Sustainable measures for assessing the impact of climate effects on livestock biological variability

Nadia Piscopo
Dept. Veterinary Medicine and Animal Productions
Federico II University
Naples, Italy
nadia.piscopo@unina.it

Lucia Trapanese
Dept. of Electrical Engineering and Information Technology
Federico II University
Naples, Italy
lucia.trapanese2@unina.it

Roberta Matera
Dept. Veterinary Medicine and Animal Productions
Federico II University
Naples, Italy
roberta.matera@unina.it

Alessio Cotticelli
Dept. Veterinary Medicine and Animal Productions
Federico II University
Naples, Italy
alessio.cotticelli@unina.it

Oscar Tamburis
Institute of Biostructures and Bioimaging
National Research Council
Naples, Italy
oscar.tamburis@ibb.cnr.it

Roberta Cimmino
Associazione Nazionale Allevatori Specie Bufalina (ANASB)
Caserta, Italy
r.cimmino@anasb.it

Angela Salzano
Dept. Veterinary Medicine and Animal Productions
Federico II University
Naples, Italy
angela.salzano@unina.it

***Abstract*—The aim of the present work was to deploy sustainable and sensor-based measures to assess the influence of climatic parameters such as environmental temperature (ET), relative humidity (RH), thermic excursion (ET) and temperature-humidity index (THI) on milk quantity and quality of two different dairy species (buffalo and cow) reared in the same farm. The climatic parameters were recorded daily through a weather station located inside the commercial dairy farm, while milk quantity (ECM) and quality parameters – such as fat (FP) and protein (PP) percentages, and somatic cell count (SCC) – were recovered monthly from test days. For each species a distinct Spearman analysis was carried out. The results denoted cows were more prone to heat stress compared to buffaloes, probably because of the tropical origin of the latter species. Moreover, in Holstein cows, ECM had strong negative correlations with weather data ($p < 0.01$). However, the correlations were very low for FP, PP and SCC and climatic parameters for both species. The findings reported in this study, although suggesting the reliability of IoT for animal welfare purposes in the dairy sector, highlight the importance of further studies to be performed to assess and validate new THI levels proper of buffalo species.**

Keywords—THI, milk production, PLF, sensors, dairy

I. Introduction

Nowadays Precision Livestock Farming (PLF) is called to cope with many issues related to growing food demand from increasing human populations, or sustainability of productions. The capacity of gathering and analyzing sometimes massive amounts of data to pursue a new kind of processing procedures is, therefore, critical. There are numerous studies on stressogenic factors carried out on different animal species. Cortisol has been used in domestic [1-3] and wild [2-4] animals to measure stress levels and evaluate the relative state of well-being/discomfort according to the different environmental stimuli or the different farming and transport conditions of the animals. In recent years, due to the well-established phenomenon of climate change, data relating to meteorological and climatic conditions have been analyzed by studying the influence that heat stress causes on animal reproduction, production performance and animal welfare [6-8].

The dairy industry is one of the most vulnerable to global warming and climate change, since dairy animals are more sensitive to heat stress due to the metabolic heat load produced by both animal digestion and milk synthesis [6,9]. In this regard, the temperature-humidity index (THI), as a bioclimatic parameter, combines the effect of air temperature and humidity and it is commonly used to study heat stress in dairy farms [10,11]. Many authors have evaluated the effects of THI and heat stress in dairy cattle, showing lower milk production and changes in milk composition with increasing THI levels [12,13]. Few studies, however, have evaluated the effect of heat stress on buffaloes, especially in buffaloes raised under intensive conditions and at our latitudes [11,14]. Although buffaloes are known to be able to adapt perfectly to different environments, they exhibit signs of great discomfort when exposed to direct solar radiation. Body temperature of buffaloes is slightly lower than that of dairy cattle, and its skin is generally black, thus, more prone to absorb heat and is poorly protected by hair [15]. In addition, buffalo skin has a density of sweat glands six times lower than cattle, a characteristic that makes heat dissipation by sweating inefficient [16].

Little information is available on the effect of THI in Italy in the light of new scientific information available. Hence, the present experiment was carried out to perform sustainable, sensor-based measures to outline the THI thresholds at which heat stress (heat or cold) arises in dairy buffaloes through the evaluation of milk quantity and quality characteristics. These intervals were compared with those obtained from dairy cattle raised under the same environmental conditions. The study aims therefore to show that the timely deployment of smart farming systems to deliver improvements in animal welfare, falls accordingly within the larger topic of pursuing targets of sustainable environmental technology for cleaner and greener growth [17].

II. Ease of Use

The field trial was carried out in a South Italy commercial dairy farm located in Baia e Latina (prov. of Caserta), where

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84 heads were reared. Data were recorded between March 2022 and February 2023. Twenty Italian Mediterranean buffaloes (3.5±0.6 parity) and twenty Holstein dairy cattle (3.6±0.2 parity), kept in free housing conditions and milked twice a day, were involved in the study. Buffaloes and cows were housed in free stall barns, independent and close, with a concrete floor. An availability of space of 15 m^2/head and 80 cm front manger were guaranteed throughout the study. Straw was used for bedding and it was renewed every two days. Information pertaining to each individual included: animal ID, birth date, calving date, parity order, days in milk (DIM), milk daily yield (Milk), fat percentage (FP), protein percentage (PP), somatic cells score (SCC) were provided by the official milk recording service of the Italian Breeders Association.

The analysis for the determination of milk quality (fat, protein) were obtained through mid-infrared spectroscopy (Milkoscan FT6000®, Foss Electric, Hillerød, Denmark). Somatic cell count (SCC) was obtained by Fossomatic FC® counter (Foss, Hillerød, Denmark). For the determination of the weather data, a solar-powered Sainlogic profi WLAN control unit with the following dimensions 21.5 x 2.2 x 15.8 cm and with an LCD display was used. The information relating to environmental temperature (ET), relative humidity (RT), air pressure, wind speed and direction, as well as precipitation and ultraviolet radiation were recorded from March 2022 to February 2023 with the Wireless Transfer System every day at an hourly interval on the breeder's computer for the data storage. From ET and RH collected each hour were obtained ET_mean (ET mean), ET_min (ET minimum), ET_max (ET maximum), RH_mean (RH mean), RH_min (RH minimum) and RH_max (RH maximum), TE (thermal excursion). Temperature-humidity index (THI) was calculated according to the literature, as follows [11,17]:

$$\text{THIijm} = (1.8 * \text{ETijm} + 32) - (0.55 - 0.55 * \text{RH}) * (1.8 * \text{ET} + 32) - 58 \quad (1)$$

where: THIijm is Temperature-humidity index (i=THI_mean, j= THI_min and k=THI_max), ETijm (i= ET_mean, j=ET_min and k=ET_max) is the environmental temperature expressed in Celsius degrees and RHijm (i= RH_mean, j= RH_min and k = RH_max) as a fraction of the unit and RH_{ijm} is the relative humidity. The (1.8×ET+32) term is used for the conversion from degree Celsius to Fahrenheit. Table 1 describes the mean and standard error of TE, ET_mean, RH_mean and THI_mean for each month.

TABLE I. SUMMARY OF METEREOLOGICAL DATA RECORDED IN THE DAIRY FARM

Month	TE_m (°c)	ET_m (°c)	RH_m (%)	THI_m
03/22	15.2± 1.2	11.3±0.5	48.0±1.9	53.7± 0.6
04/22	15.0±0.9	14.9±0.5	53.7±2	58.1±0.7
05/22	16.2±0.7	21.7±0.6	51.6±1.5	67.0±0.7
06/22	17.2±0.7	27.1±0.3	45.8±1.0	73.1±0.4
07/22	16.4±0.4	28.6±0.2	47.6±1.6	75.5±0.4
08/22	15.2±0.4	26.0±0.3	57.2±1.6	73.5±0.4
09/22	11.1±0.9	21.8±0.8	63.0±2.1	67.8±0.9
10/22	15.0±0.6	18.9±0.2	64.0±0.9	64.2±0.3
11/22	9.72±0.8	14.0±0.5	68.4±1.3	57.3±0.8
12/22	9.34±1.7	12.6±0.4	76.6±0.9	55.1±0.6
01/23	9.14±1.5	8.8±0.4	71.6±1.5	49.3±0.7
02/23	13.2±1.4	6.8±0.5	54.3±1.9	47.5±0.7

Data are shown as mean ± s.e. TE: Thermal excursion; ET: Environmental Temperature; RH: Relative Humidity; THI: Temperature-humidity index.

A. Dataset

Original dataset included 390 records for 14 numeric variables. The features regarded, the milk yield (Milk), quality parameters (FP, PP, and SCC), and the monthly minimum, mean, and maximum of temperature, humidity, THI, and monthly values of thermic excursion. The milk yield was turned in Energy Correct Milk (ECM) through the equation [18]. L, X and Z represented the amount of milk (in kg), and its fat and protein content (%):

$$ECM = L * (1 + ((X - 4) + (Z - 3.1)) * 0.1155 \quad (2)$$

In addition, new categorical variables were added to evaluate the influence of ET_mean and THI_mean on the milk yield and quality for both species. Spearman's correlation analysis was carried out, on the entire dataset, and on other two subsets based on ET and THI outset. The empirical threshold for ET_mean (ET_mean > 27°C) was set to study the correlation of ECM, FP, PP, and SCC at higher temperatures. This threshold was obtained from a mean of the ET_mean of summer months. For THI, it was chosen a threshold of 72 [19] to analyze the correlation of milk yield and quality when the animals were under heat stress conditions. The statistical analysis was performed on R software version 4.2.2. The function "rcorr" from "corrplot" package was mainly used. A p-value < 0.05 was considered statistically significant.

III. RESULTS AND DISCUSSION

The results of the daily monitoring of the breeding environmental conditions are reported in Table 1. The breeding area was characterized by a mild climate during all year. Indeed, only in June, July and August the THI_mean slightly exceeded its heat stress threshold (73.1, 75.5 and 73.5 vs THI_mean = 72) [20]. This evidence is highlighted in Figure 1, which describes the trend of THI during the experimental period. This means that animals did not suffer much the heat stress regardless of the time of the year. However, despite the warm climate, the analysis performed showed that the weather data influenced buffalo and cow's milk yield and quality [21].

A. Spearman correlation on buffaloes' data

The Spearman's correlation analysis (see Figure 2) showed that ECM, FP, PP and SCC had significative correlations with the meteorological data. Regarding buffaloes, the Spearman's correlation showed that ECM had low negative correlations with ET_min, ET_mean, ET_max and THI_min, THI_mean and THI_max, (r: -0.18, -0.21, -0.20, -0.20, -0.20, -0.21 respectively; p < 0.01). A low positive correlation was found among ECM and RH_min, RH_mean, RH_max (r: 0.17, 0.21, 0.22 respectively; p < 0.01

and for RH_max p < 0.05). No significative correlations were eventually found for FP, PP and SCC.

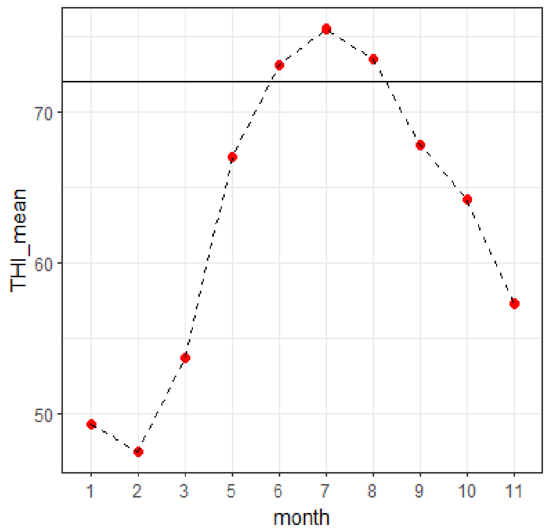

Fig. 1. Trend of THI for each month recorded by the weather station of the farm

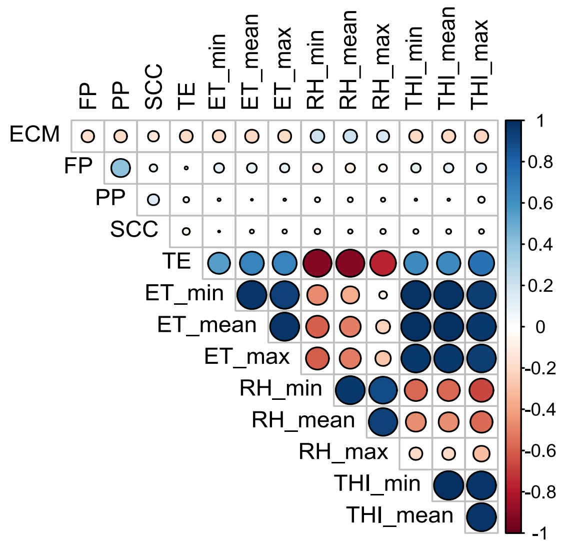

Fig. 2. Correlation matrix of buffalo performances. The size of circles represents the magnitude of correlation coefficients. ECM: Energy Corrected Milk, FP: Fat percentage, PP: protein percentage, SCC: somatic cell count TE: Thermal excursion; ET: Environmental Temperature; RH: Relative Humidity; THI: Temperature-humidity index

B. Spearman's correlation on cows' data

The Spearman's correlation analysis showed that ECM, FP, PP and SCC had significative correlation with the meteorological data. The analysis performed on cow's data showed that the ECM had strong, significant negative correlation with the ET_min, ET_mean, ET_max and THI_min, THI_mean and THI_max, (r: - 0.35, - 0.35, - 0.36, -0.35, -0.35, - 0.41, respectively; p<0.001). Positive correlations were found for the RH_min and RH_mean (r: 0.28, 0.26, respectively; p < 0.001). FP, PP and SCC had no significative correlations. Figure 3 showed the correlation matrix for Holstein cows.

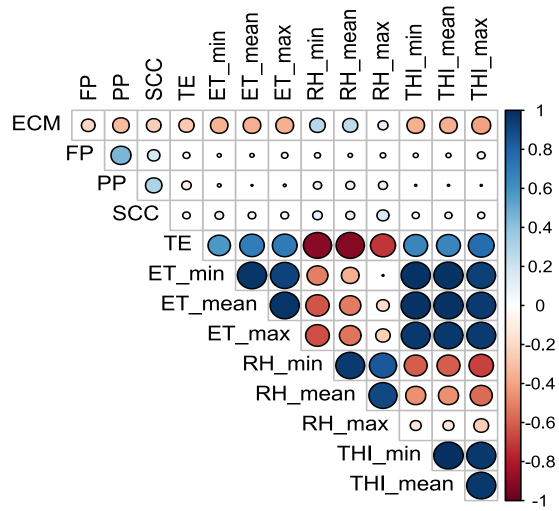

Fig. 3. Correlation matrix of Holstein cows performances. The size of circles represents the magnitude of correlation coefficients. ECM: Energy Corrected Milk, FP: Fat percentage, PP: protein percentage, SCC: somatic cell count TE: Thermal excursion; ET: Environmental Temperature; RH: Relative Humidity; THI: Temperature-humidity index

C. Effects of high temperature on buffaloes and cows

When the ET_mean exceeded the 27°C, the Spearman's correlation analysis for buffalo didn't return any significative correlations, however it was possible denote a trend (Figure 4). Indeed, the ECM was negatively correlated with ET_min, ET_mean, ET_max, THI_min, THI_mean and THI_max, RH_max and RH_mean (r: -0.05, -0.04, -0.05, -0.02, -0.04, -0.03, -0.04, -0.05 respectively; P>0.05). A low positive correlation was found between ECM and RH_min (r: 0.05; P<0.05).

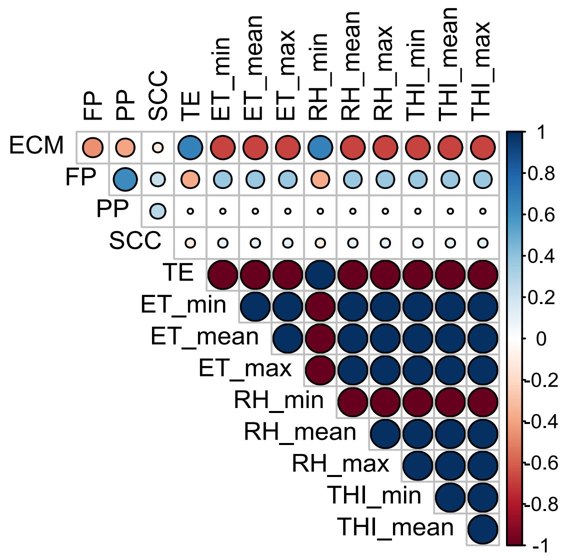

Fig. 4. Correlation matrix of cow performances when the ET_mean was > 27 °C. The size of circles represents the magnitude of correlation coefficients. ECM: Energy Corrected Milk, FP: Fat percentage, PP: protein percentage, SCC: somatic cell count TE: Thermal excursion; ET: Environmental Temperature; RH: Relative Humidity; THI: Temperature-humidity index

On the other hand, the analysis carried out on Holstein cows returned a strong negative correlation between ECM and ET_min, ET_mean, ET_max (r: -0.67, -0.66, -0.66, respectively; p <0.0001). Also, the THI_min, THI_mean and THI_max had the same behaviour with ECM (r: -0.67, -0.65,

-0.66 respectively; p<0.001). In addition, a strong negative correlation among ECM and RH_mean and RH_max (r: -0.66, -0.67, respectively; p < 0.0001) was found. Moreover, RH_min had a strong positive correlation with ECM (r: 0.65; p<0.0001). The FP, indeed, had positive correlations with the ET_min, ET_mean, ET_max, THI_min, THI_mean, THI_max, RH_mean and RH_max (r:0.35, 0.36, 0.34, 0.37, 0.36, 0.39, 0.37, 0.37, 0.37 respectively; p <0.05). A moderate negative orrelation was found between FP and RH_min (r: -0.36; p<0.05).

D. *Effects of heat stress on buffaloes and cows*

When the THI_mean was higher than 72°C no significant correlations were found for buffaloes. However, it was possible to denote the same trend of the previous analysis. The ECM was negatively correlated with ET_min, ET_mean, ET_max, THI_min, THI_mean and THI_max but the correlations did not reach the significance (r: -0.10, -0.11, -0.09, -0.02, -0.02, -0.04 respectively; P>0.05). However, in this case, RH_min, RH_mean and RH_max were positively correlated with ECM (r: 0.10, 0.07,0.08 respectively; P>0.05). The FP showed an opposite behaviour. Indeed, among FP and ET_min, ET_mean, ET_max, THI_min, THI_mean and THI_max a low and not significant positive correlation (r: 0.08,0.19,0.20, 0.08, 0.09, 0.10 respectively; P>0.05) has been found. The RH_min, RH_mean and RH_max were negatively correlated with FP (r: -0.19, -0.09, -0.09; P>0.05). The analysis performed on Holstein cows (Figure 5) showed that there were moderate significant negative correlations between ECM and ET_min, ET_mean, ET_max, THI_min, THI_mean and THI_max (r: -0.54, -0.52, -0.52, -0.54, -0.53, -0.54, respectively; p < 0.0001). The RH_min had a positive correlation with ECM (r: 0.54; p < 0.001). On the other hand, the ECM had positive significative correlations with ET_min, THI_min, THI_mean and THI_max (r :0.31, 0.30,0.31,0.32, p < 0.05).

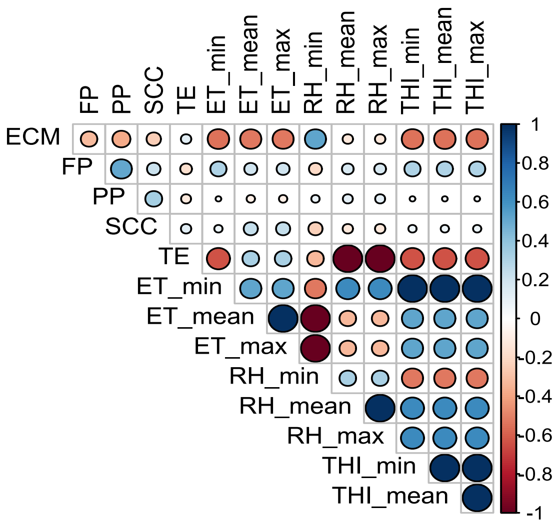

Fig. 5. Correlation matrix of cow performances when the THI threshold was > 72°C The size of circles represents the magnitude of correlation coefficients. ECM: Energy Corrected Milk, FP: Fat percentage, PP: protein percentage, SCC: somatic cell count TE: Thermal excursion; ET: Environmental Temperature; RH: Relative Humidity; THI: Temperature-humidity index

In summary, both ET and THI influenced more cows' performances, compared to buffaloes' ones. Regarding buffaloes, generally the high temperature (ET_mean > 27 °C) and a THI greater than 72°C only led to a lower (but not significant) decrease of milk yield. Holsteins cows showed the same amount but with a strongest correlation coefficient. The ECM for Holstein was positively correlated with RH and negatively correlated with ET and THI. It is important to denote that the weather data had more influence on ECM and FP than PP and SCC. Indeed, out of all cases examined, for these variables fewer significant correlations were found. Moreover, the correlation coefficient for PP and SCC were generally lower compared to ECM and FP.

IV. Conclusions

Our findings confirmed the results already present in literature for dairy cows in the presence of heat stress but pave the way for buffalo species, less prone to heat stress, probably due to its tropical origin. Further studies should be anyway performed to assess and validate new THI levels proper of this species. This paper could help to develop and improve decision support for farmers to achieve biodiversity-led environmental and economic goals, and to reduce the resources needed, to increase the sustainability of the dairy sector [22,23], in the view of the more general context of measurement sustainability [24].

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