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ORIGINAL PAPER

Influence of Mediterranean climate and lunar calendar on milk production in Lacaune breed ewes

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ABSTRACT

Environmental factors affect daily milk production in dairy animals. The aim of this study was to quantify the effects of environmental factors, specifically mean temperature (°C), relative humidity (%), temperature–humidity index (THI), solar radiation (°), pluvial precipitation (mm) and lunar calendar (full moon, waxing quarter, waning quarter, new moon), on milk production (kg/d). The analysis was based on 96,195 morning and evening milking records documented on 109 consecutive days, from 869 Lacaune ewes. Ewes were housed in groups of 174 individuals. The analysis was performed in two independent procedures, a Pearson correlation analysis and a multivariate analysis of the ewe's interrelationships, which was based on the total variance estimate and a Varimax-rotated factorial analysis. Milk yield (kg/d) was significantly ($p < 0.05$) negatively correlated with mean temperature (-0.24), relative humidity (-0.16), THI (-0.24), and radiation (-0.18), which suggests that the higher these environmental factors, the lower the milk yield. Lunar calendar had a significant ($p < 0.01$) effect on milk production yield; specifically, yields were higher on the full moon and new moon (2.25 ± 0.05 kg/day) than they were on the crescent or waning moon (2.17 ± 0.05 kg/day). In conclusion, ewes that had been exposed to higher mean temperature, relative humidity, THI and solar radiation had the lowest milk yield, and milk yields are highest on full and new moons. The results of this work may be helpful in making predictions for milk production in Lacaune ewes in the Mediterranean region throughout the year.

Keywords THI · Moon calendar · Milk yield · Dairy sheep

Introduction

Mediterranean countries, such as Greece, Spain, Italy and France, are among the most important sheep milk producers in the world because, among other reasons, of their climate. Although sheep are highly tolerant of weather extremes, temperatures in the Mediterranean region often exceed the sheep thermoneutral threshold, which affects negatively its physiological and production lactation performance (Finocchiaro et al. 2005; Sevi and Caroprese 2012; El-Tarabany et al. 2017). Indeed, it has been widely proved that heat stress has a detrimental effect on the nutritional and technical properties of milk (Sevi and Caroprese 2012).

Sheep are highly adaptable, as they are reared predominantly under extensive production systems, which are mainly widespread in marginal areas that have very limited resources (Caroprese et al. 2009). Particularly, the Lacaune dairy breed ewe, which originated from the Roquefort area of France but is very reared in the Mediterranean region, is a very rustic animal which has become one of the world's high-yielding milk ovine breeds (Elvira et al. 2013). Under good welfare conditions, those ewes have average daily milk yields of 1.59 L and a total milk yield of 270 L over a 165-day lactation period (Barillet et al. 2001).

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Recent research has investigated the factors causing welfare decline in sheep and strategies for minimizing the adverse effects of environmental challenges and inadequate management practices on sheep welfare. Field trials have shown that a careful management system significantly improved the welfare and biological condition of the ewes, which improved their productive performance (EFSA Panel on Animal Health and Welfare 2014). Furthermore, environmental factors such as ambient temperature (T), relative humidity (RH), solar radiation (SR), and precipitation (P) can influence animal welfare and, therefore, the production and composition of milk (Silanikove 2000). Indeed, temperatures outside the thermoneutral zone can affect the physiological and productive performance of lactating dairy ewes, which lead to significant reductions in profitability for farmers (Sejian et al. 2018; Mylostyvyi and Chernenko 2019). Other environmental factors can contribute to reduced milk production (Gonzalez-Ronquillo et al. 2021). Relative humidity, solar radiation, and the temperature–humidity index (THI) can significantly affect animal physiology through their effects on thermoregulation (Abdela and Jilo 2016; Laporta et al. 2017).

Under temperature and humidity stress conditions, dairy cattle reduce milk production, which has less fat and high somatic cell count (SCC), the increase in cases of mastitis (Sharma et al. 2011; Nasr and El-Tarabany 2017; Alhussien and Dang 2018). Therefore, animal welfare can be inferred by milk production and composition (Behera et al. 2018).

In addition, lunar phase is another environmental factor that must be taken into consideration when studying variations in sheep milk production. Lunar phase influences not only the tides but also all the bodily fluids (including milk) (Palacios and Abecia 2011; Mayoral et al. 2020). Researchers have shown that lunar phase exerts significant effects on lamb production through the regulation of sheep fertility and fecundity (Palacios and Abecia 2014). Nevertheless, there is no scientific literature on the effect of the lunar calendar on sheep milk production.

Considering the above, the starting hypothesis is that environmental factors, specifically meteorological conditions and lunar calendar, will influence significantly both the length of sheep milking periods and the amount of milk each ewe produces. Full and new moon might be the more influential lunar phases. This study investigated whether meteorological conditions and lunar phase influence milk production in the Lacaune breed dairy sheep in a continental Mediterranean climate. The results of this work could be very useful to make predictive estimations of the milk production of Lacaune breed ewes at different times of the year in areas with a Mediterranean climate.

Material and methods

Data collection and flock management

The dataset comprised 96,195 morning and evening milking records, which were recorded by electronic milking meters (Metatron Premium 21, GEA Farm Technologies, USA) that were connected to DairyPlan C21 software (GEA Farm Technologies, USA). The data were recorded continuously for 109 d (03/10/2016 – 06/29/2016) from a flock of 869 Lacaune ewes on a farm located in the municipality of Revenga de Campos, in the province of Palencia, Spain (42°17′13.0’’N-4°28′55.9’’W).

The ewes were housed in 14 pens that held an average of 174 ewes. The farming system was intensive, so the animals did not go outside throughout lactation. In those pens, there were no means for modulating the external atmospheric conditions. The pens had low fences to prevent the sheep from escaping and predators from entering, and roofs, with wide openings in between for natural ventilation. As such, fluctuations in conditions inside mirrored the fluctuations in the weather conditions outside.

After lambing, ewes were weaned from their lambs and milked immediately. The lambs were reared on artificial lactation until they were sold. The total daily milk production is the sum of the milk recorded in the morning and in the evening. Most of the monitored ewes (714) were within the first month post-lambing, and the others (155) had been milked at least three months post-lambing.

Meteorological data

Environmental and meteorological data for the studied period (March 2016–June 2016) were provided by the Villoldo meteorological station (42º15′07’’N-4º35′57’’W, 792 m above sea level, 9 km from the farm), which belongs to the Agroclimatic Information System for Irrigation (SiAR) of the Spanish Ministry of Agriculture, Fisheries and Food (MAPA) (https://eportal.mapa.gob.es/websiar/). The variables recorded were obtained by a Rotronic HC2 S3 Thermohygrometer (Rotronic AG, Bassersdorf, Switzerland), a Young 05,103 Anemovelette (R.M. Young Company, Michigan, USA), a Skye SP1110 Pyranometer (Skye Instruments Ltd, Llandrindod Wells, UK), a Campbell Scientific ARG100 Rain Gauge (Campbell Scientific Spain, Barcelona, Spain) and a Campbell Scientific CR10X Datalogger (Campbell Scientific Spain, Barcelona, Spain).

Temperature (T) and relative humidity (RH) were recorded every hour throughout the recording period. From those records, a temperature–humidity index (THI) was calculated based on the formula proposed by Mader et al. (2002), which is related to the effect of heat stress on the animals, as follows:

$$THI = 0.8 * T + \frac{RH * (T - 14.3)}{100} + 46.3$$

The lunar phases, i.e., full moon (34 d), waning quarter (23 d), waxing quarter (24 d) and new moon (30 d), were recorded. The lunar month is the interval between two new moons (mean = 29 d, 12 h, 4 min, and 2.98 s), which was assumed to be 30 d (Day 0 = full moon, + 14 = new moon), even though that introduces a slight imbalance at the end of the cycle (Palacios and Abecia 2011). Furthermore, the cycle was divided into "windows" of days before and after the key days. The "full moon" (34 d), "waxing quarter" (24 d), "new moon" (30 d), and "waning moon" (23 d) were the periods between Day -3 and Day + 3, between Days + 4 to + 11, between Days + 12 to -11, and Days -10 to -4, respectively.

Statistical analysis

In order to determine the significant interrelationships among the variables, the data were subjected to a Pearson's Linear Correlation analysis. Subsequently, two techniques from the field of multivariate statistics were used. To detect latent (non-observable) relationships among the variables, a factor analysis was performed using the principal components method with Varimax rotation as a particular solution, and saving the factor scores by the regression method. In addition, the clustering into homogeneous groups was identified by means of a cluster analysis, which followed a hierarchical agglomerative algorithm and applying Ward's method to achieve maximum intracluster homogeneity. From the resulting dendrogram, it was considered that the most appropriate solution or number of clusters would correspond to the one obtained from the stage of the iterative process immediately preceding the stage in which there were abrupt leaps in the distance between clusters (Ma et al. 2021).

An analysis of variance (ANOVA) was used to detect significant differences between the clusters and the effect of the lunar phase on sheep milk yield. Means and standard deviations were calculated for all variables. The statistical significance of each factor was assessed at a 95% confidence level ($\alpha = 0.05$) using Snedecor's F as the contrast statistic. To differentiate homogeneous subsets, Tukey's test was used.

Results

The characterization of the environmental factors (mean, standard deviation, minimum and maximum value as well as the variation coefficient) to which the animals were subjected, and sheep milk production are shown in Table 1. Pluvial precipitation had the highest variation coefficient because of the typical irregularity of the Mediterranean climate.

Table 1 Characterization of environmental factors and milk production in Lacaune ewes in Spain

Variable	Mean ± SD	Min–Max	VC (%)
Temperature (°C)	10.67 ± 5.05	1.92—23.20	47.33
Relative Humidity (%)	74.85 ± 10.03	48.09—95.70	13.40
THI	51.80 ± 7.69	38.28—69.14	14.85
Solar Radiation (°)	19.42 ± 7.21	4.89—31.44	37.13
Pluvial precipitation (mm)	2.22 ± 4.60	0.00—29.49	207.7
Milk yield production (kg/day)	2.22 ± 0.94	0.10—6.69	42.32

SD: standard deviation, VC: variation coefficient

Correlation analysis

Table 2 shows the correlations between the variables. Milk production (kg/d) was significantly ($p < 0.05$) negatively correlated with mean temperature (-0.24), relative humidity (-0.16), THI (-0.24) and radiation (-0.18), indicating that the higher the intensity of these environmental variables, the lower the milk production yield.

The analysis of the interrelationships between the variables allowed us to determine the factor analysis for the six variables analyzed in this study. The rotated factor analysis identified three vectors which explained 68.85% of the total variance in the data (Table 3). Eigenvalues indicated that there were three rotated factors that had an eigenvalue > 1 which explained 68.86% of the variance in the data.

Definition of the clusters

Figure 1 shows the dendrogram derived from the cluster analysis. Four clusters were identified, and an analysis of variance was performed to detect significant ($p < 0.05$) differences between clusters.

According to the results showed in Table 3, the temperature, THI and solar radiation formed the first factor, relative humidity and precipitation formed the second factor and milk yield (Kg/d) was the third factor. We proceeded to separate the sheep population into the four clusters formed and determine the descriptive statistics for each one (Table 4).

In the first cluster (C_1, n = 27,966), which we called "low average milk production", ewes had the second lowest milk production (2 L/sheep/day) among the clusters. The animals were exposed to lower average temperatures (7.33º) and THI (46).

Table 2 Correlations between the main environmental parameters (temperature, humidity, THI, radiation) in the study area in Spain between Mar and Jun 2016

Variable	Temperature (°C)	Relative humidity (%)	THI	Solar Radiation (°)	Pluvial precipitation (mm)
Relative humidity (%)	-0.60*				
THI	0.99**	-0.62*			
Solar Radiation (°)	0.66**	-0.88**	0.68**		
Pluvial precipitation (mm)	-0.19*	0.57*	-0.21*	-0.57**	
Milk yield (kg/day)	-0.24*	-0.16*	-0.24*	-0.18*	0.07[NS]

** Correlation is significant at the 0.01 level (2-tailed), * Correlation is significant at the 0.05 level (2-tailed), [NS] Not significant

Table 3 Definition of factors, integration of variables, and percentage contribution to total variance

Factor	Variable	Percentage	Cumulative percentage
1. Climatic conditions 1	Temperature (°C), THI (%) and solar radiation (°)	39.27	39.27
2. Climatic conditions 2	Relative humidity (%) and precipitation (mm)	17.49	56.73
3. Milk yield production	Milk yield (kg/day)	12.10	68.86

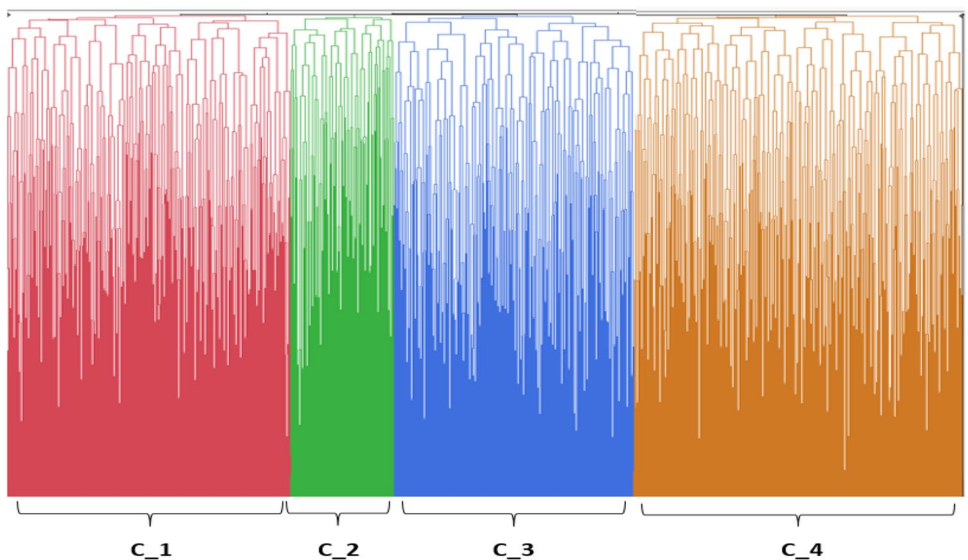

Fig. 1 Integral hierarchical dendrogram in dairy ewes according to the environmental factor descriptors and milk yield production. C_1, "medium–low milk production"; C_2 "medium–high milk production"; C_3, "higher milk production"; C_4, "lower milk production"

In the second cluster (C_2, n = 9,116), which we called "medium–high milk production", ewes milk production was medium–high (2.5 L/ewe/day). The animals were exposed to low temperature (8.13 °C), high relative humidity (89%), low THI (47), and low pluvial precipitation (1.70 mm).

In the third cluster (C_3, n = 23,135), which we called "higher milk productivity", ewes had the highest milk yields (2.87 L/ewe/day) and had been exposed to constant moderate environmental conditions.

In the fourth cluster (C_4, n = 35,960), which we called "lowest milk productivity", ewes had the lowest milk production (1.87 L/ewe/day) of the four clusters. These ewes were subjected to the highest average temperature (15.75°), a THI of 59, high solar radiation (26.47°), low relative humidity (66.34%) and pluvial precipitation (0.28 mm).

In order to confirm statistically significant differences between clusters, an analysis of variance (ANOVA) and Tukey Test were applied. Means and standard error are shown in Table 5, where differences among the different clusters are presented.

Table 4 Descriptive statistics (mean, standard deviation, minimum and maximum values, and coefficient of variation) of the variables included in the cluster analysis of Lacaune breed ewes in Spain

Variable	Cluster	Mean ± SD	Min–Max	VC (%)
Temperature (°C)	C_1	7.33 ± 2.89	1.92—15.96	39.41
	C_2	8.13 ± 2.07	4.19 – 11.48	25.46
	C_3	7.80 ± 3.02	1.92 – 15.96	38.75
	C_4	15.75 ± 3.64	5.89—23.20	223.13
Relative Humidity (%)	C_1	78.65 ± 6.26	56.02—95.70	7.96
	C_2	89.13 ± 3.64	73.50—95.70	4.09
	C_3	78.61 ± 6.77	56.02 – 91.10	8.61
	C_4	65.87 ± 7.28	48.09—82.60	11.06
THI Index	C_1	46.73 ± 4.45	38.28—60.28	9.51
	C_2	47.32 ± 3.46	41.18 – 53.11	7.31
	C_3	47.46 ± 4.67	38.28 – 60.28	9.84
	C_4	59.69 ± 5.12	45.44—69.14	8.83
Solar Radiation (°)	C_1	16.17 ± 4.45	4.89 – 30.08	27.50
	C_2	8.91 ± 2.33	4.89 – 17.27	26.15
	C_3	16.31 ± 4.61	7.62 – 28.46	28.52
	C_4	26.61 ± 3.78	13.58—31.44	14.20
Pluvial precipitation (mm)	C_1	1.53 ± 2.23	0.00—8.28	145.69
	C_2	12.81 ± 7.12	0.00 – 29.49	55.54
	C_3	1.89 ± 3.18	0.00 – 17.57	167.65
	C_4	0.28 ± 0.89	0.00—5.05	317.62
Milk yield kg/day	C_1	2.03 ± 0.86	0.10 – 6.69	43.07
	C_2	2.55 ± 1.06	0.20—6.42	41.76
	C_3	2.87 ± 0.82	0.20—6.38	28.76
	C_4	1.87 ± 0.78	0.10—6.04	41.44

C_1, "medium–low milk production"; C_2 "medium–high milk production"; C_3, "higher milk production"; C_4, "lower milk production"

THI = Temperature–humidity index

VC: variation coefficient

Effect of the moon calendar

Milk production was affected by lunar phases (Table 6). Milk yields (kg/day) were significantly ($p < 0.01$) higher on the full moon and new moon than they were on the waxing or waning moon.

Discussion

Environmental conditions can influence milk production in sheep (Casamassima et al. 2001; Gonzalez-Ronquillo et al. 2021). Specifically, air temperature and relative humidity have a direct significant effect the production potential of small ruminants (Al-Dawood 2017). Given the synchronism between inside and outside fluctuations in meteorological conditions, this work focused on the influence of the external ones on milk production. Besides, the results referred to the entire sheep population.

In this study, milk production (kg/d) in Lacaune was negatively correlated with mean temperature, relative humidity, THI and solar radiation (Table 2). Milk yields were higher if the mean daily temperature was between 7 and 8 °C than they were if the average temperature was 15 °C, and although sheep are considered tolerant of high temperatures, heat stress might have influence milk yields. Sevi and Caroprese reported that in hot weather maintenance energy needs increased by 7–25%, as body temperature and respiratory rate. Moreover, solar radiation from high-temperature and high-humidity climates led to an increase in the concentrations of neutrophils, coliforms, and staphylococci in milk, which caused udder health problems (Sevi et al. 2001). It was found that environmental conditions affected Lacaune

Table 5 Least square means and standard error of the variables included in the cluster analysis "of milk production in Lacaune ewes in Spain"

N	13,413	37,045	6,417	39,321		
Variable	C_1 (medium–low milk production)	C_2 (medium–high milk production)	C_3 (Higher milk production)	C_4 (Lower milk production)	*P Value*	*Pooled SE*
Temperature (°C)	7.33 ± 0.02^{d}	8.13 ± 0.03^{b}	7.80 ± 0.02^{c}	15.75 ± 0.02^{a}	0.0001	0.39
Relative Humidity (%)	78.65 ± 0.04^{b}	89.13 ± 0.07^{a}	78.61 ± 0.04^{b}	65.87 ± 0.04^{c}	0.0001	0.43
THI index	49.73 ± 0.03^{c}	47.31 ± 0.05^{b}	47.46 ± 0.03^{b}	59.69 ± 0.02^{a}	0.0001	0.37
Solar Radiation (°)	16.17 ± 0.03^{c}	8.91 ± 0.04^{d}	16.31 ± 0.03^{b}	26.61 ± 0.02^{a}	0.0001	0.32
Pluvial precipitation (mm))	1.53 ± 0.02^{c}	12.82 ± 0.03^{a}	1.89 ± 0.02^{b}	0.28 ± 0.02^{d}	0.0001	0.42
Milk yield (kg/day)	2.03 ± 0.01^{c}	2.54 ± 0.01^{b}	2.87 ± 0.01^{a}	1.88 ± 0.01^{d}	0.0001	0.81

[*] Different literals (a, b, c and d) indicate significant differences ($P < 0.01$), SE: Standard Error

Table 6 Least square means and standard error of milk yield (kg/day) in Lacaune ewes in Spain and lunar phase

Variable	First quarter	Full moon	Last quarter	New Moon	*P value*	*Pooled SE*
N	19,250	29,699	20,999	26,247		
Milk yield (kg/day)	2.17 ± 0.01^{b}	2.26 ± 0.01^{a}	2.18 ± 0.01^{b}	2.25 ± 0.01^{a}	0.0001	0.99

sheep milk production (Table 3) and, probably, quality, which was shown in Churra breed ewes in Spain (Gonzalez-Ronquillo et al. 2021).

The results shown in Table 6, indicated that differences in temperature, relative humidity, THI, solar radiation, precipitation, and milk production contributed significantly ($p < 0.01$) in the conformation of the four clusters. Finocchiaro et al. (2005) found that milk production in dairy sheep and THI were negatively correlated because of heat stress. Similarly, in our study, the fourth cluster had the highest THI, and the lowest milk yields, which could be related to the fact that the higher the light and heat radiation, the lower the milk production.

It was shown that an increase in precipitation had a positive effect on daily milk production, which might have been related to the THI, because if precipitation increases, temperature decreases and relative humidity increases, which reduces the THI, an action that does not subject the animal to stress conditions (Kadzere et al. 2002). In our study, precipitation was highest in the third cluster, which had the highest humidity and the second highest milk production, which suggests that milk producing ewes are not affected significantly by high humidity and precipitation, as long as ambient temperatures are not high.

The second cluster, "medium–high milk production," had the lowest temperature, THI, and precipitation, which suggests that these environmental factors influence milk production because they provide an optimal environment (greater comfort) for the sheep. Therefore, ewes are more comfortable under low temperatures, specifically when they are lower than 15 °C, as it was found by Ramón et al. in Spanish Manchega-breed sheep, indicating that, at temperatures of 25 °C, feed intake and physiological processes change significantly, which affects milk production yields. Overall, several meteorological variables significantly affected sheep milk yield, coinciding with the results of Abecia et al. (2017). Although it was not included in the present work, the effects of weather in the different stages of lactation should be taken into consideration in order to support the previous statement, following the criteria of Abecia et al. (2017).

Milk production (kg/day) of Lacaune ewes was significantly higher ($p < 0.01$) on the full moon or new moon than it was on the waxing or waning moon. Few studies have investigated the effects of the moon on the productive and reproductive parameters of animals (Palacios and Abecia 2014). Zimecki mentioned that human and animal physiology is affected by seasonal radar, lunar and circadian rhythms.

In the livestock industry, the full moon is thought to influence calving. However, research suggests that lunar phases and lambing frequencies in sheep are not correlated (Palacios and Abecia 2011). There is evidence that moon phase influences on fertility, type of estrus and number of lambs produced through artificial insemination in sheep (Palacios and Abecia 2014), and that it also influences the sex of sheep, goats, cows and pigs at the time of conception (Abecia et al. 2016). Weather variations, such as changes in atmospheric pressure and temperature, have been reported to affect the timing of birth in livestock. Yonezawa et al. revealed a relationship between spontaneous calving in Holstein cows and phase of the lunar calendar, specifically, spontaneous birth frequency increased progressively from the new moon to the full moon phase and decreased until the waxing and waning phase. This might explain the increase in milk production in the Lacaune ewes in our study because, after lambing, ewes are weaned from their lambs and milked immediately, so lambing date influences milk yields.

Conclusion

Milk production was affected negatively by environmental factors as temperature, THI, and solar radiation increase, so that the higher the intensity of these environmental variables, the lower the milk production yield. Milk production was highest on days when the Lacaune breed ewes experienced moderate environmental conditions, with high relative humidity and precipitation, and low temperatures. In addition, milk production was highest on the full moon or new moon, proving an influence of the lunar phase on milk production yields. The results of this work may be helpful in making predictions for milk production in Lacaune breed ewes throughout the year in the Mediterranean region.

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Author's contributions MGR, JAA, and CP contributed to conceptualization; MGR, JOA, and LERJ contributed to methodology; MGR, CP, JOA, and LERJ contributed to formal analysis and investigation, MGR, JOA, LERJ, JP, DMGC and CP contributed to writing—original draft preparation, MGR, JOA, LERJ, JP, DMGC, CP and JAA, contributed to writing—review and editing; MGR and CP contributed to funding acquisition; MGR and CP provided the resources; MGR, CP, JAA, JP and JOA contributed to supervision. MGR, CP, JAA, and JOA contributed to visualization.

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Data availability The datasets generated and analyzed in the current study are available from the corresponding author upon reasonable request.

Declarations

Ethical standard The data were from a pre-existing database, therefore, approval from the ethics committee was not a prerequisite for this study. The study met the Spanish Policy for Animal Protection RD1201/05, which meets the European Union Directive 2010/63 on the protection of animals used for experimental and other scientific purposes.

Competing Interests The authors have no competing interests to declare that are relevant to the content of this article.

Conflict of interest "The authors declare no conflict of interest."

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