Heat stress effects on Holstein dairy cows’ rumination

R. Moretti1†, S. Biffani2, S. Chessa2 and R. Bozzi1

1Dipartimento di Scienze delle Produzioni Agroalimentari e dell’Ambiente, Università di Firenze, Firenze, 50144, Italy; 2Istituto di Biologia e Biotecnologia Agraria (IBBA-CNR), Consiglio Nazionale delle Ricerche, Lodi, 26900, Italy

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The objective of this study was to investigate the relationship between temperature–humidity index (THI) and rumination time (RT) in order to possibly exploit it as a useful tool for animal welfare improvement. During summer 2015 (1 June to 31 August), data from an Italian Holstein dairy farm located in the North of Italy were collected along with environmental data (i.e. ambient temperature and relative humidity) recorded with a weather station installed inside the barn. Rumination data were collected through the Heatime® HR system (SCR Engineers Ltd., Hadarim, Netanya, Israel), an automatic system composed of a neck collar with a Tag that records the RT and activity of each cow. A significant negative correlation was observed between RT and THI.

Mixed linear models were fitted, including animal and test day as random effects, and parity, milk production level and date of last calving as fixed effects. A statistically significant effect of THI on RT was identified, with RT decreasing as THI increased.

Keywords: dairy cow, heat stress, temperature–humidity index, rumination time, animal welfare

Implications

Heat stress in dairy cows is a topic of high economic importance, since it reduces both productive and reproductive performances and health and welfare. This is especially true in the Mediterranean basin, where a gradual increase in temperature and humidity is expected in the coming years. Cooling systems help in reducing heat stress in dairy cows, but could be expensive if used when unnecessary. This study aims to deepen the knowledge about the effects of heat stress on rumination, electronically monitored, and to establish the basis for future research investigating the possibility of using this relationship as a useful alert.

Introduction

One of the major external factors that can negatively affect the performance of dairy cows is the thermal environment in which they live (Nardone et al., 2010). This finding is especially true in high-yielding animals of high genetic merit, which are very sensitive to heat stress (Bernabucci et al., 2014). Several studies hypothesised the ‘thermo-neutral zone’ (i.e. the thermal equilibrium between the animal and the environment where it lives) for lactating dairy cows to be between 5°C and 25°C to 26°C (Berman et al., 1985; Roenfeldt, 1998). Whenever the temperature exceeds this thermal zone, trespassing either the upper or lower limit, animal physiology changes to a disorder status in which, for example, milk production declines and its composition changes (Johnson, 1980).

Heat stress is an important threat to cattle breeding, especially in the Mediterranean basin, which is supposed to undergo a gradual increase in temperature and humidity in the coming years up to 2050 (Segnalini et al., 2013). Moreover, the current trend in the dairy industry is towards fewer but larger farms, rearing a great number of animals in the same structure (Winsten et al., 2010). Overcrowding and higher temperatures and humidity can indeed result in harsh conditions for dairy cows.

Responses of dairy cows to heat stress are copious: for example, raised respiration rates (Omar et al., 1996), and panting and sweating (Blazquez et al., 1994). However, to date, few studies have analysed the effects of heat stress on health and rumination activity of cattle. Rumination, described by Erina et al. (2013) as the process of regurgitation, remastication, salivation, and swallowing of ingesta to reduce the particle size of feedstuffs and enhance fibre digestion, is a key physiological function in ruminants, and is associated with cow welfare (Bar and Solomon, 2010). Feeding variables (e.g. feed intake) have the largest effect on rumination, being intrinsically connected to this function. However, in commercial farms, recording of feeding information is not so common, and it is almost impossible to calculate feed intake for each animal. It is, instead, quite

† E-mail: riccardo.moretti@unifi.it

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common among breeders to group animals on their productive level, optimising the quantity and quality of feed (Spahr et al., 1993).

Despite its importance, the effects of length, severity, and timing with respect to stage of lactation of heat stress on health and rumination are still unknown. The overall effect of heat stress has been assessed by measuring body temperature of dairy cows, which shows a high susceptibility to hot environments (Araki et al., 1984). The temperature–humidity index (THI) combines ambient temperature and relative humidity into a single value, and is a commonly used index (Hahn et al., 2003) to assess the effects of environmental temperature on dairy cows. However, THI does not include in its equation the effects of other environmental variables (e.g. solar radiation, wind). Several studies have already highlighted the negative relationship between THI and productive and reproductive performances in dairy cows (Bouraoui et al., 2002; García-Ispierto et al., 2007; Bernabucci et al., 2014; Biffani et al., 2016), but few studies investigated the relationship between THI and rumination time (RT). Soriani et al. (2013) found a significant negative correlation ($r = -0.32; P < 0.05$) between THI and RT, but the study was conducted monitoring only 21 cows.

Based on the aforementioned relationships, THI might be useful as a welfare index. Temperature–humidity index recording could be implemented into automatic system programmed to send an alert directly to farmers, who can subsequently act to resolve or reduce the heat stress suffered by their animals. Several studies have already shown that the use of a cooling system helps in reducing the negative effects of heat stress in dairy cows (Frazziet al., 2000; Calegari et al., 2014), but few studies investigated the relationship between THI and rumination time (RT). Schirman et al. (2009). The raw data are subsequently processed by the DataFlow™ II software (SCR Engineers Ltd.) provided by the farm with additional information about each cow, namely ID number, age, parity, dates of calving, days in milk (DIM), and the daily milk production registered by the linked parallel milking parlour. Each stall entrance was equipped with a single long-distance antenna, which read the specific signal coming from the rumination monitoring tag on each cow. A possible critical point of this study was the possible issues due to mis-identification of the animals at the milking parlour. Given the small dimensions of the herd and the milking parlour, the probability for cows to switch their positions once passed the identification antennae was low. We acknowledge that this could be an issue in larger farms. Furthermore, in order to check possible wrong association between cow ID and production/rumination

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Heatime® HR system (SCR Engineers Ltd., Hadarim, Netanya, Israel). The system is composed of a neck collar equipped with a 12-bit temperature/RH sensor cable. Schüller and Heuwieser (2016) suggested that climate conditions should be obtained at cow level because of microclimatic differences that occur in dairy barns. However, since the barn was open on all of the four sides, fresh air supply and air recirculation was similar for all the animals and areas with different microclimates were less likely to generate. Any variability due to this issue was absorbed by the random effects of the models (namely animal and date-test effects).

Both AT and RH were measured once a minute and recorded as a mean value every 5 min. The guaranteed working range, as indicated in the manufacturer manual, was from 0°C to 50°C with an accuracy of ±0.2°C for the AT and from 10% to 90% with an accuracy of ±2.5% for the RH.

Descriptive statistics for the three months (June, July and August) were calculated and the difference between the means was statistically evaluated with a Tukey’s honest significant difference (HSD) test, a multiple comparison followed by a statistical test with a distribution similar to a t distribution. The HSD test was performed using the HSD.test function from the R package agricolae (de Mendiburu, 2016).

The RT was measured and summarised in 2-h intervals using the Heatime® HR system (SCR Engineers Ltd., Hadarim, Netanya, Israel). The system is composed of a neck collar with a tag containing a microphone to monitor rumination and an accelerometer to quantify activity, as validated by Schirman et al. (2009). The raw data are subsequently processed by the DataFlow™ II software (SCR Engineers Ltd.) provided by the farm with additional information about each cow, namely ID number, age, parity, dates of calving, days in milk (DIM), and the daily milk production registered by the linked parallel milking parlour. Each stall entrance was equipped with a single long-distance antenna, which read the specific signal coming from the rumination monitoring tag on each cow. A possible critical point of this study was the possible issues due to mis-identification of the animals at the milking parlour. Given the small dimensions of the herd and the milking parlour, the probability for cows to switch their positions once passed the identification antennae was low. We acknowledge that this could be an issue in larger farms. Furthermore, in order to check possible wrong association between cow ID and production/rumination

Material and methods

Animal and environmental data collection

Data were collected from 122 Italian Holstein cows, reared in the Tadini Dairy Park experimental farm, located in Gariga di Podenzano, province of Piacenza, Northern Italy (geographical position: 44° 58’ 55.0” N, 9° 40’ 58.8” E; 68 m above the sea level). Cows were located in a freestall barn, north–south oriented, without any ventilation system, and open on all of the four sides. All of the animals inside the barn were used for this study. The mean age ($±$ SD) of the animals was 46.67 ±17.56 months and the average ($±$ SD) daily milk production was 28.17 ±9.60 kg. Animals were classified by parity as ‘1’, ‘2’ and ‘3plus’ (all the cows after the third calving) and were 48, 34, and 44, respectively. Although recent studies confirmed a significant relationship between RT and both respiration rate and panting (Magrin et al., 2016), this information is not available in commercial farms and was not considered in the present study.

Ambient temperature and relative humidity (AT and RH, respectively) were recorded from the 1 June to the 31 August 2015 using a HOBO® Micro Station Data Logger (Onset®, Cape Cod, MA, USA) installed inside the barn (next to the pen, just high enough to be out of cows’ reach) in April 2015 and equipped with a 12-bit temperature/RH sensor cable. Schüller and Heuwieser (2016) suggested that climate conditions should be obtained at cow level because of microclimatic differences that occur in dairy barns. However, since the barn was open on all of the four sides, fresh air supply and air recirculation was similar for all the animals and areas with different microclimates were less likely to generate. Any variability due to this issue was absorbed by the random effects of the models (namely animal and date-test effects).

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Temperature–humidity index

Temperature–humidity index was calculated according to the equation from Vitali et al. (2009):

\[
\text{THI} = (1.8 \times \text{AT} + 32) - (0.55 - 0.55 \times \text{RH}) \\
\times [(1.8 \times \text{AT} + 32) - 58]
\]

where AT is expressed in degrees Celsius and RH as a fraction of the unit. The \((1.8 \times \text{AT} + 32)\) term is used for the conversion from degree Celsius to Fahrenheit. Following Hahn et al. (2003), six THI thresholds for heat stress classification were used, namely ‘safe’ (THI < 68), ‘mild discomfort’ (68 ≤ THI < 72), ‘discomfort’ (72 ≤ THI < 75), ‘alert’ (75 ≤ THI < 79), ‘danger’ (79 ≤ THI < 84), and ‘emergency’ (THI ≥ 84). After merging weather and rumination data, a mean value for each 2-h interval was estimated for THI, using AT and RH information.

Statistical analyses

The correlation between THI and RT was calculated using the \text{cor} function in R (R Core Team, 2014). The effect of THI on RT was assessed with a two-step procedure: in the first step, RT was adjusted for a set of fixed and random effects (excluding the THI), fitting the following mixed linear model (Model 1):

\[
\text{RT}_{ijklm} = \text{animal}_i + \text{par}_j + \text{prod}_{jlv}_k + \text{calv}_l + \text{date}_m + \epsilon_{ijklm}
\]

where \(RT_{ijklm}\) is the rumination time in 2-h intervals; \text{animal}_i\) is the random effect of the \(i\)th animal (in order to account of the correlation between measurements recorded from the same animal); \text{par}_j\) is the fixed effect of the parity order; \(\text{prod}_{jlv}_k\) is the fixed effect of the animal milk production level \(k\), classified based on the calculated production tertiles (low, mid and high) of animals grouped by parity and lactation length (\text{DIM} < 60, 60 ≤ \text{DIM} < 100, \text{DIM} ≥ 100); \text{calv}_l\) is the fixed effect of the month and the year of the last calving event class (format mmyyyy); \text{date}_m\), the random effect of the \(m\)th test day; \(\epsilon_{ijklm}\), the random residual effect.

In the second step, THI (factor with six classes, as previously defined) were added as a fixed effect to Model 1:

\[
\text{RT}_{ijklm} = \text{animal}_i + \text{par}_j + \text{prod}_{jlv}_k + \text{calv}_l + \text{date}_m + \text{THI}_n + \epsilon_{ijklmn}\quad [\text{Model 2}]
\]

where \(\text{THI}_n\) is the fixed effect of the \(n\)th THI class.

Both models were performed using the \textit{lm}er function of R package \textsc{lme4} (Bates et al., 2015), which fits mixed model by restricted maximum likelihood \(t\)-test using Satterthwaite approximations to degrees of freedom.

Subsequently, statistical significance of the model was checked with the \textit{lmerTest} package (Kuznetsova et al., 2015). The package updates the existing function ANOVA with the capability to evaluate statistical significance of fixed effects in a mixed model adding both least squares means and confidence intervals. Q-Q plots were used to check residuals distribution. Finally, in order to test the effect of THI on RT, Model 1 and Model 2 were compared by a simple ANOVA.

Results

Environmental data

In order to check the logger recording activity, AT and RH recorded during April 2015 were compared with data collected from an external professional weather station, located nearby (<1 km). The two data sets showed a Pearson correlation rate of 98%, with the values of on-farm temperature and humidity always being slightly higher than the external ones, most likely due to the heat dissipation mechanisms (e.g. sweat evaporation and breathing) of the animals. Schüller et al. (2013) stated that to assess heat stress accurately is mandatory to measure the relevant climate data inside the barn to avoid underestimation of heat stress. However, we did not find such a strong underestimation in our study: this is most likely due to the different distance between the meteorological station and the barn in our and their study (<1 and 18 km, respectively).

A total of 288 AT and RH records per day were collected in June \((n = 8640)\), July \((n = 8928)\) and August \((n = 8928)\). For each record, THI was calculated. Descriptive statistics for the 3 months are summarised in Supplementary Table S1. For each of the 3 months, the monthly THI mean was over the ‘safe’ condition threshold: specifically, ‘mild discomfort’ in June, ‘discomfort’ in August and ‘alert’ condition in July, which was the hottest summer month. Furthermore, the daily THI mean reached the ‘danger’ condition threshold in 3 consecutive days, from the 5th to the 7th of July. The numbers of total days and maximum consecutive ones per THI category are reported in Table 1.

Rumination time and fitted models

Descriptive statistics for the RT are summarised in Supplementary Table S2. Pearson correlation between RT and THI showed a significant unfavourable correlation (\(-0.22, P < 0.001\), in agreement with Soriani et al. (2013).

Table 1 Numbers of total days and consecutive ones per temperature–humidity index (THI) category: ‘safe’ condition (THI < 68), ‘mild discomfort’ (68 ≤ THI < 72), ‘discomfort’ (72 ≤ THI < 75), ‘alert’ (75 ≤ THI < 79), ‘danger’ (79 ≤ THI < 84) and ‘emergency’ (THI ≥ 84)

<table>
<thead>
<tr>
<th>THI category</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>June</th>
<th>July</th>
<th>August</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safe</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Mild discomfort</td>
<td>16</td>
<td>6</td>
<td>8</td>
<td>1</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Discomfort</td>
<td>6</td>
<td>4</td>
<td>8</td>
<td>6</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Alert</td>
<td>3</td>
<td>23</td>
<td>8</td>
<td>3</td>
<td>18</td>
<td>6</td>
</tr>
<tr>
<td>Danger</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Emergency</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 2 Model 1: fixed effects estimates, standard error of the means and significance by P-value

<table>
<thead>
<tr>
<th>Fixed effects</th>
<th>Estimate</th>
<th>SEM</th>
<th>P-value</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>39.389</td>
<td>1.625</td>
<td>&lt;0.001</td>
<td>***</td>
</tr>
<tr>
<td>par: 1</td>
<td>0</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>par: 2</td>
<td>1.536</td>
<td>0.216</td>
<td>0.016</td>
<td>Ns</td>
</tr>
<tr>
<td>par: 3plus</td>
<td>−1.271</td>
<td>0.297</td>
<td>0.001</td>
<td>***</td>
</tr>
<tr>
<td>prod_lvl: mid</td>
<td>0</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>prod_lvl: high</td>
<td>1.147</td>
<td>0.212</td>
<td>&lt;0.001</td>
<td>***</td>
</tr>
<tr>
<td>prod_lvl: low</td>
<td>−1.492</td>
<td>0.207</td>
<td>&lt;0.001</td>
<td>***</td>
</tr>
<tr>
<td>calv: 092014</td>
<td>0</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>calv: 082014</td>
<td>4.669</td>
<td>0.032</td>
<td>&lt;0.001</td>
<td>***</td>
</tr>
<tr>
<td>calv: 102014</td>
<td>5.196</td>
<td>0.016</td>
<td>&lt;0.001</td>
<td>***</td>
</tr>
<tr>
<td>calv: 112014</td>
<td>9.334</td>
<td>0.001</td>
<td>&lt;0.001</td>
<td>***</td>
</tr>
<tr>
<td>calv: 122014</td>
<td>8.482</td>
<td>0.001</td>
<td>&lt;0.001</td>
<td>***</td>
</tr>
<tr>
<td>calv: 012015</td>
<td>10.523</td>
<td>0.001</td>
<td>&lt;0.001</td>
<td>***</td>
</tr>
<tr>
<td>calv: 022015</td>
<td>5.274</td>
<td>0.028</td>
<td>&lt;0.001</td>
<td>***</td>
</tr>
<tr>
<td>calv: 032015</td>
<td>11.462</td>
<td>0.001</td>
<td>&lt;0.001</td>
<td>***</td>
</tr>
<tr>
<td>calv: 042015</td>
<td>10.691</td>
<td>0.001</td>
<td>&lt;0.001</td>
<td>***</td>
</tr>
<tr>
<td>calv: 052015</td>
<td>9.004</td>
<td>0.005</td>
<td>&lt;0.001</td>
<td>***</td>
</tr>
<tr>
<td>calv: 062015</td>
<td>7.060</td>
<td>0.039</td>
<td>&gt;0.05</td>
<td>Ns</td>
</tr>
<tr>
<td>calv: 072015</td>
<td>11.281</td>
<td>0.001</td>
<td>&lt;0.001</td>
<td>***</td>
</tr>
<tr>
<td>calv: 082015</td>
<td>7.010</td>
<td>1.611</td>
<td>&gt;0.05</td>
<td>Ns</td>
</tr>
</tbody>
</table>

The significance codes are: 0 < *** < 0.001 < ** < 0.01 < * < 0.05 < Ns.

The fixed effects from Model 1 (estimated values, SEM and P-values reported in Table 2) were statistically tested, and the results are summarised in Table 3. Random effect variances are in Table 4. Cow and test day accounted for ~5.4% and 1.3% of the overall variance, respectively. The adjusted $R^2$ of this model was 0.07 (calculated as suggested by Xu, 2003). The fitted values from the model were plotted vs. the residuals of the same (calculated using the resid function of R), showing a symmetrical distribution without any clear pattern, suggesting that a linear model was suitable for our data.

Milk production level and the date of last calving had significant associations with RT (P < 0.001 for both the variables), while parity did not (P = 0.106). Using mid-production level as reference class, both high- and low-production levels showed a significant association with RT: the former increasing by 1.147 ± 0.212 min per unit (P < 0.001), and the latter decreasing by 1.492 ± 0.207 min per unit (P < 0.001). This result, together with a correlation of 20.2% (P < 0.001), confirmed the hypothesis validated by Moallem et al. (2010), in which RT and milk production are positively related. Differently, Byskov et al. (2015) conducted a similar study in experimental farms where feeding data was available. A negative correlation was found between milk production and RT in minutes per kilogram of DMI. Although accounting for DMI in RT could result in more precise results, it is important to keep in mind that usually, in commercial farms, it is not possible to quantify DMI for each animal. Regarding the month/year of last calving event, all of the different classes resulted in a statistically significant difference from the 092014 (i.e. September 2014) reference level.

In the second step of this work, Model 2 (which included the THI effect) was fitted, its fixed effects (estimated values, SEM and P-values reported in Table 3) were statistically tested, and the results are summarised in Table 4. Temperature–humidity index effect was statistically significant and RT decreased by 9.36, 13.33, 19.44, 25.64 and 32.19 min/2 h per unit by a mild, discomfort, alert and
Discussion

The results presented in this study confirm a significant unfavourable association between THI and RT in Holstein dairy cows: when THI increases (i.e. increasing heat stress), a reduction in the RT occurs. An intuitive explanation could be that heat stress is known to activate physiological and metabolic responses to cope with the not optimal environmental conditions. These responses might involve, for example, a reduction in feed intake which eventually causes a reduced RT. This negative correlation between RT and THI is furthermore confirmed by similar findings from a previous study (Soriani et al., 2013).

The two fitted models (with and without THI as fixed effect, respectively) were statistically different. This result supports the hypothesis that a significant association does exist between THI and RT, the latter showing a decrease as the THI classes shifted from ‘safe’ to ‘emergency’. The THI classes adopted here are effectively describing a different response to a growing non-optimal climate, as highlighted by the statistical difference between the effects on RT at different classes. Furthermore, adding the THI to the other factors statistically improved the goodness of fit of the model (twofold increase in adjusted $R^2$).

The effect of milk production was included in the model as a categorical effect using three classes (namely, low-, mid- and high-productive) and not as a linear or nonlinear covariate. The rationale behind the use of such an approach was mainly due to an attempt to reduce model complexity, especially because of the limited number of available records. Nevertheless, both Model 1 and 2 were also fitted including milk production as linear and/or quadratic effect but results did not change. Milk was included as an independent variable in the model to assess the association between variations in RT and changes in milk production. There is a positive correlation between the two variables, with RT increasing in high-productive animals and decreasing in low-productive ones. This association confirmed the results previously obtained by other authors (Moallem et al., 2010). However, a different result was reported by Byskov et al. (2015), where the correlation between RT (expressed in minutes per kilogram of DM intake) was negative. The association presented here could be therefore biased due to the absence of feed intake information. Nevertheless, Byskov et al. (2015) reported that variation in feed intake took into account for 32% of the variation in RT, whereas 48% of the total variation in RT was found between-cows. Considering that our model took into account the between-cows variation, which represents almost half of the total variation, introduced bias due to the absence of feed intake recording should not invalidate our results and, therefore, could be a reasonable compromise between scientific precision and commercial farm needs, where feed intake is rarely recorded.

The correlation between THI and RT presented in this study suggests that rumination could be a valuable tool for evaluating the heat stress effect on Holstein dairy cows.
Further studies are needed to confirm the potential predictive use of the RT changes.

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Supplementary material
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References


