.5^{b}	24.5^{a}	0.39	<0.001
Daily weight gain, g/d	136^{b}	337^{a}	346^{a}	304^{a}	285^{a}	356^{a}	10.93	<0.001
Dry matter intake, g/d	530^{d}	860^{c}	864^{c}	985^{bc}	1020^{ab}	1129^{a}	23.8	<0.001
MEI, MJ/d	5.36^{d}	8.73^{c}	8.76^{c}	9.97^{b}	10.33^{b}	11.45^{a}	0.224	<0.001
NRC predictions[1]								
MER Model 1, MJ/d	5.18^{c}	8.17^{b}	9.15^{b}	9.45^{b}	9.59^{b}	11.98^{a}	0.259	<0.001
MER Model 2, MJ/d	4.75^{a}	7.50^{b}	8.39^{b}	8.67^{b}	8.80^{b}	10.99^{a}	0.238	<0.001

[1]Model 1 includes an adjustment of the metabolisable energy required for maintenance for the effect of the level of metabolisable energy intake on visceral organ tissue energy use, while such adjustment is not included in Model 2. Within a row, least squares means without a common superscript are different by Tukey test at $p < 0.05$. SEM: standard error of the mean.

the underprediction was systematic and larger in Model 2 (8.92 and 8.18 MJ/d MER in Models 1 and 2 vs. 9.10 MJ/d MEI; Table 2). ANOVA confirmed that the MER predicted with Model 1 were not different from observed MEI ($p = 0.60$), whereas MEI differed from Model 2 predictions ($p < 0.01$). Mean bias was only significant in Model 2 ($p < 0.05$; Table 3). Linear bias was significant in both models ($p < 0.05$). In the 17 observations with MEI within one standard deviation under the mean, the average bias was −1.24 MJ/d in Model 1 and −1.69 MJ/d in Model 2. In the 13 observations with MEI within one standard deviation over the mean, the average bias was 0.72 MJ/d in Model 1 and 0.27 MJ/d in Model 2. The lack of mean bias and the higher CCC of Model 1 indicate that its precision and accuracy were better than those of Model 2. In this regard, NRC (2007) noted that the upward adjustment of MEm in accordance with MEI might not be appropriate in all instances although its use would provide a safety factor in predicted requirements. The results obtained in the present work support that such adjustment is needed to enhance the precision and accuracy of MER predicted for fattening light lambs raised in feedlot.

The MER have two components, MEm and ME for weight gain (MEg). In the present work, the average MEm, as calculated in Model 1, was 0.536 MJ/kg $BW^{0.75}$ which is almost identical to the 0.543 MJ/kg $BW^{0.75}$ obtained in a meta-analysis of data from lambs of 81 sheep breeds in warm climates by Salah et al. (2014), while it is in an intermediate position between the 0.589 MJ/kg $BW^{0.75}$ that can be derived from the findings of Berthelot and Sauvant (2016) in 26 breeds of temperate zones, and the 0.486 MJ/kg $BW^{0.75}$ found by Yang et al. (2020) in data from five calorimeter studies in the UK involving lambs from six meat-type genotypes. Therefore, the MEm prediction according to NRC (2007) may be assumed to be accurate. Consequently, the MEg can be computed by subtracting the calculated MEm from the observed MEI. This yields a MEg of 14.19 MJ/kg body weight gain (BWG) at the average values of 9.1 MJ/d for MEI, 19.3 kg for BW, and 294 g/d for BWG in the present work. The obtained MEg is markedly lower than the 32.77 MJ/kg BWG that can be derived from Berthelot and Sauvant (2016), the 24.30 MJ/kg BWG found by Salah et al. (2014), and the 22.57 MJ/kg BWG calculated according to ARC (1980), but relatively close to the 17.92 MJ/kg BWG derived from the findings of Robelin et al. (1977) in male lambs of comparable age, BW and ADG, when applying the same efficiency of ME use for BWG (k_g) in the calculations as the average in the dataset of the present work (Table 1). Again, the MEg obtained in the present work contrasts with the 12.51 MJ/kg BWG found by Criscioni et al. (2015) in nearly mature Manchega ewes gaining 285 g/d. This latter figure appears unusually low given the higher energy value of BWG expected in females and older animals (ARC 1980).

In conclusion, the method outlined by NRC (2007) that includes an adjustment of MEm for the effect of the level of MEI on visceral organ tissue energy use was precise and accurate enough to support its application for calculating the MER of fattening light lambs raised in feedlot under intensive feeding conditions.

Acknowledgments

This work is the result of a research stay of Andrés L. Martínez Marín at the Department of Veterinary Sciences of the University of Turin (Italy).

Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

Andrés L. Martínez Marín http://orcid.org/0000-0003-0052-9724
Manuela Renna http://orcid.org/0000-0003-4296-7589
Claudio Forte http://orcid.org/0000-0002-0060-3851
Emanuela Valle http://orcid.org/0000-0002-5519-3554
Achille Schiavone http://orcid.org/0000-0002-8011-6999

Data availability statement

The data that support the findings of this study are available from the corresponding author, [A. L. M. M.], upon reasonable request.

References

Aguayo-Ulloa LA, Miranda-de la Lama GC, Pascual-Alonso M, Fuchs K, Olleta JL, Campo MM, Alierta S, Villarroel M, María GA. 2013. Effect of feeding regime during finishing on lamb welfare, production performance and meat quality. Small Rumin Res. 111(1-3):147–156. doi: 10.1016/j.smallrumres.2012.09.011.

Alfonso M, Sañudo C, Berge P, Fisher A, Stamataris C, Thorkelsson G, Piasentier E. 2001. Influential factors in lamb meat quality. Acceptability of specific designations. In: Rubino R, Morand-Fehr P, editors. Production Systems and Product Quality in Sheep and Goats. Zaragoza (Spain): CIHEAM. p. 19–28.

Álvarez-Rodríguez J, Joy M, Villalba D, Sanz A. 2008. Growth analysis in light lambs raised under different management

systems. Small Rumin Res. 79(2–3):188–191. doi: 10.1016/j.smallrumres.2008.08.003.
ARC. 1980. The nutrient requirements of ruminant livestock. Farnham Royal (UK): Commonwealth Agricultural Bureaux.
Armero E, Falagán A. 2015. A comparison of growth, carcass traits, and tissue composition of 'Segureña' lambs raised either in extensive or intensive production systems. Anim Prod Sci. 55(6):804–811. doi: 10.1071/AN13342.
Avilés Ramírez C, Peña Blanco F, Horcada Ibáñez A, Núñez Sánchez N, Requena Domenech F, Guzmán Medina P, Martínez Marín A. 2019. Effects of concentrates rich in by-products on growth performance, carcass characteristics and meat quality traits of light lambs. Anim Prod Sci. 59(3):593–599. doi: 10.1071/AN17798.
Berthelot V, Sauvant D. 2016. Updating of energy and protein requirements and response laws to dietary supplies in post-weaning lamb. Renc Rech Ruminants. 23:71–74.
Blanco C, Bodas R, Prieto N, Andrés S, López S, Giráldez FJ. 2014. Concentrate plus ground barley straw pellets can replace conventional feeding systems for light fattening lambs. Small Rumin Res. 116(2-3):137–143. doi: 10.1016/j.smallrumres.2013.11.008.
Bodas R, Giráldez FJ, López S, Rodríguez AB, Mantecón AR. 2007. Inclusion of sugar beet pulp in cereal-based diets for fattening lambs. Small Rumin Res. 71(1-3):250–254. doi: 10.1016/j.smallrumres.2006.07.006.
Cannas A, Tedeschi LO, Fox DG, Pell AN, Van Soest PJ. 2004. A mechanistic model for predicting the nutrient requirements and feed biological values for sheep1. J Anim Sci. 82(1):149–169. doi: 10.2527/2004.821149x.
Costa HHA, Rogério MCP, Muir JP, Alves AA, Galvani DB, Fernandes Franco Pompeu RC, Landim AV, Carneiro MdS, Campos WÉ. 2013. Nutritional evaluation of lamb diets in a tropical setting formulated according to NRC (1985) and NRC (2007) specifications. Small Rumin Res. 113(1):20–29. doi: 10.1016/j.smallrumres.2013.02.003.
Criscioni P, López MC, Zena V, Fernández C. 2015. Heat production partition in sheep fed above maintenance from indirect calorimetry data. Open J Anim Sci. 5:13.
de Boever JL, Cottyn BG, Buysse FX, Wainman FW, Vanacker JM. 1986. The use of an enzymatic technique to predict digestibility, metabolizable and net energy of compound feedstuffs for ruminants. Anim Feed Sci Technol. 14(3-4):203–214. doi: 10.1016/0377-8401(86)90093-3.
De Boever JL, Cottyn BG, Andries JI, Buysse FX, Vanacker JM. 1988. The use of a cellulase technique to predict digestibility, metabolizable and net energy of forages. Anim Feed Sci Technol. 19(3):247–260. doi: 10.1016/0377-8401(88)90088-0.
EC. 2023. Sheep and goat meat production. Brussels (Belgium): European Commission, Directorate-General for Agriculture and Rural Development; [accessed 2023 June 6]. https://agridata.ec.europa.eu/extensions/DashboardSheepmeat/SheepmeatProduction.html.
EU. 1998. Council Directive 98/58/EC of 20 July 1998 concerning the protection of animals kept for farming purposes. Off J Eur Comm. 221:23–27.
EU. 2010. Directive 2010/63/EU of the European Parliament and of the Council of 22 September on the protection of animals used for scientific purposes. Off J Eur Union. 276:33–79.
Facciolongo AM, Rubino G, Zarrilli A, Vicenti A, Ragni M, Toteda F. 2014. Alternative protein sources in lamb feeding 1. Effects on productive performances, carcass characteristics and energy and protein metabolism. Progr Nutr. 16:105–115.
Haddad SG. 2000. Associative effects of supplementing barley straw diets with alfalfa hay on rumen environment and nutrient intake and digestibility for ewes. Anim Feed Sci Technol. 87(3-4):163–171. doi: 10.1016/S0377-8401(00)00203-0.
INRA. 2018. INRA feeding system for ruminants. Wageningen, The Netherlands: Wageningen Academic Publishers.
Jassim RAMA, Hassan SA, Al-Ani AN. 1996. Metabolizable energy requirements for maintenance and growth of Awassi lambs. Small Rumin Res. 20(3):239–245. doi: 10.1016/0921-4488(95)00775-X.
Lin LIK. 1989. A concordance correlation coefficient to evaluate reproducibility. Biometrics. 45(1):255–268. doi: 10.2307/2532051.
Lupi TM, Nogales S, León JM, Barba C, Delgado JV. 2015. Characterization of commercial and biological growth curves in the Segureña sheep breed. Animal. 9(8):1341–1348. doi: 10.1017/S1751731115000567.
MAPA. 2023. Raza Ovina Manchega: Datos Morfológicos. Madrid (Spain): Ministerio de Agricultura, Pesca y Alimentación; [accessed 2023 June 16]. https://www.mapa.gob.es/es/ganaderia/temas/zootecnia/razas-ganaderas/razas/catalogo-razas/ovino/manchega/datos_morfologicos.aspx.
Mungói M, Flores C, Casals R, Caja G. 2012. Effect of malate and starch source on digestibility and nutrient balance of growing-fattening lambs. Anim Feed Sci Technol. 174(3-4):154–162. doi: 10.1016/j.anifeedsci.2012.03.016.
NRC. 2007. Nutrient requirements of small ruminants: sheep, goats, cervids, and new world camelids. Washington, DC: The National Academies Press.
Robelin J, Theriez M, Arnal M, Ferrara M. 1977. Evolution de la composition chimique de jeunes agneaux mâles jusqu'à l'âge de 16 sémaines. Ann Zootech. 26(1):69–81. doi: 10.1051/animres:19770106.
Salah N, Sauvant D, Archimède H. 2014. Nutritional requirements of sheep, goats and cattle in warm climates: a meta-analysis. Animal. 8(9):1439–1447. doi: 10.1017/S1751731114001153.
Santos-Silva J, Mendes IA, Bessa RJB. 2002. The effect of genotype, feeding system and slaughter weight on the quality of light lambs: 1. Growth, carcass composition and meat quality. Livest Prod Sci. 76(1-2):17–25. doi: 10.1016/S0301-6226(01)00334-7.
Sañudo C, Alfonso M, San Julián R, Thorkelsson G, Valdimarsdottir T, Zygoyiannis D, Stamataris C, Piasentier E, Mills C, Berge P, et al. 2007. Regional variation in the hedonic evaluation of lamb meat from diverse production systems by consumers in six European countries. Meat Sci. 75(4):610–621. doi: 10.1016/j.meatsci.2006.09.009.
Scarpa G, Tarricone S, Ragni M. 2021. Carcass composition, meat quality and sensory quality of gentile di puglia light lambs: effects of dietary supplementation with oregano and linseed. Animals. 11(3):607. doi: 10.3390/ani11030607.

St-Pierre NR. 2003. Reassessment of biases in predicted nitrogen flows to the duodenum by NRC 2001. J Dairy Sci. 86(1):344–350. doi: 10.3168/jds.S0022-0302(03)73612-1.

Tedeschi LO. 2006. Assessment of the adequacy of mathematical models. Agr Syst. 89(2-3):225–247. doi: 10.1016/j.agsy.2005.11.004.

Tufarelli V, Khan RU, Laudadio V. 2011. Feeding of wheat middlings in lamb total mixed rations: effects on growth performance and carcass traits. Anim Feed Sci Technol. 170(1-2):130–135. doi: 10.1016/j.anifeedsci.2011.08.001.

Valenti B, Luciano G, Pauselli M, Mattioli S, Biondi L, Priolo A, Natalello A, Morbidini L, Lanza M. 2018. Dried tomato pomace supplementation to reduce lamb concentrate intake: Effects on growth performance and meat quality. Meat Sci. 145:63–70. doi: 10.1016/j.meatsci.2018.06.009.

Vergara H, Gallego L. 1999. Effect of type of suckling and length of lactation period on carcass and meat quality in intensive lamb production systems. Meat Sci. 53(3):211–215. doi: 10.1016/s0309-1740(99)00059-5.

Yang CT, Wang CM, Zhao YG, Chen TB, Aubry A, Gordon AW, Yan T. 2020. Updating maintenance energy requirement for the current sheep flocks and the associated effect of nutritional and animal factors. Animal. 14(2):295–302. doi: 10.1017/S1751731119002064.

Zygoyiannis D, Katsaounis N, Stamataris C, Arsenos G, Tsaras L, Doney J. 1999. The use of nutritional management after weaning for the production of heavier lamb carcasses from Greek dairy breeds. Livest Prod Sci. 57(3):279–289. doi: 10.1016/S0301-6226(98)00173-0.