Livestock Science 253 (2021) 104697

Contents lists available at ScienceDirect

Livestock Science

journal homepage: www.elsevier.com/locate/livsci

Fat- and protein-corrected milk formulation to be used in the life-cycle assessment of Mediterranean dairy goat systems

Juan Manuel Mancilla-Leytón [a,*], Eduardo Morales-Jerrett [b], Manuel Delgado-Pertiñez [b], Yolanda Mena [b]

[a] Departamento de Biología Vegetal y Ecología, Facultad de Biología, Universidad de Sevilla, 41012 Seville, Spain
[b] Departamento de Agronomía, Escuela Técnica Superior de Ingeniería Agronómica, Universidad de Sevilla, 41013 Seville, Spain

HIGHLIGHTS

- In life-cycle assessment (LCA) results must be referenced to a functional unit.
- In the LCA of goat dairy no specific fat-and protein-corrected milk has been reported.
- Fat and protein content are very different depending on the goat breed and management.
- Two FPCM equations have been defined according to the fat content in goat milk.

ARTICLE INFO

Keywords:
Energy content
FPCM
Murciano-Granadina
Saanen
Alpine

ABSTRACT

The aim of this paper is to develop a new specific algorithm (fat- and protein-corrected milk calculation) for dairy goat to be used in life-cycle assessment (LCA) studies. Though the contribution of goat milk to world milk production ranks third, the literature does not report any specific correction for goat's milk. Using the available bibliographic data, a multiple regression was performed that allowed obtaining the relationship between the energy content (EC) and the fat (FC) and protein content (PC) of dairy goat milk. The multiple regression resulting from the 3 variables analyzed through the data drawn from the literature was significant (R^2= 0.99; $p \leq 0.001$). The equation resulting from the correlation was used to develop algorithms for the calculation of fat- and protein-corrected milk (FPCM) at specific FC and PC. Since FC and PC are very different depending on the goat breed two different groups have been defined: i) goat breeds with FC in milk below 4% (FCB4), and ii) goat breeds with FC in milk above 4% (FCA4). The EC found for the FCB4 group $_{(FC\,=\,3.70\text{ and }PC\,=\,3.27)}$ was 728.11 kcal kg^{-1}, while that of the FCA4 group $_{(FC\,=\,4.92\text{ and }PC\,=\,3.61)}$ was 860.69 kcal kg^{-1}. After substituting the EC values obtained before, the resulting FPCM equations to calculate specific FC and PC by unit of mass (kg of milk = M), according to each group, are shown below: FCB4 group = **FPCM** $(_{FC\,=\,3.70,\;PC\,=\,3.27})$ = **M** * [(0.12 * **FC** + 0.10 * **PC** + 0.23)]; FCA4 group = **FPCM** $(_{FC\,=\,4.92,\;PC\,=\,3.61})$ = **M** * [(0.10 * **FC** + 0.08 * **PC** + 0.20)]. Finally, the variation between the FPCM values calculated using the specific equation obtained in this study for goats and those previously published (for sheep or modifications made from dairy cattle) was evaluated; in FCB4 group the differences varied between (-) 32% and (+) 14% and in FCA4 group between (-) 21% and (+) 35%. Values are overestimated if sheep's FPCM calculations are used (because sheep milk has higher fat content than goat milk) and underestimated if dairy cattle's FPCM calculations are used (because cow milk has lower fat content than goat milk). In conclusion, the results found in the present study show the need to use a specific FPCM formulation in the LCA equation for goat's milk.

1. Technical note

To improve uniformity and transparency among studies, the International Organization for Standardization established requirements and recommendations for the decision-making process in life-cycle assessment (LCA) (ISO14040). Thus, LCA results must be

* Corresponding author.
E-mail address: jmancilla@us.es (J.M. Mancilla-Leytón).

https://doi.org/10.1016/j.livsci.2021.104697
Received 12 July 2021; Received in revised form 2 September 2021; Accepted 4 September 2021
Available online 6 September 2021
1871-1413/

referenced to a functional unit (FU), which must be measurable and clearly defined according to ISO standards. Always using the same FU is crucial to be able to interpret, compare and evaluate the environmental impacts of the same product or activity. In the LCA of dairy production systems, a priority sector and category in the agriculture inventory, fat- and protein-corrected milk (FPCM) by a unit of mass (1 kg of FPCM) is the most commonly applied FU (Baldini et al., 2017). Fat (FC) and protein contents (PC) can be used indirectly to determine the energy content (EC) of milk, which depends on the level of production but also on other genetic and environmental factors (Pulina et al., 2005). Using FPCM allows a better comparison of farms reducing the differences between breeds or feeding regimes.

Even though the contribution of goat milk to the world milk production ranks third (2%) after cow and buffalo milk, being twice as large as that of sheep milk (FAOSTAT, 2021), and although the chemical composition of milk differs among species (Rezaei et al., 2016), the literature does not report any specific correction for goat's milk. Until now, the few published LCA studies on goats have used the specific calculations developed by Pulina et al. (2005) for sheep, or the modification made by Robertson et al. (2015) to the previous work by Clark et al. (2001) on dairy cattle. Other studies do not even detail the method used to perform the calculation. Results of carbon footprint (CF), when referred to FPCM, may differ depending on the corrections calculated for goat's milk. In this sense, Gutierrez-Peña et al. (2019) found that CF values are overestimated if sheep's FPCM calculations are used (because sheep milk has higher fat content than goat milk) and underestimated if dairy cattle's FPCM calculations are used (because cow milk has lower fat content than goat milk). These authors showed that the CF of a unit of milk when the cow's milk correction was used was 41% lower than when the sheep's milk correction was applied.

The aim of this paper is to develop a new specific algorithm (FPCM calculation) for dairy goat to be used in LCA studies. For the first time, a complete search of the Elsevier Scopus database was carried out using [Title-Abs-Key ("*milk*" and "*goat*" and "*energy*" and "*fat*" and "*protein*")] as the search query. The search resulted in 164 documents after limiting the time period to years comprised between 1980 and 2020. All these documents were reviewed, and those that used the same methodology to analyze the energy content of goat milk (measured directly with an adiabatic bomb calorimeter) and included the necessary information (fat and protein percentages, energy content and goat breeds) were selected. Only 7 documents were suitable for the calculation, which provided a total of 28 values for 3 different breeds (Murciano-Granadina, Alpine and Saanen; see Table 1).

Using the available data, a multiple regression was performed that allowed obtaining the relationship between the EC and the FC and PC of dairy goat milk. The multiple regression resulting from the 3 variables analyzed through the data drawn from the literature was significant (R^2= 0.99; $p \leq 0.001$). The equation obtained from indirectly calculating the energy content of milk from its fat and protein content was the following:

$$\mathbf{EC} = (89.178 * \mathbf{F}) + (69.966 * \mathbf{P}) + 169.359$$

where:

EC = energy content of milk (kcal kg^{-1})
F = fat content of milk (% of weight)
P = protein content of milk (% of weight)

Once the equation was obtained, the relationship between the direct and indirect measurements of the energy content of milk was evaluated for 28 reference values obtained from the bibliography (Fig. 1). The results of the Pearson test, after assessing the linear relationship between both methods, showed that this relationship is significantly positive (R^2 = 0.97; Pearson Test $p \leq 0.05$). The resulting linear equation was as follows:

Table 1
Fat, protein and energy content data drawn from the literature review. Different values in the same document correspond to different feeding treatments.

	Goat Breed	Fat (%)	Protein (%)	Energy (kcal kg^{-1})
Marcos et al., 2020	Murciano-Granadina	4.58	3.18	800.29
		4.78	3.29	825.82
Molina-Alcaide et al., 2010	Murciano-Granadina	4.59	3.18	801.18
		4.97	3.38	849.06
		4.27	3.11	767.74
Romero-Huelva et al., 2012	Murciano-Granadina	5.51	3.47	903.51
		5.57	3.39	903.27
		5.08	3.39	859.57
		5.44	3.39	891.67
Sanz Sampelayo et al., 1999	Murciano-Granadina	6.00	3.25	931.82
		6.57	2.87	956.06
		6.32	3.5	977.84
		6.61	3.18	981.32
Rapetti et al., 2002	Saanen	3.11	2.93	651.70
		4.13	3.03	749.66
		3.14	2.98	657.88
Tovar-Luna et al., 2010a	Alpine	3.40	2.57	652.38
		3.11	2.57	626.52
		3.95	2.97	729.41
		3.04	2.45	611.88
		2.73	2.45	584.23
		3.67	3.2	720.53
Tovar-Luna et al., 2010b	Alpine	2.77	2.35	580.80
		3.30	2.46	635.76
		3.92	4.04	801.60
		3.21	2.33	618.64
		3.49	2.74	672.30
		5.28	4.3	941.07

$$\mathbf{y} = 0.9708\mathbf{x} + 22.636$$

where:

y = milk energy content measured directly with a bomb calorimeter (kcal kg^{-1})
x = milk energy content calculated by using standard calorimetric coefficients (FC and PC) (kcal kg^{-1})

The equation resulting from the correlation was used to develop algorithms for the calculation of FPCM at specific FC and PC. Due to the fact that the FC and PC are very different depending on the goat breed (*L'Institut de l'Élevage*, IDELE, France; *Sistema Nacional de Información de Razas Ganaderas*, ARCA, Spain), two different groups have been defined: i) goat breeds with FC in milk below 4% (FCB4), and ii) goat breeds with FC in milk above 4% (FCA4). The breeds that make up the French goat herd were used as representatives of the FCB4 group, while the breeds that make up the Spanish goat herd represented the FCA4 group. From the number of lactations completed and the normalized FC and PC values obtained from the 2019 Spanish and French dairy control tests, a weighted average of FC and PC was calculated for each group (Table 2).

The EC found for the FCB4 group ($_{FC\,=\,3.70\text{ and }PC\,=\,3.27}$) was 728.11 kcal kg^{-1}, while that of the FCG4 group ($_{FC\,=\,4.92\text{ and }PC\,=\,3.61}$) was 860.69 kcal kg^{-1}. After substituting the EC values obtained before, the resulting FPCM equations to calculate specific FC and PC by unit of mass, according to each group, are shown below:

Equation 1, for the FCB4 group:

$$\mathbf{FPCM}\left(_{FC=3.70,PC=3.27}\right) = \mathbf{M} * [(0.12 * \mathbf{FC} + 0.10 * \mathbf{PC} + 0.23)]$$

Equation 2, for the FCA4 group:

$$\mathbf{FPCM}\left(_{FC=4.92,PC=3.61}\right) = \mathbf{M} * [(0.10 * \mathbf{FC} + 0.08 * \mathbf{PC} + 0.20)]$$

where:

FPCM = fat- and protein-corrected milk

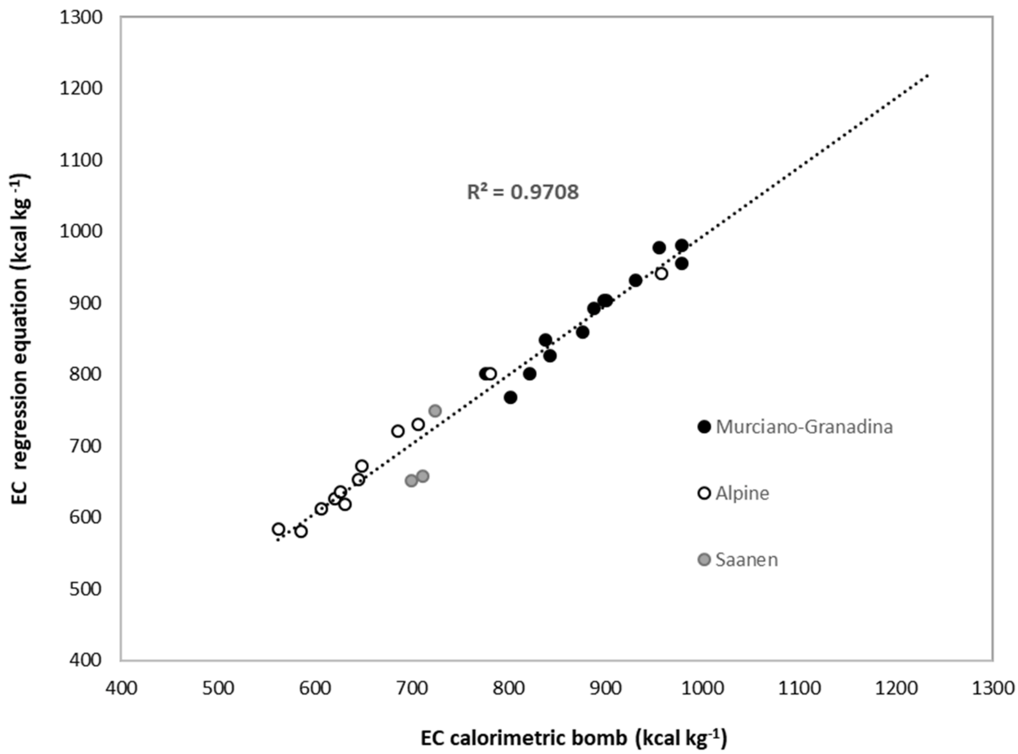

Fig. 1. Relationship between the energy content (EC) values of milk measured directly with a bomb calorimeter and those obtained indirectly from the regression equation. The trend line and the R^2 value of the Pearson test are shown.

Table 2
Fat and protein contents of milk and census of the different groups studied: i) representative breeds with fat content of milk below 4% (FCB4), and ii) representative breeds with fat content of milk above 4% (FCA4).

	Goat breed	Fat (%)	Protein (%)	Census (%)[c]
FCB4 group[a]	Alpine	3,76	3,31	60.40
	Saanen	3,6	3,21	36.33
	Croisée	3,71	3,25	2.84
	Pointevine	3,43	3,07	0.21
	Massif Central	3,84	2,95	0.03
	Other minority breeds	3,69	2,96	0.19
	Weighted mean	**3.70**	**3.27**	
FCA4[b]	Murciana-Granadina	5.1	3.6	55.68
	Florida	4.70	3.50	13.03
	Malagueña	4.61	3.61	12.97
	Payoya	4.60	3.60	6.35
	Del Guadarrama	4.90	3.60	4.33
	Majorera	4.68	3.97	2.70
	Tinerfeña	5.14	4.06	2.24
	Verata	4.52	3.47	2.18
	Palmera	5.35	4.31	0.52
	Weighted mean	**4.92**	**3.61**	

[a] Data obtained from L'Institut de l'Élevage (The French Livestock Institute, IDELE, France).
[b] Data obtained from the Sistema Nacional de Información de Razas Ganaderas (National Information System on Livestock Breeds, ARCA, Spain).
[c] Percentage of lactations completed and valid in 2019 with respect to the national total. In France, according to the National Technical Regulations for Dairy Control, and, in Spain, according to Royal Decree 368/2005.

M = milk yield (kg);
FC = milk fat content (%);
PC = milk protein content (%).

Finally, the variation between the FPCM values calculated using the specific equation obtained for goats and those previously published for other species was evaluated. In the case of the FCB4 group, for a unit of milk (1 kg of milk $_{FC\,=\,3.70\text{ and }PC\,=\,3.27}$), FPCM production decreased by 32% when the equation developed by Pulina et al. (2005) was used, and increased by 14% when the equation developed by Robertson et al. (2015) was used. For the FCA4 group, for a unit of mass (1 kg of milk $_{FC\,=\,4.92\text{ and }PC\,=\,3.61}$), FPCM production decreased by 21% when the equation developed by Pulina et al. (2005) was used and increased 35% when the equation developed by Robertson et al. (2015) was used.

In conclusion, the results found in the present study show the need to use a specific FPCM formulation in the LCA equation for goat's milk.

CRediT authorship contribution statement

Juan Manuel Mancilla-Leytón: Conceptualization, Methodology, Formal analysis, Writing – review & editing. **Eduardo Morales-Jerrett:** Conceptualization, Methodology, Investigation, Writing – review & editing. **Manuel Delgado-Pertíñez:** Conceptualization, Methodology, Writing – review & editing. **Yolanda Mena:** Conceptualization, Methodology, Writing – review & editing, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This research was financed through Measure 16 of the Rural Development Program of Andalusia 2014-2020, included in the grants for the creation and operation of the Operational Groups of the European Innovation Partnership (EIP-Agri) in matters of agricultural productivity and sustainability, and co-financed by the European Union through the European Agricultural Fund for Rural Development (90%) and by the Andalusian Regional Government (10%) (Project GOP21-GR-16-0016).

References

Baldini, C., Gardoni, D., Guarino, M., 2017. A critical review of the recent evolution of Life Cycle Assessment applied to milk production. J. Clean. Prod. 140, 421–435.

Clark, J., Beeded, D..K., Erdman, R..A., 2001. Nutrient Requirements of Dairy Cattle, seventh ed. Natural Academy Press, Washington, DC.

Food and Agriculture Organization of the United Nations (FAOSTAT). 2021. Statistics database, crop statistics. http://www.fao.org/faostat/en/#data/QC (archived on 18th june 2021).

Gutiérrez-Peña, R., Mena, Y., Batalla, I., Mancilla-Leytón, J.M., 2019. Carbon footprint of dairy goat production systems: A comparison of three contrasting grazing levels in the Sierra de Grazalema Natural Park (Southern Spain). J. Environ. Manage. 232, 993–998.

Marcos, C.N., Carro, M.D., Yepes, J.F., Haro, A., Romero-Huelva, M., Molina-Alcaide, E., 2020. Effects of agroindustrial by-product supplementation on dairy goat milk characteristics, nutrient utilization, ruminal fermentation, and methane production. J. Dairy Sci. 103, 1472–1483.

Molina-Alcaide, E., Morales-García, E.Y., Martín-García, A.I., Salem, H..B., Nefzaoui, A., Sanz-Sampelayo, M.R., 2010. Effects of partial replacement of concentrate with feed blocks on nutrient utilization, microbial N flow, and milk yield and composition in goats. J. Dairy Sci. 93, 2076–2087.

Pulina, G., Macciotta, N., Nudda, A., 2005. Milk composition and feeding in the Italian dairy sheep. Italian J. Anim. Sci. 4, 5–14.

Rapetti, L., Crovetto, G.M., Galassi, G., Sandrucci, A., Succi, G., Tamburini, A., Battelli, G., 2002. Effect of maize, rumen-protected fat and whey permeate on energy utilisation and milk fat composition in lactating goats. Italian J. Anim. Sci. 1, 43–53.

Rezaei, R., Wu, Z., Hou, Y., Bazer, F.W., Wu, G., 2016. Amino acids and mammary gland development: nutritional implications for milk production and neonatal growth. J. Anim. Sci. Biotechnol. 7, 20. https://doi.org/10.1186/s40104-016-0078-8.

Robertson, K., Symes, W., Garnham, M., 2015. Carbon footprint of dairy goat milk production in New Zealand. J. Dairy Sci. 98, 4279–4293.

Romero-Huelva, M., Ramos-Morales, E., Molina-Alcaide, E., 2012. Nutrient utilization, ruminal fermentation, microbial abundances, and milk yield and composition in dairy goats fed diets including tomato and cucumber waste fruits. J. Dairy Sci. 95, 6015–6026.

Sanz Sampelayo, M., Pérez, M.L., Extremera, F.G., Boza, J.J., Boza, J., 1999. Use of different dietary protein sources for lactating goats: milk production and composition as functions of protein degradability and amino acid composition. J. Dairy Sci. 82, 555–565.

Tovar-Luna, I., Puchala, R., Sahlu, T., Freetly, H.C., Goetsch, A.L., 2010a. Effects of stage of lactation and dietary concentrate level on energy utilization by Alpine dairy goats. J. Dairy Sci. 93, 4818–4828.

Tovar-Luna, I., Puchala, R., Sahlu, T., Freetly, H.C., Goetsch, A.L., 2010b. Effects of stage of lactation and level of feed intake on energy utilization by Alpine dairy goats. J. Dairy Sci. 93, 4829–4837.